CALCAREOUS PLANKTON HIGH RESOLUTION BIO-MAGNETOSTRATIGRAPHY FOR THE LANGHIAN OF THE MEDITERRANEAN AREA

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Abstract. High-resolution quantitative and qualitative analyses of the planktonic foraminifer and calcareous nannofossil content have been carried out on three Middle Miocene sections, from the Mediterranean area. Such sections (Cretaccio section, Tremiti Islands, Southern Italy; Moria section, Marche Region, Central Italy; DSDP Site 372 succession, Balearic Basin), all well known in the literature, have been chosen because of their high-quality biostratigraphic potential.

Remarkable magnetostratigraphic data were provided by the Site 372 succession where all chrons and subchrons of the interval C5Br-C5AAn have been recognised.

The investigated interval falls between the First Occurrence (FO) of *Praeorbulina glomerosa sicana* and the Last Occurrences (LO) of *Sphenolithus heteromorphus* and *Globorotalia peripheroronda*. The LO of *S. heteromorphus* was detected in the uppermost part of the investigated sequence of Site 372 at the same stratigraphic level as the *G. peripheroronda* LO. A drastic decrease in abundance of *S. heteromorphus* (Last Common Occurrence -LCO) was detected slightly below its last occurrence; this event is well correlatable with the same event astronomically calibrated at *Ras-il Pellegrin* section (Malta Island), which has been recently ratified as the Global Stratotype Section and Point (GSSP) for the base of the Serravallian by the International Union of Geological Sciences.

The stratigraphic correlation of the studied sections is based on first and last occurrences, abundance fluctuations of selected taxa and additional biohorizons. In particular the peculiar distribution pattern of some taxa, e.g. *Paragloborotalia siakensis* and *Helicosphaera waltrans*, offered the opportunity to increase the biostratigraphic resolution of the Langhian interval. The resulting integrated calcareous plankton bio-magnetostratigraphic scheme represents the downward extension of that one previously established for the Serravallian - Tortonian interval.

The biostratigraphic correlation of the studied sections with the Langhian historical Stratotype pointed out its low degree of reliability. On the other hand, none of the sections here studied is suitable to be proposed as candidate for defining the Langhian GSSP. Thus the problem of finding, in the Mediterranean area, a valid section which could yield a new GSSP for the Langhian Stage is still open.

Riassunto. Vengono presentati i risultati di uno studio biostratigrafico integrato ad alta risoluzione, basato sull'analisi qualitativa e quantitativa di nannofossili calcarei e foraminiferi planctonici. Tale studio è stato condotto su tre successioni del Miocene Medio dell'area mediterranea: la sezione del Cretaccio (Isole Tremiti, Puglia, Italia meridionale), la sezione Moria (Marche, Italia centrale) e il Site 372 del Leg DSDP 42A (Bacino Balearico). Nonostante si tratti di successioni note in letteratura, esse sono state scelte per questo nuovo studio considerato il loro eccellente contenuto micropaleontologico e le potenziali qualità di risoluzione biostratigrafica e di continuità stratigrafica.

Ottimi risultati sono stati ottenuti dalle analisi paleomagnetiche eseguite sulla successione del Site 372, consentendo di individuare tutti i chron compresi nell'intervallo C5Br-C5AAn.

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Le sezioni sono caratterizzate da un apprezzabile contenuto in plancton calcareo, in generale discretamente conservato, tranne nella parte basale della sezione Moria dove la conservazione dei foraminiferi è a volte scarsa, con esemplari spesso rotti o deformati e con gusci frequentemente ricristallizzati. Per piccoli tratti, anche nella porzione basale della sezione Cretaccio, si registra un grado di conservazione piuttosto mediocre delle associazioni a plancton calcareo.

Nell'intervallo studiato sono state eseguite analisi quantitative e qualitative e sono state riportate in forma grafica le distribuzioni dei taxa più significativi ai fini biostratigrafici. L'intervallo esaminato risulta compreso fra la prima comparsa (*First Occurrence*) di *Praeorbulina glomerosa sicana* e le estinzioni (*Last Occurrence*) di *Sphenolithus heteromorphus* e *Globorotalia peripheroronda*. Il riconoscimento del primo di questi biorizzonti è incerto, in quanto presente unicamente nella sezione Moria, che mostra un grado di conservazione dei foraminiferi non sempre ottimale. Le scomparse di *Sphenolithus heteromorphus* e *G. peripheroronda* sono state riconosciute nella parte sommitale del Site 372 allo stesso livello. Poco al di sotto della estinzione di *S. heteromorphus* si individua molto chiaramente l'ultima comparsa comune (*Last Common Occurrence*) della specie; questo evento permette di correlare facilmente la successione del Site 372 con altre sezioni dell'area mediterranea (es. *Ras-il Pellegrin*, Isola di Malta, recentemente accettata come *Global Stratotype Section and Point – GSSP –* del Serravalliano dalla Commissione Internazionale di Stratigrafia).

Eventi di comparsa e scomparsa già noti, insieme a biorizzonti secondari e a significative variazioni di frequenza, hanno consentito di strutturare un quadro di correlazione affidabile. In particolare, un acme di *Paragloborotalia siakensis* caratterizzato da una popolazione costituita da forme sia destrorse che sinistrorse in percentuali simili, e la limitata distribuzione stratigrafica di *Helicosphaera waltrans*, hanno consentito di aumentare la risoluzione biostratigrafica del Langhiano. Il risultato è uno schema biostratigrafico integrato a plancton calcareo che aggiorna quelli già esistenti, in cui vengono adottate le nomenclature sintetiche delle zone a Foraminiferi (Zone MMi) e a nannofossili calcarei (Zone MNN), sullo stile di quanto in precedenza fatto da altri autori per l'intervallo Serravalliano-Tortoniano.

Il tentativo di correlare i bioeventi individuati nel presente studio con quelli documentati nella sezione tipo del Langhiano, ha messo in evidenza i grossi limiti di quest'ultima. La sezione Moria è l'unica, tra quelle presentate, che contenga il limite Burdigaliano/Langhiano, ma lo stato di conservazione delle microfaune, non sempre ottimale, impedisce di proporla quale sezione adatta alla definizione dello stratotipo del suddetto limite. Rimane pertanto ad oggi aperto il problema di individuare, nella regione mediterranea, una sezione adatta alla definizione del GSSP del Langhiano.

Introduction

During the last years, much progress has been made in the Neogene Global Chronostratigraphic Scale by defining Global Stratotyope Section and Points (GSSPs) (Zanclean to Serravallian stages) and improving the resolution of the calcareous plankton stratigraphy of the Mediterranean through integrated studies (biostratigraphy, magnetostratigraphy and cyclostratigraphy).

Recent accurate cyclostratigraphic studies, integrated with high resolution calcareous plankton biostratigraphy and magnetostratigraphy, provided detailed zonal schemes for the late Middle Miocene to Pleistocene of the Mediterranean area and their correlation to the Astrochronological Time Scale (e.g. Hilgen 1991;

Sprovieri 1992, 1993; Hilgen et al. 1995, 2000a, 2000b, 2003; Sprovieri et al. 1996, 1998, 2002a; Lirer and Iaccarino 2005; Iaccarino et al. 2004; Sierro et al. 2001, 2003; Lourens et al. 1996a, 1996b, 2004; Abels et al. 2005). All these data contributed to the construction of a new Astronomical Tuned Neogene Time Scale (ATNTS 2004, Lourens et al. 2004) that extends to the base of the Serravallian (13. 82 Ma) (Hilgen et al. submitted).

The logical next step was to search for continuous marine sequences useful for extending the astrochronological time scale back to the base of the Langhian in terms of high resolution biostratigraphy calibrated to a reliable magnetostratigraphy (the best tool for first order calibration), also in the aim of finding a suitable section to be proposed as a new Langhian GSSP.

The aim of the present study is to extend the integrated stratigraphic analyses already tested for the younger intervals to the lower Middle Miocene record. Three well known successions (DSDP Site 372 - Balearic Basin, Moria section - Central Italy, and Cretaccio section - Tremiti Islands), which on the whole cover the stratigraphic interval between the upper Burdigalian and the lower Serravallian, have been re-examined through an integrated high resolution calcareous plankton quantitative study. In addition, all the calcareous plankton biohorizons recognised in the present study have been calibrated to the good magnetostratigraphic framework recently provided by Abdul Aziz et al. (2008) for DSDP Site 372 (Balearic Islands).

On the basis of the new analyses several new biohorizons within the nannofossil and foraminifer assemblages have been recognized resulting in an amelioration of the biostratigraphic schemes for the Langhian interval previously defined by Iaccarino & Salvatorini (1982), Iaccarino (1985), Fornaciari et al. (1996), and Fornaciari & Rio (1996) for the Mediterranean area.

Finally, biostratigraphic correlations have been tempted with the historical Langhian Stratotype section (Cita & Premoli Silva 1960) in order to verify if it could still represent a valid and suitable section for an updated Langhian GSSP definition.

Studied sections

Moria section (43° 30.15' N; 12° 35.57' E)

This section outcrops on the west side of Monte Petrano, between the villages of Palcano and Moria (Marche region, central Italy) (Fig. 1), that was previously described and studied by Deino et al. (1997). The stratigraphic interval considered in the present study encompasses the uppermost part of the "lower marly member", the "siliceous-calcareous intermediate member" and the "upper marly member" of the Schlier
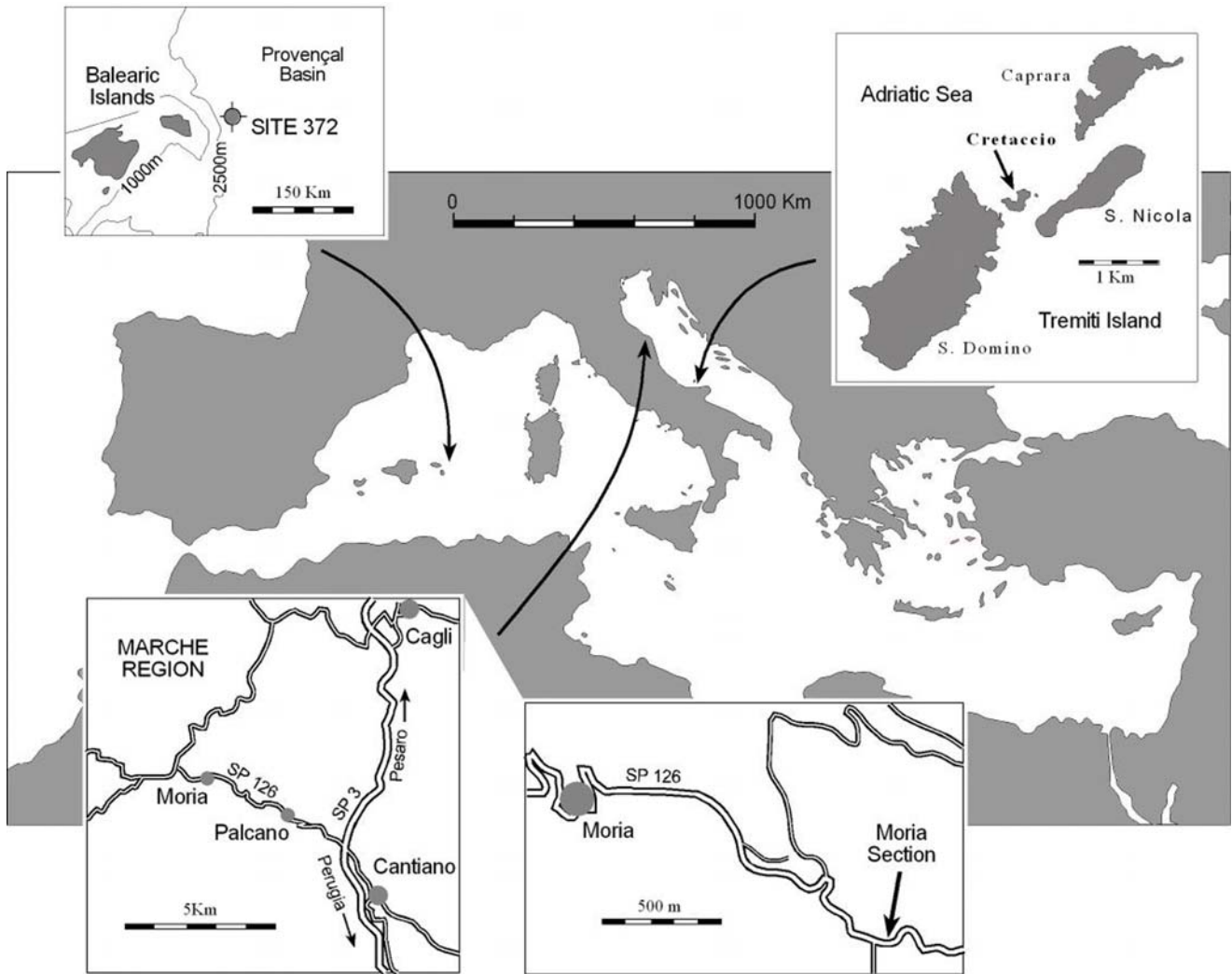
Fig. 1 - Location map showing the positions of the investigated sections.

Formation (Figs. 2-3). The "siliceous-calcareous intermediate member" is about 30 m thick and is composed of indurated calcarenites and marly limestone regularly alternated to soft marls. The calcarenites are fine-grained turbidites showing normal gradation. The "upper marly member" is about 23 m thick, six of which covered by detritus. It is mostly composed of soft grey-blue marls bearing pteropods ("Marne a pteropodi" Auct.) with intercalation of hard calcareous marls in the lower part.

Within the examined section, six deeply altered volcanoclastic levels are observed as described by Deino et al. (1997). Montanari et al. (1994) and Assorgia et al. (1994) suggested western Sardinia as the volcanic source for such levels. The radiometric age of two of these volcanoclastic layers (Fig. 3) is available (Deino et al. 1997): the one, indicated as MOR/91-58.4, which corresponds to the level located at 13 m in the present section, has an age of 16.18 ± 0.16 Ma; the second one, indicated as MOR/91-76.8 and corresponding to the level located at 28 m, has a radiometric age of 15.5 ± 0.16 Ma.

Deino et al. (1997) attributed the succession to the planktonic foraminifer *Globigerinoides trilobus* Zone (*pars*) – *Praeorbulina glomerosa* s.l. Zone (*pars*) (Iaccarino & Salvatorini 1982; Iaccarino 1985) and to the calcareous nannofossil MNN4a Zone – MNN5a Subzone (Fornaciari et al. 1996). The same authors also attributed the "siliceous-calcareous intermediate member" to magnetic Chron 5Br.

Along the section 329 samples were collected, at an average distance of about 16 cm. No samples were collected from the covered interval (between 31.5 and 37.5 m, Fig. 2, 5).

DSDP Leg 42, Site 372 (40°01.86'N; 04°47.79'E)

This hole was drilled on the eastern part of the Menorca escarpment (Balearic Basin) at 2699 m water depth (Fig. 1).

The interval from Core 31 (425.3 mbsf) to Core 21 (313.5 mbsf) has been investigated and sampled for the present study. Unfortunately this Site is affected by no-recovery and no cored intervals (Fig. 2).

Fig. 2 - Lithologic logs and sample positions of the studied sections. Mbsf = meters below sea floor.

The succession consists of homogeneous nanno-fossil marls or foram-nannofossil marls, light bluish grey to greenish grey in colour and moderately to intensely mottled by burrowing, which become more lithified in Core 31. According to the Shipboard Scientific Party (1978, p. 68), the studied interval "is interpreted as one of quite open-marine sedimentation, free of any coarse terrigenous input..." totally lacking of turbidite-type sediments.

The planktonic foraminifera were studied by Bizon et al. (1978), Bizon & Glaçon (1978), Cita et al. (1978), Thunell (1979), Foresi (1993), and Foresi et al. (1998), while the calcareous nannofossils were investigated by Müller (1978), Theodoridis (1984), Negri (1989), Fornaciari et al. (1996), and Maiorano (1998). According to these authors, the considered succession spans the interval from the *Praeorbulina glomerosa sicana* Subzone to *Dentoglobigerina altispira altispira* Zone of Iaccarino & Salvatorini (1982) and the interval between MNN4b Zone and MNN6b Subzone of Fornaciari et al. (1996).

In the present study 281 samples collected at a distance of 20-40 cm were investigated.

Cretaccio section (42° 07.30' N, 15° 29.98' E)

The investigated section outcrops on the homonymous islet of the Tremiti Islands, located in the southern part of the Adriatic Sea (Fig. 1). The section consists of several partially overlapping subsections, which have been correlated through geological field survey, ash layers, and sedimentary cyclicity. The total thickness of the composite section is about 45 m (Fig. 2).

The whole section belongs to the Cretaccio Formation (Selli 1971). The Cretaccio composite section was described in detail by Iaccarino et al. (2001) as a nearly regular rhythmic alternation of yellow dolomitic, more indurated marls and reddish dolomitic marls corresponding to the *lithofacies 2*, and whitish indurated marls and soft grey marls corresponding to the *lithofacies 3*; the distinct colour change from yellow/reddish to white/grey is recorded at 15 m and coincides with the beginning of the marly sedimentation (Fig. 4). The most peculiar feature is the presence of more indurated levels (characterised by higher percentages of $CaCO_3$) regularly alternated to softer ones. Four distinct ash layers, at 10.2 m, 22.9 m, 24.8 and 29.7 m, and two calcareous turbiditic layers at 36.6 m and 39 m are also distinguished along the succession (Fig. 2).

Previous calcareous plankton biostratigraphic studies were performed on the whole Miocene record of the Tremiti Islands (Foresi et al. 1998; Foresi et al. 2001; Iaccarino et al. 2001), pointing out the excellent micro-paleontological content and the high biostratigraphic potential of the succession. According to Iaccarino et al. (2001), the considered section is referable to the in-
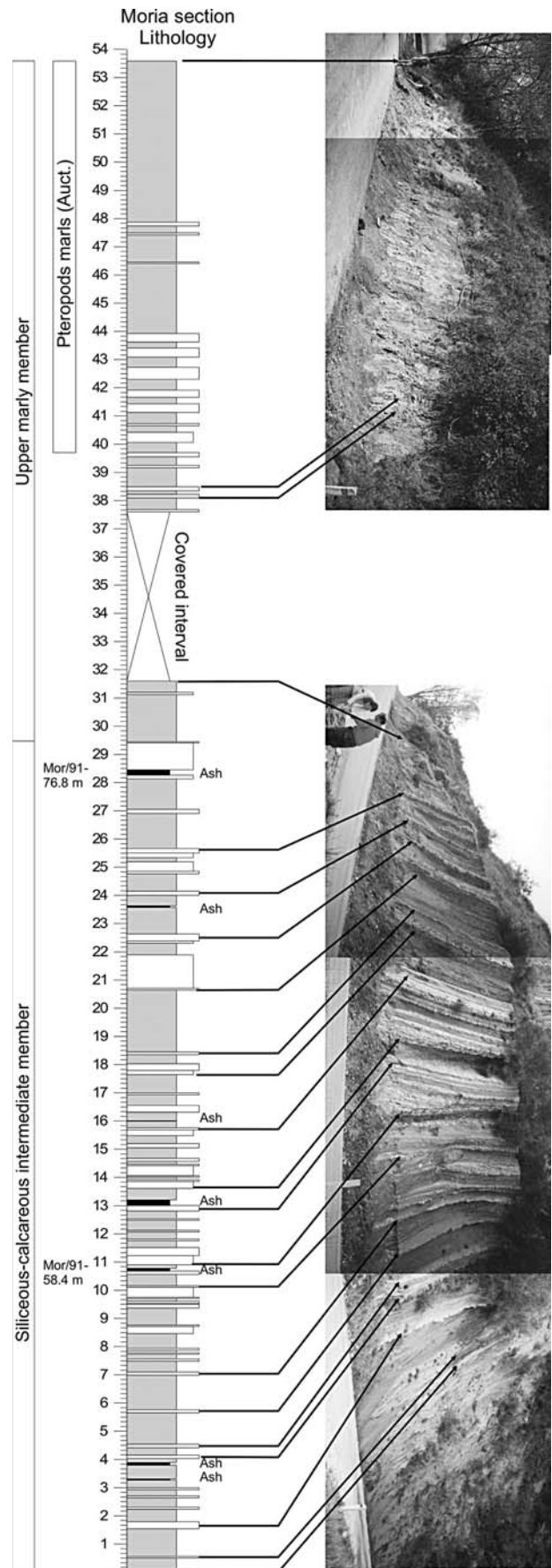

Fig. 3 - Panoramic view of the Moria section and lithological log of the measured section.
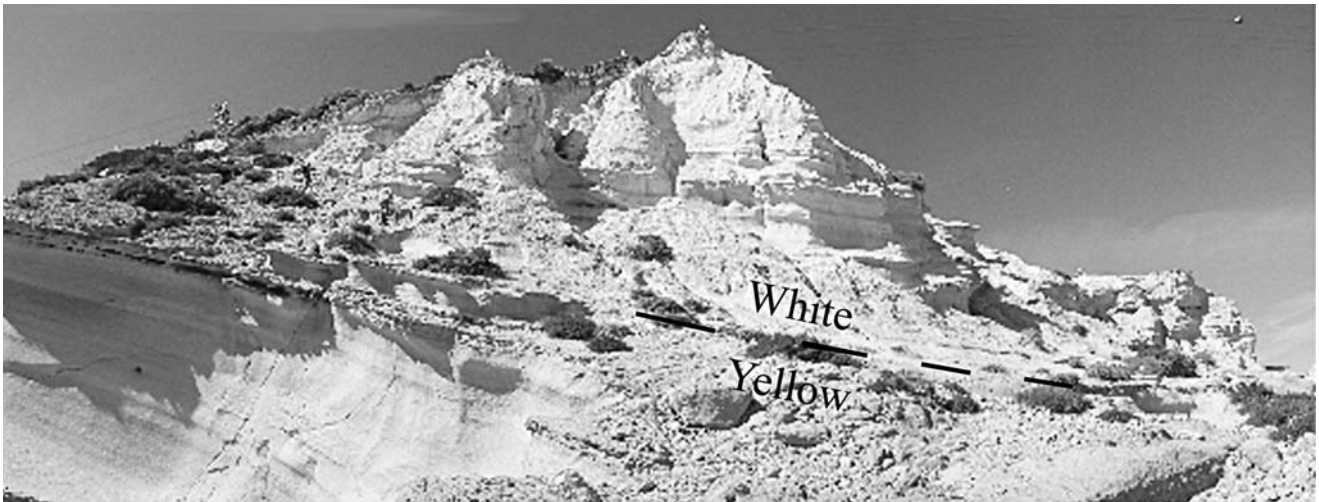
Fig. 4   - Panoramic view of the composite Cretaccio section. The line marks the lithological change between the yellow and withish *lithofacies*.

terval *Praeorbulina glomerosa sicana* Subzone – *Orbulina universa* Subzone of Iaccarino & Salvatorini (1982) and to the *Discoaster exilis – Sphenolithus heteromorphus* Zone of Fornaciari et al. (1996).

Along the section 494 samples were collected, at an average distance of 11 cm.

Methodology

Planktonic foraminifera
Samples for foraminifer analyses were first dehydrated in oven at 40 degrees, subsequently disaggregated in distilled water and washed with a 63 μm sieve. Quantitative analyses were performed on all the samples. Semi-quantitative and qualitative analyses have been carried out on 1/3 of the total samples equally distributed along the sections. Distribution patterns have been reconstructed counting about 300 specimens from splits of the > 125 μm fraction.

Taxon abundance is expressed as percentage of the total assemblages.

The graphs in Figs. 5, 6 and 7 represent the quantitative distribution patterns of 18 planktonic foraminifer categories showing biostratigraphic or abundance significance. In some cases these categories represent a single species; sometimes they group different taxa linked by morphological or phyletic affinities (see Appendix for description).

Nannofossils
Light microscope techniques were used for examination of smear slides which were prepared using standard method (Fornaciari et al. 1996 and reference therein). Quantitative data were collected counting the index species relative to a prefixed number of taxonomically related forms (species of helicoliths relative to 30 to 50 helicoliths; those of sphenoliths relative to 50 sphenoliths; *Discoaster deflandrei* frequencies at Site 372 were calculated counting a maximum of 30 discoasterids). The *Cyclicargolithus floridanus* and *Reticulofenestra pseudoumbilicus* (> 7 μm; Fornaciari et al. 1996) distribution patterns at Site 372 were calculated within a minimum of 100 specimens of the genera *Cyclicargolithus* and *Reticulofenestra* (> 3.5 μm), respectively. Advantages as well as the limits of applicability of the quantitative methodology were discussed by Backman & Shackleton (1983) and Rio et al. (1990).

Quantitative patterns of the selected taxa are plotted in Figs. 5, 6 and 7.

Most of the calcareous nannofossil species considered in this paper are referenced in Theodoridis (1984), Aubry (1984), Perch-Nielsen (1985) and Bown (1998).

Biohorizons

The major calcareous plankton biohorizons, recognised by means of both quantitative and qualitative analyses, allowed the correlation between the three studied successions (Fig. 8). Further, secondary and/or additional biohorizons were taken into account reinforcing the correlation among the sections and improving the biostratigraphic resolution. Such biohorizons, summarized in Tab. 1, are here discussed focusing mainly on the new ones. Calcareous nannofossil and planktonic foraminifer biohorizons are respectively indicated with letters and numbers along the text as in Tab. 1 and in Figs. 5-8.

Helicosphaera ampliaperta Last Common Occurrence (LCO) and Last Occurrence (LO) (A)

In the standard nannofossil zonations the LO of *Helicosphaera ampliaperta* defines the NN4/NN5 boundary of Martini (1971) and, together with the First Occurrence (FO) of *Calcidiscus macintyrei* (sensu Bukry 1975, 1978) and the Acme End (AE) of *Discoaster deflandrei*, the CN3/CN4 boundary of Okada & Bukry (1980).

In the Mediterranean, however, the level of *H. ampliaperta* LO is difficult to recognise, as the species shows a low frequency pattern (*queue*) in its final range, very often lengthened by reworking (Fornaciari et al. 1996).

The last specimens of *H. ampliaperta* are recorded along the examined sections at three different stratigraphic levels (Fig. 8); for this reason, in agreement with Fornaciari et al. (1996), the LO of *H. ampliaperta* cannot be considered a reliable event for stratigraphic correlations. On the contrary its LCO, well documented at Moria section, appears to be an easily detectable horizon (Figs. 5 and 8).
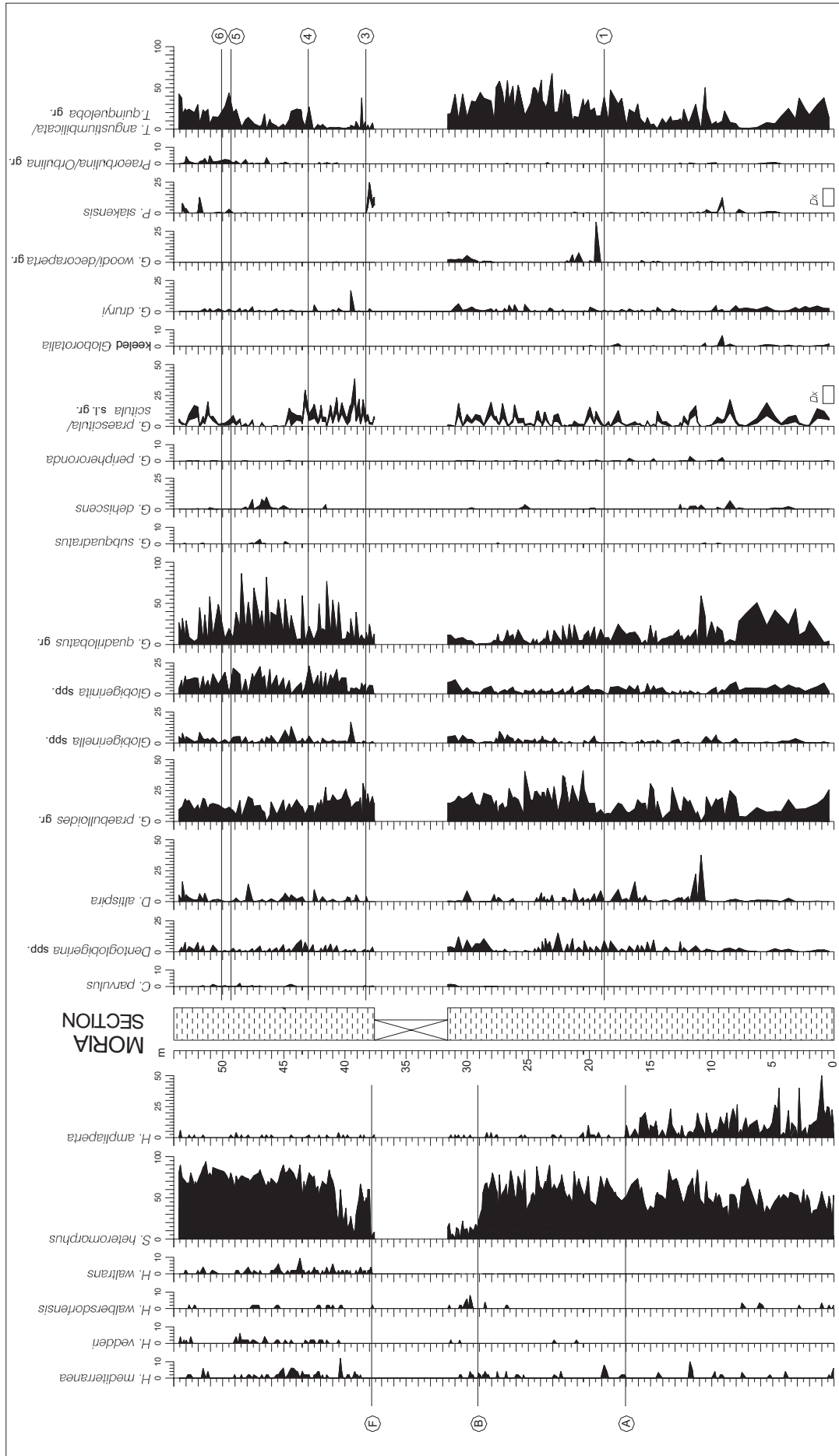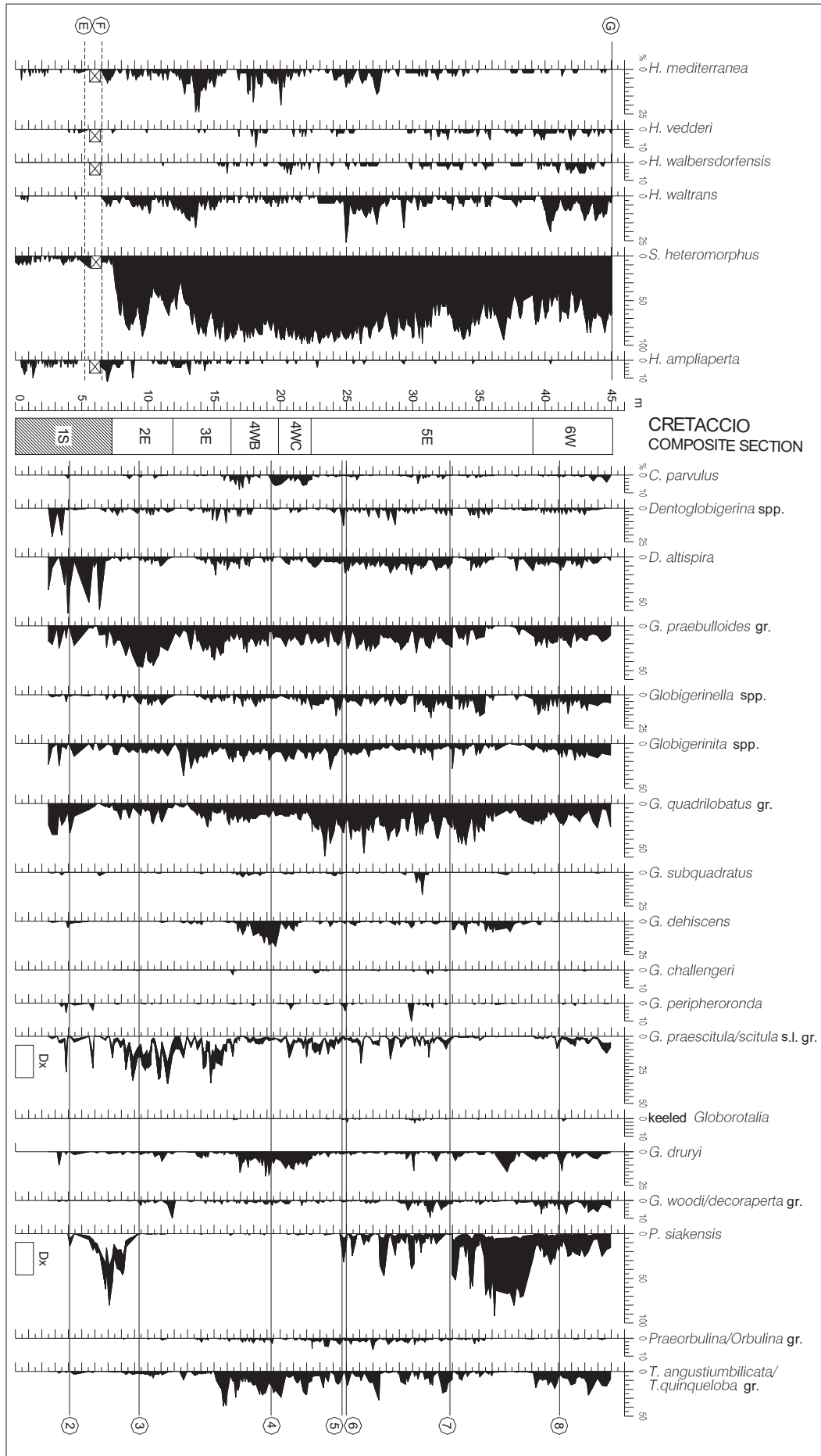
Fig. 5 - Quantitative distribution patterns of planktonic foraminifera and calcareous nannofossils from Moria section. The events, indicated with numbers (foraminifera) and letters (nannofossil) are listed in Tab. 1 and Fig. 8.

Fig. 6 - Quantitative distribution patterns of planktonic foraminifera and calcareous nannofossils from Cretaccio section. The events, indicated with numbers (foraminifera) and letters (nannofossil) are listed in Tab. 1 and Fig. 8. The barren boxes indicate that poor preservation hampered quantitative analysis of the calcareous nannofossil assemblages.
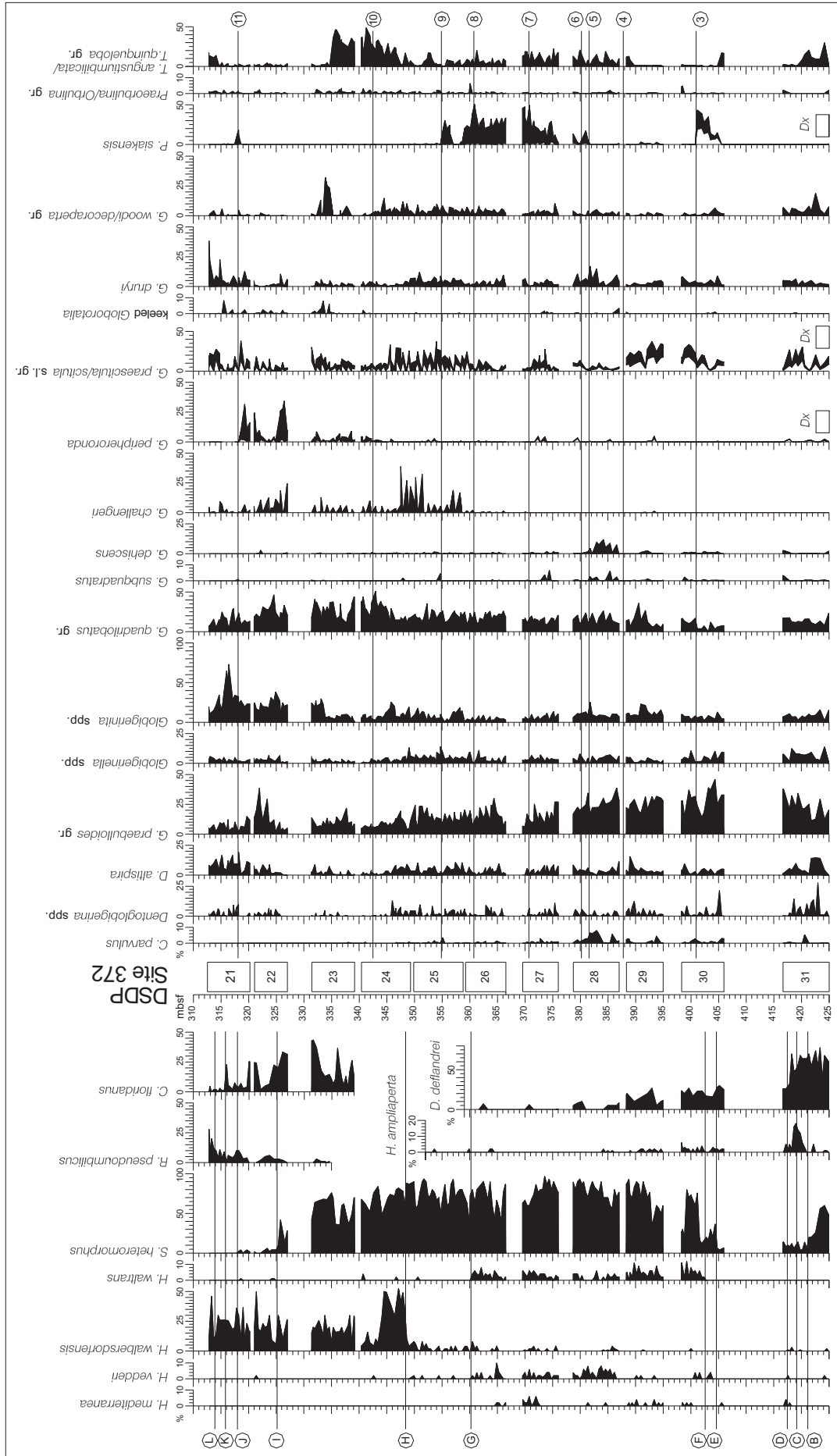
Fig. 7 - Quantitative distribution patterns of planktonic foraminifera and calcareous nannofossils at DSDP Site 372. The events, indicated with numbers (foraminifera) and letters (nannofossil) are listed in Tab. 1 and Fig. 8.
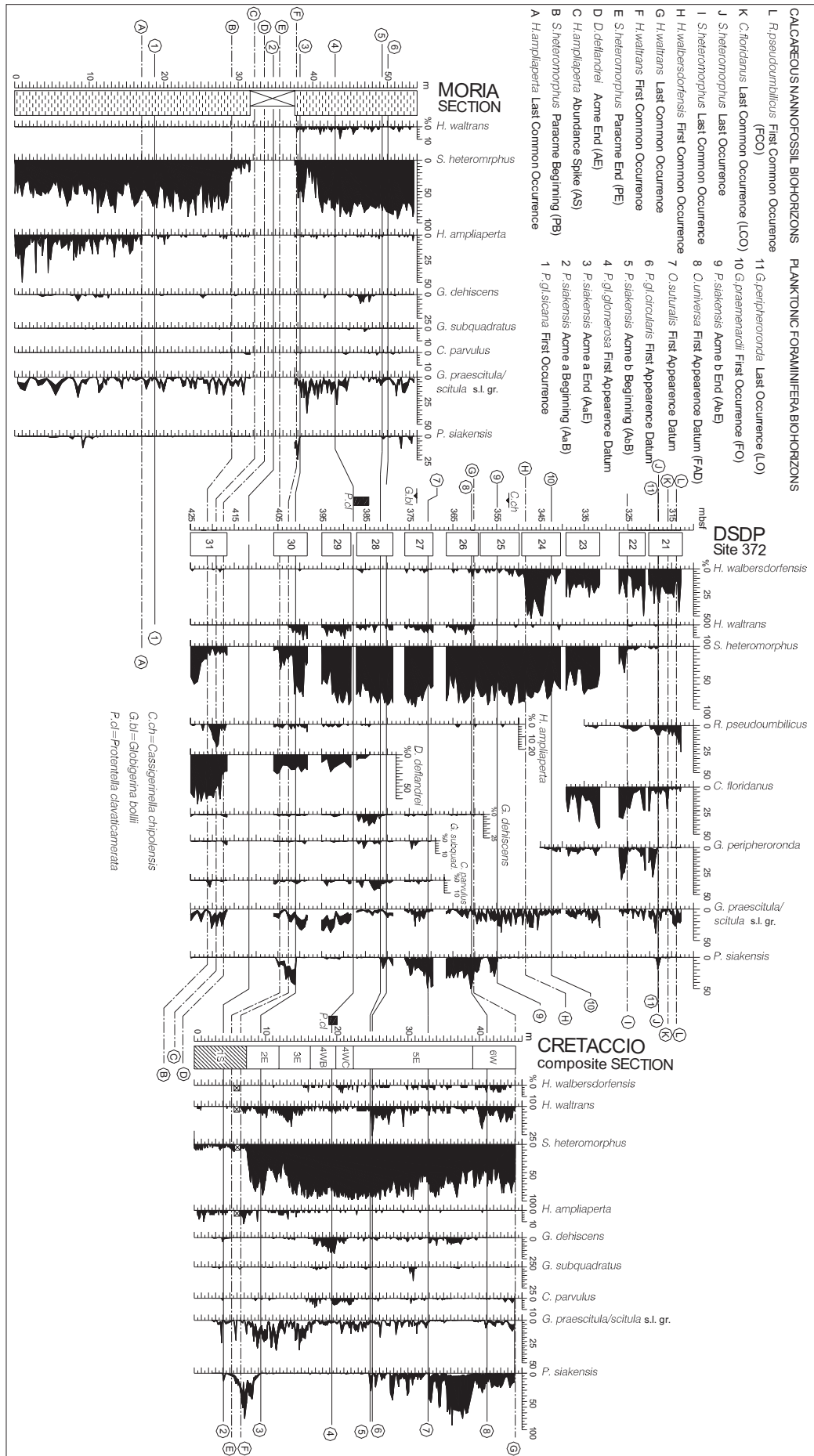
Fig. 8 – Biostratigraphic correlation between the upper Burdigalian-lower Serravallian sections considered in this work, based on the distribution of selected taxa.

	bioevent	samples	m	m	event	error +/-	samples	mbsf	mbsf	event	error +/-	samples	m	m	event	error +/-
L	R. pseudoumbilicus FCO						21/2 112_114 - 21/2 70_73	314,12	313,70	**313,91**	0,21					
K	C. floridanus LCO						21/4 4_6 - 21/3 110_112	316,04	315,60	**315,82**	0,22					
11	G. peripheroronda LO						21/5 70_72 - 21/5 0_2	318,20	317,50	**317,85**	0,35					
J	S. heteromorphus LO						21/5 70_72 - 21/5 30_32	318,20	317,80	**318,00**	0,20					
I	S. heteromorphus LCO						22/3 138_140 - 22/3 98_100	325,38	324,98	**325,18**	0,20					
10	G. praemenardii FO						24/2 108_110 - 24/2 1_3	343,00	341,93	**342,47**	0,53					
H	H. walbersdorfensis FCO						24/6 70_72 - 24/6 30_32	348,62	348,22	**348,42**	0,20					
9	P. siakensis A_bE						25/4 70_72 - 25/4 30_32	355,11	354,71	**354,91**	0,20					
G	H. waltrans LCO						26/2 0_2 - 26/1 110_112	360,50	360,10	**360,30**	0,20	TCR 02 59-58	45,09	45,03	**45,06**	0,03
8	O. universa FAD						26/2 36_38 - 26/2 0_2	360,86	360,50	**360,68**	0,18	TCR 02 21-20	41,02	40,92	**40,97**	0,05
7	O. suturalis FAD						27/2 81_83 - 27/2 38_40	370,81	370,38	**370,60**	0,22	TCRE 137-135	32,98	32,66	**32,82**	0,16
6	P. glom. circularis FAD	MOR 305 - 303	50,35	49,82	**50,09**	0,27	28/3 0_2 - 28/2 0_2	381,00	379,50	**380,25**	0,75	TCRE 62-60	25,07	24,89	**24,98**	0,09
5	P. siakensis A_bB	MOR 302 - 300	49,48	49,14	**49,31**	0,17	28/3 78_80 - 28/3 38_40	381,78	381,38	**381,58**	0,20	TCRE 59-57	24,79	24,50	**24,65**	0,15
4	P. glom. glomerosa FAD	MOR 266 - 260	43,49	42,51	**43,00**	0,49	29/1 130_132 - 28/6 148_150	388,80	386,98	**387,89**	0,91	TCR 02 212-210	19,40	19,15	**19,28**	0,13
3	P. siakensis A_aE	MOR 225 - 224	38,34	38,25	**38,30**	0,05	30/3 118_120 - 30/3 78_80	401,18	400,78	**400,98**	0,20	TCR 02 93-91	9,47	9,23	**9,35**	0,12
F	H. waltrans FCO	MOR 220 - 219	37,88	37,75	**37,82**	0,07	30/4 128_130 - 30/4 89_91	402,78	402,39	**402,59**	0,19	TCR 02 351-335	6,82	5,86	**6,34**	0,48
E	S. heteromorphus PE						30/5 138_140 - 30/5 98_100	404,78	404,38	**404,58**	0,20	TCR 02 331-319	5,61	4,79	**5,20**	0,41
2	P. siakensis A_aB											TCR 02 309-307	4,12	4,06	**4,09**	0,03
D	D. deflandrei AE						31/2 10_12 - 31/1 120_122	417,60	417,20	**417,40**	0,20					
C	H. ampliaperta AS						31/3 117_119 - 31/2 75_77	420,17	418,25	**419,21**	0,96					
B	S. heteromorphus PB	MOR 198 - 197	29,18	29,07	**29,13**	0,05	31/4 87_89 - 31/4 48_50	421,37	420,98	**421,18**	0,19					
1	P. glom. sicana FO	MOR 120 - 114	19,26	18,12	**18,69**	0,57										
A	H. ampliaperta LCO	MOR 109 - 108	17,12	16,96	**17,04**	0,08										

Tab. 1 – Summary of the stratigraphic positions of the biohorizons within the investigated sections. Calcareous nannofossils and planktonic foraminifera events are indicated by letters and numbers, respectively.

The LCO of *H. ampliaperta* is here defined as the level above which the *H. ampliaperta* distribution is scattered and characterised by very low percentages (less than 10%), with the exception of a peculiar "Abundance Spike" (Figs. 7-8).

Praeorbulina glomerosa sicana First Occurrence (FO) (1)

The *P. glomerosa sicana* First Appearence Datum (FAD) represents the "*Praeorbulina* datum" within the *Globigerinoides/Praeorbulina/Orbulina* lineage (Jenkins et al. 1981) and is considered the event which better approximates the Burdigalian/Langhian boundary in the historical meaning (e.g. Rio et al. 1997). The evolutive stages of *Praeorbulina/Orbulina* lineage are used to define zonal boundaries in the biostratigraphic schemes both in the Mediterranean (Bizon & Bizon 1972; Iaccarino & Salvatorini 1982; Iaccarino 1985) and in open ocean regions (Bolli 1957; Blow 1969; Kennett & Srinivasan 1983; Bolli & Saunders 1985).

Not all the evolutive stages of this group of taxa are clearly described, and different taxonomic concepts are suggested by the authors (Blow 1956; Jenkins et al. 1981). The main uncertainties concern the taxonomic concepts of *Globigerinoides bisphericus*, *P. glomerosa sicana* and *P. glomerosa curva* (Iaccarino & Salvatorini 1982; Foresi et al. 2001 and reference therein). The adopted taxonomic and nomenclatural criteria to distinguish these taxa are discussed in the Appendix.

The first appearance of *P. glomerosa sicana* was detected at 18.12 m (sample 120) only at the Moria section slightly above the *H. ampliaperta* LCO (Fig. 5), whereas at Site 372 and Cretaccio section *P. glomerosa sicana* is present from the lowermost samples. However, it is difficult to state if the first appearance of *P. glomerosa sicana* at Moria section represents the FAD of the species due to the bad preservation of planktonic foraminifera. In addition, the occurrence of some specimens of *P. transitoria* below the FO of *P. glomerosa sicana* at Moria renders uncertain the reliability of the latter biohorizon; in fact, the *P. transitoria* FO generally follows the *P. glomerosa sicana* FAD (Blow 1969; Kennett & Srinivasan 1983; Foresi et al. 2001).

Sphenolithus heteromorphus Paracme Beginning (PB) (B)

Fornaciari et al. (1996) first described an interval of virtual absence or reduced abundance ("paracme") of *S. heteromorphus* in many Langhian sections of the Mediterranean area, and defined two biohorizons, the PB and the Paracme End (PE), using them as lower and upper boundaries of the MNN4b biozone.

The paracme interval of *S. heteromorphus*, here defined as the interval characterised by percentages of this species lower than 20%, is well detectable in the three investigated sections (Figs 5-7). Within this interval the whole sphenolith group is poorly represented in the nannofossil assemblage.

The *S. heteromorphus* PB is very well documented at Moria and at Site 372, although in both sequences the paracme interval is not completely recorded (Figs. 5, 6).

Helicosphaera ampliaperta Abundance Spike (AS) (C)

As previously discussed, the distribution of *H. ampliaperta* above its LCO is scattered, and in some cases it is difficult or impossible to separate *in situ* specimens from the reworked ones. Nevertheless, an abundance spike higher than 10% of *H. ampliaperta* is easily detectable in closely sampled sections (Fornaciari et al. 1996). This abundance spike can be considered the last *in situ* presence of the species and thus potentially useful for correlations.

The *H. ampliaperta* AS is well evident only at Site 372, just above the *S. heteromorphus* PB (Fig. 7). At Moria section this event should fall within the covered interval, while at Cretaccio section it should occur below its base.

Discoaster deflandrei Acme End (AE) (D)

The quantitative distribution pattern of *D. deflandrei* was obtained only at Site 372 (Fig. 7) because the bad preservation and the scarce presence of discoasterids hampered the recognition of this species in the other two sections. At Site 372 the *D. deflandrei* AE (Bukry 1973) closely postdates the *H. ampliaperta* AS, and it does not appear suitable for stratigraphic correlations as already stated by Fornaciari et al. (1996).

Paragloborotalia siakensis Acme$_a$ Beginning (A$_a$B) (2)

The quantitative distribution pattern of *P. siakensis* shows two acme intervals, particularly useful for stratigraphic correlations. They are here indicated as Acme$_a$, the lowest one, and Acme$_b$ the uppermost one, to distinguish them from those recorded in the Serravallian and named "Acme 1" and "Acme 2" (Sprovieri et al. 2002a). The *P. siakensis* Acme$_a$, already reported by Dall'Antonia et al. (2001), is characterised by the presence of both left and right-coiled specimens; the A$_a$B is well detectable at the base of the Cretaccio section, in spite of the bad preservation of the foraminiferal assemblages (Fig. 6), suggesting that *P. siakensis* might be a taxon resistant to dissolution. At Moria section this event should occur within the covered interval and at Site 372 in the no-recovery interval between cores 30 and 31 (Figs 5 and 7).

Sphenolithus heteromorphus Paracme End (PE) (E)

The *S. heteromorphus* PE is well documented at Site 372 below the First Common Occurrence (FCO) of

H. waltrans, and within the *P. siakensis* Acme$_a$ interval (Fig. 7). The end of the paracme interval of *S. heteromorphus* is characterised by a remarkable "tri-furcated peak" well visible in all the three sections. At Site 372, this peak is preceded by a "small peak" with percentages exceeding 35%. In our concept the base of the "small peak" corresponds to the PE of *S. heteromorphus*. However, at Cretaccio section the "small peak" is not present because of the poor preservation of nannofossils and thus the PE of *S. heteromorphus* has been placed tentatively at 5.2 m. At Moria section, this biohorizon should fall in the covered interval.

Helicosphaera waltrans First Common Occurrence (FCO) (F)

Theodoridis (1984) and later Fornaciari et al. (1996) pointed out the restricted stratigraphic range of *H. waltrans* and its biostratigraphical potential.

In the studied successions, *H. waltrans* is sporadically present and very rare in the lower part of its distribution range; subsequently it becomes continuously and more commonly present with abundances rarely exceeding 10% of the helicoliths. At Moria and Cretaccio sections and at Site 372 the FCO of *H. waltrans* occurs between the *S. heteromorphus* PE and the *P. siakensis* Acme$_a$ End (A$_a$E) (Figs. 5-8) and represents a useful biohorizon for correlations.

Paragloborotalia siakensis Acme$_a$ End (A$_a$E) (3)

Although at Site 372 and Moria section only the uppermost part of the *P. siakensis* Acme$_a$ is present, this event was recognised in all the three sections and it represents one of the most useful horizons for biostratigraphical correlations, easily detectable also in routine analyses. In fact, in addition to the drastic drop of abundance, this level also represents the last occurrence of random (left and right) coiling direction of *P. siakensis*. The *P. siakensis* A$_a$E occurs just above the *S. heteromorphus* PE and is associated to an increase in abundance of the *Globorotalia praescitula/scitula* s.l. group in all the three investigated successions (Figs 5-8).

Praeorbulina glomerosa glomerosa First Appearance Datum (FAD) (4)

The second stage in the *Praeorbulina-Orbulina* evolutive lineage is the FAD of *Praeorbulina glomerosa glomerosa*. At this stage, many specimens of this group show a high degree of chamber envelopment, but *Praeorbulina glomerosa glomerosa* can be distinguished because of the presence of several slit-like sutural apertures.

In our sections the first specimens of *P. glomerosa glomerosa*, recognised in all the investigated sections, occur at different stratigraphic levels with respect to the distribution patterns of *H. waltrans*, *G. praescitula*, *Globoquadrina dehiscens*, *Catapsydrax parvulus*, *Globi-*

gerinoides subquadratus and *Protentella clavaticamerata* which are instead well comparable in the three sections (Fig. 8). The slight diachroneity for this biohorizon is probably due to problems of rarity and/or bad preservation.

Paragloborotalia siakensis Acme$_b$ Beginning (A$_b$B) (5)

The Acme$_b$ of *P. siakensis* starts gradually following an absence interval of the species. Within this acme interval *P. siakensis* is often very abundant reaching frequencies over 50% of the total planktonic foraminifer assemblage and shows exclusively a left coiling direction. The *P. siakensis* A$_b$B occurs above an interval with common *G. subquadratus* and *G. dehiscens* (Fig. 8).

This trend permits to detect the *P. siakensis* A$_b$B also in the Moria section where only the basal part of the acme is recorded (Fig. 8).

Helicosphaera waltrans Last Common Occurrence (LCO) (G)

The LO of this species was used by Theodoridis (1984) as subzonal boundary event; later on, Fornaciari et al. (1996) recognised the biostratigraphical potential of this species but they did not use either its LCO or the LO in their zonal scheme, due to its low frequencies within the helicoliths. The distribution pattern of the species in the studied sections indicates that the LCO of *H. waltrans* is a useful biohorizon for stratigraphic correlations. This event is clearly recorded at Site 372 and probably at Cretaccio section slightly above the *Orbulina universa* FAD (Fig. 8).

Paragloborotalia siakensis Acme$_b$ End (A$_b$E) (9)

This event is recorded only at Site 372, as the top of the Cretaccio section is older than this event (Fig. 8). The *P. siakensis* A$_b$E, occurs just below the LO of *Cassigerinella chipolensis* (Fig. 8), a secondary event detected only through qualitative analysis (see Appendix).

Helicosphaera walbersdorfensis First Common Occurrence (FCO) (H)

Müller (1981) first drew the attention to the distribution of the small but easily recognisable *Helicosphaera walbersdorfensis* for the biostratigraphic subdivision of the Miocene. According to Theodoridis (1984), this species first occurs close to the *S. heteromorphus* FO, and becomes common close to the *H. ampliaperta* LO. Fornaciari & Rio (1996) reported the presence of this taxon between the *Sphenolithus belemnos* LCO and the *S. heteromorphus* FCO (i.e. in the upper Burdigalian), and its "virtual absence" in the lower Langhian. Fornaciari et al. (1996) used the FCO of this species for defining the base of their MNN5b Subzone.

The lower range of *H. walbersdorfensis* is well evident at Site 372 (Fig. 7): the taxon occurs rarely and discontinuously from the base of the succession and its abundance rarely reaches 10% of the total helicoliths. It becomes very abundant above the *P. siakensis* A$_b$E and below the FO of *Globorotalia praemenardii* (Fig. 7). The FCO of *H. walbersdorfensis* is here defined as the level above which the species is continuously present in the helicoliths assemblage, with percentages higher than 10%, and its stratigraphical potential is confirmed.

Globorotalia praemenardii First Occurrence (FO) (10)

Keeled globorotalias are very rare in the Langhian of the Mediterranean area. At Site 372 the FO of *G. praemenardii* has been observed through qualitative analyses (Fig. 7). This is a remarkable datum since it falls within a long stratigraphic interval (from the FCO of *H. walbersdorfensis* to the LCO of *S. heteromorphus*) devoid of other significant bioevents. At Site 372 the FO of *G. praemenardii* is followed by a turnover in abundance between the *Tenuitellinata angustiumbilicata-Turborotalita quinqueloba* group (see Appendix) and *Globigerinita* spp. (Fig. 7).

Sphenolithus heteromorphus Last Common Occurrence (LCO) (I) and Last Occurrence (LO) (J)

The LO of *S. heteromorphus* appears as one of the most easily determinable biohorizons both in the Mediterranean area (Müller 1978; Ellis & Lohman 1979; Theodoridis 1984; Fornaciari et al. 1996; Foresi et al. 2002a) and in open ocean (e.g. Fornaciari et al. 1990; Olafsson 1989, 1991; Raffi et al. 1995; Backman & Raffi 1997; Shackleton et al. 1999; Turco et al. 2002). This event has been calibrated at 13.523 ± 0.011 Ma in the low-latitude Atlantic Ocean ODP Site 926 (Backman & Raffi 1997) and at 13.57 Ma in the equatorial Pacific Ocean ODP Leg 138 (Shackleton et al. 1999). Foresi et al. (2002a) recorded the uppermost quantitative distribution pattern of *S. heteromorphus* at "Ras il-Pellegrin" section (Malta Island) and Sprovieri et al. (2002a) established for the LO of the species an astronomical age of 13.59 Ma; more recently, Abels et al. (2005) astronomically calibrated the LO of *S. heteromorphus*, at Malta and Tremiti Islands at 13.65 Ma, suggesting an almost synchronous age for the event both in Mediterranean and oceanic areas.

Martini (1971) and Okada & Bukry (1980) used the *S. heteromorphus* LO in their oceanic zonal schemes; the bioevent is present as well in the Mediterranean zonations of Fornaciari et al. (1996) and Foresi et al. (2001). Furthermore, several authors (Fornaciari et al. 1996; Rio et al. 1997; Sprovieri et al. 2002a; Turco et al. 2002; Iaccarino et al. 2004; Lourens et al. 2004) considered the disappearance of the taxon as the most suitable event approximating the Langhian/Serravallian boundary (as-

tronomically dated at 13.82 Ma in correspondence of the oxygen isotope shift Mi3b event in Abels et al. 2005; Hilgen et al. 2006 http://www.geo.uu.nl/sns).

At Site 372 the quantitative curve of *S. heteromorphus* indicates that the taxon is very abundant in its final range, showing average percentages of 70%; such an abundance suddenly drops down, at 325 mbsf, to values lower than 10% and its distribution becomes scattered. The same trend has been observed in the succession recoverd at ODP Leg 138 (Raffi & Flores 1995) and at Site 926 (Backman & Raffi 1997; Turco et al. 2002), as well as at the "Ras il-Pellegrin" section (Foresi et al. 2002a; Abels et al. 2005). The specimens of *S. heteromorphus* observed above the drastic decrease in abundance were considered as reworked by most of the mentioned authors. However, comparing the quantitative curve of *S. heteromorphus* from the different sections, the final distribution pattern, characterised by low abundance of the species, may represent the uppermost distribution range of the taxon.

For this reason, the level of the remarkable decrease in abundance of this species, which is the most reliable event suitable for correlations, is here considered as the LCO and it correlates with the LO of *S. heteromorphus* of Fornaciari et al. (1996) and of subsequent authors.

At Site 372 the LCO of *S. heteromorphus* is recorded about 7 m below its LO which is observed at the same level as the LO of *G. peripheroronda* (Fig. 7).

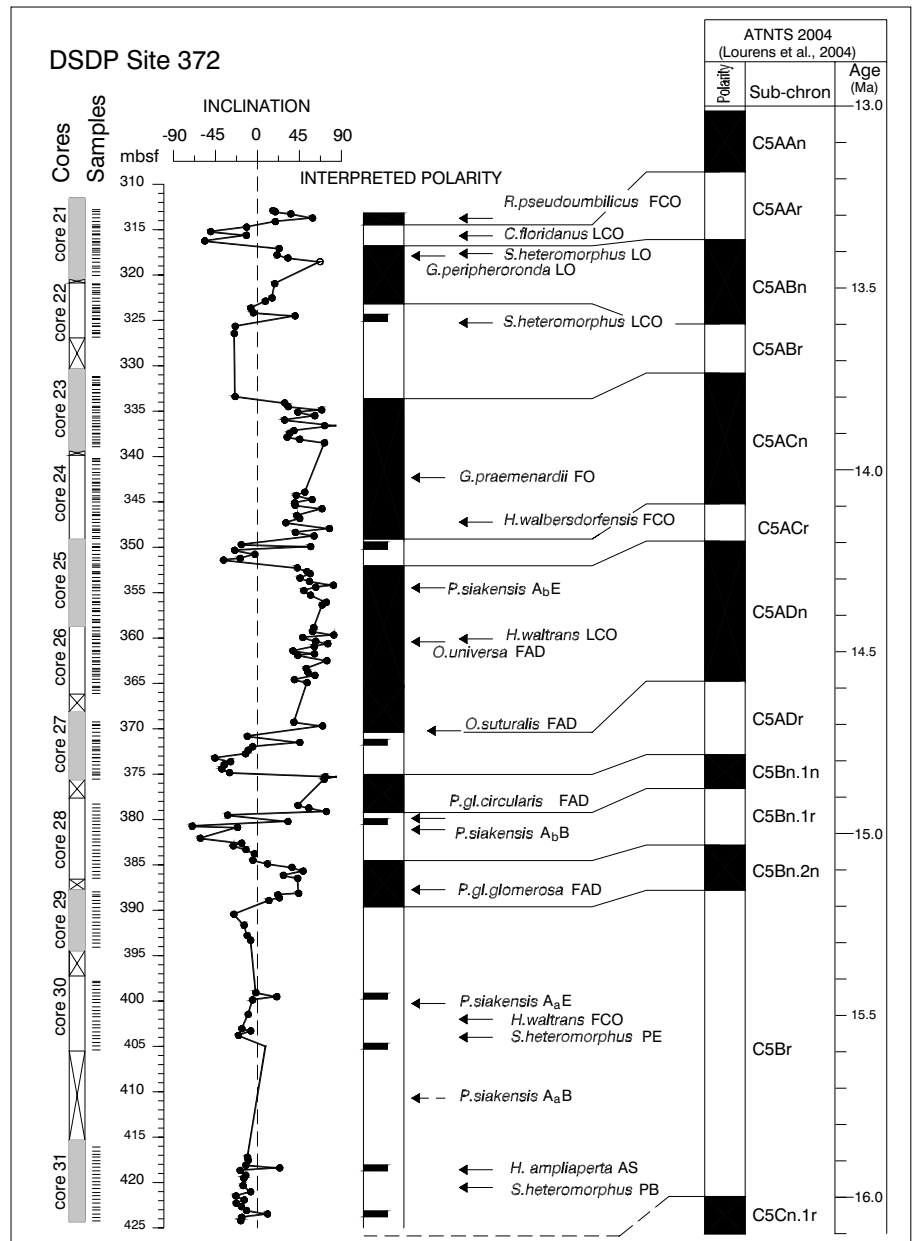### *Globorotalia peripheroronda* Last Occurrence (LO) (11)

The LO of *G. peripheroronda* is a very important bioevent in the Middle Miocene biostratigraphy both for middle latitude open ocean (e.g. Berggren et al. 1983) and for the Mediterranean area (Bizon & Bizon 1972; Iaccarino & Salvatorini 1982; Iaccarino 1985). The disappearance of the taxon is not isochronous on global scale (Iaccarino & Salvatorini 1982; Iaccarino 1985; Lirer & Iaccarino 2005) being younger in the Mediterranean (13.39 Ma or 13.52 Ma in the Malta succession, respectively in Sprovieri et al. 2002b; Abels et al. 2005) than in the low latitude open ocean (13.87 Ma at Site 926, Turco et al. 2002). The LO of *G. peripheroronda* is recorded at Site 372 at the same stratigraphic level as the LO of *S. heteromorphus* (Fig. 7).

Two additional events in foraminifer distribution pattern were observed close to the LO of *G. peripheroronda*: a small abundance peak of *P. siakensis* coincident with this event and an isolated influx of *G. dehiscens* about 5 m below (Fig. 8).

Magnetostratigraphy

Remarkable data derive from the paleomagnetic measurements conducted on 227 samples of Site 372.

Fig. 9 - Magnetostratigraphy at DSDP Site 372 (Abdul Aziz et al. 2008), compared to the standard Geopolarity Time Scale, and position of the biostratigraphic events recognised in the present paper. The position of *P. siakensis* A_aB (marked by asterisk) is supposed to fall in the no-recovery interval between cores 31 and 30.

Langhian integrated and emended calcareous plankton Zonal Scheme

The high resolution quantitative analyses of calcareous plankton assemblages here reported, allowed the recognition of secondary/additional events, which improve the resolution of pre-existing foraminifer and nannofossil biozonations (Iaccarino & Salvatorini 1982; Iaccarino 1985; Fornaciari et al. 1996). In the integrated calcareous plankton zonal scheme of Figure 10, planktonic foraminifer and the calcareous nannofossil zones are annotated with the acronyms MMi ("Mediterranean Miocene", Sprovieri et al. 2002a) and MNN ("Mediterranean Neogene Nannofossil", Fornaciari & Rio 1996; Fornaciari et al. 1996), respectively.

In particular, (1) the LCO of *H. ampliaperta* has been used to better subdivide the lower Langhian inter-

All the chrons and subchrons falling within the interval C5Br – C5AAn of the Geomagnetic Polarity Time Scale (Cande & Kent 1992, 1995) were detected (Fig. 9). The correlation of the biohorizons recognised in the present paper to the GPTS represents an excellent result as very few biochronological data are available for Langhian successions. Detailed information on magnetostratigraphy at Site 372 are reported in Abdul Aziz et al. (2008) and synthetised in Tab. 2. At Moria section, the magnetozones were already established by Deino et al. (1997), thus no new paleomagnetic analysis has been performed on this section; according to the authors the considered interval of the Moria section belongs to Chron 5Br.

The paleomagnetic analyses carried out on 50 samples from the Cretaccio section did not provided useful data.

bioevent	samples	mbsf range	mean depth	(sub)chron	CK95 (ka) (a)	ATNTS04 (ka) (b)
R. pseudoumbilicus FCO	21/2 112_114 - 21/2 70_73	314.12 - 313.70	313.91 ± 0.21	C5AAn ?	13097 ± 16	13135 ± 19
C. floridanus LCO	21/4 4_6 - 21/3 110_112	316.04 - 315.60	315.82 ± 0.22	C5AAr	13245 ± 17	13304 ± 19
G. peripheroronda LO	21/5 70_72 - 21/5 0_2	318.20 - 317.50	317.85 ± 0.35	C5ABn	13342 ± 11	13414 ± 12
S. heteromorphus LO	21/5 70_72 - 21/5 30_32	318.20 - 317.80	318.00 ± 0.20	C5ABn	13346 ± 6	13419 ± 7
S. heteromorphus LCO	22/3 138_140 - 22/3 98_100	325.38 - 324.98	325.18 ± 0.20	C5ABr	13544 ± 4	13628 ± 3
G. praemenardii FO	24/2 108_110 - 24/2 1_3	343.00 - 341.93	342.47 ± 0.20	C5ACn	13900 ± 12	13924 ± 11
H. walbersdorfensis FCO	24/6 70_72 - 24/6 30_32	348.62 - 348.22	348.42 ± 0.20	C5ACn	14032 ± 4	14053 ± 4
P. siakensis A_bE	25/4 70_72 - 25/4 30_32	355.11 - 354.71	354.91 ± 0.20	C5ADn	14240 ± 4	14250 ± 4
H. waltrans LCO	26/2 0_2 - 26/1 110_112	360.50 - 360.10	360.30 ± 0.20	C5ADn	14360 ± 4	14357 ± 4
O. universa FAD	26/2 36_38- 26/2 0_2	360.86 - 360.50	360.68 ± 0.18	C5ADn	14369 ± 4	14364 ± 4
O. suturalis FAD	27/2 81_83 - 27/2 38_40	370.81 - 370.38	370.60 ± 0.22	C5ADn	14589 ± 5	14561 ± 4
P. glom. circularis FAD	28/3 0_2 - 28/2 0_2	381.00 - 379.50	380.25 ± 0.75	C5Bn.1n/C5Bn.1r	14900 ± 17	14890 ± 19
P. siakensis A_bB	28/3 78_80 - 28/3 38_40	381.78 - 381.38	381.58 ± 0.20	C5Bn.1r	14938 ± 5	14930 ± 6
P. glom. glomerosa FAD	29/1 130_132 - 28/6 148_150	388.80 - 386.98	387.89 ± 0.91	C5Bn.2n	15100 ± 22	15102 ± 23
P. siakensis A_aE	30/3 118_120 - 30/3 78_80	401.18 - 400.78	400.98 ± 0.20	C5Br	15415 ± 5	15435 ± 5
H. waltrans FCO	30/4 128_130 - 30/4 89_91	402.78 - 402.39	402.59 ± 0.19	C5Br	15454 ± 5	15476 ± 5
S. heteromorphus PE	30/5 138_140 - 30/5 98_100	404.78 - 404.38	404.58 ± 0.20	C5Br	15502 ± 5	15527 ± 5
H. ampliaperta "spike"	31/3 117_119 - 31/2 75_77	420.17 - 418.25	419.21 ± 0.96	C5Br	15854 ± 23	15899 ± 24
S. heteromorphus PB	31/4 87_89 - 31/4 48_50	421.37 - 420.98	421.18 ± 0.19	C5Br	15901 ± 5	15949 ± 5

Tab. 2   - Magnetostratigraphic calibrated ages for calcareous plankton bioevents in DSDP Site 372 (after Abdul Aziz et al. 2008). (a) Ages of bioevents through interpolation of subchron ages according to the Cande & Kent (CK95) and (b) Astronomically Tuned Neogene Time Scale (ATNTS04) time scales.

val, and the FO and the LCO of *H. waltrans* to further subdivide the MNN5 Zone of Fornaciari et al. (1996). Therefore, the previous zonation is enriched of two subzones; (2) the Acme$_a$ of *P. siakensis* is an interval easily and unequivocally identified in the Langhian successions of the Mediterranean region, and it complements the planktonic foraminifer zonation of Iaccarino & Salvatorini (1982). Therefore, the two zones previously recognised in the Langhian Stage are now subdivided in 7 subzones which are named MMi4a to MMi5c.

Calcareous nannofossil Zones
Helicosphaera ampliaperta Interval Zone (MNN4)
Authors: Bramlette & Wilcoxon (1967), emended.
Definition: interval between the First Common Occurrence of *S. heteromorphus* and its Paracme End.
Magnetostratigraphy: from C5Dr (Fornaciari & Rio 1996) to C5Br.
Remarks: this zone covers the same biostratigraphic interval as the MNN4a and MNN4b Zones of Fornaciari et al. (1996), but it includes three subzones, easily recognisable on the basis of the distribution of *H. ampliaperta* and the paracme interval of *S. heteromorphus*.

Sphenolithus heteromorphus/Helicosphaera ampliaperta Concurrent Range Subzone (MNN4a)
Authors: this paper.
Definition: interval between the First Common Occurrence of *S. heteromorphus* and the Last Common Occurrence of *H. ampliaperta*.
Reference section: Moria.

Magnetostratigraphy: from C5Dr (Fornaciari & Rio 1996) to C5Br.
Remarks: it corresponds to the lower part of the MNN4a Zone of Fornaciari et al. (1996). In this subzone *S. heteromorphus* and *H. ampliaperta* are both continuously present with high frequencies. *Discoaster deflandrei* is the dominant species within the discoasterids.

Helicosphaera ampliaperta-Sphenolithus heteromorphus Interval Subzone (MNN4b)
Authors: Fornaciari, Di Stefano & Rio (in Fornaciari et al. 1996), emended.
Definition: interval between the Last Common Occurrence of *H. ampliaperta* and the Paracme Beginning of *S. heteromorphus*.
Magnetostratigraphy: entirely within C5Br (Deino et al. 1997).
Remarks: it corresponds to the upper part of the homonymous MNN4a Zone of Fornaciari et al. (1996). *Helicosphaera ampliaperta* shows reduced abundance (generally lower than 10%) and not continuous distribution. *Discoaster deflandrei* is still the dominant species within the discoasterids. The FO of *P. glomerosa sicana* is recorded just above the lower boundary of this subzone.

Coronocyclus nitescens Interval Subzone (MNN4c)
Authors: Fornaciari, Di Stefano & Rio (in Fornaciari et al. 1996), emended.
Definition: interval between the Paracme Beginning and the Paracme End of *S. heteromorphus*.
Magnetostratigraphy: entirely within C5Br.

Fig. 10 - Integrated calcareous plankton biostratigraphic scheme for the Langhian of the Mediterranean area. The age of the events is based on the magnetostratigraphy of Site 372 (Abdul Aziz et al. 2008). The position of *C. chipolensis* LO and *P. siakensis* A$_a$B is defined by the closest calibrated events while the position of *P. glomerosa sicana* FAD and *H. ampliaperta* LCO (marked by asterisk) is not magnetostratigraphically constrained.
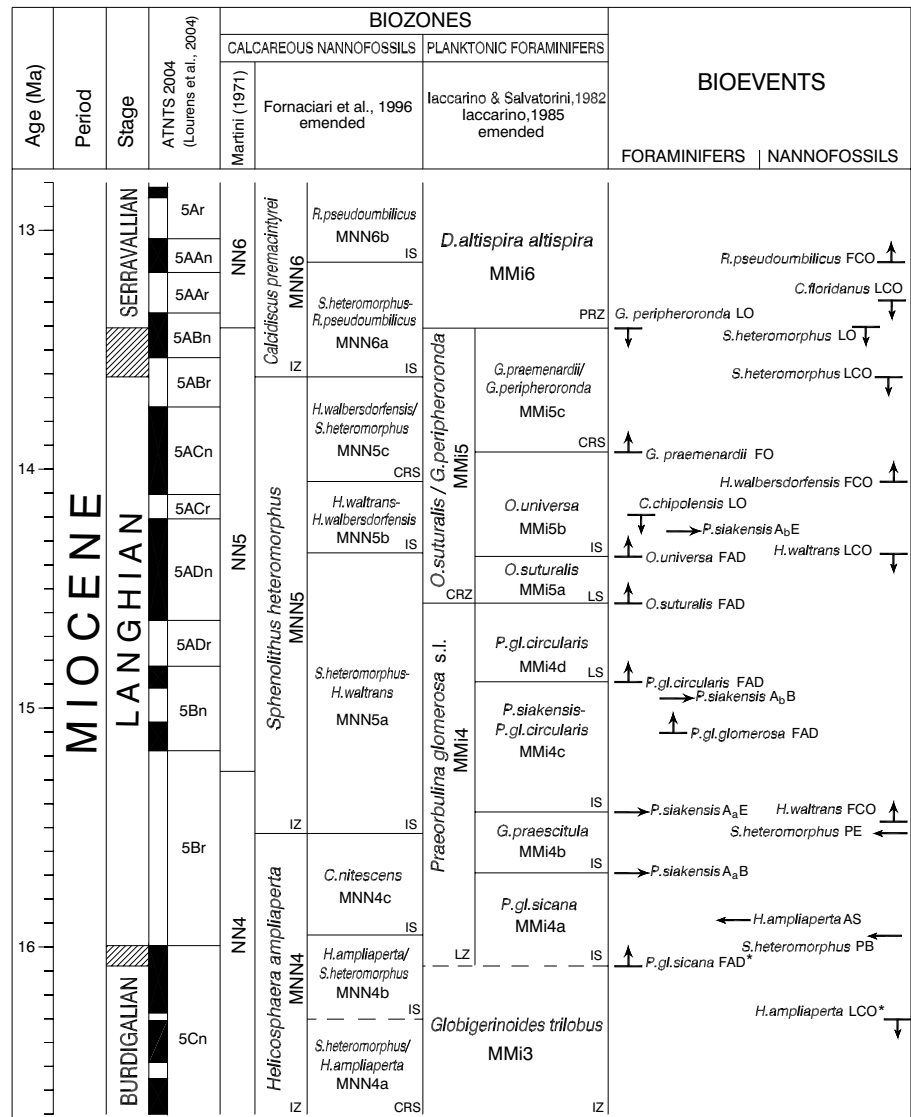
Remarks: it corresponds to the *S. heteromorphus* Absence Interval (Paracme) Zone (MNN4b) of Fornaciari et al. (1996).

The name of this subzone was changed to avoid confusion. In fact, Fornaciari et al. (1996) used the same index species *S. heteromorphus* for identifying subzone MNN4b as well as zone MNN5; in addition, the International Stratigraphic Code does not consider any biozone defined as "Absence Interval" or by "Paracme". In the present scheme the zone MNN4b of Fornaciari et al. (1996) becomes a subzone as its lower and upper boundaries can be traced only by quantitative analyses. The new index species, *Coronocyclus nitescens*, is one of the components of the nannofossil assemblage within this interval.

Helicosphaera ampliaperta is scatterly distributed in low frequencies with the exception of its AS, just above the *S. heteromorphus* PB. *Discoaster deflandrei*

shows its AE at the base of this subzone and is replaced by specimens of the *Discoaster variabilis* group.

Sphenolithus heteromorphus Interval Zone (MNN5)

Authors: Bramlette & Wilcoxon (1967), emended Fornaciari et al. (1996), re-emended.

Definition: interval between the Paracme End of *S. heteromorphus* and its Last Common Occurrence.

Magnetostratigraphy: from C5Br to the upper part of C5ABr.

Remarks: this zone basically corresponds to the *S. heteromorphus* Zone (MNN5) of Fornaciari et al. (1996) but the upper boundary is here defined by the LCO of *S. heteromorphus* and not by its LO. In this zone *S. heteromorphus* is always abundant.

Three subzones have been distinguished on the basis of the LCO of *H. waltrans* and the FCO of *H. walbersdorfensis*.

Sphenolithus heteromorphus - Helicosphaera waltrans **Interval Subzone (MNN5a)**

Authors: this paper.

Definition: interval between the Paracme End of *S. heteromorphus* and the Last Common Occurrence of *H. waltrans*.

Reference sections: DSDP Site 372.

Magnetostratigraphy: from C5Br to C5ADn.

Remarks: it corresponds to the lower part of the MNN5a Subzone of Fornaciari et al. (1996). The FCO of *H. waltrans* falls slight above the lower boundary of the subzone, followed by the *P. siakensis* A_aE. The subzone is characterised by the continuous presence of *H. waltrans*. *Helicosphaera mediterranea* is common especially in the lower-intermediate part of the interval; low frequencies (< 10%) of *H. walbersdorfensis* and rare specimens of *H. ampliaperta* may also occur. This subzone comprises the FO of *P. glomerosa glomerosa*, the FADs of *P. glomerosa circularis*, *O. suturalis*, and the *P. siakensis* A_bB. The FAD of *O. universa* occurs slightly below the top.

Helicosphaera waltrans - Helicosphera walbersdorfensis **Interval Subzone (MNN5b)**

Authors: this paper.

Definition: interval between the Last Common Occurrence of *H. waltrans* and the First Common Occurrence of *H. walbersdorfensis*.

Reference section: DSDP Site 372.

Magnetostratigraphy: from C5ADn to lowermost C5ACn.

Remarks: it corresponds to the upper part of the MNN5a Subzone of Fornaciari et al. (1996); *H. walbersdorfensis* may occur in low frequencies. The *P. siakensis* A_bE falls within this subzone.

Helicosphaera walbersdorfensis/Sphenolithus heteromorphus **Concurrent Range Subzone (MNN5c)**

Authors: Fornaciari, Di Stefano & Rio (in Fornaciari et al. 1996), emended.

Definition: interval between the First Common Occurrence of *H. walbersdorfensis* and the Last Common Occurrence of *S. heteromorphus*.

Magnetostratigraphy: from lowermost C5ACn to top of C5ABr.

Remarks: it basically coincides with the MNN5b Subzone of Fornaciari et al. (1996) but the upper boundary defined by the drastic decrease in abundance of *S. heteromorphus* corresponds to the LO of Fornaciari et al. (1996) as previously discussed; the base of the subzone is characterised by very high frequencies (over 50%) of *H. walbersdorfensis*. The upper boundary of this subzones slightly predates the LO of *G. peripheroronda*.

Calcidiscus premacintyrei **Interval Zone (MNN6)**

Authors: Fornaciari, Di Stefano & Rio (in Fornaciari et al. 1996), emended.

Definition: interval between the Last Common Occurrence of *S. heteromorphus* and the Last Common Occurrence of *C. premacintyrei*.

Magnetostratigraphy: from C5ABr to C5AAn (Lourens et al. 2004).

Remarks: the zone consists of the following two subzones.

Sphenolithus heteromorphus - Reticulofenestra pseudoumbilicus **Interval Subzone (MNN6a)**

Authors: Fornaciari, Di Stefano & Rio (in Fornaciari et al. 1996), emended.

Definition: interval between the Last Common Occurrence of *S. heteromorphus* and the First Common Occurrence of *R. pseudoumbilicus*.

Magnetostratigraphy: from C5ABr to lowermost C5AAn.

Reticulofenestra pseudoumbilicus **Interval Subzone (MNN6b)**

Authors: Fornaciari, Di Stefano & Rio (in Fornaciari et al. 1996), emended.

Definition: interval from the First Common Occurrence of *R. pseudoumbilicus* to the Last Common Occurrence of *C. premacintyrei*.

Planktonic foraminifer Zones
Praeorbulina glomerosa s.l. **Lineage Zone (MMi4)**

Authors: Iaccarino & Salvatorini (1982).

Definition: interval from the evolutionary appearance (First Appearance Datum) of *P. glomerosa sicana* to the First Appearance Datum of *O. suturalis*.

Magnetostratigraphy: from C5Br (Deino et al. 1997) to the base of C5ADn.

Remarks: this zone consists of the following four subzones, subdivided on the basis of the distribution pattern of *P. siakensis* and of the *P. glomerosa circularis* FAD.

Praeorbulina glomerosa sicana **Interval Subzone (MMi4a)**

Authors: Iaccarino & Salvatorini (1982), emended.

Definition: interval between the First Appearance Datum of *P. glomerosa sicana* and the *P. siakensis* $Acme_a$ Beginning.

Magnetostratigraphy: entirely within C5Br.

Remarks: the FO of *Catapsydrax parvulus* is recorded within this subzone at Site 372. This subzone comprises the *S. heteromorphus* PB, the *H. ampliaperta* AS and the *D. deflandrei* AE.

Globorotalia praescitula **Interval Subzone (MMi4b)**

Authors: this paper.

Definition: interval from the Acme$_a$ Beginning to the Acme$_a$ End of *P. siakensis*.

Reference section: Cretaccio.

Magnetostratigraphy: entirely within C5Br.

Remarks: the LO of *Paragloborotalia birnageae* is recorded within this subzone as well as the presence of transitional forms from *G. praescitula* to *G. archeomenardii*. This subzone comprises the PE of *S. heteromorphus* and the FCO of *H. waltrans*.

Paragloborotalia siakensis-Praeorbulina glomerosa circularis **Interval Subzone (MMi4c)**

Authors: this paper.

Definition: interval between the *P. siakensis* Acme$_a$ End and the First Appearance Datum of *P. glomerosa circularis*.

Reference section: Cretaccio.

Magnetostratigraphy: from C5Br to C5Bn.1r.

Remarks: this interval is characterised by high frequencies of *G. praescitula* and by an almost continuous occurrence of *C. parvulus*. This interval comprises the *P. glomerosa glomerosa* FAD and the first typical specimens of *Globigerina bollii* and *Globorotalia archeomenardii*. In the uppermost part of the subzone *P. siakensis* reappears with left-coiled specimens (A$_b$B).

Praeorbulina glomerosa circularis **Lineage Subzone (MMi4d)**

Authors: Iaccarino & Salvatorini (1982).

Definition: interval from the First Appearance Datum of *P. glomerosa circularis* to the First Appearance Datum of *O. suturalis*.

Magnetostratigraphy: from C5Bn.1r to lowermost C5ADn.

Remarks: the FAD of *P. glomerosa circularis* (biohorizon 6 in Figs. 5-7) occurs just above the *P. siakensis* A$_b$B. The LOs of *Globigerina bollii*, *G. archeomenardii* and *P. glomerosa glomerosa* are recorded within this subzone

Orbulina suturalis/Globorotalia peripheroronda **Concurrent Range Zone (MMi5)**

Authors: Bizon & Bizon (1972).

Definition: interval from the First Appearance Datum of *O. suturalis* to the Last Occurrence of *G. peripheroronda*.

Magnetostratigraphy: from lowermost C5ADn to the upper part of C5ABn.

Remarks: the basal boundary (biohorizon 7 in Figs. 6-7) postdates the top of the second interval with common *G. subquadratus*, and the LO of *Globigerina bollii* (see the Appendix for further details about this taxon) (Fig. 8).

This zone is subdivided in three subzones.

Orbulina suturalis **Lineage Subzone (MMi5a)**

Authors: Cita & Premoli Silva (1971-1973, in Cita 1976).

Definition: interval from the First Appearance Datum of *O. suturalis* to the First Appearance Datum of *O. universa*.

Magnetostratigraphy: entirely within C5ADn.

Remarks: high frequencies of left-coiled *P. siakensis* (Acme$_b$) are recorded within this subzone.

Orbulina universa **Interval Subzone (MMi5b)**

Authors: Iaccarino & Salvatorini (1982).

Definition: interval between the First Appearance Datum of *O. universa* and the First Occurrence of *G. praemenardii*.

Magnetostratigraphy: from C5ADn to the upper part of C5ACn.

Remarks: the *O. universa* FAD has been recorded at Cretaccio section and at Site 372 (biohorizon 8 in Figs. 6-7). In the lower part of its range this species is characterised by very few specimens. Only an accurate qualitative analysis allows the correct placement of the event. The *O. universa* FAD occurs slightly below the LO of *H. waltrans* (Fig. 8). The A$_b$E of *P. siakensis*, the LOs of *Cassigerinella chipolensis* and *P. glomerosa circularis* occur within this subzone; *Catapsydrax parvulus* temporarily disappears within this interval (the taxon occurs again in the Serravallian; Foresi et al. 2001, 2002a). The LO of *H. waltrans* and the FCO of *H. walbersdorfensis* occur at the base and at the top of the subzone, respectively.

Globorotalia praemenardii/Globorotalia peripheroronda **Concurrent Range Subzone (MMi5c)**

Authors: Iaccarino & Salvatorini (1982).

Definition: interval of co-occurrence of the nominal taxa from the First Occurrence of *G. praemenardii* to the Last Occurrence of *G. peripheroronda*.

Magnetostratigraphy: from C5ACn to the upper part of C5ABn.

Remarks: a turn-over in abundance between *Tenuitellata angustiumbilicata/Turborotalita quinqueloba* gr. and *Globigerinita* spp. occurs within this zone. This subzone comprises the LCO and LO of *S. heteromorphus*.

Correlation between DSDP Site 372 and "Ras Il-Pellegrin" section (Malta) across the Langhian/Serravallian boundary

Among the examined sections, the uppermost meters of the investigated interval of Site 372 can be correlated to the astronomically calibrated Ras il-Pellegrin
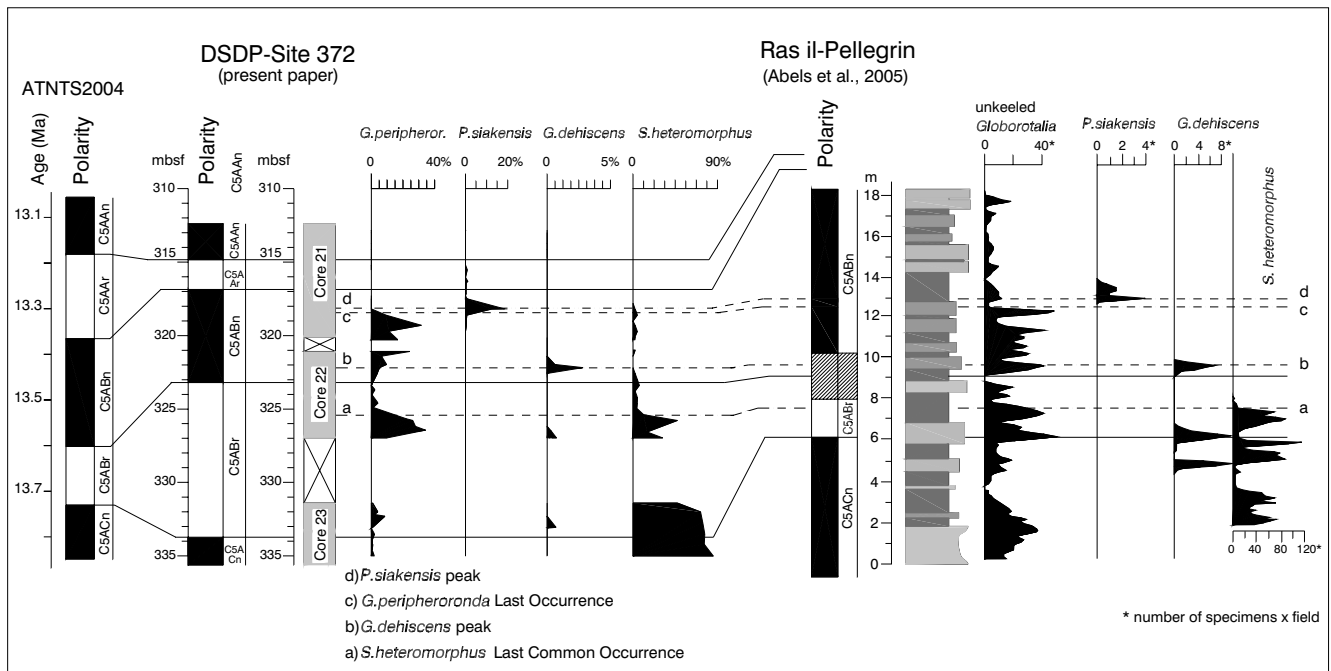
Fig. 11   - Magnetostratigraphic and biostratigraphic correlation based on selected taxa between the upper part of Site 372 succession (Cores 23 to 21) and the lower part of the Ras il-Pellegrin section (Malta Island) (Abels et al. 2005).

section of Malta Island (Foresi et al. 2002a; Sprovieri et al. 2002b; Abels et al. 2005), recently accepted by the International Commission on Stratigraphy (ICS) and ratified by the International Union of Geological Sciences (IUGS) as GSSP for the base of the Serravallian (Hilgen et al. submitted) (Fig. 11). Furthermore, the magnetostratigraphic data available for the Ras il-Pellegrin section (Abels et al. 2005) make the comparison more straightforward. Both successions yield the LCO of *S. heteromorphus* followed, after few meters, by the LO of *G. peripheroronda*. These two bioevents, whose high biostratigraphical reliability has widely been documented, fall within C5ABr and C5ABn, respectively. Such a correlation is further confirmed by minor events: an abundance spike of *P. siakensis* in correspondence with the LO of *G. peripheroronda* and an isolated peak of *G. dehiscens* between the LCO/LO of *S. heteromorphus* and the LO of *G. peripheroronda* (Fig. 11). In addition, the position of the LCO of *Cyclicargolithus floridanus* and the FCO of *R. pseudoumbilicus* with respect to the LCO of *S. heteromorphus* and to the LO of *G. peripheroronda* is well comparable at Site 372 and at Ras il-Pellegrin (Foresi et al. 2002a); in these successions the LCO of *C. floridanus* occurs at the same stratigraphic level as the *G. peripheroronda* LO while the FCO of *R. pseudoumbilicus* occurs slightly above. This succession of bioevents allows unambiguously to correlate Site 372 and Ras-il Pellegrin section across the Langhian/Serravallian boundary.

Comparisons with the historical Langhian Stratotype

The historical Langhian Stratotype (Cita & Premoli Silva 1960) has been re-examined by Fornaciari et al. (1997) who performed a new and more detailed sampling and biostratigraphic analysis of the succession. The section is a composite one and includes three segments (A, B and C), encompassing the uppermost part of the Cortemilia Formation, the Cessole Formation (corresponding to the stratotype of Vervloet 1966) and the lower part of the Cassinasco Formation, respectively. Many uncertainties concern the exact relationships and the correct correlation among the three subsections.

Comparison of biostratigraphic events recorded in the historical Langhian Stratotype with those from the studied sections, pointed out that:

1) the PE of *S. heteromorphus* is clearly identified also in the stratotype section, but most of the paracme interval probably falls within the interval between segments A and B of the composite section;

2) the two acme intervals of *P. siakensis* are recognisable in the semiquantitative distribution pattern; in fact, this taxon is commonly present in the lower part of the stratotype and from the topmost part of *P. glomerosa circularis* Subzone up to the *O. universa* Subzone;

3) the AE of *D. deflandrei* could not be detected in the Langhian Stratotype as in the present study sections;

4) the position of the LO of *H. waltrans* in the stratotype section is of difficult identification;

5) the relative position of the evolutive stages of the *Praeorbulina-Orbulina* lineage to other calcareous plankton events shows discrepancies between the hystorical stratotype section and the successions studied in this paper. For instance, the FOs of *P. glomerosa sicana* and *P. glomerosa glomerosa* precede the LCO of *H. ampliaperta* which in the Moria section is older than the *P. glomerosa sicana* FO.

The discrepancies, together with the uncertainties in correlating the three sub-sections, make the Langhian stratotype, as historically defined, not sufficiently suitable to represent a modern reference section.

Taking in account its historical significance and the recommendation of Rio et al. (1997), at the present, the most suitable biohorizon approximating the base of the Langhian still remains the FAD of *P. glomerosa sicana*.

However, on the basis of this research it is worth stressing that other biostratigraphic and/or physical criteria should be found for defining the base of the Langhian since the FAD of *P. glomerosa sicana* is difficult to be precisely identified and correlated at both regional and global scale owing to the rarity of this taxon in planktonic foraminifer assemblages and different taxonomic concept applied by various authors.

Conclusions

The integrated high-resolution analysis of the planktonic foraminifer and calcareous nannofossil content from the three sections, Moria, Cretaccio and DSDP Site 372, that on the whole cover stratigraphically the upper Burdigalian-lower Serravallian interval, results in improving the biostratigraphic resolution of the zonal schemes currently available for the Langhian (lower Middle Miocene) record of the Mediterranean area (Iaccarino & Salvatorini 1982 and Iaccarino 1985 for planktonic foraminifera; Fornaciari et al. 1996 for calcareous nannofossils). To note that the biostratigraphic value of most of the events used in such zonal schemes, widely used in Mediterranen correlations, is confirmed by the present study.

Quantitative analyses of both planktonic groups revealed significant fluctuations in abundance of several single taxa or group of taxa including some marker species resulting in distribution patterns similar from one section to the others, thus assuming a stratigraphic value. In addition, combining the distribution patterns of calcareous nannofossils and planktonic foraminifera, single bioevent in one group could be constrained by those of the other one resulting in a more detailed and precise biostratigraphic framework. In particular, the most significant features in the abundance curves used in improving the biostratigraphic zonal schemes are the acme intervals of *Paragloborotalia siakensis* among planktonic foraminifera and the LCOs of *H. ampliaperta* and *H. waltrans* among calcareous nannofossils.

The thick grid of calcareous plankton biohorizons calibrated to the magnetostratigraphy available for the Moria section (Deino et al. 1997) and Site 372 (Abdul Aziz et al. 2008), represents undoubtedly a valid base for subsequent cyclostratigraphic studies and astrochronological calibrations, in order to extend downward the Astronomical Tuned Neogene Time Scale (Lourens et al. 2004).

The Site 372 succession has been correlated to the astronomically calibrated Ras-il-Pellegrin section (Malta Island), which recently has been ratified by IUGS as the GSSP of the base of the Serravallian (Hilgen et al. submitted). The comparison shows the perfect fitting of the two sections across the Langhian/Serravallian boundary. On the contrary, the new improved zonal scheme was not applicable to the Langhian Stratotype as a whole owing to the uncertainty of its stratigraphic completness and to the lack of some key biohorizons that prevented a reliable correlation.

Among the investigated sections, Moria is the only one which encompasses the Burdigalian/Langhian boundary and could have been a potential candidate for the GSSP of the Langhian. However, because of the poor preservation of its calcareous plankton content and the uncertain position of the *P. glomerosa sicana* and *P. glomerosa glomerosa* FOs with respect to the other bioevents (as evidenced by the comparison with the Langhian historical stratotype section and the correlation of the three studied sections) it does not appear to be a good candidate. For concluding, it is recommended to search for a continuous pelagic succession suitable to verify if all the evolutionary stages of the *Globigerinoides-Praeorbulina* lineage represent unequivocal bioevents in order to better evaluate the reliability of the first occurrence of *P. glomerosa sicana* as biostratigraphic criterium for identifying the Burdigalian/Langhian boundary.

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Appendix

A list of the eighteen foraminiferal categories used for the quantitative analyses is here reported in alphabetical order and briefly discussed. It follows a list of further species or group of species recorded in the studied sections through qualitative analysis.

1. *Catapsydrax parvulus* Bolli, Loeblich & Tappan 1957.
According to Foresi et al. (2001, 2002b) *Globorotaloides falconarae* Giannelli & Salvatorini is a younger synonym of *C. parvulus*. The species occurs within the MMi4a Subzone at Site 372; rare and dubious specimens occur at Moria below the FO of *P. glomerosa sicana*. This taxon has been more frequently recorded in the upper part of MMi4c (Site 372 and Cretaccio) and within the MMi5b Subzone (Cretaccio). It disappears within the MMi5b Subzone.

2. *Dentoglobigerina* spp. This group includes: *D. baroemoenensis* (Le Roy, 1939); *D. langhiana* (Cita & Gelati, 1960).
Dentoglobigerina langhiana and *D. baroemoenensis* are considered as synonyms by some authors (Blow 1969; Kennett & Srinivasan 1983) but they are here considered as two different species (e.g. Foresi et al. 2001). Typical specimens (common in many samples) of *D. baroemoenensis* were recorded within levels not younger than MMi5b Subzone. The distribution of *D. langhiana* is similar to that of *D. baroemoenensis*.

3. *Dentoglobigerina altispira* gr. This group includes: *D. altispira altispira* (Cushman & Jarvis, 1936); *D. altispira globosa* (Bolli, 1957).
Dentoglobigerina altispira altispira represents the most common taxon within the *Dentoglobigerina* genus and it occurs along all the investigated successions. *Dentoglobigerina altispira globosa* shows the same stratigraphic distribution of *D. altispira altispira*, generally in much lower frequencies.

4. *Globigerina praebulloides* gr. This group includes: *G. praebulloides* Blow, 1959; *G. bollii* Cita & Premoli Silva, 1960; *G. falconensis* Blow, 1959.
The name of this group is that of the most representative taxon among those listed above. The occurrence of *G. bollii* in the investigated interval is noteworthy. This species, rarely mentioned in the literature, probably because it has been considered a younger synonym of *G. falco-*

nensis (e.g. Crescenti 1966; Blow 1969), shows larger and more inflated text, more inflated chambers and less sharp sutures than *G. falconensis* (see also Foresi et al. 2001). *Globigerina bollii* has been recorded from uppermost Oligocene to the lower Langhian (Foresi et al. 2001 and reference therein).
The taxon is scatterly present at Moria section and more common at Site 372 and at Cretaccio section. In the three studied sections the FO of typical *G. bollii* occurs in the MMi4c Subzone and predates the *Praeorbulina glomerosa glomerosa* FAD. Dubious specimens are also present in the uppermost part of the MMi4b Subzone at Moria section. The LO seems to be a reliable biostratigraphic event. In fact, both at Site 372 and Cretaccio, it closely predates the FAD of *O. suturalis* (the Moria section ends before both the *O. suturalis* FAD and *G. bollii* LO).

5. *Globigerinella* spp. This group includes: *G. obesa* (Bolli, 1957); *G. praesiphoniphera* (Blow, 1969); *G. pseudobesa* (Salvatorini, 1966).
Globigerinella obesa is present with consistent frequencies along all the sections. *Globigerinella praesiphoniphera* occurs as rare specimens in the examined successions within levels not older than the MMi4c Subzone. *Globigerinella pseudobesa* is a very rare species and it has been recognised, with questionable specimens, at Cretaccio section in the MMi4b-MMi4c interval.

6. *Globigerinita* spp. This group includes: *G. glutinata* Egger, 1893; *G. uvula* (Ehrenberg, 1861).

7. *Globigerinoides quadrilobatus* gr. This group includes *G. quadrilobatus* (d'Orbigny, 1846); *G. trilobus* (Reuss, 1850); *G. sacculifer* (Brady, 1877).

8. *Globigerinoides subquadratus* Bröennimann, 1954.
The taxon is absent or very rare in the successions with the exception of two interval within the MMi4c-MMi4d Subzones; its distribution frequency is always lower than 10%.

9. *Globoquadrina dehiscens* (Chapman, Parr & Collins, 1934).

10. *Globorotalia challengeri* Srinivasan & Kennett, 1981.
This species has been recorded from the MMi5a Subzone at Site 372 often in high frequencies and rare and scattered at Cretaccio. The taxon was not recognised at Moria probably because of the poor preservation of the foraminifera.

11. *Globorotalia peripheroronda* Blow & Banner, 1966.

12. *Globorotalia praescitula-scitula* s.l. gr.
Specimens referable to *G. praescitula* Blow, occur since the base of the succession up to the MMi5b. The first specimens of *G. scitula* s.l. are recognised from the MMi5b Subzone.

13. *Globoturborotalita druryi* (Akers, 1955).

14. *Globoturborotalita woodi-decoraperta* gr. This group includes: *G. decoraperta* (Takayanagi & Saito, 1962); *G. woodi* (Jenkins, 1960). The taxon occurs from the MMi4a Subzone (Site 372) up to the highest part of MMi5b (Site 372). *Globoturborotalita woodi* occurs at Moria from MMi3 Zone to MMi4a Subzone; at Site 372 it occurs in the MMi4a-MMi5c Subzones interval.

15. "keeled" *Globorotalia*. This group includes: *G. praemenardii* Cushman & Stainforth, 1945; *G. miozea* Finlay, 1938; *G. archeomenardii* Bolli, 1957.
Rare specimens of *G. archeomenardii* occur from the MMi4c Subzone. At Site 372 it occurs up to the MMi5a Subzone; few specimens were recorded at the top of the Cretaccio section within the MMi5b Subzone. Rare transitional specimens from *G. praescitula* have been recognised. Specimens of *G. miozea* scatterly occur along the whole Site 372 succession; from Core 24 (upper part of subzone MMi5b) the presence is more continuous and common.

16. *Paragloborotalia siakensis* (Le Roy, 1939).

17. *Praeorbulina/Orbulina* gr. This group includes: *P. glomerosa circularis* (Blow, 1956); *P. glomerosa glomerosa* (Blow, 1956); *P. glomerosa sicana* (De Stefani, 1952); *P. transitoria* (Blow, 1956); *O. bilobata* (d'Orbigny, 1839); *O. suturalis* Brönnimann, 1951; *O. universa* d'Orbigny, 1839.
The taxonomic criteria of Blow (1956) and suggestion reported in Iac-

carino & Salvatorini (1982) and in Foresi et al. (2001) have been adopted. These authors confirm, as suggested by Jenkins (1981), that *Globigerinoides sicanus* has to be referred to the genus *Praeorbulina* naming it as *P. glomerosa sicana*. At the same time Iaccarino & Salvatorini (1982) considered *P. glomerosa curva* as a younger synonym of *P. glomerosa sicana*. Some authors consider *Globigerinoides bisphericus* Brönnimann as ancestor of *P. glomerosa sicana*. In our opinion *G. bisphericus* is not a valid species and has to be considered as a variant within *G. trilobus* population.

The *Praeorbulina/Orbulina* group is very important from a biostratigraphic point of view, but it is always characterised by frequencies lower than 10%. The first specimens were detected in the middle-lower part of the Moria section: *P. transitoria* occurs in sample MOR 103 and *P. glomerosa sicana* in MOR 120. The poor preservation of the foraminifer assemblage in this part of the section probably does not allow to refer undoubtedly this first occurrences as the FAD of *P. glomerosa sicana*. On the contrary, all the evolutive transitions of the other taxa belonging to this group (with the exception of *O. bilobata*), were detected by means of qualitative analysis; on this basis the position of the FAD of all the taxa was located along the sequences. The first specimens of *O. bilobata* occur very close to the FAD of *O. universa*.

18. *Tenuitellinata angustiumbilicata - Turborotalita quinqueloba* gr. This group includes: *T. angustiumbilicata* (Bolli, 1957); *T. quinqueloba* (Natland, 1938). These two similar taxa have been grouped as they cannot be distinguished in bad preserved material, due to their reduced dimensions.

Cassigerinella chipolensis (Cushman & Ponton, 1932).
Because of its small size (< 100 μm) *C. chipolensis* is out of the counting performed on the >125 μm fraction. Anyway, the LO of this species has been detected throughout qualitative analysis, and it represents a very reliable event due to the peculiar morphology of the taxon, which makes very easy its identification in spite of its reduced size.

Cassigerinella martinezpicoi (Bermudez & Seigliei, 1967).
Rare specimens of this species occur in the Cretaccio section (between 18 and 20 m) and at Site 372 (core 28). Both intervals are referable to the MMi4c Subzone.

Clavatorella sturanii Giannelli & Salvatorini, 1976.
Very rare specimens are recorded from MMi4c (at Cretaccio and Moria sections) up to MMi5c (at Site 372).

Globigerina eamesi Blow, 1959.
Very rare specimens were recorded only at Cretaccio section, from levels referable to the MMi4c and MMi5a Subzones.

Globigerina foliata Bolli, 1957.
Very rare specimens occur at different stratigraphic levels within the examined successions.

Globigerina venezuelana Hedberg, 1937.
It occurs in rare specimens within the MMi4a-MMi4c Subzones interval.

Globigerinoides bulloideus Crescenti, 1966.
Very rare specimens occur in the examined sections.

Globigerinoides mitra Todd, 1957.
Very rare specimens occur only at Site 372 within the MMi4a Subzone and at Cretaccio section within the MMi4c Subzone.

Globigerinoides obliquus Bolli, 1957.
Specimens of this species sporadically occur in the successions; in very rare cases it shows higher frequencies.

Globoturborotalita cf. *ciperoensis* (Bolli, 1957).
Specimens referable to this taxon occur in the lower part of the Cretaccio section within MMi4a and MMi4b Subzones.

Paragloborotalia bella (Jenkins, 1967).
Very rare specimens are present in Subzones MMi4a and MMi4b at Cretaccio section; rare to common specimens below the First Occurrence of *P. glomerosa sicana* at Moria section.

Paragloborotalia birnageae (Blow, 1959).
Rare to common specimens occur in stratigraphic levels not younger than MMi4b Subzone.

Protentella clavaticamerata Jenkins, 1977.
It is present in a short and well correlable interval within MMi4c both at Site 372 and Cretaccio section.

Sphaeroidinellopsis disjuncta (Finlay, 1940).
Very rare specimens occur in the lowermost part of the Cretaccio section within the MMi4b Subzone and at Site 372, within few samples since MMi4d Subzone.