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ASTRONOMICAL CALIBRATION OF THE SERRAVALLIAN/TORTONIAN CASE PELACANI SECTION (SICILY, ITALY)

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Riassunto: Uno studio ciclostratigrafico è stato condotto su una sequenza sedimentaria (sezione di Case Pelacani) affiorante nella zona sud-orientale della Sicilia (Italia) e ricoprente l'intervallo stratigrafico Serravalliano superiore/Tortoniano inferiore. Dati biostratigrafici a plancton calcareo riportati in un altro lavoro dimostrano che tutti gli eventi generalmente riconosciuti poco al di sotto e al di sopra del limite S/T sono presenti nella successione studiata. Essi hanno permesso una dettagliata comparazione con la sezione di Gibliscemi. I dati preliminari relativi allo studio magnetostratigrafico dei sedimenti suggeriscono una forte componente di rimagnetizzazione secondaria che rende difficile il riconoscimento della corretta sequenza di "chrons" paleomagnetici lungo l'intervallo sedimentario considerato.

Lo studio combinato della ciclicità litologica lungo la successione sedimentaria di Case Pelacani e la applicazione di metodologie di indagine spettrale ai dati di abbondanza di una specie di foraminiferi planctonici (*Globigerinoides quadrilobatus*) hanno inoltre permesso di individuare le forzanti astronomiche relative alla precessione, obliquità ed eccentricità dell'orbita.

La correlazione con le diverse periodicità presenti nella curva di insolazione dei pattern litologici individuati lungo la successione e delle diverse armoniche estratte dal segnale microfaunistico a disposizione ha permesso di calibrare astronomicamente il record sedimentario e, conseguentemente, di datare tutti i bioeventi a plancton calcareo riconosciuti lungo l'intervallo studiato.

Abstract: We performed a cyclostratigraphic study of a sedimentary sequence (Case Pelacani section) outcropping in the southeastern margin of Sicily (Italy) and covering the Upper Serravallian/Lower Tortonian stratigraphic interval. Calcareous plankton biostratigraphic data reported in another paper proved that all the sequence of bio-events generally reported from just below and above the S/T boundary is present in the section. They allowed a detailed correlation with the Gibliscemi section.

Preliminary paleomagnetic data suggest that a secondary remagnetization component prevents the recognition of the correct sequence of paleomagnetic chrons along the studied interval. The sedimentary record has been compared, on the basis of an integrated calcareous plankton biostratigraphy, with that of the Gibliscemi section.

Cyclostratigraphic analysis of the lithological patterns recognized throughout the succession and the application of spectral methodologies to the abundance fluctuations of the planktonic foraminifer *Globigerinoides quadrilobatus* highlighted the presence in the signal of the classic Milankovitch frequencies (precession, obliquity and eccentricity).

Correlation of the lithological patterns and of the different frequency bands extracted by numerical filtering from the faunal record with the same components modulating the insolation curve provided an astronomic calibration of the sedimentary record and, consequently, a precise age for all the calcareous plankton bioevents recognized throughout the studied interval.

Introduction

A reliable astrochronological time scale from the Tortonian (Hilgen et al. 1995; Krijsgman et al. 1995) to the middle Serravallian (Hilgen et al. 2000) has been obtained by detailed cyclostratigraphic investigation of several Mediterranean sections. The calcareous plankton bioevents recognized in these stratigraphic intervals have been dated by these authors on the basis of an astronomical calibration of the studied sedimentary sequences.

This paper presents the cyclostratigraphic results obtained from the study of the Case Pelacani section, which includes the Serravallian/Tortonian (S/T) boun-

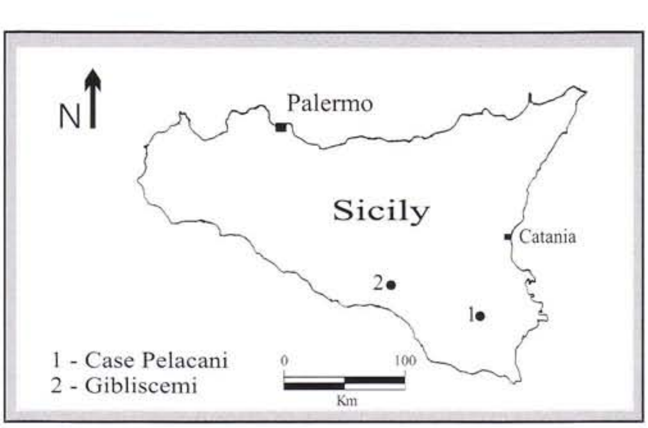

Fig. 1 - Location map of the sections discussed in the paper.

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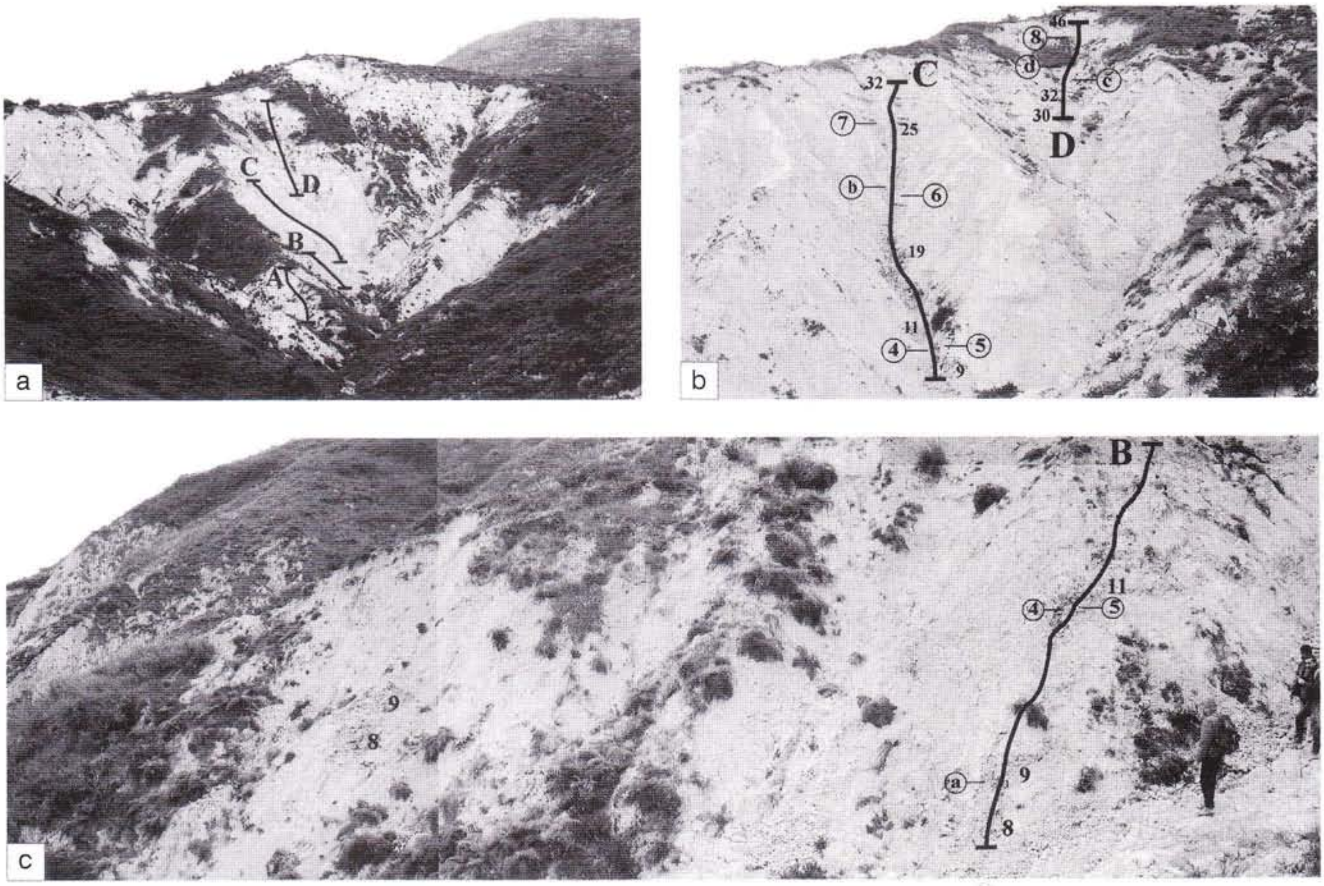


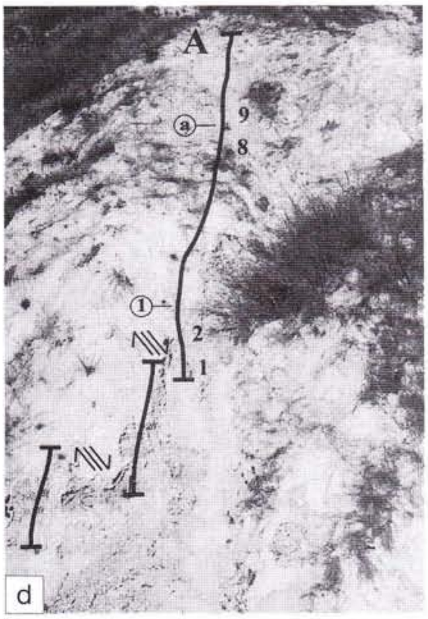


Fig. 2 - Pictures of the Case Pelacani segments; a) general view of the studied section; b) details of segments C and D; c) detail of segment B; d) detail in segment A. The progressive numbers 1 to 46 correspond to the lithological cycles recognized on the field. The number and letter encircled correspond to calcareous plankton biostratigraphic events reported in Fig. 3.

dary, commonly recognized by the first occurrence (FO) of *Neogloboquadrina acostaensis*. This section shows lithological patterns similar to those recognized along the Gibliscemi section recently indicated by Hilgen et al. (2000) as possible candidate for the definition of the GSSP of the Tortonian.

Geological setting and location

The Case Pelacani section outcrops along the Bianco river, 4 km west of the Palazzolo Acreide village, in the Iblean region of SE Sicily (Fig. 1). The succession is characterized by middle-upper Miocene hemi-pelagic sediments. It belongs to the Tellaro Formation (Fm.) which is underlain by the calcarenites and marls of the Ragusa Formation and overlain by the calcarenites of the Palazzolo Formation (Rigo & Barbieri 1959).

The succession outcrops in the Iblean foreland, where some compressive and distensive tectonic disturbances are present, in relation to the stacking of nappes thrusted southward from the Caltanissetta Basin (Bianchi et al. 1987) during the uplifting of the Appenninic-Maghrebid belt.

Some low angle compressive faults are present in the Case Pelacani section, with small displacements of the stratigraphic sequence. These small faults are associated to the main decollement of the Tellaro Fm. from the Ragusa Fm.

Materials and methods

The section is well exposed in a series of gullies along the southern slope of Mountain Cozzo Mastica (Lat. 37°02'54"; Long. 14°53'00"). It is composed of four segments (Pelacani A/B/C/D) (Fig. 2, 3) that have been correlated in the field by matching lithological patterns constrained by biostratigraphic events.

A total of 46 lithological cycles (about 0.7/1.5 m thick), numbered progressively upward, have been identified throughout a total stratigraphic thickness of 66.35 m. The composite sequence was sampled on average every 20 cm in the lower part (cycles 1-20) and every 20-25 cm in the upper part (cycles 21 to 46). A total of 316 samples were collected and studied.

A detailed calcareous plankton biostratigraphy, based on quantitative analyses on the planktonic foraminifers and calcareous nannofossil assemblages are reported in Di Stefano et al. (2002), and enabled the recognition of the most important biostratigraphic events throughout the succession. In Fig. 3 we report the most important calcareous plankton bioevents recognized along the record.

Numerical methodologies of spectral analysis and filtering are based on the standard approach of Jenkins & Watts (1968).

Lithology and sedimentary cyclicity

Segment A, with a total thickness of 12 m (Fig. 2, 3), includes cycles 1 to 9, characterized by a not regular alternation of homogeneous whitish marls and faintly laminated dark marls (possibly representing sapropelitic layers). This segment has been sampled at the base of the first gully (Fig. 2, d) just above a small fault. Another fault is present slightly above cycle 9 and the succession was continued in segment B (Fig. 2c), using cycles 8 and 9 as correlation horizons. In the 6.40 m thick segment B, characterized by alternations of whitish marls and faintly laminated dark marls, the cycles 8 to 14 are included. Also segment B is closed at the top by a fault. Therefore, the following samples have been collected in segment C (Fig. 2b), 26 m thick, in which 24 lithological cycles (9 to 32), are present. Segments B and C were biostratigraphically correlated using the *G. subquadratus* LCO and *G. obliquus obliquus* FRO biohorizons and the lithological pattern distribution of cycles 8 to 14. Between cycles 9 and 19 a regular alternation of whitish and dark marls occurs, but between cycle 19 and cycle 20, a 2 m thick interval of homogeneous grey marls is present (Fig. 3).

Between 23 and 34.20 meters above the base of the sequence the lithological alternations are not very clear (Fig. 3, 4). We could identify four cycles (20 to 23) consisting of alternating whitish and light whitish marls. Between cycles 24 and 25, a 2 m thick interval of homogeneous grey marls is again present (Fig. 3). From cycle 25 to cycle 32 the lithological cyclicity is very clear with grey marls alternated to indurated whitish layers. The sequence has been completed in segment D (cycles 30 to 46) using the lithological cycles 30 to 32 (Fig. 2 and 3) to correlate segments C and D. In segment D, an alternation of grey marls and indurated whitish layers is evident from cycle 30 to 43. A 6.8 m thick homogeneous interval of grey-whitish marls is present between cycles 43 and 44. In this segment the lithological cycles were possibly not recognised because of the difficulty to analyse in detail the outcrop, that is not well exposed and particularly steep.

In the uppermost part of the section, between 66.35 m and the top of the section (Fig. 3), two faintly laminated dark marls (44 and 45) alternated to whitish marls and one indurate whitish layer (46), close the section.

Astronomical calibration

Lithological pattern distribution

In the sedimentary record of the Case Pelacani section four different intervals can be distinguished. The first interval, from cycle 1 to cycle 8, is characterized by a not regular alternation of whitish marls and dark marls (Fig. 3). The thickness for each cycle ranges between 60 and 100 cm. The faintly laminated dark marls have been assumed as the base of each lithological cycle and have been correlated with high precessional minima/insolation maxima. In the segments characterized by a homogeneous lithology (between cycles 2-3, 4-5, 7-8 and 9-10, respectively) several precessional cycles have been successively identified on the basis of the spectral analysis applied to a selected faunal record. The regular alternation of dark and homogeneous marls from cycle 9 to 19 (Fig. 3) represents the second interval. In the third interval, from cycle 20 to cycle 24, the light whitish marls represent the base of each cycle (Fig. 3). These cycles are relatively thicker probably because of a rather higher sedimentation rate, with an average thickness of each cycle of about 120-150 cm. The interval from cycle 25 to cycle 46, is characterized by a marked cyclicity, with indurated whitish layers alternated to whitish marls. Each cycle is 100-150 cm thick. The indurated layers are probably distal turbidites and, following Potsma et al. (1993) and Sierro et al. (2001), we compared them to sapropelitic layers. We have assumed the indurated whitish layers as the base and the grey marls as the top of each cycle (Fig. 3).

Lithological clusters (quadruplets and/or triplets), related to the short-eccentricity component of the insolation curve, were not recognized in the lower interval of the succession, but between cycles 25 and 31, 34 and 41 they are evident.

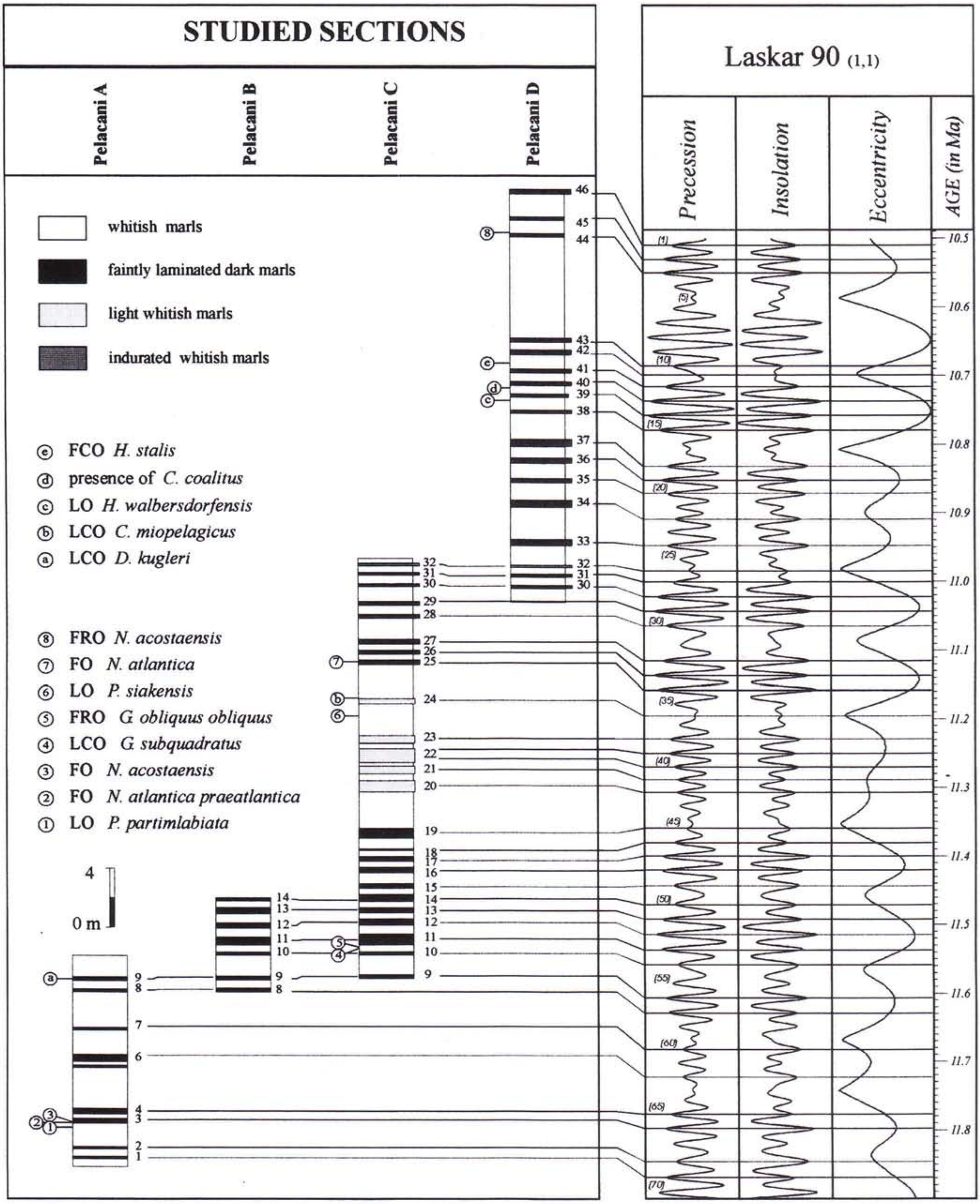
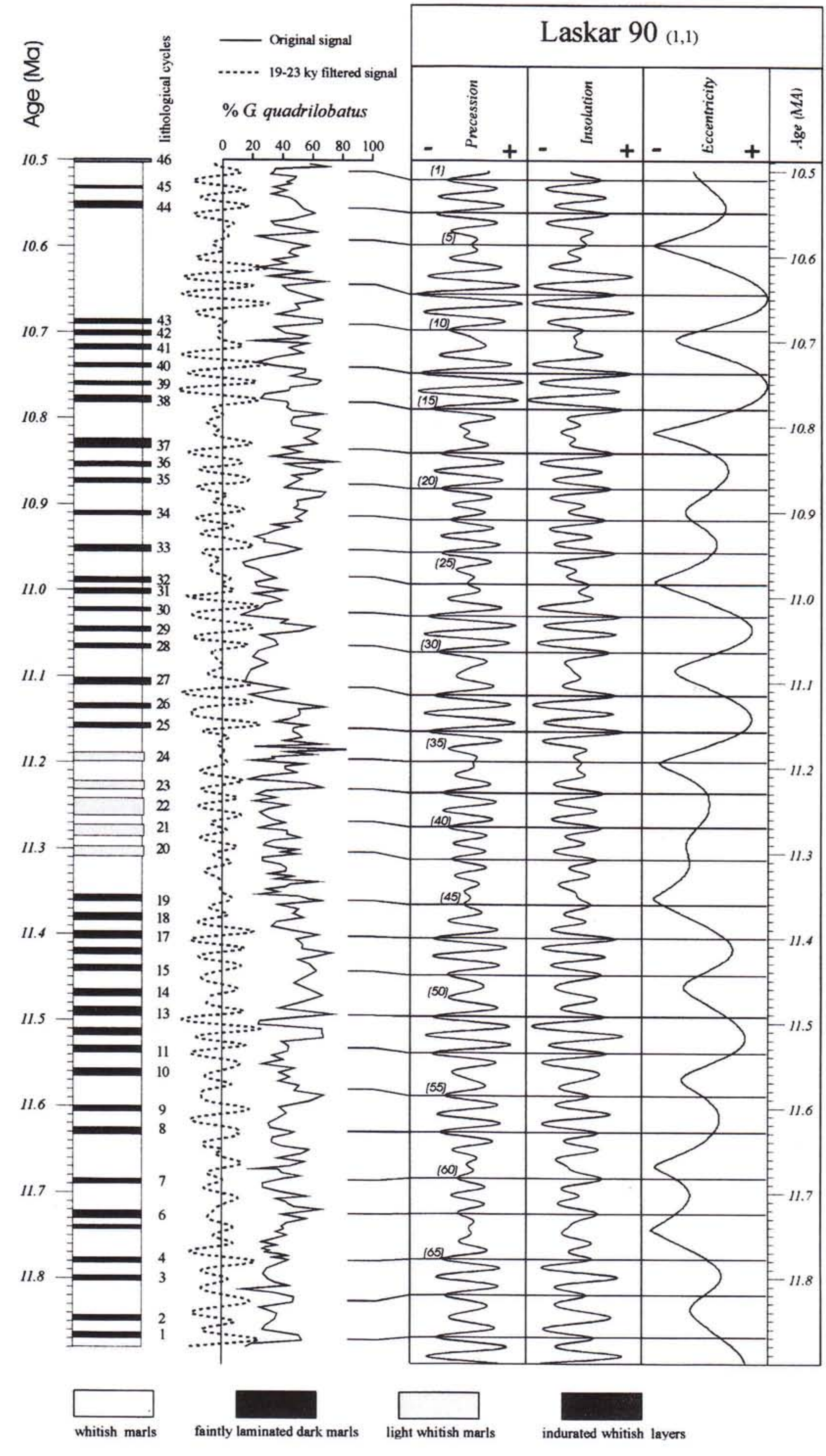
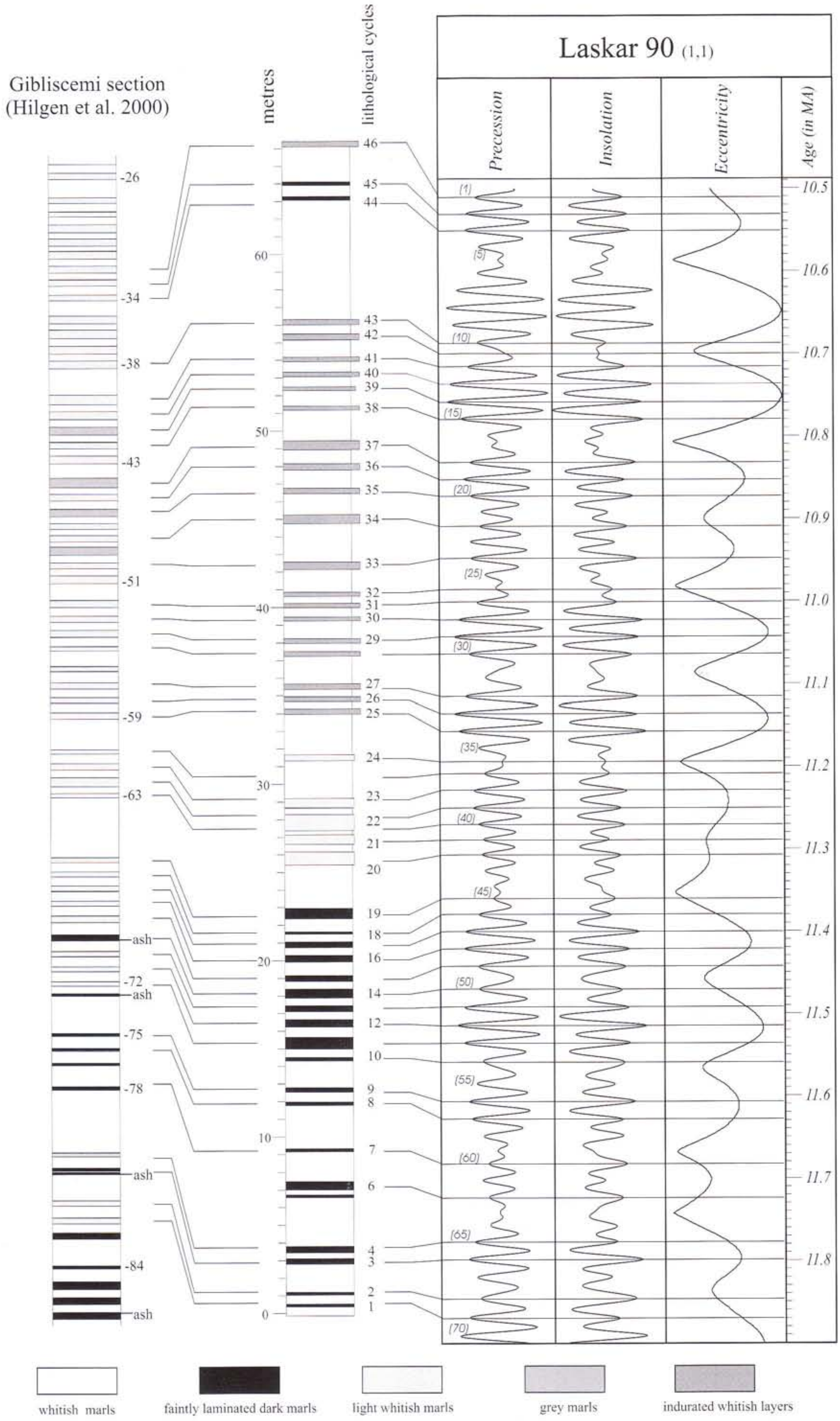


Fig. 3 - Correlation between lithologic cycles and astronomic curve. Bioevents are reported throughout the composite section. On the right of the lithological column the number of the lithological cycles are reported. In brackets the progressive numbers of the precessional cycles (1 to 70).

Fig. 4 - Correlation of the lithological cycles recognized in the Case Pelacani section with the lithological cycles identified at Gibliscemi by Hilgen et al. (2000).


Age (Ma)
lithological cycles
Original signal
19-23 ky filtered signal
% G. quadrilobatus
0 20 40 60 80 100
Laskar 90 (1,1)
Precession
Insolation
Eccentricity
Age (MA)
10.5
10.6
10.7
10.8
10.9
11.0
11.1
11.2
11.3
11.4
11.5
11.6
11.7
11.8
whitish marls
faintly laminated dark marls
light whitish marls
indurated whitish layers


Gibliscemi section
(Hilgen et al. 2000)
metres
lithological cycles
Laskar 90 (1,1)
Precession
Insolation
Eccentricity
Age (in MA)
-26
-34
-38
-43
-51
-59
-63
ash
-72
ash
-75
-78
ash
-84
ash
10.5
10.6
10.7
10.8
10.9
11.0
11.1
11.2
11.3
11.4
11.5
11.6
11.7
11.8
whitish marls
faintly laminated dark marls
light whitish marls
grey marls
indurated whitish layers

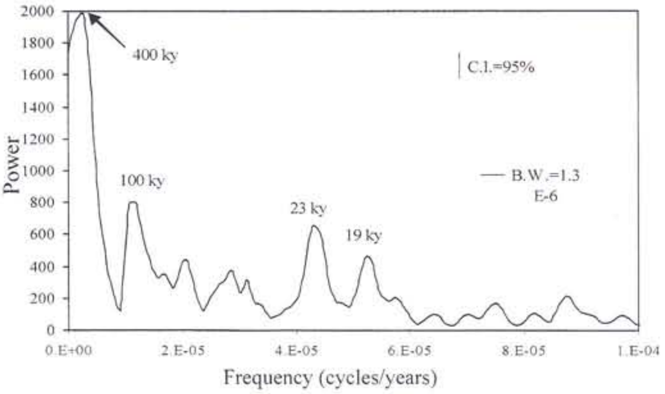


Fig. 6 - Power spectra of the *Globigerinoides quadrilobatus* signal. C.I.= confidence interval. B.W.= bandwidth.

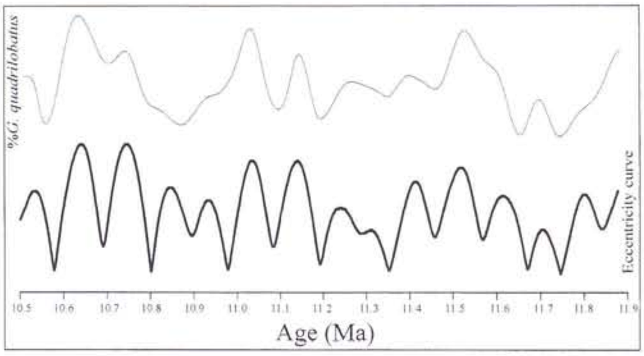


Fig. 7 - Comparison between the astronomic eccentricity curve (thick line) and the 100 and 400 Ky of *G. quadrilobatus* filtered signal (thin line).

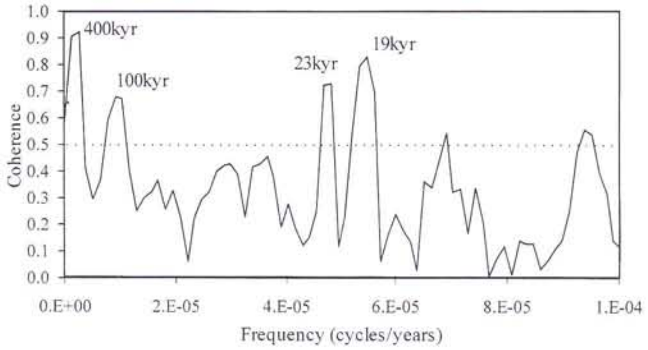


Fig. 8 - Coherence spectra between the insolation curve Laskar 90 $_{(1,1)}$ and *Globigerinoides quadrilobatus* signal.

Fig. 5 - Comparison between original and filtered (in the precession frequency bands) *Globigerinoides quadrilobatus* signal and correlation with the same two harmonics extracted from the insolation curve Laskar 90 $_{(1,1)}$. See text for cycles labelling. The lithological log is in function of time.

Lithological tuning

The astronomical solution of Laskar et al. (1993), with present-day values for the dynamical ellipticity of the Earth and tidal dissipation by Sun and Moon (La $90_{1,1}$), has been selected to calibrate the studied sedimentary sequence. Hilgen et al. (1995), Lourens et al. (1996) and Hilgen et al. (2000) demonstrated that this is the most accurate solution for the calibration of late Miocene-Plio-Pleistocene sedimentary records.

To calibrate the lithological patterns with the insolation curve of Laskar et al. (1993) the results from the Gibliscemi section reported by Hilgen et al. (2000) have been used as starting point. Initially, we verified that the sequence of biostratigraphic events along the Case Pelacani and Gibliscemi sections was the same, apart from some differences due to different taxonomic interpretations (see Di Stefano et al. 2002, for more detail). We compared the quantitative abundance fluctuations of the studied planktonic taxa. The LCO of *G. subquadratus* was considered the most appropriate bio-horizon to be used as tie point to correlate the two sedimentary sequences. The *G. subquadratus* LCO has been recognized at the top of cycle 10 at Case Pelacani and at the top of cycle -72 (11.539 Ma) by Hilgen et al. (2000) at Gibliscemi (Fig. 4). The regular alternations of dark and homogeneous marls present in the interval from cycle 10 to cycle 19 (Fig. 3) have been correlated with the 10 precessional minima/insolation maxima between 11.561 Ma and 11.361 Ma (45-54) and have been correlated with the lithological cycles -64 to -72 at Gibliscemi. This double control corroborated the good correlation of these two segments (Fig. 4).

On the basis of this preliminary correlation, we proceeded to compare the larger-order lithological cycle patterns present in the Case Pelacani section with the sequence of eccentricity oscillations of the insolation curve. In particular, between 11.56 Ma and 11.36 Ma the eccentricity insolation curve is characterized by 2 strong maxima that we have correlated with lithological cycles 10 to 19.

Between cycles 20 and 24, lithological changes are weak and difficult to be recognized in the field. We correlated this sedimentary interval with the low insolation eccentricity oscillations recorded between 11.19 and 11.36 Ma. Each light whitish marls layer has been correlated with the precession minima/insolation maxima cycles recorded in the same time interval.

The group of cycles 25 to 32 is characterized by an evident lithological cyclicity that we correlated with the interval of high eccentricity insolation between 10.98 and 11.16 Ma. Consequently, each lithological cycle has been correlated to the strong oscillations present in the precession/insolation index curve. The characteristic triplet of cycles 25 to 27 and the quadruplet of cycles 28 to 31 (Fig. 4), correlated with the strong eccentricity maxima recorded in the insolation curve from 10.98 to

Lithological cycle (Pelacani)	Mid-point (m)	precessional cycles	Age (ka)	Hilgen et al. (2000) (Gibliscemi)
Cycle 46	66.10	(1)	10.511	cycle -32
Cycle 45	64.30	(2)	10.531	cycle -33
Cycle 44	63.30	(3)	10.551	cycle -34
Cycle 43	56.35	(10)	10.668	cycle -38
Cycle 42	55.50	(11)	10.702	
Cycle 41	54.35	(12)	10.716	cycle -39
Cycle 40	53.40	(13)	10.738	cycle -40
Cycle 39	52.30	(14)	10.759	cycle -41
Cycle 38	51.45	(15)	10.780	cycle -42
Cycle 37	49.50	(18)	10.832	cycle -44
Cycle 36	48.30	(19)	10.853	cycle -45
Cycle 35	46.80	(20)	10.873	cycle -46
Cycle 34	45.00	(21)	10.910	cycle -48
Cycle 33	42.40	(24)	10.949	cycle -50
Cycle 32	40.60	(26)	10.988	
Cycle 31	40.10	(27)	11.002	cycle -52
Cycle 30	39.90	(28)	11.023	cycle -53
Cycle 29	37.90	(29)	11.044	cycle -54
Cycle 28	37.10	(30)	11.065	cycle -55
Cycle 27	35.70	(32)	11.116	cycle -57
Cycle 26	35.10	(33)	11.137	cycle -58
Cycle 25	34.00	(34)	11.158	cycle -59
Cycle 24	31.10	(36)	11.195	
Cycle 23	28.90	(38)	11.230	cycle -61
Cycle 22	27.70	(39)	11.251	cycle -62
Cycle 21	26.80	(40)	11.288	
Cycle 20	25.10	(42)	11.307	
Cycle 19	21.30	(45)	11.361	cycle -64
Cycle 18	20.70	(46)	11.381	cycle -65
Cycle 17	19.90	(47)	11.401	cycle -66
Cycle 16	18.90	(48)	11.422	cycle -67
Cycle 15	18.10	(49)	11.440	cycle -68
Cycle 14	17.10	(50)	11.472	cycle -69
Cycle 13	16.30	(51)	11.493	cycle -70
Cycle 12	15.50	(52)	11.515	cycle -71
Cycle 11	14.50	(53)	11.536	cycle -72
Cycle 10	14.10	(54)	11.561	
Cycle 9	12.90	(56)	11.608	cycle -75
Cycle 8	12.05	(57)	11.630	cycle -76
Cycle 7	9.50	(60)	11.684	cycle -78
Cycle 6	7.30	(62)	11.725	
Cycle 5	6.75	(63)	11.739	
Cycle 4	3.70	(65)	11.778	cycle -79
Cycle 3	2.90	(66)	11.800	cycle -80
Cycle 2	1.20	(68)	11.847	cycle -81
Cycle 1	0.40	(69)	11.871	cycle -82

Tab. 1 - Stratigraphic positions and astronomical ages of the sedimentary cycles from 1 to 46 at Case Pelacani A/B/C/D composite section. Ages refer to the mid-point of whitish layers or faintly laminated dark marls (sapropels) and are correlated with precession minima.

11.06 Ma and from 11.11 to 11.16 Ma respectively, represent a further control for the calibration of this sedimentary interval.

The segments characterized by more or less thick homogeneous whitish marls (between cycles 32 and 33, 33 and 34, 37 and 38, 43 and 44) have been correlated to the lows in the eccentricity insolation curve between 0.99 and 10.95 Ma, 0.91 and 10.94 Ma, 10.83 and 10.78 Ma, 10.60 and 10.57 Ma, respectively.

In the basal part of succession (cycles 1 to 9) the irregular presence of dark marls has been ascribed to the very low modulation of the long- and short-eccentricity component of the insolation curve between 11.61 and 11.80 Ma. The dark marls of cycles 1 to 9 have been correlated with the highest peaks of the precession index curve.

Spectral analysis

Spectral and filtering methodologies have been applied to the curve of the relative abundance fluctuations of the planktonic species *G. quadrilobatus* reported by Di Stefano et al. (2002) throughout the Case Pelacani section, to essentially reconstruct the correct sequence of precession cycles where high-frequency lithologic alternations cannot be recognized.

Correlation between the insolation curve and the fluctuations recorded in the *G. quadrilobatus* signal in all the Milankovitch frequencies has been performed associating the lower Northern Hemisphere summer insolation values to the lower percentages of the faunal record according to the paleoclimatic indications of this species reported for the present day Mediterranean area by Pujol & Vergnaud-Grazzini (1995). The astronomical calibration previously obtained by lithological tuning of the section allowed us to transform the faunal signal from the space to the time domain (Fig. 5) and the signal was interpolated at 3 kyr using a Gaussian weighting filter which ensures that more interpolated data than original points are never present in a given interval.

The power spectrum of the *G. quadrilobatus* signal (Fig. 6) shows the classic Milankovitch precession, obliquity, short- and long-eccentricity frequency bands.

A Tukey-Hinnov pass-band filter (Jenkins & Watts 1968) has been applied to the original signal to extract the long- and short-eccentricity frequency bands.

A comparison of the *G. quadrilobatus* curves filtered in the long- and short-eccentricity bands with the same periodicities of the insolation signal shows a good match (Fig. 7). Cross-spectral analysis between the two signals shows high coherency values for the Milankovitch periodicity bands, confirming that this calibration was appropriate (Fig. 8).

Successive filtering of the original signals in the precession frequency bands and consequent correlation with the 19-23 kyr cycles present in the insolation curve produced a more complete calibration of the studied record (Fig. 9). In some intervals a not perfect coincidence between the sapropelitic layers (faintly laminated dark marls, light whitish marls and indurated whitish marls) and peaks of *G. quadrilobatus* occurs. It may be due to a not sufficiently detailed sampling in the corresponding intervals.

A progressive number (1 to 69) from the top to the base of the succession has been used to label all the consecutive precession peaks in the *G. quadrilobatus* signal and in the precession index curve (Fig. 3. Tab. 1).

Chronology

The obtained astronomical calibration of the Case Pelacani succession suggests an age of 10.50 and 11.89 Ma for the top and the base of the studied interval. In Tab. 1 we report the astronomical age for each lithological cycle and the corresponding precession cycles.

The estimated astronomical age of all the bioevents recognized in the Case Pelacani section are reported in Tab. 2. They are compared with results obtained from the Gibliscemi section (Hilgen et al. 2000).

The small dissimilarities in age obtained for some bioevents between the Case Pelacani and Gibliscemi sections can be substantially attributed to: i) different interpretation of the biomarkers (particularly for the planktonic species *P. partimlabiata*), ii) a different interpretation of the LCO and FCO events (*C. miopelagicus* and *H. walbersdorfensis*), iii) small local tectonic disturbances and/or deformations in the two sections.

Conclusive remarks

Two different methodological approach, lithological patterns calibration and spectral analysis applied to a faunal climate-sensitive record, have been used to astronomically tune the Case Pelacani section to the insolation curve La $90_{(1,1)}$. Our results are well comparable with the data proposed for the Gibliscemi section by Hilgen et al. (2000). They provide an accurate time control of several calcareous plankton biomarkers useful for

species	Event	Cycle (Pelacani)	Position (m)	Age (Ma) this paper	Hilgen et al. (2000) (lithological cycles)	Age (Ma) (Gibliscemi)
Planktonic foraminifera						
Neogloboquadrina acostaensis	FRO	44	63.35	10.551	(-33/-34)	10.554
Neogloboquadrina atlantica	FO	25	34.40	11.151	(-57/-58)	11.121
Paragloborotalia siakensis	LO	23/24	30.60	11.203	(-60)	11.205
Paragloborotalia siakensis	LCO	23	29.00	11.225		
Globigerinoides obliquus obliquus	FCO	10	15.20	11.541		
Globigerinoides subquadratus	LCO	10	14.80	11.546	(-72/-73)	11.539
Neogloboquadrina a. praeatlantica	FO	3	2.95	11.800		
Neogloboquadrina acostaensis	FO	3	2.95	11.800	(-79/-80)	11.781
Paragloborotalia partimlabiata	LO	2/3	2.70	11.804	(-80/-81)	11.800
Calcareous nannofossil						
Helicosphaera stalis	FCO	41/42	54.95	10.710	(-39)	10.717
Catinaster coalitus	presence	39/40	53.25	10.742	(-40)	10738
Helicosphaera walbersdorfensis	LO	38/39	52.37	10.763	(-40/-41)	10.743
Coccolithus miopelagicus	LCO	24	31.80	11.190		
Discoaster kugleri	LCO	9	12.85	11.608	(-75)	11.604

Tab. 2 - Stratigraphic positions and astronomical ages of the calcareous plankton bioevents.

regional stratigraphic correlation.

Despite the magnetostratigraphic analysis did not give significant results, the Case Pelacani succession may be considered a good candidate for the definition of the Serravallian/Tortonian boundary.

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REFERENCES

Bianchi F., Carbone S., Grasso M., Invernizzi G., Lentini F., Longaretti G., Merlini S. & Mostardini F. (1987) - Sicilia orientale: Profilo geologico Nebrodi-Iblei. *Mem. Soc. Geol. It.*, 38: 429-458, Roma.

Di Stefano E., Bonomo S., Caruso A., Dinarés-Turell J., Foresi L.M., Salvatorini G. & Sprovieri R. (2002) - Calcareous plankton bio-events in the Miocene Case Pelacani section (South eastern Sicily, Italy). In Iaccarino S.M. (ed.) - Integrated Stratigraphy and Paleoceanography of the Mediterranean Middle Miocene. *Riv . Ital. Paleont. Strat.*, 108: 307-323, Milano.

Hilgen F.J. (1991a) - Astronomical calibration of Gauss to Matuyama sapropels in the Mediterranean and implication for the Geomagnetic Polarity Time Scale. *Earth Planet. Sc. Lett.*, 104: 226-244, Amsterdam.

Hilgen F.J. (1991b) - Extension of the astronomically calibrated (polarity) time scale to the Miocene/Pliocene boundary. *Earth Planet. Sc. Lett.*, 107: 349-368, Amsterdam.

Hilgen F.J., Krijgsman W., Langereis C.G., Lourens L.J., Santarelli A. & Zachariasse W.J. (1995) - Extending the astronomical (polarity) time scale into the Miocene. *Earth Planet. Sci. Lett.*, 136: 495-510, Amsterdam.

Hilgen F.J., Krijgsman W., Raffi I., Turco E. & Zachariasse W.J. (2000) - Integrated stratigraphy and astronomical calibration of the Serravallian/Tortonian boundary section at monte Gibliscemi (Sicily, Italy). *Marine Micropal.*, 38: 181-211, Amsterdam.

Jenkins G.M. & Watts D.G. (1968) - Spectral analyses and its applications, *Holden day*, 410 pp., Oakland.

Krijgsman W., Hilgen F.J., Langereis C.G., Santarelli A. & Zachariasse W.J. (1995) - Late Miocene magnetostratigraphy, biostratigraphy and cyclostratigraphy in the Mediterranean. *Earth Planet. Sc. Lett.*, 136: 475-494, Amsterdam.

Laskar J., Joutel F. & Boudin F. (1993) - Orbital, precessional, and insolation quantities for the Earth from -20 Myr to +10Myr. *Astron. Astrophys.* 270: 522-533, Washington.

Lourens L.J., Antonarakou A., Hilgen F.J., Van Hoof A.A.M., Vergnaud-Grazzini C. & Zachariasse W.J. (1996) - Evaluation of the Pliocene to early Pleistocene astronomical time scale. *Paleoceanography*, 11: 391-413, Washington.

Potsma G., Hilgen F.J. & Zachariasse W.J. (1993) - Precession punctuated growth of a late Miocene submarine-fan lobe on Gavdos (Greece). *Terranova*, 5: 438-444, Oxford.

Pujol C. & Vergnaud-Grazzini C. (1995) - Distribution patterns of live planktic foraminifers as related to regional hydrography and productive systems of the Mediterranean Sea. *Mar. Micropal.*, 25: 187-215, Amsterdam.

Rigo M. & Barbieri F. (1959) - Stratigrafia pratica applicata in Sicilia. *Boll. Ser. Geol. It.*, 80: 351-441, Roma.

Sierro F.J., Hilgen F.J., Krijgsman W. & Flores J.A. (2001) - The Abad composite (SE Spain): a Messinian reference section for the Mediterranean and the APTS. *Paleogeogr. Paleoclim. Paleoec.* 168: 141-169, Amsterdam.

Sprovieri R. (1993) - Pliocene-early Pleistocene astronomically forced and chronology of Mediterranean calcareous plankton bio-events. *Riv. Ital. Paleont. Strat.*, 99: 371-414, Milano.

Sprovieri R., Di Stefano E., Becquey S. & Caravà N. (1996) - Calcareous plankton biostratigraphy and cyclostratigraphy at the Serravallian-Tortonian boundary. *Paleopelagos*, 6: 437-453, Roma.

Weedon G.P. (1991) - The spectral analysis of stratigraphic time series. In: Cycles and events in Stratigraphy (Ed. by Einsele G., Ricken W. & Seilacher A.). Springer Verlag, pp. 840-863, Berlin.