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CALCAREOUS PLANKTON BIO-EVENTS IN THE MIOCENE CASE PELACANI SECTION (SOUTHEASTERN SICILY, ITALY)

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Riassunto. La sezione di Case Pelacani, affiorante nella Sicilia Sud-orientale, è composta da una alternanza più o meno fitta e regolare di marne biancastre e livelli nerastri, a volte debolmente laminati, nella parte bassa e da marne biancastre e livelli biancastri più induriti nella parte alta. Campionata lungo quattro segmenti limitrofi e tra loro facilmente correlabili, essa ha uno spessore totale di 66.35 metri. Con una età riferibile al Serravalliano superiore e al Tortoniano inferiore, essa fa parte della Formazione Tellaro. La distribuzione dei più comuni taxa tra i foraminiferi planctonici e tra i nannofossili calcarei è stata valutata quantitativamente in 316 campioni raccolti ogni 20 cm. Essa ha permesso di individuare undici bio-eventi tra i foraminiferi planctonici (dei quali solo otto sono stati valutati su basi quantitative) e cinque eventi tra i nannofossili calcarei. La loro astrocronologia è stata ottenuta per correlazione con i dati ciclostratigrafici riportati per questa sezione in un altro lavoro. Le età sono del tutto comparabili con quelle ottenute per gli stessi eventi in altre successioni mediterranee. Le analisi paleomagnetiche di circa 30 metri campionati nella parte centrale della sezione hanno fornito risultati ambigui e pertanto non è stato possibile ottenere una magnetostratigrafia attendibile. La sezione di Case Pelacani, che copre un intervallo stratigrafico compreso tra poco sotto la comparsa di *Neogloboquadrina acostaensis* e poco sopra la prima comparsa regolare di questa specie, è un valido candidato per la definizione del GSSP (Global Stratigraphic Section and Point) della base del Tortoniano. Indipendentemente dalla scelta della sezione di riferimento per la definizione del GSSP, si suggerisce di definire il limite Serravalliaño/Tortoniano in coincidenza o vicino alla più alta presenza di *Paragloborotalia siakensis*, come già proposto, o in coincidenza o vicino alla più alta presenza comune (LCO) di *Globigerinoides subquadratus*. Questo livello è praticamente coincidente con la prima presenza regolare (FRO) di *Globigerinoides obliquus obliquus* e di poco successiva al livello di LCO di *Discoaster kugleri*, riconosciuto solo 2.25 metri (e 3 cicli precessionali) più in basso, nella sezione studiata.

Abstract. The upper Serravallian-lower Tortonian Case Pelacani section in Sicily is composed of the epipelagic sediments of the Tellaro Formation. The section, made of four easily correlated segments, records a more or less continuous sequence of lithologic couplets, with whitish marls and blackish levels in the lower part and whitish marls and whitish, more indurate levels in the upper part. The distribution of the most common taxa of planktonic foraminifera and calcareous nannofossils was estimated quantitatively in 316 samples, collected every 20 cm along the section which is 66.35 m thick. Eleven planktonic foraminifera (only the eight marker events were estimated quantitatively) and five calcareous nannofossil bio-events were identified. Their astrochronology was extrapolated by correlating them with the cyclostratigraphic results obtained for this section, and published separately. The ages compare well with the ages published for the same events in other Mediterranean sections. Paleomagnetic analysis along 30 meters in the central part of the section gave puzzling results and therefore no reliable magnetostratigraphy could be obtained. The Case Pelacani section, straddling the stratigraphic interval which starts slightly below the first occurrence and ends slightly above the first regular occurrence of *Neogloboquadrina acostaensis*, is a good candidate for the definition of the GSSP (Global Stratigraphic Section and Point) of the Tortonian. Independently from the section selected, we suggest to define the Serravallian/Tortonian boundary in a level coincident with or near the last occurrence of *Paragloborotalia siakensis*, as previously proposed, or coincident with or near the last common occurrence (LCO) of *Globigerinoides subquadratus*. This latter level virtually coincides with the first common occurrence (FCO) of *Globigerinoides obliquus obliquus* and is slightly above the last regular occurrence (FRO) of *Discoaster kugleri*, which occurs only 2.25 meters (and 3 precessional cycles) below in the section under study.

Introduction

The Italian project "Paleoceanography and chronology of the middle to late Miocene in the Mediterranean realm through the calcareous plankton stratigraphy, cyclostratigraphy and stable isotope stratigraphy. Comparison with oceanic areas" (MURST, 1998) studied Mediterranean sequences to obtain data on astrochronology, based on different cyclostratigraphic approaches, and paleoceanography for the stratigraphic interval between the latest Langhian and the early Tortonian. Sections cropping out in three different localities were studied (Fig. 1). The Case Pelacani section, in eastern Sicily, covers the uppermost Serravallian-lower Tortonian interval.

In this paper we report the quantitative distribu-

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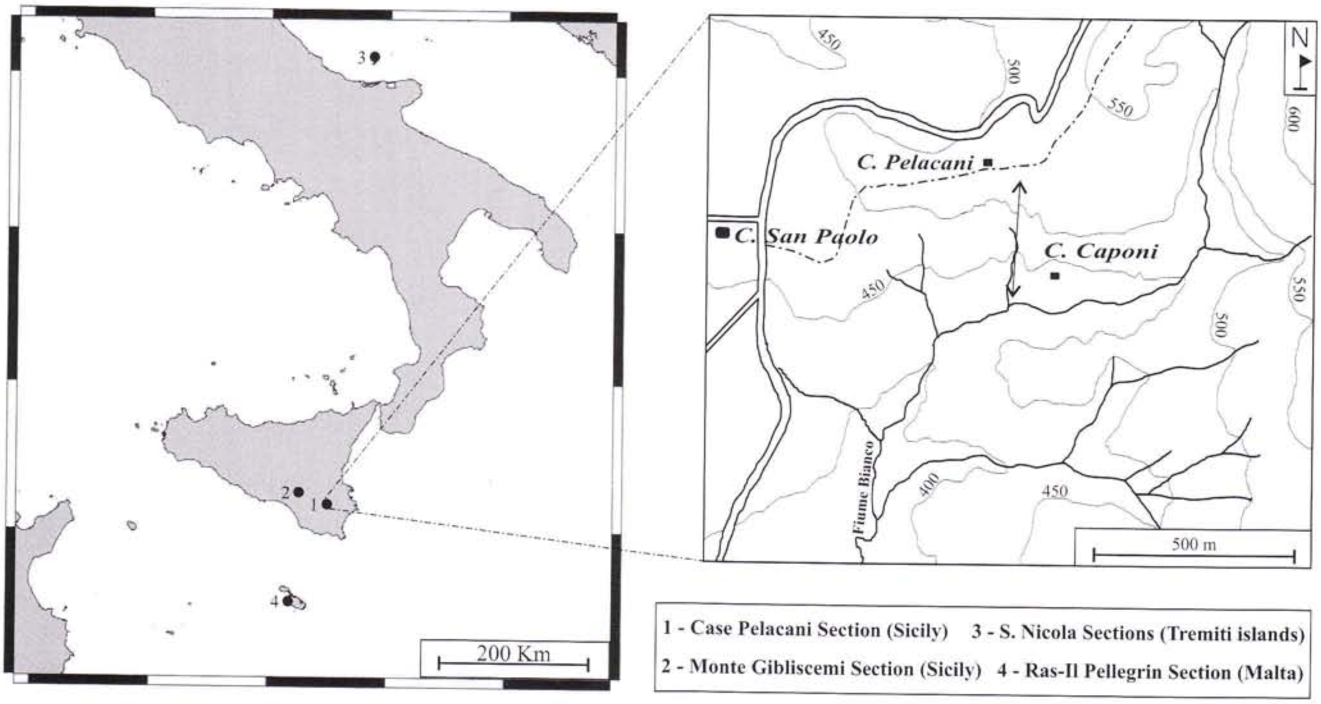

Fig. 1 - Location map and topographic sketch of the Case Pelacani section.

tion of the main calcareous plankton taxa (foraminifera and nannofossils) identified in the upper Serravallian-lower Tortonian segment of the Case Pelacani section. The more or less detailed and complete biostratigraphy of this section is presented in Romeo & Sciuto (1987), Di Stefano (1995) and Fornaciari et al. (1996), who report a total thickness between 60 and 130 meters for this section. The lower and upper parts of their logged section were not used in this study because of major tectonic disturbances in the lower part and relatively long covered segments in the upper part. Only the middle part, with a thickness of 66.35 meters, could be sampled continuously in detail.

Methods

The section was sampled every 20 cm. The lithological changes were identified visually in the field and their elevation above the base was reported accurately. Fifty grams of dry sediment for each of the 316 studied samples were washed through a 63 µm sieve for the analyses of foraminifera. Quantitative data are based on results from counting about 300 specimens of planktonic foraminifera from the residue > 125 µm. The relative abundance fluctuations of the most important taxonomic units were plotted. Identification of the bio-events of the planktonic foraminifera was based initially on a semi-quantitative study of the residue > 63 µm, obtained from 100 grams of dry sediments of samples studied for each meter. This analysis was integrated by the quantitative analysis of all the samples.

Smear slides were prepared from unprocessed sediments following standard techniques. The distribution of selected calcareous nannofossil taxa was obtained by light microscope analysis (transmitted light and crossed nicols) at about 1000 X magnification. Abundance data were collected using the methodology described by Backman & Shackleton (1983) and Rio et al. (1990). They are extensively used in Mediterranean or extra-Mediterranean quantitative biostratigraphic studies of Neogene marine records in both ODP sequences and land sections (Raffi & Flores 1995; Raffi et al. 1995; Fornaciari et al. 1996; Backman & Raffi, 1997; Di Stefano 1998; Hilgen et al. 2000).

In detail, the following counting methods were used:

1 = Index species vs. a prefixed number of taxonomically related forms.

2 = Number of specimens of an index species or genus in a prefixed area of the slide (4.52 mm^2).

Method 1 was adopted to detect abundance patterns of *Reticulofenestra pseudoumbilicus* (within 100 reticulofenestrids), *Coccolithus miopelagicus* (within 100 *Coccolithus*), *Helicosphaera walbersdorfensis* and *H. stalis* (within 100 helicoliths).

Method 2 was adopted to detect the abundance patterns of *Discoaster* as genus, of some selected *Discoaster* species and of *Catinaster coalitus*.

Taxonomic concepts of considered taxa follow Perch-Nielsen (1985), Theodoridis (1984) and Fornaciari et al. (1996). The adopted biostratigraphic scheme is from Fornaciari et al. (1996).

A paleomagnetic sampling survey for magnetostratigraphic purposes was conducted along the central part of the Case Pelacani section. It encompasses a stratigraphic thickness of about 30.40 m. A total of 59 sampling sites, consisting of two core samples per site, was retrieved. Samples were collected using a portable gasoline-powered drill and were oriented in situ with a compass mounted on a special device. Three to four standard specimens, 2.54 cm in diameter and 2.10 cm in length, were cut from each sample in the laboratory. Natural remanent magnetization (NRM) and remanence through demagnetization were measured on a 2G Enterprises DC SQUID high-resolution pass-through cryogenic magnetometer (manufacturer noise level of 10^{-12} Am^2) operating in a shielded room at the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Rome, Italy. A Pyrox oven located in the shielded room was used for thermal demagnetization. Alternating field (AF) demagnetisation was performed with three orthogonal coils installed in line with the cryogenic magnetometer. Orthogonal vector demagnetisation plots (Zijderveld 1967) were used to represent demagnetization data.

Geological setting and location.

The section crops out in eastern Sicily, near the village of Palazzolo Acreide, along the river Bianco, a tributary of the Tellaro river. Its middle point has the following geographic coordinates: Lat. 37°02'54", Long. 14°53'00". The top of the segment under study ends near locality Case Pelacani (Fig. 1), which may be easily accessed following a small path which starts off the main road, 5 km from Palazzolo Acreide (SW direction).

The section belongs to the Ragusa Platform of the southeastern Sicily Foreland and covers the middle-upper part of the Miocene Tellaro Formation (Rigo & Barbieri 1959). The first calcarenitic beds of the overlying Palazzolo Formation (Rigo & Barbieri 1959) are present slightly above the top of the section. The logged sequence is composed of four segments (Fig. 2), which crop out near each other. They were easily correlated on the basis of small-scale lithological cycles and biostratigraphic events.

Lithology

The section consists of open marine, epibathyal sediments that show a cyclic alternation of two different main lithologies (Fig. 3). In the lower part, up to about 24 m from the base (Fig. 4), the lithologic sequence consists of an alternation of whitish homogeneous marls and dark, faintly laminated marls. In the upper part, from 24 to 57 m, it consists of whitish and soft or indurated marls. Above 57 m an apparently homogeneous, thick marly interval is present up to just below the top of the section. It is possible, though , that we failed to recognize lithological cycles in the portions where the outcrop is poorly exposed and particularly steep. In this part of the sequence the sediment accumulation rate apparently increases slightly, as evidenced by an increase of silt and reworked nannofossil specimens in the smear slides from about 54 m above the base. Thus, the increased sedimentation rate may be ascribed essentially to the additional input of very fine-grained sediments.

Each of the lithologic couplets is interpreted as a small-scale cycle. Where present, the lithologic alternation displays a characteristic cycle pattern. Essentially, it

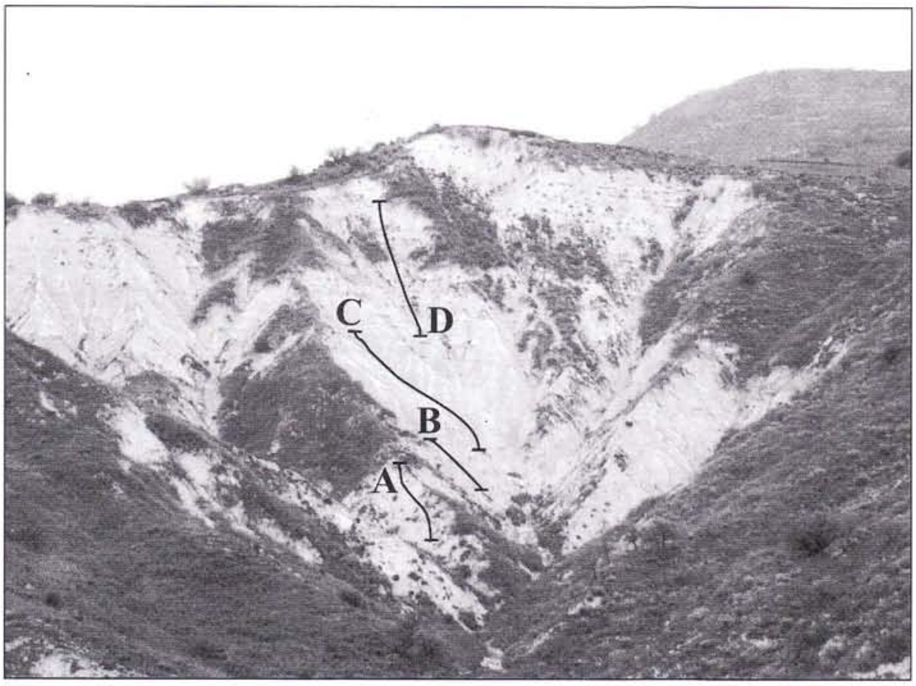

Fig. 2 - Picture of the Case Pelacani segments. Segments A, B, C, and D are indicated.

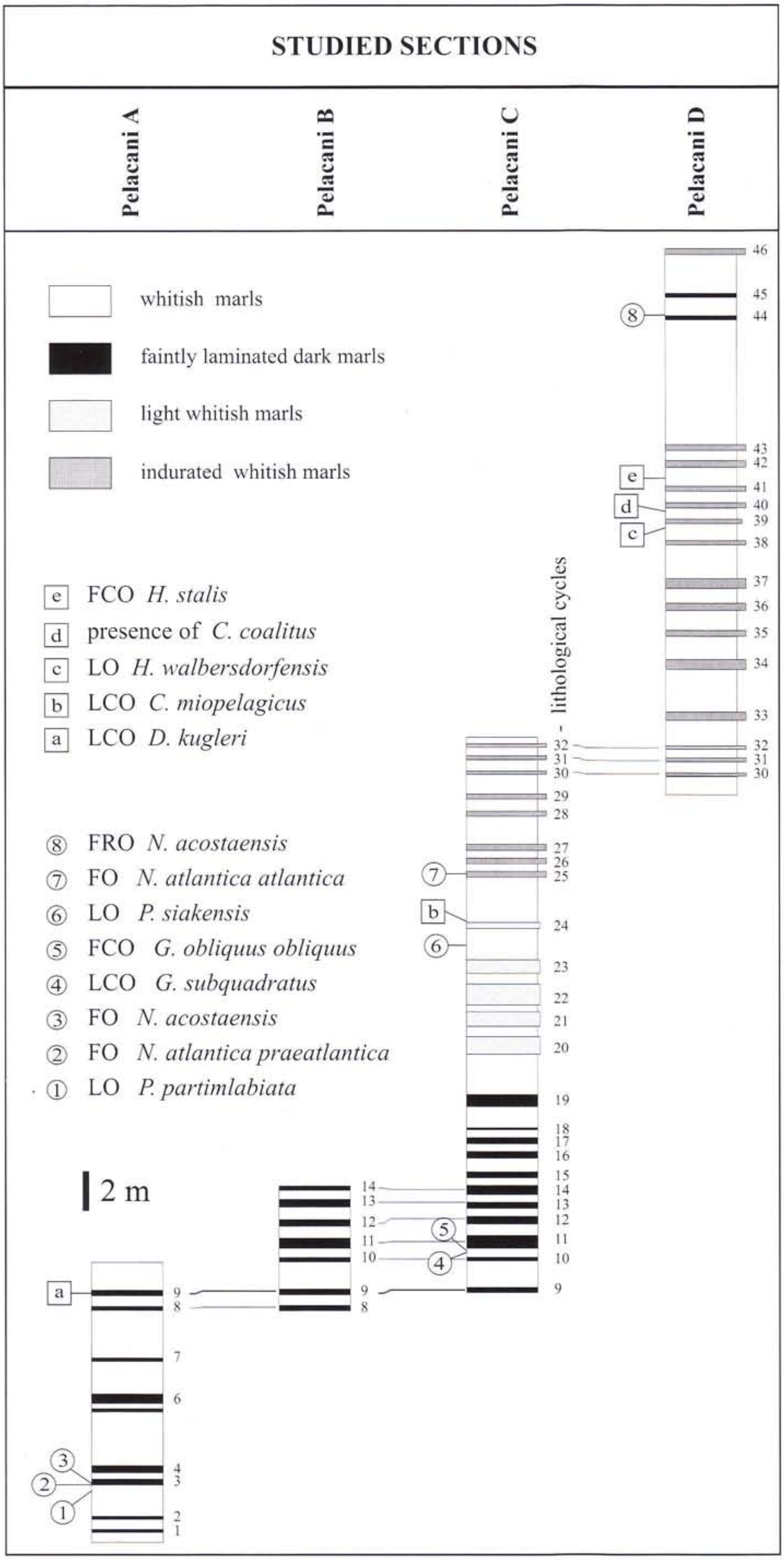

Fig. 3 - Correlation of the four segments. Bio-events are reported throughout the composite section. The number of the lithological cycles is reported to the right of the lithological column.

occurs in small-scale cycle clusters, which generally include 3 or 4 cycles. Generally, each cluster is separated from the adjacent small-scale cluster by segments of more or less thick homogeneous marls.

Calcareous plankton bio-events

Calcareous nannofossils

Calcareous nannofossils are generally abundant to common and well diversified. Low abundance and low diversity occur in coincidence with some discrete levels, mainly in the upper part of the section where nannofloras are strongly diluted by the presence of abundant silt. Broken specimens are also present consistently in these levels. Reworked Late Cretaceous to Paleogene forms (*Microrhabdulus* spp., *Micula* spp., *Isthmolithus recurvus*) are rare in the lower and middle part of the section, but their abundance increases upwards, where some reworked taxa (*Sphenolithus heteromorphus, Calcidiscus premacintyrei*) of Miocene age also occur.

Preservation is variable, with moderate to strong degree of overgrowth and/or dissolution occurring repeatedly. As a consequence, in some samples the identification at specific level was problematic (mainly within the genus *Discoaster*).

Large- to medium-sized placoliths (*Calcidiscus, Coccolithus, Dictyococcites, Reticulofenestra*) are the most frequent nannofossils. Helicoliths are common throughout the section and represented mainly by small forms such as *Helicosphaera walbersdorfensis* and, in the upper part of the section, by *Helicosphaera stalis* and *Helicosphaera orientalis*. Discoasterids are rare to common in the

Fig. 4 - Quantitative distribution of selected calcareous nannofossil taxa. (*) indicates the presence of an extremely rare specimen of *C. coalitus* found in a qualitative analysis.

species	Event	Precessional Cycle (Pelacani)	Position (m)	Age (Ma)	Hilgen. et al., (2000) (lithological cycles)	Age (Ma) (Gibliscemi)
Planktonic foraminifera						
Neogloboquadrina acostaensis	FRO	3	63.35	10.55	(-33/-34)	10.554
Neogloboquadrina a. atlantica	FO	34	34.40	11.15	(-57/-58)	11.121
Paragloborotalia siakensis	LO	37	30.60	11.21	(-60)	11.205
Paragloborotalia siakensis	LCO	38	29.00	11.23		
Globigerinoides obliquus obliquus	FRO	53/54	15.20	11.54		
Globigerinoides subquadratus	LCO	53/54	14.80	11.54	(-72/-73)	11.539
Neogloboquadrina a. praeatlantica	FO	66	2.95	11.80		
Neogloboquadrina acostaensis	FO	66	2.95	11.80	(-79/-80)	11.781
Paragloborotalia partimlabiata	LO	66	2.70	11.80	(-80/-81)	11.800
Calcareous nannofossil						
Helicosphaera stalis	FCO	11/12	54.95	10.71	(-39)	10.717
Catinaster coalitus	presence	13/14	53.25	10.74	(-40)	10738
Helicosphaera walbersdorfensis	LO	14/15	52.37	10.76	(-40/-41)	10.743
Coccolithus miopelagicus	LCO	35/36	31.80	11.19		
Discoaster kugleri	LCO	56	12.85	11.60	(-75)	11.604

Tab. 1 - Stratigraphic positions and astronomical ages of the calcareous plankton bio-events recognized in the Case Pelacani section, and comparison with previous calibrations.

assemblages. Semi-quantitative analysis proved that their abundance is highest in the basal part of the section, decreases in the middle part of the sequence and increases again above cycle 35. The total *Discoaster* abundance variation was estimated quantitatively only in two stratigraphic intervals, in the lower and upper part of the section, where the occurrence of *Discoaster kugleri* and *Catinaster coalitus*, respectively, was investigated in detail.

The abundance data of some of the most common and biostratigraphically relevant taxa are plotted in Fig. 4. The following bio-events (First Common Occurrence [FCO]; Last Common Occurrence [LCO]; Last Occurrence [LO]) were recognized and are listed below in stratigraphic order.

LCO *Discoaster kugleri*
LCO *Coccolithus miopelagicus*
LO *Helicosphaera walbersdorfensis*
presence of *Catinaster coalitus*
FCO *Helicosphaera stalis*

Age estimates for these events, obtained by cyclostratigraphic calibration (Caruso et al. 2002), are reported in Tab.1. They agree well with the ages reported by Hilgen et al. (2000).

The biostratigraphic distribution of *D. kugleri* in low-latitude Middle Miocene oceanic records was used in the standard zonations proposed by Martini (1971) and by Okada & Bukry (1980). In the Mediterranean, the biostratigraphic value of this taxon was controversial (for a review see Mazzei 1986; Theodoridis 1984; Fornaciari & Rio 1996) due to its well-known scanty presence and to the often atypical development of the specimens. The significance of the presence and abundance of *D. kugleri* in the Mediterranean was re-evaluated recently by Hilgen et al. (2000). According to these authors a short interval of common and continuous presence of *D. kugleri* can be detected by means of high resolution sampling. This type of analysis also allows the identification of the FCO and of the LCO horizons of this species, which are easy to correlate with the same events in the open oceans. They can be used in the Mediterranean to distinguish a "*D. kugleri* subzone" within the MNN 7 Zone of Fornaciari et al. (1996). For these two levels, Hilgen et al. (2000) report absolute age values of 11.889 and 11.604 Ma, respectively, which makes them very close to those reported in the equatorial Atlantic (Backman & Raffi 1997). In the Case Pelacani section *D. kugleri* occurs with low abundance and with discontinuity from the base of the section up to lithological cycle 9, where its LCO horizon was identified. Above this interval *D. kugleri* is extremely rare and was found only in three samples. In the interval below its LCO, its abundance fluctuates between very low and low values with a maximum density of only 2.21 specimens per mm^2 in a *Discoaster* population which has abundance values up to 30 specimens/mm^2. Furthermore, within this interval six rayed asteroliths are present that, due to poor preservation or to their atypical development, can only be compared tentatively with the holotype. Their abundance was plotted as *D.* sp. cf. *D. kugleri* in Fig. 4. An estimated age of 11.60 Ma was obtained for the LCO level of *D. kugleri* (Tab. 1; Caruso et al. 2002). It agrees well with the age of 11.604 Ma reported by Hilgen et al.(2000) for this bio-event in the Monte Gibliscemi section. Consequently, this bio-horizon is reliable to correlate the two sections. Our abundance data suggest that *D. kugleri* is more frequent in levels where also the total *Discoaster* abundance increases. Therefore the interval with relatively common specimens of *D. kugleri* may be identified with difficulty in sediments in which the *Discoaster* population is small and/or poorly preserved. Abundance data of *D. kugleri* were also collected in a segment sampled below the Case Pelacani section. This segment was not included in our study due to a small fault between the two segments. *D. kugleri* is very rare and scattered in the basal part of this segment and increases slightly in abundance upwards. The age of this bio-event could not be estimated at Case Pelacani because a continuous section was not cropping out between the two segments.

Coccolithus miopelagicus occurs in the assemblages from the base of the Case Pelacani section, but its distribution pattern is quantified only starting from 22 m above the base (Fig. 4). Continuous, but highly fluctuating values are present up to lithological cycle 24 above which a persistent absence interval occurs. Above this interval, specimens of *C. miopelagicus* occur again with repeated and discontinuous low abundance values, at least up to cycle 32. The quantitative analysis of *C. miopelagicus* was not extended upwards because in several samples above this level this taxon was not found. We selected the abundance decrease mentioned previously, coincident with cycle 24, to identify its LCO level. This distribution pattern compares well with other distributions reported in the Mediterranean region (Fornaciari et al. 1996; Hilgen et al. 2000). In the Case Pelacani section an age estimate of 11.19 Ma was obtained for the *C. miopelagicus* LCO (Tab. 1). In the Monte Gibliscemi section Hilgen et al. (2000) dated a LRO (Last Regular Occurrence) horizon of this taxon at 10.977 Ma. Our LCO horizon is slightly older than their LRO horizon, and is possibly correlable with the decrease in abundance of *C. miopelagicus* detected in coincidence of lithological cycle -60 by Hilgen et al. (2000).

The change in the relative abundance between *Helicosphaera walbersdorfensis* and *H. stalis* was proposed by Fornaciari et al. (1996) to recognize two bio-horizons that define a very short stratigraphic interval (MNN8a) in the Serravallian Mediterranean record. They are easily detectable and may be correlated using quantitative analyses. We have collected the abundance data of these two taxa only in the upper part of the section, even if both occur from the lower part of the section, with *H. stalis* very rare and scattered. The distribution pattern of *H. walbersdorfensis* shows wide fluctuations with some very high and continuous occurrence up to lithological cycle 38 where a sharp abundance decrease occurs. *H. walbersdorfensis* is present again with more or less high abundance values between this cycle and the top of the section. Reworked nannofossils abundances and silty fraction increase, and *H. walbersdorfensis* specimens are poorly preserved in this interval. In the same interval peaks of abundance of well-preserved *H. stalis* never coincide with the abundance peaks of *H. walbersdorfensis*. Below its FCO *H. stalis* is always very rare in the Mediterranean record (Fornaciari et al. 1996), and consequently its increase in abundance can hardly be explained by reworking. In conclusion, we interpret the presence of more or less abundant specimens of *H. walbersdorfensis* above 52.37 m as due to reworked specimens and we selected the sharp abundance decrease in coincidence with the upper part of cycle 38 to identify its LO horizon. This falls below the level that marks the beginning of *H. stalis* increase in abundance and its continuous occurrence (Fig. 4). This level coincides with the marly interval of cycle 41 and allows the identification of the FCO of *H. stalis*. These two horizons, used to identify the MNN 8a subzone (Fornaciari et al., 1996), were dated at 10.76 Ma and 10.71 Ma respectively (Tab. 1). These ages agree well with the ages reported by Hilgen et al. (2000), confirming that they are reliable horizons for intra-Mediterranean correlations.

Catinaster coalitus was reported from absent to very rare and scattered in the Mediterranean Miocene record and therefore its distribution was considered not useful as a biostratigraphic tool (Theodoridis 1984; Fornaciari et al. 1996; Hilgen et al. 2000). The abundance data collected in the upper part of the Case Pelacani section allowed us to recognize the occurrence of extremely rare specimens of this taxon only in two samples (Fig. 4), between the LO of *H. walbersdorfensis* and the FCO of *H. stalis* horizons. The estimated age of this level is 10.74 Ma (Tab.1). This agrees well with the age of 10.738 Ma reported for the lowest occurrence of *C. coalitus* in the record of the Gibliscemi section (Hilgen et al. 2000), that can be correlated with the Case Pelacani section. *C. coalitus* occurs again in the topmost part of the sequence, at about 65.6 m above the base, where quantitative data were not collected in detail, due to dilution and poor preservation. The lowest occurrence of rare and scattered specimens of *Discoaster brouweri* was found at the base of lithological cycle 37. However, *D. micros*, the taxon from which the genus *Catinaster* evolved (Raffi et al. 1998), could not be found.

Planktonic foraminifera

In the generally well-preserved foraminiferal assemblage the planktonic population is always dominant over the benthic foraminifera, which are found also in the black, faintly laminated beds. Rare fragments of molluscs and bryozoa are present only in the uppermost part, above 54 m, indicating that shallow water sediments were added to the autochthonous sedimentation.

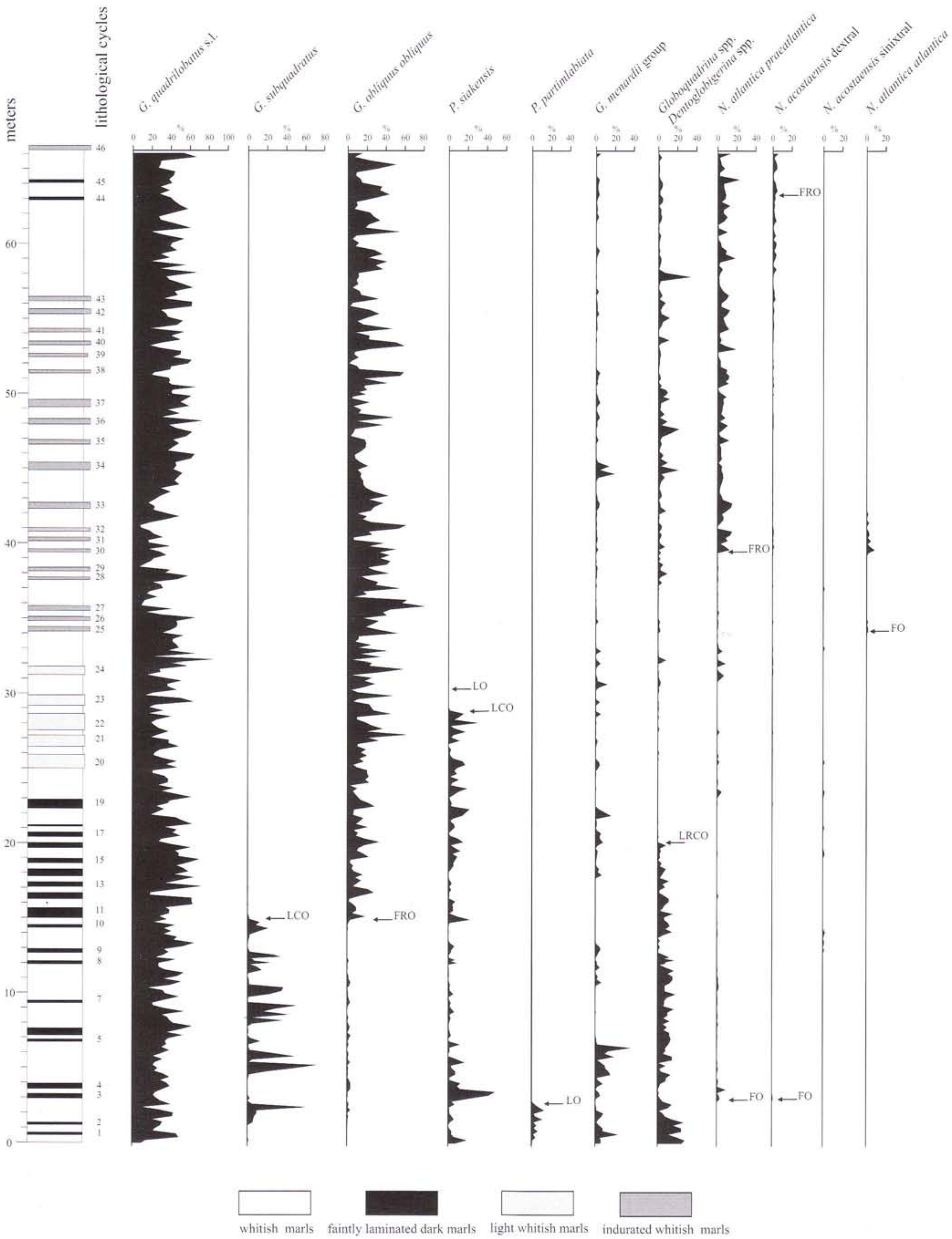

Fig. 5 - Quantitative distribution of the selected planktonic foraminiferal taxonomic units.

Eleven bio-events were detected along the section. The quantitative distribution of the eight marker species is plotted in Fig. 5.

Paragloborotalia partimlabiata disappears at 2.70 m above the base, just below a black, laminated bed. Our interpretation of this medium sized species is highly conservative. We ascribe to *P. partimlabiata* only specimens with a strictly rounded peripheral margin, an incomplete apertural lip and a clearly undulated last intercameral suture on the spiral side. Essentially, this last character distinguishes *P. partimlabiata* from *Paragloborotalia challengeri*. The last occurrence of *P. partimlabiata*, a cool water species (Chamley et al. 1986; Foresi et al. 1998) coincides with a relative increase in abundance of *Globigerinoides* spp. A sharp decrease in *Paragloborotalia siakensis* and the FCO of *D. kugleri* was detected in a lithological sequence below the base of our section. We did not include this segment in our section because a fault, with a small (but possibly significant from a cyclostratigraphic point of view) displacement is present between the two segments. Nevertheless, it seems reasonable that the LO of *P. partimlabiata* occurs slightly above these two bio-events.

Virtually coincident with the LO of *P. partimlabiata*, the Neogloboquadrinids population appears at 2.95 m, with *N. acostaensis* (very rare) and *Neogloboquadrina atlantica praeatlantica*, which includes *N. continuosa* Auct. (not Blow, 1969) (see Foresi et al. 2002a). The rarity of these species and a different interpretation of transitional forms in these levels may give rise to a slightly different identification of the level of their relative appearance.

The first occurrence of *N. acostaensis* is not an easily detectable event, because this species is extremely rare and scattered in the lower part of its range. In the Case Pelacani section this species increases slightly in abundance and is more regularly present only from 63.55 m. We tentatively placed at this level the first regular occurrence (FRO) of this species, which is present here only with right coiling specimens. In the underlying levels it includes right and left coiling specimens, but the number of the specimens counted is too low to discriminate a reliable coiling preference. In the level of its first appearance all the rare specimens are right coiling. The Neogloboquadrinid appearance is considered a synchronous event within the Mediterranean and, possibly, in extra-Mediterranean areas (Foresi et al. 1998). Nevertheless Hilgen et al. (2000) report thet this event is not synchronous between the Mediterranean basin and the Ceara Rise in Atlantic Ocean (Site 926). The lithological cycle in which they appear can be correlated fully with the cycle reported by Hilgen et al. (2000). These bio-events occur in the lower part of the interval in which the common occurrence of the calcareous nannofossil *D. kugleri* was detected.

The LCO of *Globigerinoides subquadratus* was identified at 14.90 m, just below the base of a black level. Only rare and scattered specimens, often not included in the counted population, are present in the section above this level. Some authors (Stainforth et al. 1975; Bolli & Saunders 1985) do not consider *G. subquadratus* a valid name and use the name *G. ruber* also for this essentially Middle Miocene species. We prefer to consider it as a discrete species, recognizable by a more oval peripheral shape, more elongated sutural apertures on the spiral side and four chambers per whorl, with only the last whorl including three chambers (Cordey 1967). This event is virtually coincident with the FRO of *G. obliquus obliquus* (Fig. 5). Both events are very well defined, appear to be synchronous in the Mediterranean and, possibly, in extra-Mediterranean areas (see Foresi et al. 1998), and slightly postdate the LCO of *D. kugleri*. Considered together, these three events represent a well recognizable integrated calcareous plankton event within the Mediterranean and in the Atlantic Ocean. Its age at Case Pelacani is 11.54 Ma.

At 29 m the sharp decrease in abundance (LCO) of *Paragloborotalia siakensis* just predates the LO of this species, identified at 30.60 m. With its radial sutures on the spiral side, we consider it a species distinct from *P. mayeri* (Foresi et al. 1998), which, with its strongly curved intercameral sutures on the spiral side, is a short living species in the upper part of the Serravallian (Foresi et al. 2002b). *P. siakensis* is essentially a Middle Miocene species and its easily recognizable extinction level was proposed by Foresi et al. (1998) as a candidate for the recognition or approximation of the Serravallian/Tortonian boundary.

Apart from an isolated presence in the sample at 31.40 m, large, essentially right coiling specimens of *Neogloboquadrina atlantica atlantica* with strongly incised umbilical sutures and a coarse granular test surface are present discontinuously, with varying frequency, in the segment between 34.40 m and 42.20 m. In this segment *Globigerinoides quadrilobatus* decreases in abundance, but the concomitant relevant increase of *G. obliquus obliquus* results in high abundance peaks of the *Globigerinoides* population. The presence of large specimens of *N. atlantica atlantica* in Tortonian sediments was already reported by Coccioni & Galeotti (1995), Sprovieri et al. (1996) and Hilgen et al. (2000), who correlated this migration with a general cooling event.

Other minor events were identified in the Case Pelacani section. They are discussed briefly below, but they are not included in Fig. 5.

The FO of *Globoturborotalita nepenthes* occurs at 16 m. The first occurrence of this species is difficult to be detected, because its transition from *G. druryi* is gradational and the two species co-occur in the basal part of the section.

The last regular common occurrence (LRCO) of *Dentoglobigerina altispira* s.l. (plotted together with

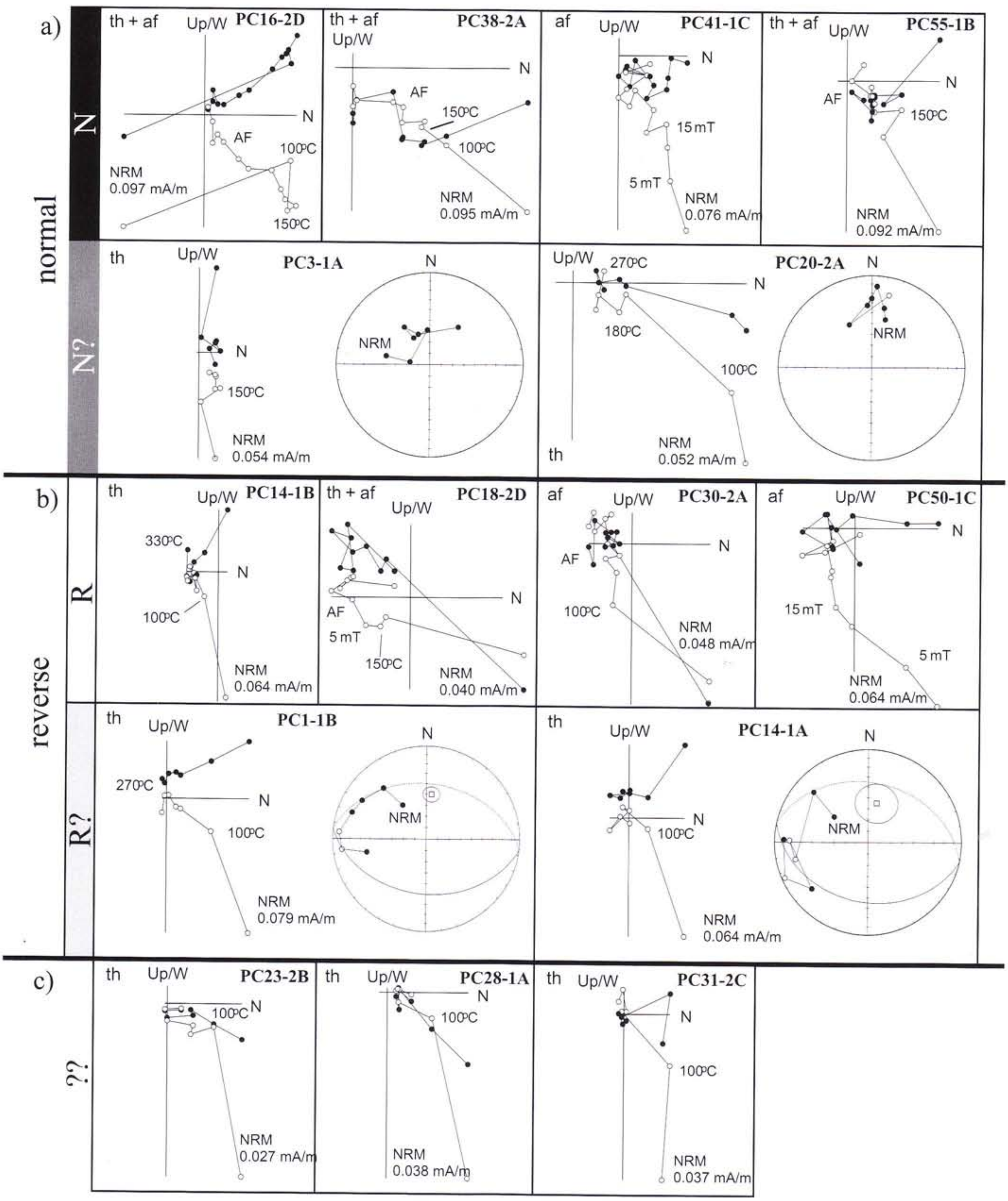

Fig. 6 - Typical orthogonal plots and stereographic projections of thermal (TH), alternating field (AF) and combined demagnetization of the Case Pelacani samples. Solid (open) symbols represent projections on the horizontal (vertical) plane: a) represent normal ChRM direction with different quality rating (see text and Appendix1): b) represent reverse ChRM direction and c) represent samples discarded for polarity interpretation.

Globoquadrina spp. in Fig. 5) occurs at 20 m, 4.80 m above the LCO of *Globigerinoides subquadratus*. This LRCO event is possibly coeval in other Mediterranean sections, as reported by Martinotti (1981), Zachariasse & Spaak (1983) and Foresi et al. (1998) among others.

The FCO of *Catapsydrax parvulus* (= *Globorotaloides falconarae*) occurs at 24.20 m with an age of 11.327 Ma. Only rare and scattered specimens occur below, above the appearance of *N. atlantica praeatlantica*, after a long paracme interval which covers most of the Middle Miocene (Foresi et al. 2002b).

The first occurrence in the section of *Globorotalia lenguaensis* is at 50.35m with an age of 10.807 Ma. This level surely postdates the evolutionary appearance of the species which, according to many authors, predates the LO of *P. siakensis* in the oceans, but is possibly a coeval event in the Mediterranean.

Finally, the LO of *Globorotalia* gr. *G.* aff. *menardii* - *Globorotalia praemenardii* occurs at 51.10 m with an age of 10.787 Ma, just above the FO of *G. lenguaensis*.

Magnetostratigraphy

Paleomagnetic analysis was conducted on 59 samples for each sample 2-4 specimens were analyzed (see Appendix 1). Progressive stepwise thermal (TH), and alternating field (AF) demagnetization methods and a combination of both were used. Thermal demagnetization included intervals of 30-50°C, usually up to a maximum temperature of 330°C. AF demagnetisation up to 100 mT included 14 steps with intervals of 5 mT, 10 mT and 20 mT. The combined TH and AF demagnetization protocol involved thermal demagnetization at 100°C and 150°C followed by the standard AF demagnetization procedure.

The characteristic remanent magnetization (ChRM) is defined conventionally as the linear segment trending toward the origin of the demagnetization diagram. The quality of the demagnetization trajectories for the Case Pelacani samples is generally not good enough to define confidently such a component. However, the trajectory defined by the first demagnetization steps in some instances does not trend toward the origin of the demagnetization diagram. This is taken as evidence of a dual-component nature of the NRM. The NRM intensity was weak (below 100 μA/m). A set of blank measurements of the empty holder was conducted to test the reliability of the measurement of such low values. These measurements indicated that the noise level of the system is around 5 μA/m, and may double if the empty sample holder is not measured often during the demagnetisation protocol. The magnetization directions measured in the blank intervals were oriented randomly. Consequently, the attempt to interpret the polarity of the poorly-resolved ChRM directions from the Pelacani samples seems justified, since the intensity after some demagnetization is still above the system's noise level. Both AF and thermal demagnetization revealed magnetic overprinting directed along the recent Earth's magnetic field (in addition to a viscous component removed at about 100°C or 5-10 mT). The recent overprint is removed at about 240-270°C or at about 25 mT. These observations are seen more clearly in samples where the ChRM component is reverse (Fig. 6-b, class R). In other instances the reverse ChRM component is not so clearly shown, although the trajectory of the remanence vector still traces out a great-circle path from the overprinting direction towards a reverse ChRM direction, albeit not reaching a stable end point (Fig. 6-b, class R?). Similar criteria were used to interpret the normal ChRM components (Fig. 6-a). Samples were discarded for interpretation (25 % of the total) when the demagnetization trajectory was very doubtful or the intensity of magnetization was unreasonably weak after the first demagnetization steps (Fig. 6-c). Full details on the polarity rating and demagnetization protocols for individual specimens are given in Appendix 1. An overall polarity was assigned to all sampling sites, based on the polarity of the individual 2 to 4 specimens available for each sampling site (Appendix 1 and Fig. 7). In cases when specimens were displayed the two polarities for any single sampling site, an "intermediate" polarity was retained for that site (shaded fill in Fig. 7).

The quality of the retrieved magnetostratigraphy at Case Pelacani is poor and somewhat questionable but it is the best estimate that can be obtained. Most likely further sampling will not improve the results.

The succession of the established magnetozones in the section was compared with the Geomagnetic Polarity Time Scale (GPTS) of Cande & Kent (1995; CK95) (Fig. 7), updated for the presence of two short normal polarity intervals within chron C5r.2r, and possibly a third one within chron C5r.3r, as documented from a Spanish astronomically forced continental succession (Abdul Aziz et al. 2000). The succession of many normal and reverse magnetozones at Case Pelacani, some with a short apparent duration (straddling only one or two precession-cycles), appears difficult to correlate with the GPTS (Fig. 7). Several reasons can account for this situation and include the following: 1) the retrieved magnetostratigraphy is an artefact due to overinterpretation of the results; 2) all or some of the normal ChRM directions may actually reflect samples fully overprinted by the present Earth's field; 3) the details and age calibration of the GPTS along the time interval of interest are not well known. Point 3 would require excessive changes to the GPTS and/or to the sedimentation rate at Case Pelacani, despite the discovery of new intervals of normal polarity within chron C5r (Abdul Aziz et al. 2000). Even the uncertainty of the age calibration for reversal boundaries along the Serravallian/Tortonian

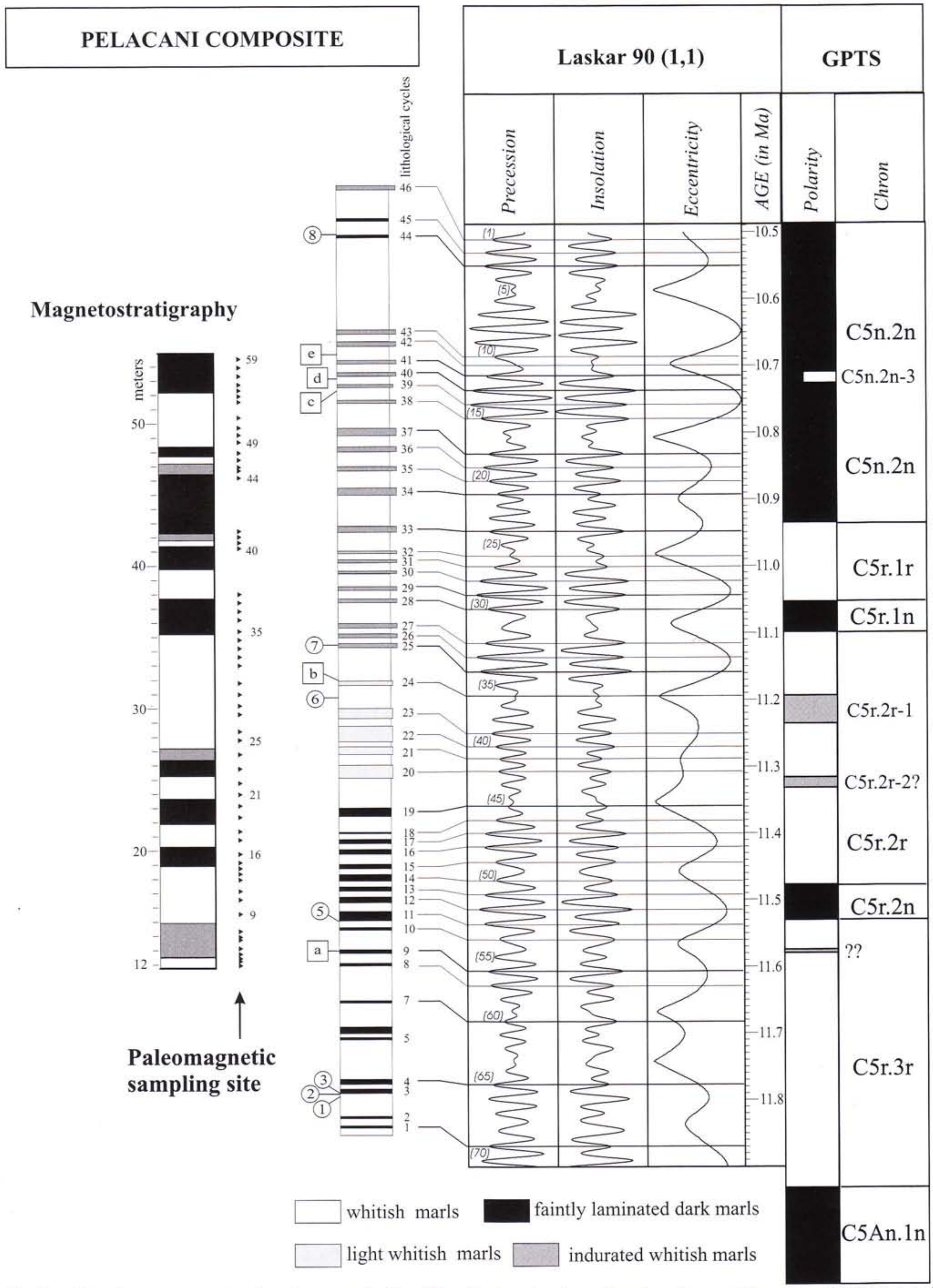

Fig. 7 - Tentative magnetostratigraphy as interpreted at Case Pelacani, referred to the cyclostratigraphic correlation proposed in Caruso et al. (2002) and comparison with the Geomagnetic Polarity Time Scale (GPTS) of Cande & Kent (1995) with the addition of recently discovered normal intervals (shaded), as reported in Abdul Aziz et al. (2000).

boundary appears insufficient to reconcile the observations at Case Pelacani with the GPTS. Note that reversal boundaries appear to be consistently older than the CK95 ages (Hilgen et al. 2000). These ages could be either younger, depending on the use or not of the *C. coalitus* FO as nannofossil datum plane indirectly astronomically dated. This datum, together with other datum planes, allowed Hilgen et al. (2000) to linearly interpolate the sedimentation rate at ODP Site 845 in the eastern equatorial Pacific ocean. The possibility that some ChRM normal directions represent the present Earth's field cannot be ruled out, considering the gentle dip of the strata (~15°). Seemingly, the presence of a pervasive secondary reverse overprint throughout the entire interval cannot be excluded. Interestingly, such a feature was reported to occur at the Tortonian and Messinian interval of the Gibliscemi section (Gomis-Coll et al. 1995), which is also characterized by similar magnetic properties and low NRM intensities. Relatively complex diagenetic pathways involving remagnetization are not rare in cyclically bedded marine strata from Sicily, as documented from the Trubi marls at Punta di Maiata (Dinarès-Turell & Dekkers 1999). A secondary diagenetic overprint, in addition to a (sub-recent) weathering-induced overprint, was considered also for the Serravallian and early Tortonian part of the Gibliscemi section (Hilgen et al. 2000). However, it must be stressed that data from the Case Pelacani section are only partly reliable and therefore no unambiguous deciphering between the several possibilities outlined above can actually be made.

Biochronology

All the identified calcareous plankton events are directly correlated with the sequence of lithological and/or faunal cycles reported for the Case Pelacani section (Caruso et al. 2002). The tuning of these cycles to the astronomical target curve produced astrochronology for each cycle, correlated to the precession astronomical cycles. Consequently, astrochronological estimates were obtained for the bio-events, as reported in Tab. 1. They correlate well with the ages reported recently by Hilgen et al. (2000), with the same number of precession cycles intercalated between the same couples of bio-events. Apparently, some discrepancies are present and must be discussed, because they are only a matter of interpretation of the taxonomic concept. The LO of *Paragloborotalia partimlabiata* differs because of our different, more restricted morphological interpretation of the species. We consider that our last occurrence level of *P. partimlabiata* coincides with the sharp decrease in abundance recorded for this taxon by Hilgen et al. (2000) in coincidence of their lithologic level 80. Following Foresi et al.(2002a) we suggest that similar (but, possibly smaller and with a radial, not sinuous suture between the ultimate and penultimate chambers on the spiral side) specimens reported by Hilgen et al. (2000) above this level may be ascribed to *P. challengeri*. As discussed above, *P. mayeri* is not present in our section. In our more restricted specific terminology, *P. mayeri* has a short range in older levels (Foresi et al. 1998 and 2002b). We identified as *P. siakensis* the specimens present in the Case Pelacani section and we ascribe to this species the specimens attributed to *P. mayeri* in the Gibliscemi section by Hilgen et al. (2000), according to the illustrations reported in their plate 4. Consequently, the LO of (our) *P. siakensis* is totally comparable with the last occurrence of (their) *P. mayeri*.

As far as calcareous nannofossils are concerned, we identify the LCO of *Coccolithus miopelagicus* at a level virtually coincident with the LO of *P. siakensis*, at 11.19 Ma. This level can be correlated with the major decrease in abundance of *C. miopelagicus* reported by Hilgen et al. (2000) just below their lithological cycle -60.

Conclusions

The Case Pelacani section covers a stratigraphic interval that extends from slightly below the FO to slightly above the FRO of *N. acostaensis*. The definition of the GSSP of the Tortonian may be identified between these two events, as discussed by Hilgen et al. (2000). The Case Pelacani section is a potential candidate for its definition. The poorly resolved magnetostratigraphy may be overridden by the accurate astrochronology based on the sequence of lithological and faunal cycles (Caruso et al. 2002). The generally well-preserved calcareous plankton allowed us to recognize easily the sequence of bio-events, and therefore compile a detailed integrated biostratigraphy of the interval.

Foresi et al. (1998) proposed the LO of *P. siakensis* as a good reference for the definition of the Serravallian/Tortonian boundary. We suggest that also the level coincident with the *G. subquadratus* LCO may be considered for the definition of the Serravallian-Tortonian boundary. It is virtually coincident with the FRO of *G. obliquus obliquus* and slightly above the LCO of *D. kugleri* in the Mediterranean region (see also Foresi et al. 2002; Hilgen et al. 2000). Possibly it is recognizable in a comparable stratigraphic position in the Atlantic Ceara Rise sequence (Hilgen et al. 2000 for the last common occurrence level of *D. kugleri*). The so-identified level is well below the base of the historical Rio Mazzapiedi Tortonian stratotype (Cita & Blow 1969). In particular, the base of the Tortonian, which according to its stratotype is within the nannofossil MNN8b Zone of Fornaciari et al. (1996), would be within nannofossil zone MNN7 (Fig. 8). A thus-defined level may be correlated better outside the Mediterranean basin than a level near or coincident with the *P. siakensis* LO (Foresi et al. 1998). In our interpretation of bio-events in the Case

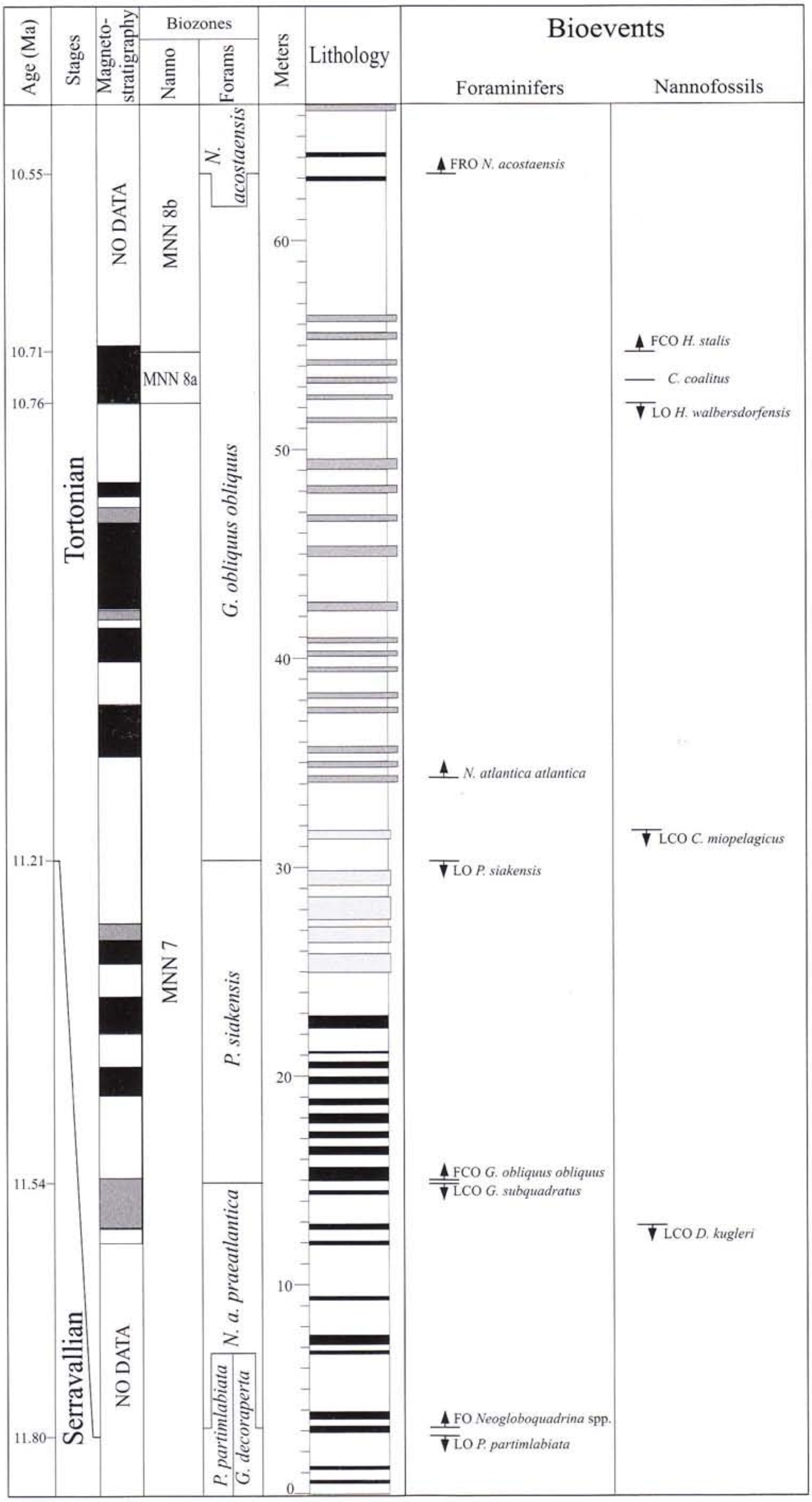

Fig. 8 - Integrated calcareous plankton biostratigraphy, chronostratigraphy and tentative magnetostratigraphy of the Case Pelacani section.

Pelacani section this event occurs very close to the LCO of *C. miopelagicus*. Therefore, also in this case two bio-events, belonging to two different fossil groups, would concur in the recognition of the Serravallian/Tortonian boundary. However, the LCO of *C. miopelagicus* may be interpreted differently (cfr. Hilgen et al. 2000). Furthermore, at present it is not clear how well these two bio-events correlate with oceanic sequences (Shackleton et al. 1995, ODP Leg 138) as it is possible that the events are more or less diachronous. Therefore it would be difficult to recognize correctly this boundary only on the basis of biostratigraphic correlations.

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Appendix 1

Details of demagnetisation protocols and polarity ratings for indivizual specimens and stratigraphic levels.

Notes: TH150+AF indicates combined thermal demagnetization at 100°C and 150°C followed by alternating field demagnetization at 5 mT steps up to 50 mT and then at 60 mT, 80 mT and 100 mT. TH1 and TH2 indicates thermal demagnetisation at 100°C, 150°C, 180°C, 210°C, 240°C, 270°C, 300°C, 330°C, AF indicates alternating field demagnetization only as outlined above. Polarity ratings R and R? and R?? (N, N?, N??) indicate reverse (normal) ChRM directions with different grade of reliability (shown in the schematic column as white, black or shades of grey respectively). "??" and N/A in the schematic column indicate discarded samples.

Appendix 1

Specimen	Level (m)	Treatment	Polarity rating	Polarity column specimen	Polarity column site
PC59-1B	54.45	TH150+AF	N??		
PC59-1A	54.45	TH2	??	N/A	
PC57-1D	53.25	TH150+AF	N		
PC57-1C	53.25	TH2	N?		
PC57-1B	53.25	AF	N?		
PC56-1D	52.65	TH150+AF	N		
PC56-1C	52.65	TH2	??	N/A	
PC56-1B	52.65	AF	N		
PC55-1B	52.25	TH150+AF	N		
PC55-1A	52.25	TH2	N		
PC54-1D	51.85	TH150+AF	R		
PC54-1C	51.85	TH2	R		
PC54-1B	51.85	AF	R??		
PC53-1B	51.45	TH150+AF	??	N/A	
PC53-1A	51.45	TH2	??	N/A	
PC52-1A	50.35	TH150+AF	N??		
PC51-1C	49.65	TH2	R		
PC51-1B	49.65	TH150+AF	R?		
PC50-1D	49.15	TH150+AF	??	N/A	
PC50-1C	49.15	AF	R		
PC50-1A	49.15	TH150+AF2	R		
PC49-1C	48.65	AF	R		
PC49-1B	48.65	TH150+AF	R??		
PC48-1C	47.90	AF	N		
PC48-1B	47.90	TH150+AF	N?		
PC47-1C	47.40	TH150+AF	R		
PC47-1B	47.40	AF	R		
PC46-1D	46.90	TH150+AF	R?		
PC46-1C	46.90	AF	R		
PC46-1A	46.90	TH150+AF2	N		
PC45-1B	46.65	TH150+AF	??	N/A	
PC44-1C	46.15	TH150+AF	N?		
PC44-1B	46.15	AF	N		
PC43-1D	42.40	TH150+AF	N??		
PC43-1C	42.40	AF	N		
PC43-1A	42.40	TH150+AF2	N??		
PC42-1E	42.40	TH150+AF	??	N/A	
PC42-1C	42.00	AF	N		
PC42-1B	42.00	TH1	R		
PC42-1A	42.00	TH150+AF2	??	N/A	
PC41-1D	41.60	TH150+AF	R		
PC41-1C	41.60	AF	N		
PC41-1B	41.60	TH1	R		
PC41-1A	41.60	TH150+AF2	??	N/A	
PC40-1C	41.20	TH150+AF	??	N/A	
PC40-1B	41.20	AF	N?		
PC40-1A	41.20	TH1	N?		
PC39-2B	38.00	TH150+AF	R??		
PC39-2A	38.00	TH1	??	N/A	
PC38-2D	38.00	TH150+AF	R?		
PC38-2C	38.00	AF	R		
PC38-2B	38.00	TH1	??	N/A	
PC38-2A	38.00	TH150+AF2	N		
PC37-2C	36.80	TH150+AF	N??		
PC37-2B	36.80	TH1	??	N/A	
PC37-2A	36.80	TH150+AF2	N		
PC36-2C	36.20	TH150+AF	??	N/A	
PC36-2B	36.20	TH1	N?		
PC36-2A	36.20	TH150+AF2	N		
PC35-2C	35.40	TH150+AF	N??		
PC35-2B	35.40	TH1	R		
PC35-2A	35.40	TH150+AF2	N??		
PC34-2D	34.80	TH150+AF	N??		
PC34-2C	34.80	TH1	R?		
PC34-2A	34.80	TH150+AF2	R		
PC33-1C	34.20	TH150+AF	??	N/A	
PC33-1B	34.20	TH1	??	N/A	
PC33-1A	34.20	TH150+AF2	??	N/A	
PC32-1D	33.60	TH150+AF	R??		
PC32-1B	33.60	TH1	??	N/A	
PC32-1A	33.60	TH150+AF2	R		
PC31-2D	33.00	TH150+AF	R??		
PC31-2C	33.00	TH1	??	N/A	
PC31-2B	33.00	TH150+AF2	R		
PC30-2C	31.80	TH150+AF	??	N/A	
PC30-2B	31.80	TH1	R?		
PC30-2A	31.80	TH150+AF2	R?		
PC29-1D	31.00	TH150+AF	??	N/A	
PC29-1C	31.00	TH1	N??		
PC29-1B	31.00	TH2	R		
PC29-1A	31.00	TH150+AF2	R		
PC28-1B	30.20	TH150+AF	R		
PC28-1A	30.20	TH1	??	N/A	
PC27-1D	29.60	TH150+AF	??	N/A	
PC27-1C	29.60	TH2	??	N/A	
PC27-1B	29.60	TH1	N??		
PC27-1A	29.60	TH150+AF2	R		
PC26-2D	28.40	TH150+AF	??	N/A	

Specimen	Level (m)	Treatment	Polarity rating	Polarity column specimen	Polarity column site
PC26-2C	28.40	TH2	??	N/A	
PC26-2B	28.40	TH1	R?		
PC26-2A	28.40	TH150+AF2	R		
PC26-1C	28.40	TH150+AF	??	N/A	
PC26-1C	28.40	TH150+AF2	??	N/A	
PC26-1B	28.40	TH2	R??		
PC25-2C	27.80	TH150+AF	R		
PC25-2B	27.80	TH2	R??		
PC25-2A	27.80	TH1	R?		
PC25-1B	27.80	TH2	R??		
PC25-1A	27.80	TH150+AF	R		
PC24-1D	26.80	TH150+AF	??	N/A	
PC24-1C	26.80	TH2	R??		
PC24-1B	26.80	TH1	N		
PC24-1A	26.80	TH150+AF2	R		
PC23-2D	25.80	TH150+AF	??	N/A	
PC23-2C	25.80	TH2	N??		
PC23-2B	25.80	TH1	??	N/A	
PC23-2A	25.80	TH150+AF2	N??		
PC22-1D	24.80	TH150+AF	R?		
PC22-1C	24.80	TH2	R?		
PC22-1B	24.80	TH1	??	N/A	
PC22-1A	24.80	TH150+AF2	R??		
PC21-1D	24.00	TH150+AF	R		
PC21-1C	24.00	TH2	??		
PC21-1B	24.00	TH1	R		
PC21-1A	24.00	TH150+AF2	??	N/A	
PC20-2C	23.20	TH150+AF	R??		
PC20-2B	23.20	TH2	N?		
PC20-2A	23.20	TH1	N?		
PC19-1C	22.40	TH150+AF	R??		
PC19-1B	22.40	TH2	N??		
PC19-1A	22.40	TH1	N?		
PC18-2D	21.40	TH150+AF	R		
PC18-2C	21.40	TH2	R		
PC18-2A	21.40	TH1	R		
PC17-2D	20.80	TH150+AF	N??		
PC17-2C	20.80	TH2	??	N/A	
PC17-2B	20.80	TH1	R		
PC17-2A	20.80	TH150+AF2	??	N/A	
PC16-2D	19.80	TH150+AF	N		
PC16-2C	19.80	TH2	N??		
PC16-2A	19.80	TH1	N?		
PC15-2C	19.20	TH150+AF	N		
PC15-2B	19.20	TH1	N?		
PC15-2A	19.20	TH2	??	N/A	
PC14-1C	18.80	TH150+AF	R		
PC14-1B	18.80	TH2	R		
PC14-1A	18.80	TH1	R		
PC13-2C	18.40	TH150+AF	R		
PC13-2B	18.40	TH1	R??		
PC12-1D	18.00	TH150+AF	R		
PC12-1C	18.00	TH1	R?		
PC12-1B	18.00	TH150+AF2	R		
PC11-2C	17.20	TH150+AF	R		
PC11-2B	17.20	TH1	R?		
PC11-2A	17.20	TH150+AF2	R??		
PC10-1C	16.60	TH150+AF	R		
PC10-1B	16.60	TH1	??	N/A	
PC10-1A	16.60	TH150+AF2	N??		
PC09-1D	15.60	TH150+AF	??	N/A	
PC09-1C	15.60	TH150+AF2	R??		
PC09-1B	15.60	TH1	R?		
PC08-1C	14.40	TH150+AF	N?		
PC08-1B	14.40	TH1	R?		
PC08-1A	14.40	TH150+AF2	N??		
PC07-1D	14.00	TH150+AF	??	N/A	
PC07-1C	14.00	TH1	??	N/A	
PC07-1B	14.00	TH150+AF2	R		
PC06-2C	13.80	TH150+AF	N??		
PC06-2B	13.80	TH150+AF2	N??		
PC06-2A	13.80	TH1	??	N/A	
PC05-2C	13.20	TH1	??	N/A	
PC05-2C	13.20	TH150+AF	INT		
PC05-2B	13.20	TH150+AF2	N??		
PC04-1B	12.80	TH150+AF	INT		
PC04-1A	12.80	TH1	??	N/A	
PC03-1C	12.50	TH150+AF2	R		
PC03-1B	12.50	TH150+AF	??	N/A	
PC03-1A	12.50	TH1	N?		
PC02-1C	12.30	TH150+AF	R?		
PC02-1B	12.30	TH1	R		
PC02-1A	12.30	TH150+AF2	??	N/A	
PC01-1C	12.00	TH150+AF	R		
PC01-1B	12.00	TH1	R?		
PC01-1A	12.00	TH150+AF2	R??		