

Bollettino della Società Paleontologica Italiana	36 (1-2), 1997	ISSN 0375-7633	167-177	-	Parma, Dicembre 1997
--	----------------	----------------	---------	---	----------------------

Astronomical Tuning of Planktonic Foraminiferal Records from the Radicofani Basin (southern Tuscany, central Italy)

Cristina CONTI
Dipartimento di Scienze della Terra
Università di Firenze

KEY WORDS - *Planktonic Foraminifera, Astronomical Cycles, Pliocene, Southern Tuscany.*

ABSTRACT - A study of planktonic foraminiferal assemblages in the Neogene Radicofani Basin (Tuscany, central Italy) is reported. The sequences analysed are represented by clays and silty clays with thin turbiditic layers and the basin is characterized by a high sedimentation rate and the lack of key-beds. Factor analyses on planktonic foraminifera and some climatic proxy records, such as ratio of planktonic versus planktonic plus benthic foraminifera (P/P+B), sea surface productivity (SSP) and sea surface temperature (SST), were carried out.

Spectral analyses were applied to factor analysis results and climatic proxy record patterns and showed power spectra with frequencies comparable with the orbital cycles of precession and obliquity of the Earth. Moreover, it was possible to take out the orbital components from raw data and correlate them to the astronomical curves, using two bioevents, *Globorotalia puncticulata* FO and *Dyscoaster asymmetricus* FCO, as calibration points.

Since these planktonic foraminifera abundance fluctuations were calibrated to astronomical curves, they were used to age-calibrate the studied sections. So these variations could be an important tool in areas where stratigraphic correlations are difficult.

RIASSUNTO - [Calibratura astronomica dell'associazione a foraminiferi planctonici del Bacino di Radicofani (Toscana meridionale, Italia centrale)] - Dettagliate analisi quantitative condotte sull'associazione a foraminiferi planctonici nel bacino pliocenico di Radicofani (Toscana meridionale) hanno permesso di ottenere un riferimento più preciso sul posizionamento delle sezioni analizzate entro la scala temporale. La difficoltà presentata dallo studio del bacino riguardava l'impossibilità di correlare le sezioni e di valutare l'intervallo temporale relativo a cui possono essere riferite le stesse successioni stratigrafiche.

Sui dati di abbondanza dell'associazione a foraminiferi planctonici ottenuti è stata applicata l'analisi fattoriale in Q-mode (Cabfac program). Lo studio delle curve così ottenute, assieme a quelle del rapporto specie planctoniche sul totale dei foraminiferi (P/P+B), della produttività superficiale delle acque (SSP) e della temperatura superficiale delle acque (SST), mostra la presenza di fluttuazioni cicliche. Queste fluttuazioni hanno un periodo ben comparabile con i cicli astronomici di precessione ed obliquità della Terra, come evidenziato dall'analisi spettrale.

Successivamente le variazioni di abbondanza dei foraminiferi planctonici estratte con l'analisi fattoriale e le curve climatiche costruite (P/P+B, SSP e SST) sono state correlate e confrontate con le oscillazioni orbitali. I due bioeventi, *Globorotalia puncticulata* FO e *Dyscoaster asymmetricus* FCO, sono stati usati per tale correlazione. Ciò ha permesso di calibrare le successioni analizzate e determinare l'intervallo cronologico coperto, rendendo possibili correlazioni stratigrafiche difficili da ottenere in altro modo.

INTRODUCTION

Astronomical influence on the Earth's processes has been studied for a long time. The orbital parameters (eccentricity, obliquity and precession) cause variations in the spatial distribution of solar energy reaching the Earth's surface. Over the year, these parameters influence both the distribution of climatic zones and the variation of the solar energy with respect to latitude (de Boer & Smith, 1994). Many researchers have documented the relationship between astronomical cycles and rhythmic sequences on a wide variety of rock types, such as sapropels (Ryan, 1972; Cita *et al.*, 1978; Vergnaud Grazzini *et al.*, 1977; Thunell *et*

al., 1984; Rohling & Gieskes, 1989), marl-limestone alternations in the Cretaceous southern Alps (Claps *et al.*, 1991), the "Scisti a Fucoidi" Formation in the Aptian-Albian (Tornaghi *et al.*, 1989), turbidite deposits (Weltje & de Boer, 1993), diatomites (McKenzie *et al.*, 1979) and marl sequences with differing CaCO₃ content in southern Italy (Hilgen, 1987).

The astronomical parameters produce different effects such as changes in summer-winter contrast and in monsoon intensity, and in the position of climate belts and their boundaries (Berger, 1978; Kutzbach & Otto-Bliesner, 1982). In addition, the relative abundance of planktonic foraminiferal taxonomic groups fluctuates in

response to climatic changes.

Abundance fluctuations in the planktonic foraminiferal assemblages from several Pliocene-lower Pleistocene Mediterranean sections have been identified (Channell *et al.*, 1992; Sprovieri, 1992, 1993) and their periodicity well related to the astronomical cycles. Proxy records for sea surface productivity (SSP) and sea surface temperature (SST) in the Mediterranean reveal orbital control on planktonic foraminifera microfauna (Lourens *et al.*, 1992). In this work a similar approach is proposed in the study of the Neogene Radicofani Basin (Tuscany, central Italy).

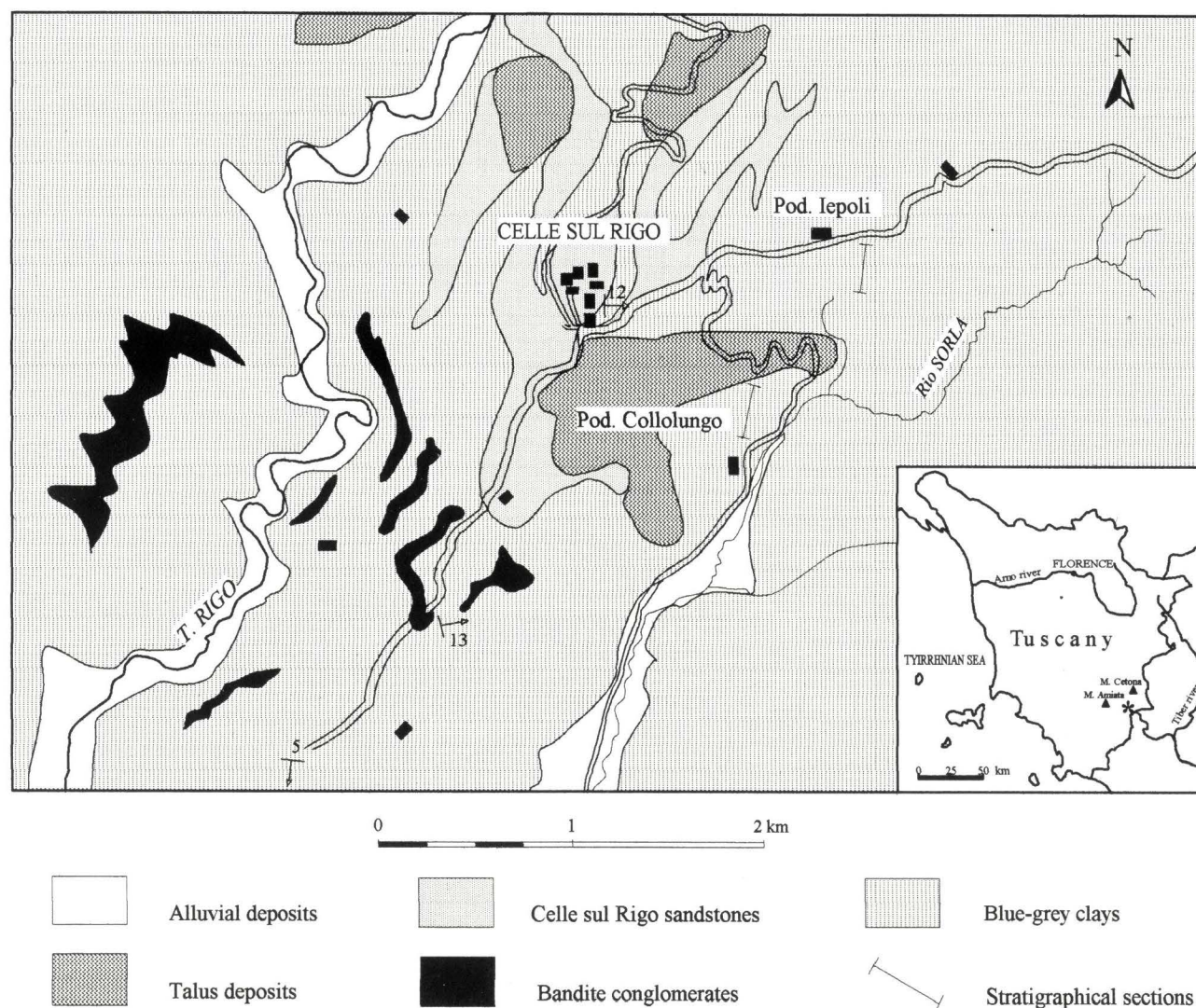
GEOLOGICAL SETTING

The Radicofani Basin (Text-fig. 1) is a marine basin affected by a complex geological evolution

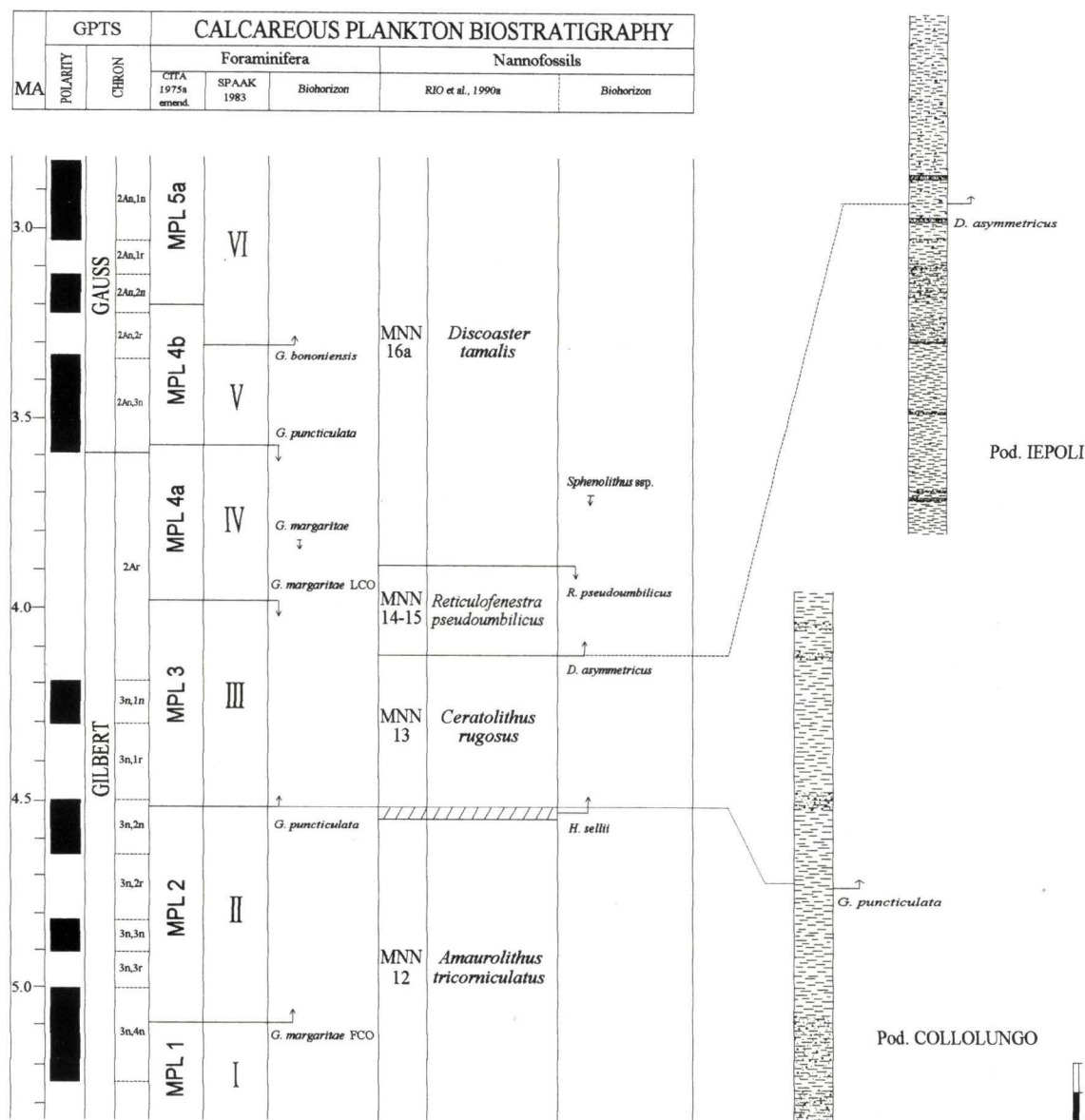
during Neogene times (Ambrosetti *et al.*, 1978; Bartolini *et al.*, 1982; Boccaletti *et al.*, 1992; Bossio *et al.*, 1993).

The Neogene sequence consists of continental conglomerates recorded only in boreholes, referred to the late Messinian, and of clays with intercalations of debris flows and turbiditic layers referred to the Pliocene. The basin is characterized by a high sedimentation rate: 16 cm/kyr according to Liotta & Salvatorini (1994); 13,8 cm/kyr deduced by Iaccarino *et al.* (1994). These sedimentation rates are average values for the whole basin.

Two pliocenic sedimentary cycles can be distinguished (Iaccarino *et al.*, 1994): the first one, the lowermost, is characterized by the deposition of a sedimentary sequence up to thousands of meters thick and is attributed to the *Sphaeroidinellopsis seminulina* s.l.-*Globorotalia puncticulata*



Text-fig. 1 - Location map of the Radicofani Basin, indicated by an asterisk, and geological map of the south-eastern side of Radicofani Basin from Iaccarino *et al.* (1994) modified.



Text-fig. 2 - Biostratigraphic framework of the sections studied. Chronobiostratigraphic scale is taken from Rio *et al.* (1994) emended, according to Lourens *et al.* (1996) for microfossil datum planes and geomagnetic polarity reversal ages. (Pod. Collolungo and Pod. Iepoli are not in scale with the Geomagnetic Reversal Time Scale used).

Zones (the biostratigraphic scheme is from Rio *et al.*, 1994, emended for bioevents and magnetostratigraphic ages as in Lourens *et al.*, 1996). The sediments belonging to the *Sphaeroidinellopsis* s.l. Zone and part of *Globorotalia margaritae* Zone are not outcropping. The second one is attributed to the *Globorotalia aemiliana* Zone and is a few meters thick. It is only present in the north-eastern part of the Basin.

Near Celle sul Rigo, the Pliocene sequence is more than 2600 m thick, but only about 1650 m outcrop. In this area two sections were investigated: the Podere Collolungo section and the Podere

Iepoli section. They are well exposed sequences corresponding to the first sedimentary cycle. The Pod. Collolungo and Pod. Iepoli sections consist of about 44.5 m and 43.5 m of clays and silty clays respectively, with thin fine grain-sized turbiditic levels. *Globorotalia puncticulata* FO is found in the Pod. Collolungo section and *Dyscoaster asymmetricus* FCO is found in the Pod. Iepoli section (Text-fig. 2). It is not possible, in the field, to correlate the two sections on the basis of lithologic features. No faults or other discontinuities are known to exist in this area (Liotta & Salvatorini, 1994).

METHODS

Quantitative analyses were carried out on planktonic foraminiferal assemblages. All the samples were disaggregated in normal water and washed with 63 and 125 micron sieves. About 300 specimens, from fractions greater than 125 microns, were counted on splits (using a micro-splitter). The results are based on the analysis of 17 (plus *Sphaeroidinellopsis* spp. in Pod. Collolungo section) planktonic foraminiferal taxonomic units (Tab. 1).

The raw data were elaborated by Q-mode factor analysis using the Cabfac program (Imbrie & Kipp, 1971; Klován & Imbrie, 1971), in order to reduce a large number of variables to a few meaningful, uncorrelated factors. The scaled factor scores and the variance explained by each Factor are reported in Tabs. 2 and 3.

The ratio of planktonic versus planktonic plus benthic foraminifera (P/P+B), sea surface productivity (SSP) and sea surface temperature (SST) proxy records were considered (as in Lourens *et al.*, 1992).

The SSP proxy record is based on plotting the cumulative percentages of *Neogloboquadrina* (d+s) and *Globigerina bulloides*. These species are considered the most sensitive indicators of sea surface productivity. The SST proxy record is constructed by using a selection of temperature-sensitive planktonic foraminifera and represents a

- *Globigerina falconensis*.
- Intermediate group: specimens with intermediate morphologic characteristics between *G. falconensis* and *G. bulloides*.
- *Globigerina bulloides*.
- *Globoturborotalita apertura*.
- *Globigerinoides obliquus* s.l.: *G. obliquus obliquus* and *G. obliquus extremus*.
- *Globorotalia margaritae*.
- *Globorotalia scitula*.
- *Globorotalia puncticulata*.
- *Neogloboquadrina* (s): *N. pachyderma* and *N. acostaensis* (very rare) with left coiled specimens.
- *Neogloboquadrina* (d): *N. pachyderma* and *N. acostaensis* (very rare) with right coiled specimens.
- *Turborotalita quinqueloba*.
- *Globigerinita glutinata*.
- *Globigerinella siphonifera*.
- *Orbulina* spp.
- *Globoquadrina altispira* s.l.: *G. altispira altispira* and *G. altispira globosa*.
- *Globigerinoides trilobus*: includes also *G. sacculifer*.
- *Sphaeroidinellopsis* spp. (only in Pod. Collolungo section).
- Indeterminable group: unidentified specimens.

Tab. 1 - Taxonomic units recognized in the planktonic foraminiferal assemblage.

	Factor 1	Factor 2	Factor 3
<i>G. falconensis</i>	.943	3.239	1.025
Intermediate group	-.220	1.428	.066
<i>G. bulloides</i>	-.063	.660	.225
<i>G. apertura</i>	.528	1.492	.302
<i>G. obliquus</i> s.l.	-.284	.649	.543
<i>G. margaritae</i>	-.113	.133	.268
<i>G. scitula</i>	-.020	.028	.149
<i>G. puncticulata</i>	-1.089	-.934	3.865
<i>Neogloboquadrina</i> (s)	.060	.282	.098
<i>Neogloboquadrina</i> (d)	3.912	-1.107	.817
<i>T. quinqueloba</i>	.197	-.019	-.005
<i>G. glutinata</i>	.319	.221	-.033
<i>G. siphonifera</i>	.005	.057	-.019
<i>Orbulina</i> spp.	.003	.077	.196
<i>G. altispira</i> s.l.	-.185	.350	.031
<i>G. trilobus</i>	.031	-.017	.103
<i>Sphaeroidinellopsis</i> spp.	-.041	.079	.012
Indeterminable group	.126	.074	.866
Variance	43.002	28.633	25.858

Tab. 2 - Scaled varimax factor scores matrix and explained variance of planktonic foraminifera assemblage in the Pod. Collolungo section.

plot of the ratio of warm-water versus cold plus warm water indicators (Warm indicators: *Globigerinoides sacculifer*, *Globigerinoides trilobus*, *Globigerinoides obliquus*, *Globoturborotalita apertura*, *Globigerinella siphonifera*, *Orbulina universa*. Cold indicators: *Globigerina falconensis*, *Neogloboquadrina* (s), *Globorotalia scitula*, *Turborotalita quinqueloba*).

Semiquantitative analyses were performed on calcareous nannofossil assemblages and 400 fields

	Factor 1	Factor 2	Factor 3
<i>G. falconensis</i>	.391	.059	-.534
Intermediate group	.011	.368	-.046
<i>G. bulloides</i>	.198	.005	.097
<i>G. apertura</i>	3.985	.765	.318
<i>G. obliquus</i> s.l.	.360	.176	.652
<i>G. margaritae</i>	.085	-.044	-.124
<i>G. scitula</i>	.010	.008	-.022
<i>G. puncticulata</i>	-.740	2.551	2.436
<i>Neogloboquadrina</i> (s)	.014	.075	.016
<i>Neogloboquadrina</i> (d)	-.373	2.995	-2.433
<i>T. quinqueloba</i>	.060	.093	-.081
<i>G. glutinata</i>	-.139	.702	-.158
<i>G. siphonifera</i>	.027	-.011	-.001
<i>Orbulina</i> spp.	-.004	.122	.027
<i>G. altispira</i> s.l.	.018	-.014	.013
<i>G. trilobus</i>	-.215	.405	2.063
Indeterminable group	.175	.274	.128
Variance	66.039	29.925	1.750

Tab. 3 - Scaled varimax factor scores matrix and explained variance of planktonic foraminifera assemblage in the Pod. Iepoli section.

of view were investigated with an optical microscope at 1000 magnification. Although the nanofossil assemblages are abundant and well diversified (24-27 species), the discoasterids are absent or very rare. Consequently the count of 100 *Discoaster* spp. as proposed by Rio *et al.* (1990), in order to define the first common occurrence of *D. asymmetricus* at the base of MNN14/15 Zone, was not possible and only 0-17 specimens were counted on 400 fields of view.

Spectral analyses were carried out on planktonic foraminiferal assemblage. Spectral analysis is possibly the best way of establishing cyclic behaviour in stratigraphic records and it allows the investigation of complex cycles which consist of several oscillations. In the power spectra the relative position of the frequency maxima provides characteristic data which may lead to an identification of the cycles (Schwarzacher, 1993). The StrataBase program (Ripepe, 1988) was used to elaborate data from factor analysis and P/P+B, SSP and SST proxy records. The Fourier transform and filters, used to eliminate random disturbing fluctuations from the frequency range of the record, were applied to obtain spectral peaks.

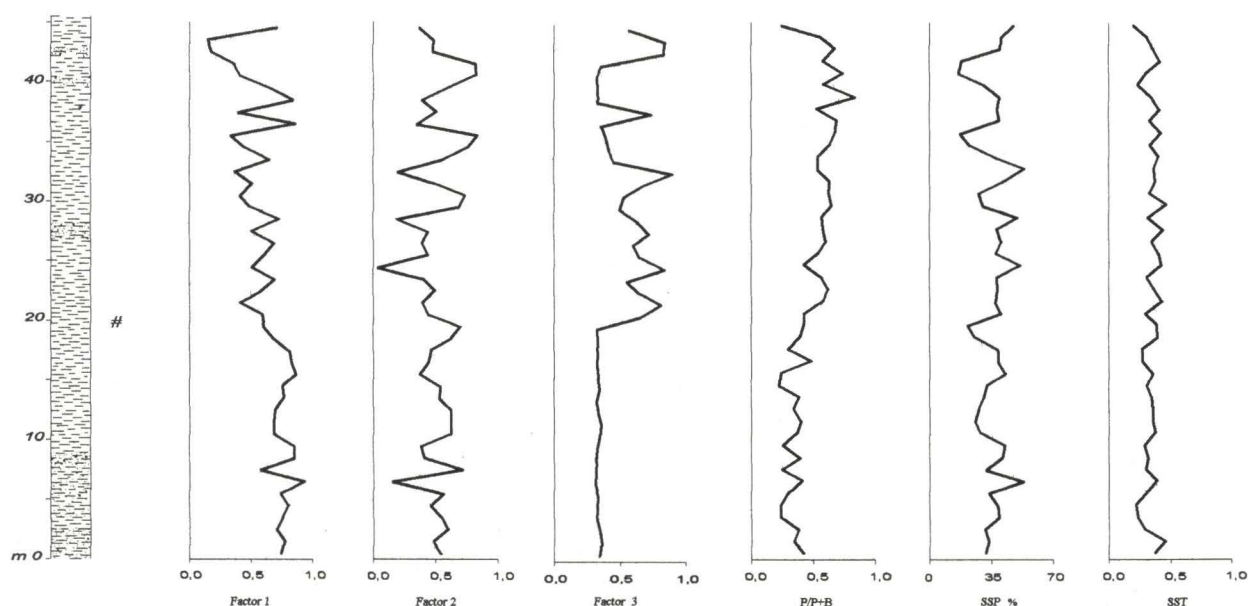
INTERPRETATION OF THE DATA

Statistical analysis carried out in the Pod. Collolungo section reduced the original variables to 3 factors, dominated by different planktonic foraminifera species. These factors, retained from

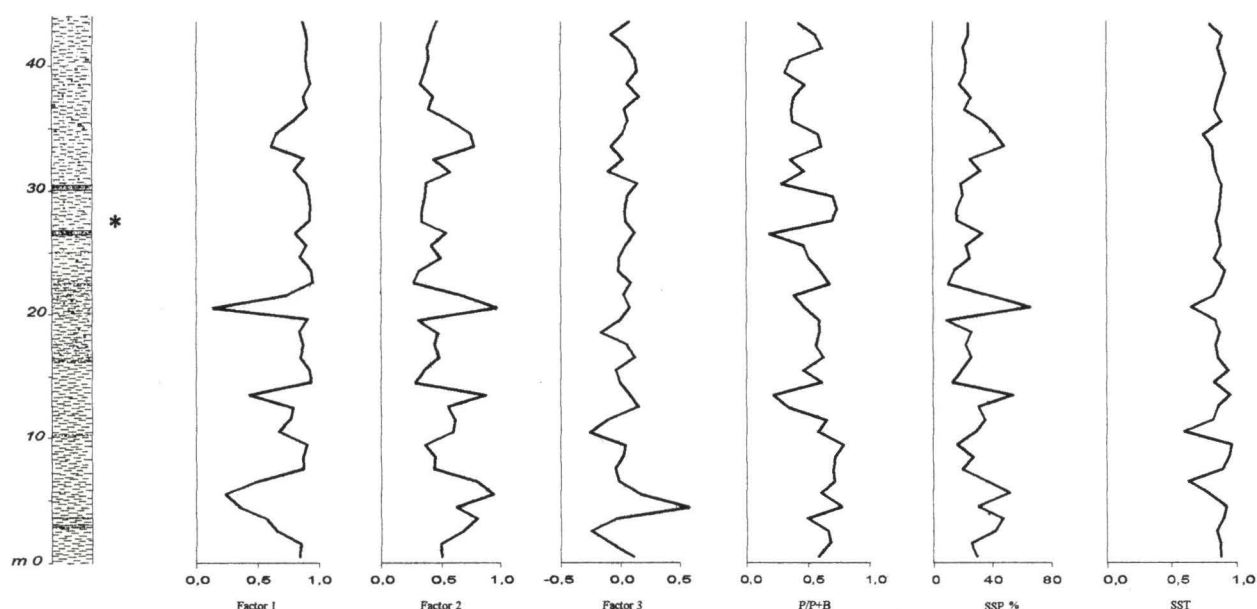
varimax rotation, explain a cumulative variance of 97%. Communalities are high (above 0.93), proving the good efficiency of the reduction to 3 factors from the original 18 variables. Factor 1 is dominated by *Neogloboquadrina* (d). Factor 2 is dominated by *G. falconensis* but *G. apertura* is also present with high scores. Factor 3 is dominated by *G. puncticulata* which appears at about mid-section. Changes in abundance patterns along the sequence of the 3 factor loadings retained are plotted in Text-fig. 3 with P/P+B, SSP and SST proxy record patterns.

In the Pod. Iepoli, section factor analysis indicated 3 other independent variables. The cumulative variance is 97% and communalities are high (above 0.88). Factor 1 is dominated by *G. apertura*, Factor 2 by *Neogloboquadrina* (d) and *G. puncticulata*. Factor 3 is characterized by *G. trilobus* and highly weighted by *G. puncticulata*. The loadings of the factors retained from varimax rotation of the Q-mode analysis are reported in Text-fig. 4 with P/P+B, SSP and SST proxy record patterns.

The application of spectral analysis to the proxy record patterns of the sequences analysed indicated the presence of frequencies in the power spectra related to the Earth's orbital variations. In fact, the coherence of the spectral response of each parameter suggested the existence of a single forcing mechanism or, at least, a principal one affecting environmental changes and consequently abundance fluctuations in foraminiferal assemblage.



Text-fig. 3 - Distribution patterns of factor loadings of planktonic foraminifera assemblage in the Pod. Collolungo section. The P/P+B, SSP and SST proxy records are also shown. # indicates the first occurrence of *G. puncticulata*.



Text-fig. 4 - Distribution patterns of factor loadings of planktonic foraminifera assemblage in the Pod. Iepoli section. The P/P+B, SSP and SST proxy records are also shown. * indicates the first common occurrence of *D. asymmetricus*.

ge. Spectral evidence for eccentricity, obliquity and precessional frequencies confirm astronomical control over the Radicofani Basin foraminiferal assemblage.

In the power spectra of the Pod. Collolungo section peaks in a range of frequencies between 20,000 and 27,000 years, correlated to the precessional signal, are present. The amplitude of the precessional peak is particularly high in the SST power spectrum. Frequencies between 33,000 and 49,000 years are attributed to the obliquity signal and the amplitude of the peaks is high in each power spectrum except for the SST one. The influence of eccentricity is not so clear, since it is only present in two of the power spectra of the parameters analysed (P/P+B and SST), with a frequency of 98,000 years. In Factor 1 a peak with a frequency of 73,000 years is considered as being a random disturbing signal. In Factor 3 spectral analysis was not considered because *G. puncticulata*, which characterizes this Factor, appears at about mid - section. In the power spectra of the Pod. Collolungo section's parameters, 14 cycles at precessional frequency, 6.5 cycles at obliquity frequency and 2 cycles at eccentricity frequency can be observed (Text-fig. 5).

In the power spectra of the Pod. Iepoli section, peaks in a range of frequencies between 18,000 and 26,000 years, correlated to the precessional signal, are present. The amplitude of the precessional peak is high in Factor 3 and P/P+B power spectra while it is weak in Factor 1. Frequencies between 30,000 and 48,000 years are attributed to

the obliquity signal and the amplitude of the peaks is particularly high in each power spectrum. Spectral evidence for the eccentricity frequency is weak and is shown only in the power spectra of Factor 3 and P/P+B parameters with a frequency of 119,000 years. Probably the weakness of the eccentricity signal in the sections is related to the high sedimentation rate and sequence thickness. In Factor 1 and Factor 2 a peak with a frequency of 79,000 years is considered as being a random disturbing signal. In the power spectra of the Pod. Iepoli section's parameters, 12 cycles at precessional frequency, 6 cycles at obliquity frequency and 2 cycles at eccentricity frequency can be observed (Text-fig. 6).

DISCUSSION

Analysis of the curves of the two sections shows the presence of cyclicity in abundance fluctuations. Several papers have proved that the relative abundance of different planktonic foraminiferal taxonomic groups fluctuates in response to climatic changes (Sprovieri, 1992, among others). It has also been observed that during the Plio-Pleistocene time interval the cyclicity of the abundance fluctuations in planktonic foraminiferal assemblage has a period well comparable with precession and obliquity astronomical cycles (Sprovieri, 1993; Sprovieri *et al.*, 1994). In fact, variations in the Earth's orbital parameters can markedly influence several environmental factors such as water temperature, nutrient supply, water

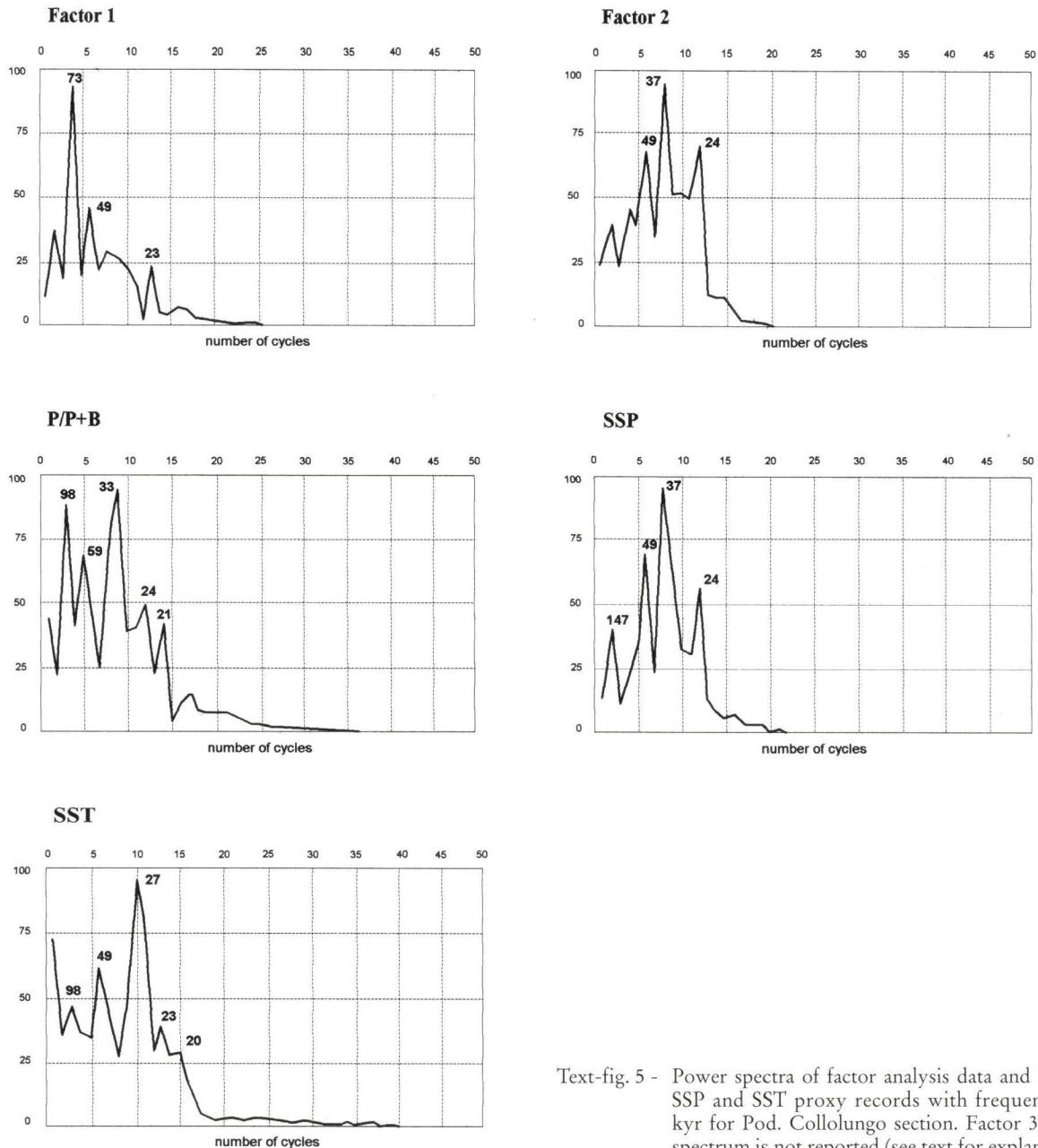
oxygen concentration and CaCO_3 supply, which, in turn, affect fossil communities.

Spectral analysis revealed the presence of cyclic variations in the foraminiferal assemblage of the Pod. Collolungo and Pod. Iepoli sections, and fluctuations in abundance patterns have been related to precession and obliquity oscillations. The presence of the eccentricity signal is not clear in the power spectra and it was not considered. The covered time interval of the sections was inferred from the average number of precessional cycles in the power spectra of each parameter considered. It was possible to estimate the time duration of

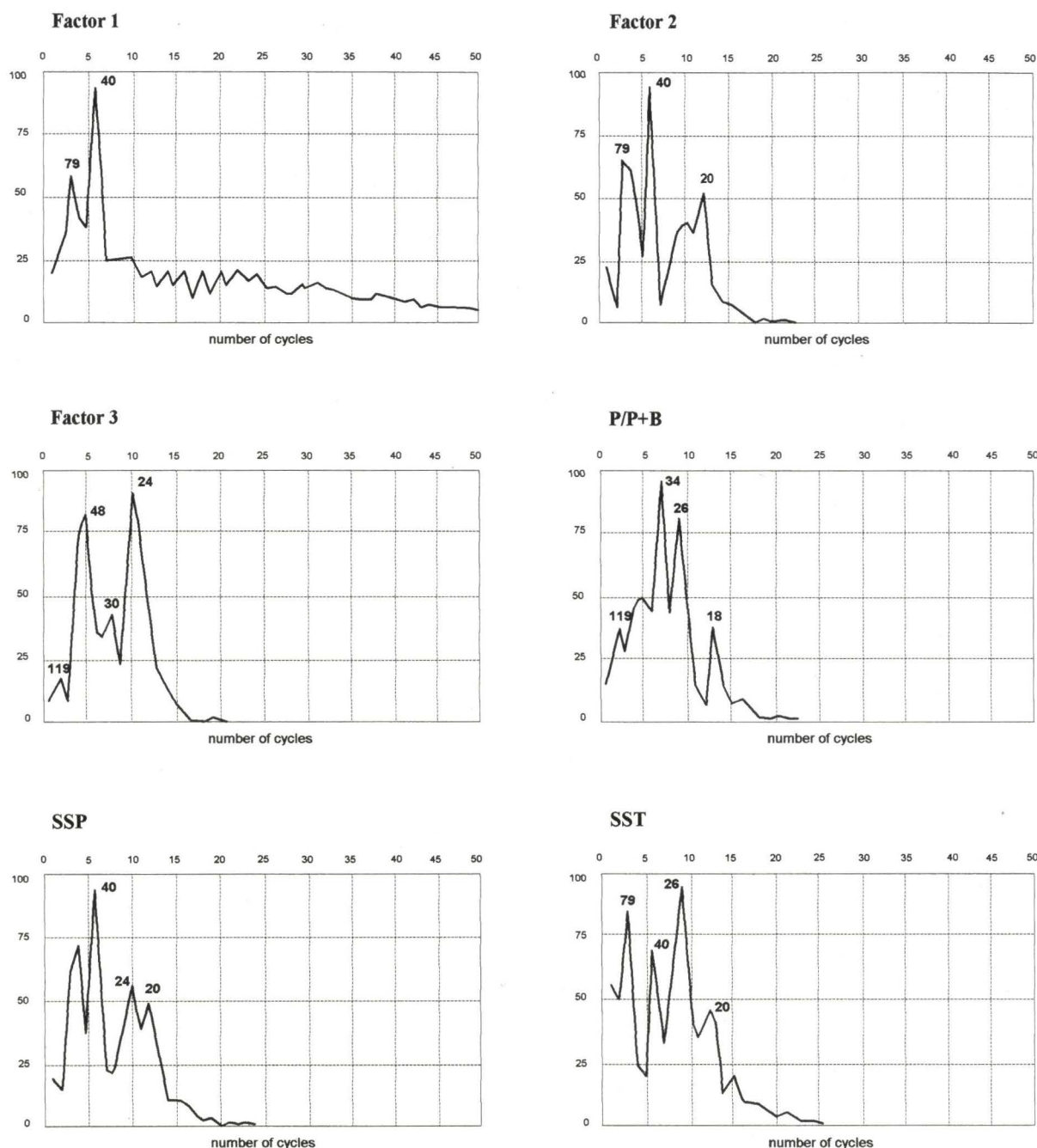
the Pod. Collolungo and Pod. Iepoli sections, at 290,000 yrs and 250,000 yrs respectively.

Moreover, the number of precessional cycles and the presence of two bioevents, *G. puncticulata* FO and *D. asymmetricus* FCO, recognized in the Pod. Collolungo and Pod. Iepoli sections respectively, allowed the age-calibration of the sequences, using the bioevents as calibration points. The ages of the bioevents are from Lourens *et al.* (1996). An age of 4.52 Ma is reported for *G. puncticulata* FO and 4.12 Ma for *D. asymmetricus* FCO.

Several papers (Channell *et al.*, 1988; Channell *et al.*, 1990; Driever, 1988; Glaçon *et al.*, 1990;



Text-fig. 5 - Power spectra of factor analysis data and P/P+B, SSP and SST proxy records with frequencies in kyr for Pod. Collolungo section. Factor 3 power spectrum is not reported (see text for explanation).



Text-fig. 6 - Power spectra of factor analysis data and P/P+B, SSP and SST proxy records with frequencies in kyr for Pod. Iepoli section.

Hilgen, 1991; Langereis & Hilgen, 1991; Rio *et al.*, 1990) have proved that *G. puncticulata* FO and *D. asymmetricus* FCO are synchronous in the Mediterranean. But the physical features of the Radicofani Basin, semi-enclosed and with high terrigenous fluxes, could have delayed taxa occurrences. Curves obtained from factor analysis on the foraminiferal assemblage were therefore compared with similar curves studied on the sedimentary sequence at Site 653 ODP Leg 107 in the

Tyrrhenian Sea and reported in Sprovieri (1993) (Text-fig. 7). Factor 3 (*G. inflata* TU) in Sprovieri (1993), here indicated by Curve a, was compared with the Factor 3 curve of the Pod. Collolungo section, dominated by *G. puncticulata*, and with the Factor 2 curve of the Pod. Iepoli section, also highly represented by *G. puncticulata*. Comparison of the curves showed that the first common occurrence of *D. asymmetricus* is synchronous and the first occurrence of *G. puncticulata*

has a time-lag of less than 10,000 years in the Radicofani Basin compared with Tyrrhenian Sea sediments. The time-lag of *G. puncticulata* FO is short enough to consider the bioevent synchronous in the two areas. Consequently, the Pod. Collolungo section ranges from 4.64 Ma to 4.35 Ma and the Pod Iepoli section from 4.28 to 4.03 Ma (Early Pliocene); the final position of the sections in the chronological scheme is shown in Text-fig. 8.

CONCLUSIONS

Detailed analyses of abundance fluctuations of planktonic foraminiferal assemblages can be used to refine stratigraphic correlations of sedimentary sequences. These kinds of analyses can also be done in sequences in which problems such as

high sedimentation rate, lithologic uniformity, the absence of two or more bioevents or the absence of paleomagnetic data, make it difficult to correlate the sections studied to a chronological scale.

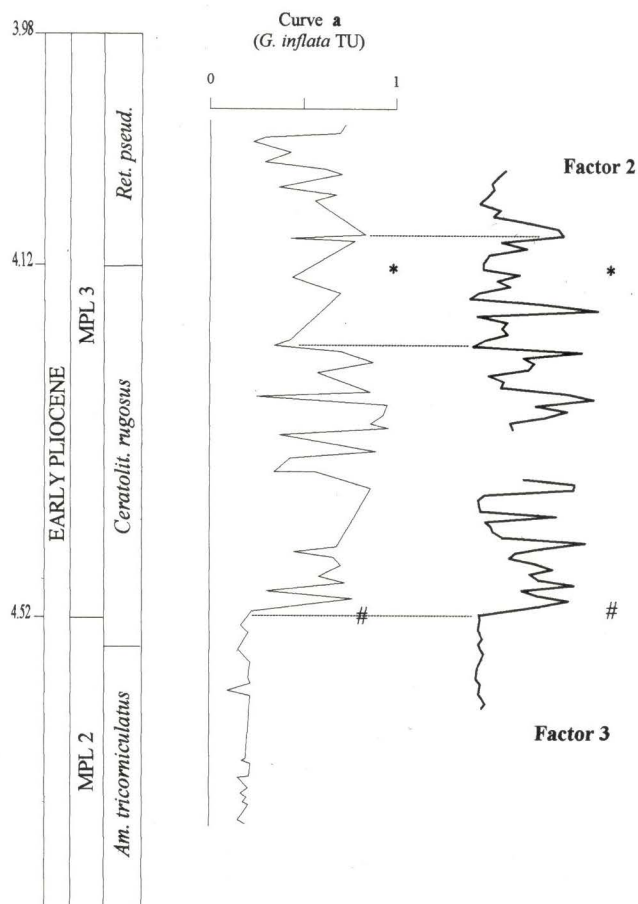
Planktonic foraminiferal abundance variations in the Radicofani Basin show frequencies comparable with the orbital cycles of precession, obliquity and eccentricity, as revealed by spectral analysis. Since these abundance fluctuations are correlated to astronomical curves, using *G. puncticulata* FO and *D. asymmetricus* FCO as calibration points, they can be used to age-calibrate the sections studied. Thus, foraminiferal abundance variations are a useful tool in basins where stratigraphic correlations are difficult. Since astronomically calibrated time scales are more accurate and have higher resolution than time scales based on a limited number of radiometric dates in marine seafloor anomaly profiles, this method can be used with good results.

ACKNOWLEDGEMENTS

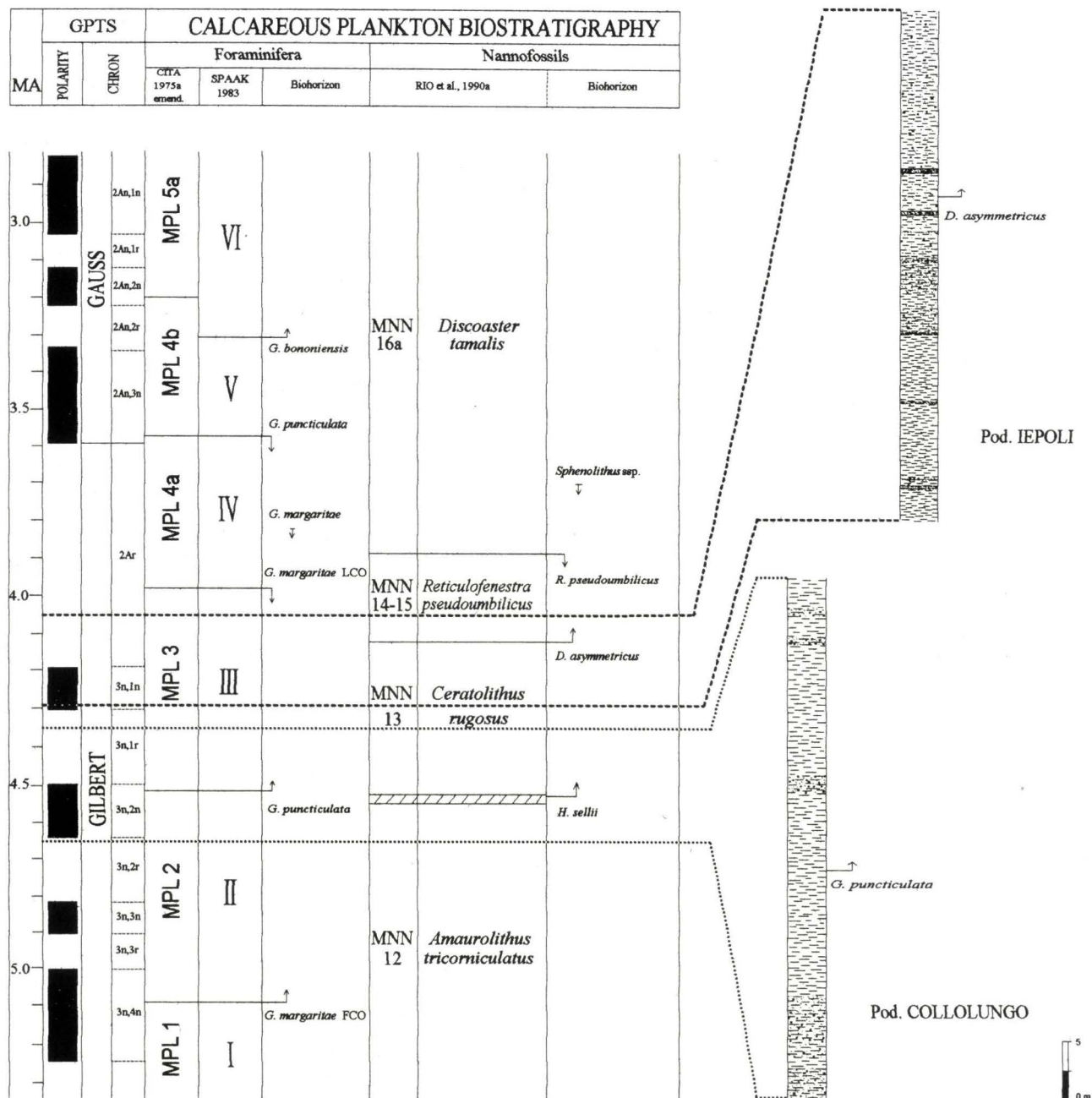
I would like to thank Dr. M. Marino for providing calcareous nannofossil data, Dr. A. Albanielli for spectral analyses and Prof. F. Masini for statistical analyses. I am very grateful to Dr. G. Valleri for critically reading an earlier version of this manuscript. Finally, Dr. F. Hilgen, Prof. R. Sprovieri and Prof. S. Iaccarino are gratefully acknowledged for reviews and critical comments. This study was supported by Murst grants, 60% (Valleri).

REFERENCES

- AMBROSETTI, P., CARBONI, M.G., CONTI, M.A., COSTANTINI, A., ESU, D., GANDIN, A., GIROTTI, O., LAZZAROTTO, A., MAZZANTI, R., NICOSIA, U., PARISI, G. & SANDRELLI, F., 1978, Evoluzione paleogeografica e tettonica nei bacini toscano-umbro-laziali nel Pliocene e nel Pleistocene inferiore: Mem. Soc. Geol. It., 19: 573-580.
- BARTOLINI, C., BERNINI, M., CARLONI, G.C., COSTANTINI, A., FEDERICI, P.B., GASPERI, G., LAZZAROTTO, A., MARCHETTI, G., MAZZANTI, R., PAPANI, G., PRANZINI, G., RAU, A., SANDRELLI, F., VERCESI, P.L., CASTALDINI, D. & FRANCAVILLA, F., 1982, Carta neotettonica dell'Appennino settentrionale. Note illustrative: Boll. Soc. Geol. It., 101: 523-549.
- BERGER, A., 1978, Long-term variations of caloric insolation resulting from the Earth's orbital elements: Quatern. Res., 9: 139-167.
- BOCCALETTI, M., CERRINA FERONI, A., MARTINELLI, P., MORATTI, G., PLESI, G. & SANI, F., 1992, L'alternanza distensione-compressione nel quadro evolutivo dei bacini neogenici dell'Appennino Settentrionale: Studi Geologici Camerti, Vol. Speciale (1991/1): 187-192.
- BOSSIO, A., COSTANTINI, A., LAZZAROTTO, A., LIOTTA, D., MAZZANTI, R., MAZZEI, R., SALVATORINI, G. & SANDRELLI, F., 1993, Rassegna delle conoscenze sulla stratigrafia del neautoctono toscano: Mem. Soc. Geol. It., 49: 17-98.



Text-fig. 7 - Comparison between Factor 3 and Factor 2 curves, in Pod. Collolungo and Pod. Iepoli sections respectively, with Curve a (Factor 3, *G. inflata* TU, in Sprovieri, 1993). Ages for biochronologic scheme are from Lourens *et al.* (1996). # represents *G. puncticulata* FO; * represents *D. asymmetricus* FCO.



Text-fig. 8 - Stratigraphic position of the sections studied in the Geomagnetic Reversal Time Scale, deduced by astronomical tuning. The Time Scale is from Rio *et al.* (1994) emended according to Lourens *et al.* (1996) for microfossil bioevents and geomagnetic polarity reversal ages.

CHANNELL, J.E.T., DI STEFANO, E. & SPROVIERI, R., 1992, Calcareous plankton biostratigraphy, magnetostratigraphy and paleoclimatic history of the Plio-Pleistocene Monte S. Nicola section (southern Sicily): *Boll. Soc. Paleont. Ital.*, 31 (3): 351-382.

—, RIO, D., SPROVIERI, R. & GLAÇON, G., 1990, Biomagnetostratigraphic correlations from Leg 107 in the Tyrrhenian Sea (Western Mediterranean, Leg 107). In Kastens K.A. *et al.* (eds), *Proc. ODP, Scient. Results*, 107, College Station, TX: 669-682.

—, — & THUNELL, R.C., 1988, Miocene/Pliocene boundary magnetostratigraphy at Capo Spartivento, Calabria, Italy: *Geology*, 16: 1096-1099.

CITA, M.B., VERGNAUD GRAZZINI, C., ROBERT, C., CHAMLEY, H., CIARANFI, N. & D'ONOFRIO, S., 1978, Paleoclimatic record of a long deep-sea core from the eastern Mediterranean: *Quatern. Res.*, 8: 205-235.

CLAPS, M., MASETTI, D., PEDRIELLI, F. & LUCCHI GARAVELLO, A., 1991, Analisi spettrale e cicli di Milankovitch in successioni cretache del Sudalpino orientale: *Riv. It. Paleont. Strat.*, 97 (2): 153-174.

- DE BOER, P.L. & SMITH, D.G., 1994, Orbital forcing and cyclic sequences. *In* De Boer, P.L. & Smith, D.G. (eds), *Orbital forcing and cyclic sequences: Spec. Publs Int. Ass. Sediment.*, Blackwell Scientific Publ., Oxford, 19: 1-14.
- DRIEVER, B.W.M., 1988, Calcareous nannofossil biostratigraphy and paleoenvironmental interpretation of the Mediterranean Pliocene: *Utrecht Micropal. Bull.*, 36: 245 pp.
- GLAÇON, G., RIO, D. & SPROVIERI, R., 1990, Calcareous plankton Pliocene-Pleistocene biostratigraphy in the Tyrrhenian Sea (western Mediterranean, Leg 107). *In* Kastens, K.A. *et al.* (eds), *Proc. ODP, Scient. Results*, 107, College Station, TX: 683-693.
- HILGEN, F.J., 1987, Sedimentary rhythms and high-resolution chronostratigraphic correlations in the Mediterranean Pliocene: *News. Stratigr.*, 17: 109-127.
- , 1991, Extension of the astronomically calibrated (polarity) time scale to the Miocene/Pliocene boundary: *Earth and Planetary Science Letters*, 107: 349-368.
- IACCARINO, S., VERNIA, L., BATTINI, P. & GNAPPI, G., 1994, Osservazioni stratigrafiche sul bordo orientale del Bacino di Radicofani (Toscana meridionale): *Mem. Descr. Carta Geol. d'It.*, XLIX: 151-168.
- IMBRIE, J. & KIPP, N.G., 1971, A new micropaleontological method for quantitative paleoclimatology: Application to a Late Pleistocene Caribbean core. *In* Turekian, K.K. (ed), *The Late Cenozoic Glacial Ages*, Yale Univ. Press: 71-81.
- KLOVAN, J.E. & IMBRIE, J., 1971, An algorithm and Fortran IV program for large scale Q-mode factor analysis: *J. Intern. Assoc. Mathematical Geol.*, 3 (1): 61-77.
- KUTZBACH, J.E. & OTTO-BLIESNER, B.L., 1982, The sensitivity of the African-Asian monsoonal climate to orbital parameter changes for 9000 years BP in a low-resolution general circulation model: *J. Atmos. Sci.*, 39: 1177-1188.
- LANGEREIS, C.G. & HILGEN, F.J., 1991, The Rossello composite: A Mediterranean and global reference section for the early to early late Pliocene: *Earth and Planetary Science Letters*, 104: 211-225.
- LIOTTA, D. & SALVATORINI, G.F., 1994, Evoluzione sedimentaria e tettonica della parte centro-meridionale del bacino pliocenico di Radicofani: *Studi Geologici Camerti, Vol. Speciale* (1994/1): 65-77.
- LOURENS, L.J., HILGEN, F.J., GUDJONSSON, L. & ZACHARIASSE, W.J., 1992, Late Pliocene to early Pleistocene astronomically forced sea surface productivity and temperature variations in the Mediterranean: *Mar. Micropal.*, 19: 49-78.
- , ANTONARAKOU, A., HILGEN, F.J., VAN HOOFF, A.A.M., VERGNAUD GRAZZINI, C. & ZACHARIASSE, W.J., 1996, Evaluation of the Plio-Pleistocene astronomical timescale: *Paleoceanography*, 11 (4): 391-413.
- MCKENZIE, J.A., JENKINS, H.C. & BENNET, G.G., 1979, Stable isotope study of the cyclic diatomite-claystones from the Tripoli Formation, Sicily: A prelude to the Messinian salinity crisis: *Palaeogeog., Palaeoclimat., Palaeoecol.*, 29: 125-141.
- RIO, D., RAFFI, I. & VILLA, G., 1990, Pliocene-Pleistocene calcareous nannofossil distribution patterns in the western Mediterranean. *In* Kastens, K.A. *et al.* (eds), *Proc. ODP, Scient. Results*, 107, College Station, TX: 513-533.
- , SPROVIERI, R. & DI STEFANO, E., 1994, The Gelasian Stage: a proposal of a new chronostratigraphic unit of the Pliocene series: *Riv. It. Paleont. Strat.*, 100 (1): 103-124.
- RIPEPE, M., 1988, Stratabase: a stratigraphical database and processing program for microcomputers: *Comput. Geosci.*, 14: 369-375.
- ROHLING, E.J. & GIESKES, W.W.C., 1989, Late Quaternary changes in Mediterranean intermediate water density and formation rate: *Paleoceanography*, 4: 531-545.
- RYAN, W.B.F., 1972, Stratigraphy of late Quaternary sediments in the eastern Mediterranean. *In* Stanley, D.J. (ed), *The Mediterranean Sea: A natural sedimentation laboratory*, Stroudsburg, Pennsylvania, Dowden, Hutchinson & Ross Inc.: 146-169.
- SCHWARZACHER, W., 1993, Milankovitch cycles in the pre-Pleistocene stratigraphic record: a review. *In* Hailwood, E.A. & Kidd, R.B. (eds), *High Resolution Stratigraphy: Geol. Soc. Special Publ.*, 70: 187-194.
- SPROVIERI, R., 1992, Mediterranean Pliocene biochronology: a high resolution record based on quantitative planktonic foraminifera distribution: *Riv. It. Paleont. Strat.*, 98 (1): 61-100.
- , 1993, Pliocene-Early Pleistocene astronomically forced planktonic foraminifera abundance fluctuations and chronology of Mediterranean calcareous plankton bio-events: *Riv. It. Paleont. Strat.*, 99 (3): 371-414.
- , DI STEFANO, E., RIGGI, A. & BUSALACCHI, P., 1994, La sezione intra-pliocenica di Gibil-Gabel (Caltanissetta, Sicilia centrale): un esercizio di biostratigrafia ad alta risoluzione: *Boll. Soc. Paleont. Ital.*, 33 (3): 289-298.
- THUNELL, R.C., WILLIAMS, D.F. & BELYEA, P.R., 1984, Anoxic events in the Mediterranean Sea in relation to the evolution of late Neogene climates: *Mar. Geol.*, 59: 105-134.
- TORNAGHI, M.E., PREMOLI SILVA, I. & RIPEPE, M., 1989, Lithostratigraphy and planktonic foraminiferal biostratigraphy of the Aptian-Albian 'Scisti a Fucoidi' in the Piobbico core, Marche, Italy: background for Cyclostratigraphy: *Riv. It. Paleont. Strat.*, 95 (3): 223-264.
- VERGNAUD GRAZZINI, C., RYAN, W.B.F. & CITA, M.B., 1977, Stable isotope fractionation, climatic change and episodic stagnation in the eastern Mediterranean during the late Quaternary: *Mar. Micropal.*, 2: 353-370.
- WELTJE, G.J. & DE BOER, P.L., 1993, Astronomically induced paleoclimatic oscillations reflected in Pliocene turbidite deposits on Corfu (Greece): implications for the interpretation of higher order cyclicity in fossil turbidite system: *Geology*, 21: 307-310.

(manuscript received November 30, 1996
accepted June 30, 1997)

Cristina CONTI
Dipartimento di Scienze della Terra
Via G. La Pira 4, 50121 Firenze, Italy