PLIOCENE-EARLY PLEISTOCENE ASTRONOMICALLY FORCED PLANKTONIC FORAMINIFERA ABUNDANCE FLUCTUATIONS AND CHRONOLOGY OF MEDITERRANEAN CALCAREOUS PLANKTON BIO-EVENTS

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Riassunto. Le valutazioni di età assolute per numerosi eventi a plancton calcareo, proposti dallo scrivente in un recente lavoro, vengono discusse con riferimento alle scale di età assolute recentemente proposte. Una re-interpretazione della successione di cicli litologici riconosciuti nella "Rossello composite section" permette di riconoscere lo stesso numero di fluttuazioni di abbondanza nelle associazioni a Foraminiferi planctonici e di cicli litologici in questo intervallo stratigrafico.

La base del Pliocene, quale definita nella sezione di Capo Rossello, risulta avere una età di 5.33 MA.

La analisi quantitativa di dettaglio della associazione a Foraminiferi planctonici in numerose sezioni mediterranee riferibili al Pleistocene inferiore ha permesso di evidenziare una successione di fluttuazioni di abbondanza relativa, la cui periodicità è di circa 41 kyr. Essa è pertanto ben correlabile alla periodicità dei cicli astronomici della obliquità. La correlazione tra la successione di fluttuazioni di abbondanza e gli eventi biostratigrafici presenti in questo intervallo ha permesso di riconoscere che i singoli bio-eventi sono isocroni e coincidono sempre con la medesima fluttuazione. Secondo tale correlazione è stato possibile attribuire ad ogni bio-evento una precisa età assoluta e datare con accuratezza tutti i limiti cronostratigrafici di questo intervallo. In particolare sono valutati a 1.83 MA e a 0.89 MA rispettivamente il limite inferiore e superiore del Pleistocene inferiore.

Viene inoltre proposta, basata sulla integrazione dei dati paleomagnetici e biostratigrafici, una re-interpretazione della curva isotopica proposta per la sezione Singa.

In base ai dati isotopici, paleomagnetici e biostratigrafici del pozzo 607 carotato nel Nord Atlantico, gli eventi di comparsa di *Gephyrocapsa oceanica* s.l., di scomparsa di *Calcidiscus macintyrei* e di comparsa di *Gephyrocapsa* sp. 3 nell'Atlantico settentrionale e nel Mediterraneo risultano leggermente diacroni.

Abstract. The absolute age estimates for calcareous plankton events proposed by the writer in a recent paper are discussed according to the new proposed paleomagnetic time scales. A re-interpretation of the sequence of lithological cycles recognized in the "Rossello composite section" makes their number perfectly comparable with the number of planktonic foraminifera abundance fluctuations in the same stratigraphic interval.

An absolute age of 5.33 MA is estimated for the base of the Pliocene, as defined in the Capo Rossello section.

Periodicity of the relative abundance fluctuations of the planktonic foraminiferal assemblages during the Early Pleistocene stratigraphic interval is estimated at about 41 kyr, well comparable with the periodicity

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of the obliquity astronomical cycles. By correlation of the sequence of biostratigraphic events recorded in the Early Pleistocene interval in the Mediterranean sections with the sequence of abundance fluctuations, their absolute ages have been obtained, as well as the absolute age of chronostratigraphic boundaries. The base of the Pleistocene is at 1.83 MA and the top of the Early Pleistocene, coincident with the top of the Sicilian, is at 0.89 MA.

A re-evaluation of the Oxygen isotopic Stages of the upper Singa section is proposed, on the base of paleomagnetic and calcareous plankton biostratigraphic data reported for this section. Correlation with the North Atlantic Site 607 proved that the *G. oceanica* s.l. FO, the *C. macintyrei* LO and the *Gephyrocapsa* sp. 3 FO are slightly diachronous between the Mediterranean and the mid-North Atlantic high latitudes.

Introduction.

Absolute ages for several calcareous plankton events recorded in the Mediterranean Pliocene stratigraphic interval are reported by Sprovieri (1992). A detailed quantitative analysis of the planktonic foraminiferal assemblages from several Mediterranean Pliocene sequences (Fig. 1), included the ODP Leg 107 Site 653, evidenced periodic fluctuations essentially well documented for the *Globigerinoides quadrilobatus* and *Globigerinoides obliquus* TUs (Taxonomic Units) in the MPl 1 and MPl 2 Zones (Cita, 1973, 1975a; Rio et al., 1984), for the *Globorotalia puncticulata* TU in the MPl 3 and early MPl 4 Zones and for the *Globigerinoides ruber* TU in the following part of the MPl 4, in MPl 5 and MPl 6 Zones. Periodicity of fluctuations within each paleomagnetic or biostratigraphic interval, with lower and upper boundary ages estimated with reference to the polarity time scale of Berggren et al. (1985), was well
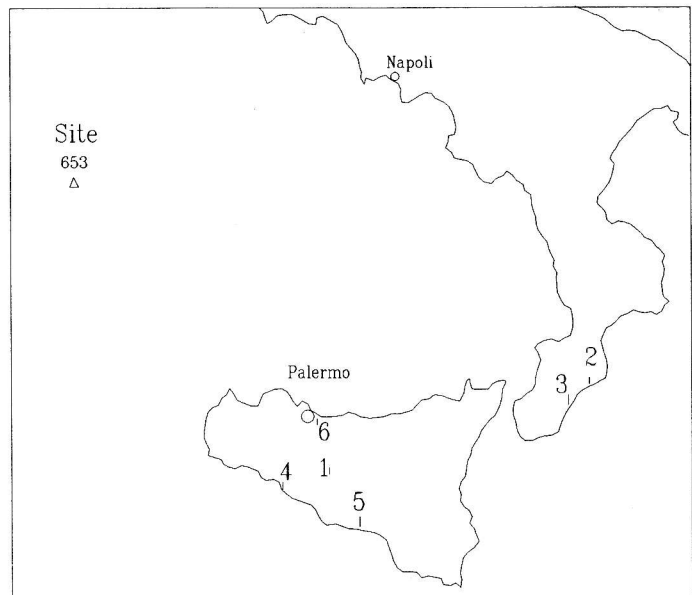

Fig. 1   - Index map of the studied sections. 1) Gibil-Gabel; 2) Vrica; 3) Singa; 4) Capo Rossello; 5) Monte S. Nicola; 6) Ficarazzi. Location of ODP Leg 107 Site 653 is also indicated.

referable to the precession astronomical cycles for the Early Pliocene and the early Late Pliocene, with a mean interval of about 21 kyr. A mean periodicity of 41 kyr, well referable to the obliquity astronomical cycles, was obtained for the upper part of the Pliocene, from below the *Discoaster tamalis* extinction level. According to the identified periodicities the age of the abundance fluctuations of the above mentioned taxonomic units was estimated and the biostratigraphic events coincident with abundance fluctuations could be estimated as well. The new proposed polarity time scales of Hilgen (1991) and of Cande & Kent (1992) introduce changes in the age of the polarity reversals. Consequently the ages of the recognized fluctuations are also changed. In this paper the estimated ages of the biostratigraphic events reported by Sprovieri (1992) are updated according to the adopted polarity time scale.

Quantitative data of the planktonic foraminiferal assemblage in the segment of Site 653 (ODP, Leg 107) ascribed to the Early Pleistocene (Glaçon et al., 1990; Rio et al., 1990) have been obtained and compared with quantitative data from several other Mediterranean land-sections. In the planktonic foraminiferal assemblage of this interval relative abundance fluctuations are present and their periodicity allows a detailed absolute age estimate of the Early Pleistocene Mediterranean biostratigraphic events. They have been compared with the proposed absolute ages reported for the same bio-events in the extra-Mediterranean Site 607 (DSDP, Leg 94).

Materials.

Results are essentially based on the analysis of the interval of Site 653 (ODP, Leg 107) between the base of the Pliocene at 210 mbsf (meters below sea floor) and the level at 53 mbsf, which is coincident with oxygen isotope Stage 22, according to Vergnaud-Grazzini et al. (1990). Site 653 was drilled in the central part of the Tyrrhenian basin (Fig. 1) (Kastens et al., 1987) in order to obtain a deep-sea reference sequence for the Mediterranean Plio-Pleistocene stratigraphic interval. Quantitative data for the Early Pleistocene interval come from 136 samples, with an average of 6 samples per section, at a mean interval of 0.25 cm.

Reference is made to Sprovieri (1992) for the Pliocene Mediterranean land-sections which have been compared with the Pliocene segment of Site 653. In the Early Pleistocene stratigraphic interval results from Site 653 were compared with quantitative data from five Pliocene-Early Pleistocene Mediterranean land-sections (Fig. 1). Data from the upper part of the Early Pleistocene segment studied at Site 653 were compared with quantitative data from the Pleistocene sequence drilled by a continuously cored well in Cava Puleo (Ficarazzi, Palermo, Sicily), type locality of the Sicilian chronostratigraphic unit and with data from the Croce Valanidi section, outcropping near Reggio Calabria (Scarantino, 1993). Data from the lower part of the Early Pleistocene segment of Site 653 were compared with quantitative data from the Pleistocene segment of the Vrica section (Crotone, Calabria), stratotype section of the Plio-Pleistocene boundary (Aguirre & Pasini, 1985) and with the upper part of the Pliocene - Early Pleistocene Capo Rossello and Monte S. Nicola sections (Channell et al., 1992;

Di Stefano et al., 1993). In the Ficarazzi sequence 96 samples have been studied, at a mean interval of 0.30 cm. In the Croce Valanidi section 65 samples were studied, at a mean interval of 50 cm. In the Vrica section 70 samples have been studied, at a mean interval of 1.60 m. In the Pleistocene segment of Capo Rossello and Monte S. Nicola sections 53 and 21 samples were studied respectively, at a mean interval of 100 cm. The obtained sequence of fluctuations and chronological results are compared with data from the Singa section (Lourens et al., 1992) and from the mid-high North Atlantic latitudes Site 607 (DSDP, Leg 94) (Ruddiman et al., 1989; Raffi et al., 1993).

Methods.

Samples coming from the Early Pleistocene studied sequences were washed on a 63 μm sieve. Only fraction greater than 125 μm have been used for quantitative analysis. From the split samples not less than 300 specimens of planktonic foraminifera were counted in every sample, with reference to the taxonomic units reported in Sprovieri (1992). Left and right coiling specimens of *N. pachyderma* have been lumped together.

The relative abundance of the *N. pachyderma* TU from Ficarazzi, Vrica and Croce Valanidi and of the *Gd. ruber* TU from Capo Rossello and Monte S. Nicola sequences were used to identify frequencies in the abundance fluctuations.

Ruddiman et al. (1986, 1989) report that in the Early Pleistocene stratigraphic interval of DSDP Site 607 sea-surface temperature (SST), estimated by a simplified transfer function based on counting of only four species of planktonic foraminifera, among which *N. pachyderma* is generally frequent to abundant (Ruddiman & Esmay, 1986) responds in phase with the oxygen isotope record. The sense of linkage of this in-phase relationship has low SST values equated with positive oxygen isotope values and viceversa. Lourens et al. (1992) report a similar relationship between SST values and oxygen isotope values for the Pliocene and Early Pleistocene "Upper Singa section". Warm SST values, coincident with positive relative abundance values of *Globigerinoides* spp., among which *Gd. ruber* is dominant, equate with negative oxygen isotope values and viceversa. It is therefore assumed that abundance fluctuations of the *Gd. ruber* and *Neogloboquadrina pachyderma* TUs or positive fluctuations of the loadings of the Factors dominated by the *Gd. ruber* or *N. pachyderma* TUs respond in phase with the oxygen isotope record. High relative abundance fluctuations of *Gd. ruber* TU equate negative values of the oxygen isotope values and viceversa. High relative abundance fluctuations of *N. pachyderma* TU equate positive values of the oxygen isotope values and viceversa.

The proposed relationship is also proved by the correlation of the sequence of abundance fluctuations to the paleomagnetic or biostratigraphic events. At Monte S. Nicola the Gilbert/Gauss boundary coincides with fluctuation 104 (Sprovieri, 1992). In the Vrica section the top of the Olduvai subchron coincides with fluctuation 63 and the increase in abundance of *Neogloboquadrina pachyderma* coincides with fluctuation 64, as discussed below. At Site 607 (Ruddiman et al., 1986, 1989) and in the Singa

section (Lourens et al., 1992) these paleomagnetic and biostratigraphic events are correlated with oxygen isotope Stage 104, 63 and 64 respectively.

Pliocene.

Correlation between planktonic foraminifera abundance fluctuations and lithological cycles.

The number of fluctuations reported by Sprovieri (1992) within every considered interval is unchanged. Recent results from a section outcropping in the Gibil-Gabel locality, near Caltanissetta (central Sicily) and covering the interval from just below the *Gt. puncticulata* LO (Last Occurrence) to just above the *Discoaster tamalis* LCO (Last Common Occurrence)(Sprovieri et al., 1993) (Fig. 2) prove that the previous interpretation of the number of fluctuations in this stratigraphic interval was correct. The number of abundance fluctuations of the *Gd. ruber* TU reported by Sprovieri (1992) in the stratigraphic interval between the *Discoaster pentaradiatus* LO and the base of the Pleistocene has been recently obtained in the same stratigraphic interval of the Capo Rossello section (Di Stefano et al., 1993) (Fig. 3).

The number of fluctuations in the Early Pliocene and early Late Pliocene, up to just above the top of Kaena paleomagnetic event, is well comparable with the number of lithological cycles recognized by Langereis & Hilgen (1991) in the Capo Rossello composite section. But some minor discrepancies exist. Between the base of the Pliocene and the Gilbert/Gauss boundary 79 abundance fluctuations in the planktonic foraminiferal assemblage are present. In the Rossello composite section (including the Punta di Maiata section) 77 lithological cycles are recognized in the same stratigraphic interval by Langereis & Hilgen (1991), with the Gilbert/Gauss boundary occurring between cycle 77 and 78. At Capo Spartivento within the Sidufjall interval 4 fluctuations are present (Sprovieri, 1992) and 4 lithological couplets have been recognized by Channell et al. (1988) (Fig. 4). But only 2 cycles are reported in this interval of the Rossello composite section by Hilgen & Langereis (1988) and Langereis & Hilgen (1991), who correlate the top of Sidufjall subchron with cycle 22. The solution from Capo Spartivento is preferred (Fig. 4) since Hilgen & Langereis (1988) (and Hilgen, 1991) recognize that the disproportional thick cycles 21 and 22, included in the Sidufjall interval, "probably each contains an additional cycle which lacks sedimentary expression". The Capo Spartivento solution, with the base of Sidufjall within fluctuation 20 and the top within fluctuation 24, allows to maintain the mean value of the precession astronomical periodicity for the fluctuations (and lithological cycles) included in the Sidufjall interval. This solution implies that, since 2 cycles are added in the Sidufjall interval, in order to correlate abundance fluctuations and lithological cycles the number of the lithological cycles in the Punta di Maiata section between the top of Sidufjall (which occurs on fluctuation/cycle 24) and the Gilbert/Gauss boundary must be increased by 2.

In conclusion, according to the here proposed interpretation, along the interval above the base of Sidufjall, which is coincident with fluctuation/cycle 20, the top of
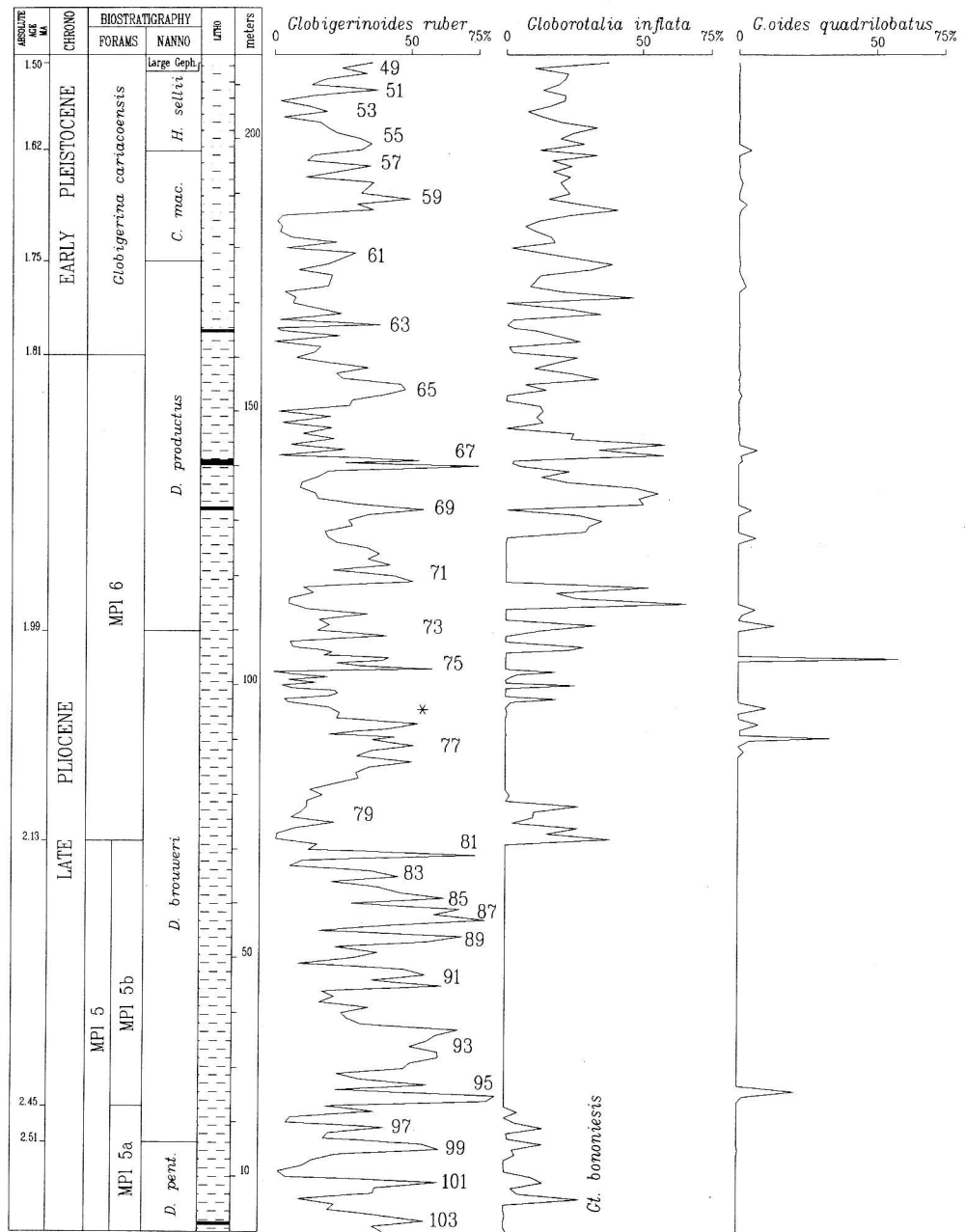
Fig. 2 - Distribution of the Loadings of Factor 3 in the Gibil-Gabel section. Factor 3 is dominated by the *Gd. ruber* TU. Black bar indicates a laminitic level. Asterisks indicate the presence of frequent left coiling *Neogloboquadrina atlantica.* Numbers in Italic style indicate fluctuations with precession periodicity. Numbers in Roman style indicate fluctuations with obliquity periodicity. From Sprovieri et al. (1993).

Fig. 5 - Relative abundance fluctuations of 3 taxonomic units in the marls of the Monte Narbone Formation of the Capo Rossello section. Black bars indicate laminitic levels. Asterisk indicates the *Globorotalia truncatulinoides* FO. From Di Stefano et al. (1993).
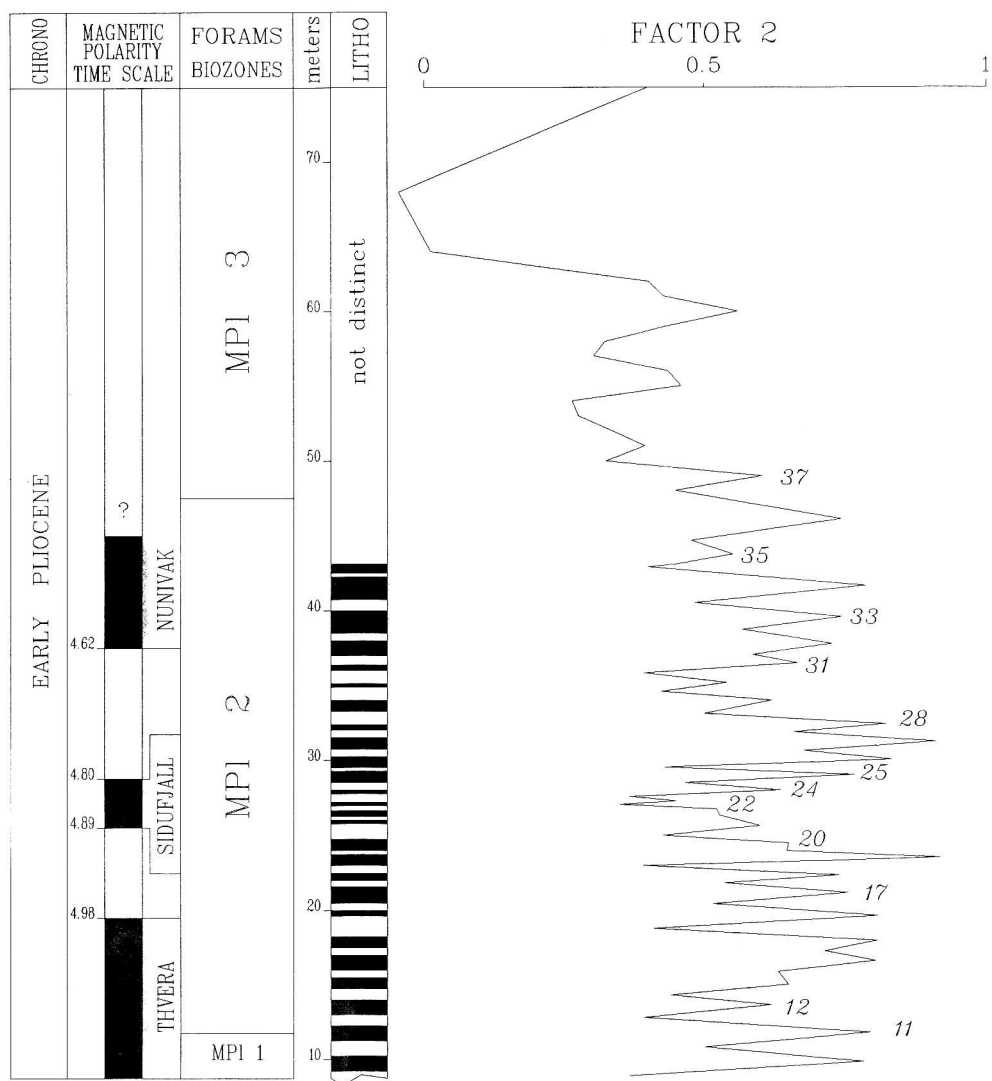
Fig. 4 - Factor Loadings fluctuations of Factor 2 in the Capo Spartivento section. Factor 2 is dominated by the *Gd. obliquus* and *Gd. quadrilobatus* TUs. From Sprovieri (1992).

Sidufjall falls within cycle 24, the base of Nunivak within cycle 32, the top of Nunivak within cycle 38, the top of Cochiti within cycle 52 and the Gilbert/Gauss boundary between cycle 79 and 80. If also the number of lithological cycles between the Gilbert/Gauss boundary and the level in which the Base of the Glacial Regime is recognized (BGR) (Sprovieri, 1992) is increased by 2, it again perfectly matches the sequence of the number of fluctuations of the planktonic foraminiferal assemblages. Fluctuations are numbered in Fig. 2-9. Italic style is used for fluctuations between the
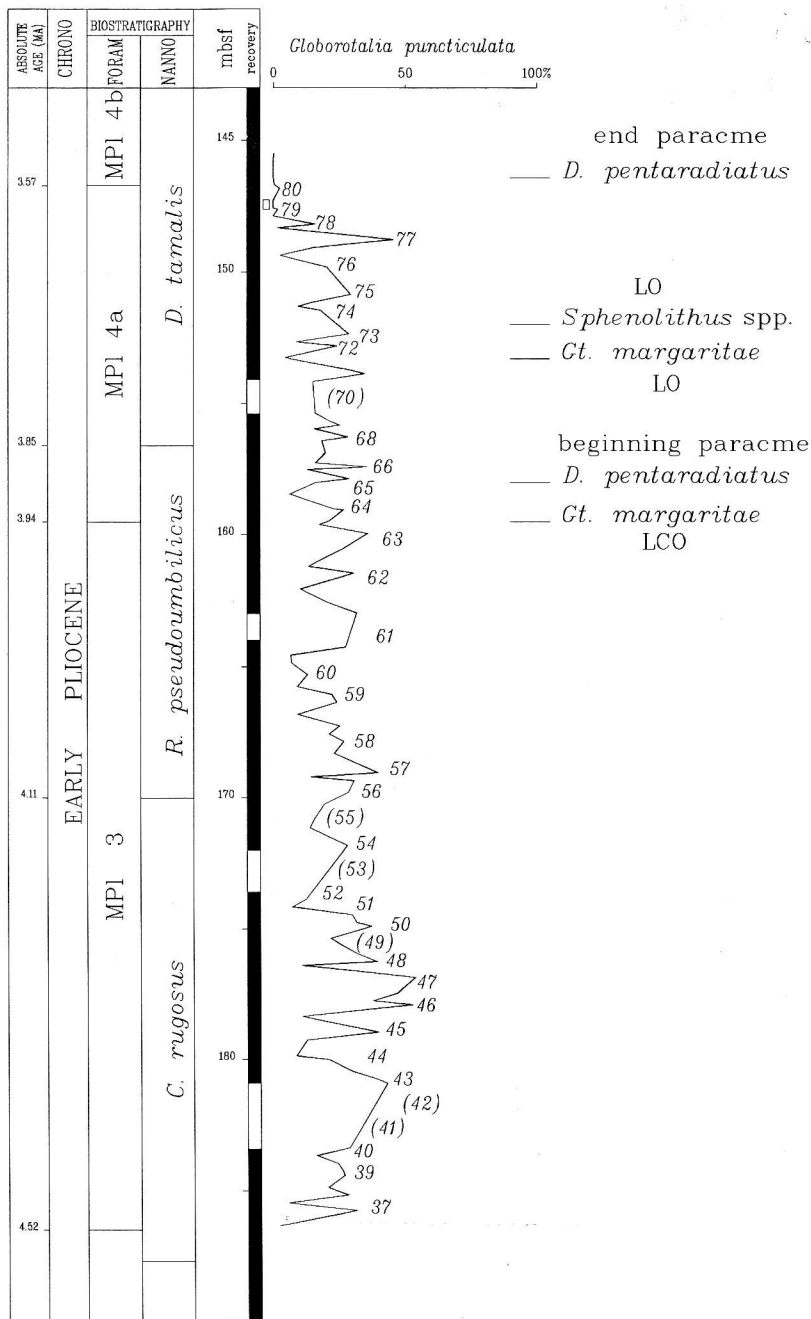
Fig 5 - Interpretation of the relative abundance fluctuations of *Globorotalia puncticulata* in the MPl 3 - MPl 4 (pars) stratigraphic interval at Site 653. The small open box at about 147 mbsf indicates the implied Gilbert/Gauss boundary. Modified from Sprovieri (1992).
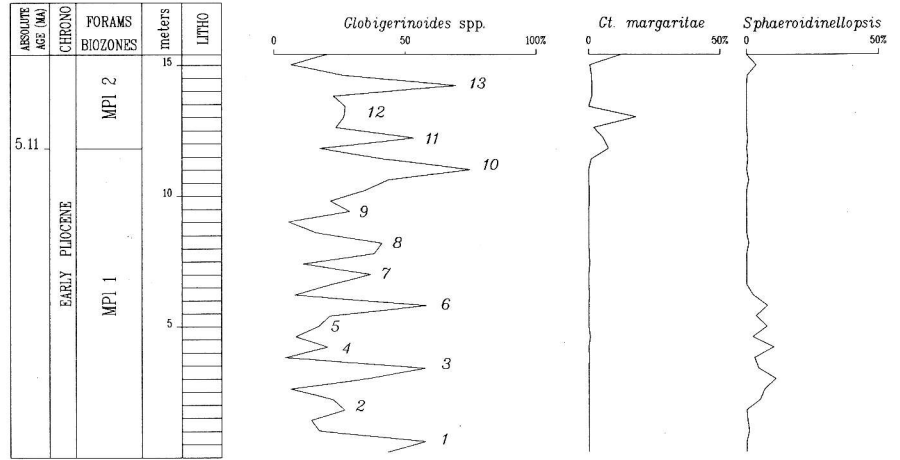
Fig. 6   -   Relative abundance fluctuations of 3 taxonomic units at the base of the Capo Rossello section.
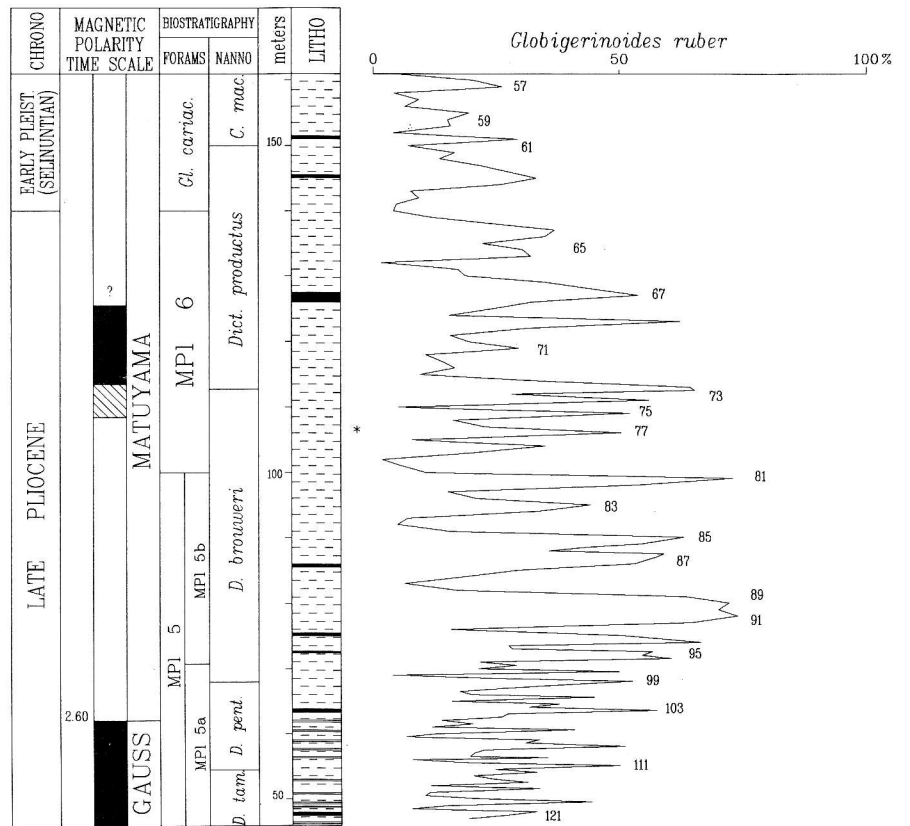

Fig. 7   -   Relative abundance fluctuations of the *Gd. ruber* TU in the upper part of the Monte S. Nicola section. Modified from Channell et al. (1992).
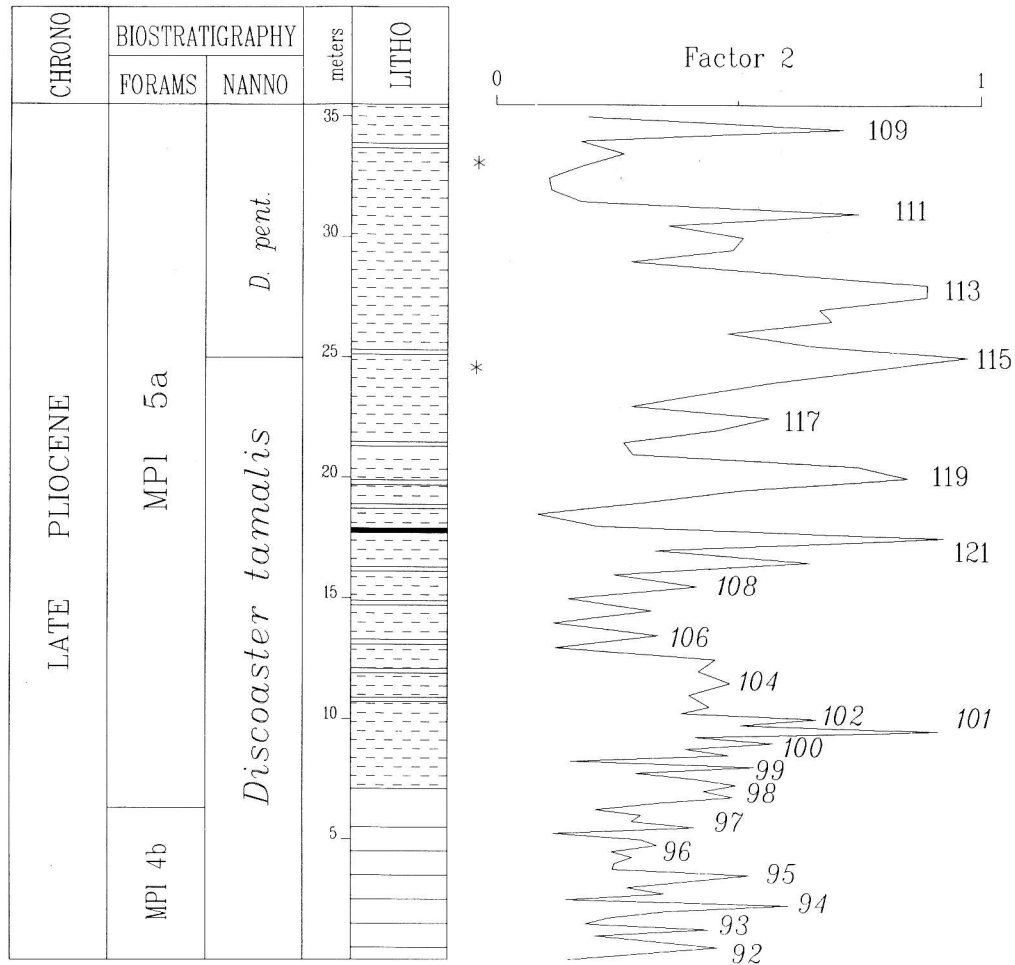
Fig. 8 - Factor Loadings fluctuations of Factor 2 in the Punta Piccola section. Factor 2 is dominated by the *Gd. ruber* TU. Asterisks indicate the presence of frequent left coiling *Neogloboquadrina atlantica*. From Sprovieri (1992).

base of the Pliocene and the BGR, which have a periodicity referable to the precession astronomical cycles. Roman style is used for fluctuations between the BGR and the top of the Pliocene, which have a periodicity referable to the periodicity of the obliquity astronomical cycles.

The abundance fluctuations and the paleomagnetic intervals.

Paleomagnetic data are not available in all the studied sequences. Nevertheless, where not available, the position of the reversal boundaries may be inferred in the sequences by correlation with biostratigraphic events. The adopted correlations and
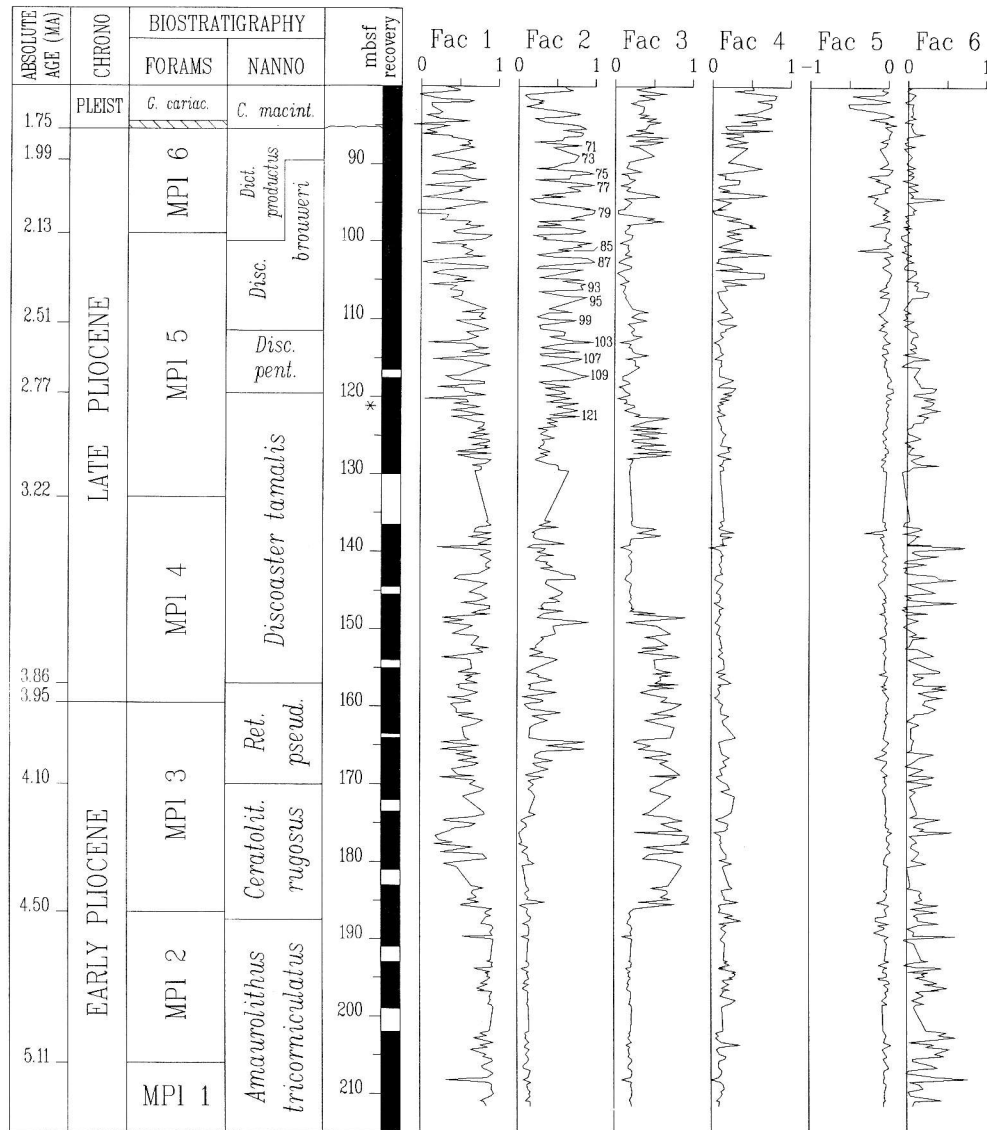
Fig. 9   -   Distribution of Factor Loadings in the Pliocene-Lowermost Pleistocene interval at ODP Hole
653A. Asterisk indicates the first entrance of left coiling *Neogloboquadrina atlantica*. Factor 1 is
dominated by *G. bulloides* TU, Factor 2 by *Gd. ruber* TU, Factor 3 by *Gt. inflata* TU, Factor 4
by *N. pachyderma* TU, Factor 5 by *T. quinqueloba* TU and Factor 6 by *Gd. quadrilobatus* TU.
Black vertical bars = recovered intervals. Some "warm" abundance fluctuations of Factor 2 are
numbered according to those proposed by Raymo et al. (1989) for oxygen isotopic Stages. From
Sprovieri (1992).

ʹent	Fluctuation		Reference
Top Olduvai	base	63	*N. pachyderma* left FCO in 64 (1)
Base Olduvai	base	61	*D. brouweri* LO in 73 (1)
Gauss/Matuyama	within	104	(1,2)
Top Mammoth	base	97	*Sphaeroidinellopsis* LO top *97* (3)
Base Mammoth	base	92	*Gt. bononiensis* FO top *93* (2)
Gilbert/Gauss	base	80	*Gt. puncticulata* LO in *80* (2,3,4)
Top Cochiti	within	52	*D. asymmetricus* FCO in *56* (4)
Top Nunivak	within	38	*Gt. puncticulata* FO in *37* (4)
Base Nunivak	top	32	(5)
Top Sidufjall	within	24	(5)
Base Sidufjall	within	20	(5)
Top Thvera	within	*15*	(5)
Base Thvera	within	*5*	(5)

Tab. 1 - Correlations between paleomagnetic boundaries, abundance fluctuations and biostratigraphic events in the Mediterranean Pliocene stratigraphic interval. 1) Singa section (Lourens et al., 1992; Sprovieri, 1993); 2) Monte S. Nicola (Channell et al., 1992; Sprovieri, 1992); 3) Gibil-Gabel section (Sprovieri et al., 1993); Punta Piccola section (Zachariasse et al., 1989; Sprovieri, 1992); 4) Capo Rossello Composite section (Langereis & Hilgen, 1991; Hilgen, 1991; Di Stefano, personal communication); 5) Capo Spartivento (Channell et al., 1988; Sprovieri, 1992).

references are reported in Tab. 1, where fluctuations referred to obliquity periodicity are reported in Roman type and fluctuations referred to precession periodicity are reported in Italic type. Base of Cochiti is not used since it is not coincident or is not approximated by biostratigraphic events. From ODP Leg 107 Sites 652 and 654 (Glaçon et al., 1990) the top of the nannofossil Zone *Ceratholithus rugosus*, identified by the *Discoaster asymmetricus* first common occurrence (FCO) (Rio et al., 1990), is just above the top of Cochiti (Channell et al., 1990). A detailed set of samples from Punta di Maiata section evidenced that the *D. asymmetricus* FCO occurs 4 cycles (and 4 abundance fluctuations of *Gt. puncticulata* TU) above the top of Cochiti as reported by Langereis & Hilgen (1991) (Di Stefano, personal communication). Consequently the *D. asymmetricus* FCO is coincident with cycle 56. According to this correlation, in the sequence of Site 653, in which this calcareous nannofossil event occurs at 169.90 mbsf (Rio et al., 1990), the positive fluctuation of *Gt. puncticulata* at this depth is labelled with number 56 and the top of Cochiti is implied in coincidence of fluctuation 52, just below the base of the not recovered interval between about 171 and 173.5 mbsf (Fig. 5).

Abundance fluctuations are regularly spaced in the considered intervals and their periodicities are estimated within every paleomagnetic interval simply by dividing the corresponding time interval by the number of included fluctuations. Following Hilgen (1991), in the evaluation of the periodicities and of the absolute ages fluctuation *6* (= *6* of Hilgen, 1991), *43* (= cycle 41 of Hilgen, 1991) and *61* (= cycle 59 of Hilgen, are each correlated with 2 precession cycles. The obtained values are reported in

1	2	3	4	5	6
Top Olduvai-Base Olduvai	0.16	*0.226*	4	40.000	*56.500*
Base Olduvai-Top Gauss	0.65	*0.617*	16.25	40.000	*37.969*
Top Gauss-Base Glacial Regime	(0.34)	*(0.323)*	8.5	(40.000)	*(37.969)*
Base Glacial Regime-Top Kaena	(0.10)	*(0.131)*	4.5	(22.222)	*(29.170)*
Top Kaena-Base Kaena	0.07	*0.073*	3	23.333	*24.333*
Base Kaena-Top Mammoth	0.11	*0.093*	5	22.000	*18.600*
Top Mammoth-Base Mammoth	0.11	*0.105*	5	22.000	*21.000*
Base Mammoth-Top Gilbert	0.25	*0.228*	12	20.833	*19.000*
Top Gilbert-Top Cochiti	0.60	*0.480*	28.5	21.053	*16.842*
Top Cochiti-Top Nunivak	0.30	*0.232*	15	20.000	*15.467*
Top Nunivak-Base Nunivak	0.14	*0.167*	5.5	25.454	*30.363*
Base Nunivak-Top Sidufjall	0.18	*0.179*	8.5	21.176	*21.058*
Top Sidufjall-Base Sidufjall	0.09	*0.083*	4	22.500	*20.750*
Base Sidufjall-Top Thvera	0.09	*0.118*	5	18.000	*23.600*
Top Thvera-Base Thvera	0.25	*0.234*	11.25	22.222	*20.800*

Tab. 2 - Time intervals (MA), number of abundance fluctuations and periodicity (kyr) in the considered paleomagnetic intervals (1). 2) According to the polarity time scale of Hilgen (1991); 3) according to the polarity time scale of Cande & Kent (1992); 4) number of fluctuations; 5) periodicity according to the polarity time scale of Hilgen (1991); 6) periodicity according to the polarity time scale of Cande & Kent (1992). Time intervals and periodicity just above and below the base of the Glacial Regime are reported in brackets, since this level is not a paleomagnetic event.

Tab. 2 in which the time intervals, number of abundance fluctuations and periodicities between paleomagnetic reversals are reported. Data obtained following Hilgen (1991) are reported in Roman style and data obtained following Cande & Kent (1992) are reported in Italic style. Data between the Gauss/Matuyama boundary and the top of Kaena are reported in brackets since the introduction of the level coincident with the BGR is not a paleomagnetic event.

Data clearly show that if the Hilgen's (1991) polarity ages are adopted (Tab. 3), periodicity of fluctuations is generally well comparable with the periodicity of the precession or obliquity astronomical cycles. But if the new geomagnetic polarity time scale of Cande & Kent (1992) is used (Tab. 3), the periodicity within every magnetic interval strongly differs and generally differs more or less from the mean precession and obliquity periodicity. For instance, within the Olduvai interval a periodicity of 40 kyr is obtained if the Hilgen's (1991) ages are adopted, but a periodicity of 56 kyr is obtained if the time scale of Cande & Kent is used. In the Nunivak interval periodicities of 25.454 kyr and 30.363 kyr are respectively obtained if the ages proposed by Hilgen (1991) and Cande & Kent (1992) are used. Consequently, since abundance fluctuations in the planktonic foraminiferal assemblages are clearly affected by the astronomical cycles, the time scale of Hilgen (1991) is preferred and used in this paper. In Tab. 4(a-c) the age estimates for the abundance fluctuations according to the 2 polarity time scales are reported.

1	2		3		4	5
Top Olduvai	base	63			1.79	*1.757*
Base Olduvai	base	71			1.95	*1.983*
Top Gauss	mid	104			2.60	*2.600*
Top Kaena			base	105	3.04	*3.054*
Base Kaena			base	102	3.11	*3.187*
Top Mammoth			base	97	3.22	*3.221*
Base Mammoth			base	92	3.33	*3.325*
Top Gilbert			base	80	3.58	*3.553*
Top Cochiti			mid	52	4.18	*4.033*
Top Nunivak			mid	38	4.48	*4.265*
Base Nunivak			base	33	4.62	*4.432*
Top Sidufjall			mid	24	4.80	*4.611*
Base Sidufjall			mid	20	4.89	*4.694*
Top Thvera			mid	15	4.98	*4.812*
Base Thvera			mid	5	5.23	*5.046*

Tab. 3 - Correlation of paleomagnetic events (1) with abundance fluctuations and their absolute ages. 2) Obliquity fluctuations; 3) precession fluctuations; 4) paleomagnetic ages (MA) according to Hilgen (1991); 5) paleomagnetic ages (MA) according to Cande & Kent (1992).

Chronology of calcareous plankton events.

The absolute age of every calcareous plankton event can be obtained from the absolute age of the abundance fluctuation with which it can be correlated (Fig. 2-9). The resulting values are reported in Tab. 5, in which the adopted ages of the bio-events are the ages of the correlatable fluctuation, independently from the position of the event within the correlative cycle (base, middle or top).

In the previous paper (Sprovieri, 1992) the top of the *Discoaster tamalis* Zone was reported, according to Rio et al. (1990) and to Channell et al. (1992) at the level at which the *D. tamalis* percent values in the *Discoaster* population drop below 1%. This level is difficult to be detected in terrigenous sequences in which reworking noise easily affects so small percent values. Therefore Sprovieri et al. (1993) propose to define the top of the *D. tamalis* Zone in coincidence of the LCO (Last Common Occurrence) of the species, above the top of the *D. tamalis* paracme. Consequently the top of the *D. tamalis* Zone, recognized by Sprovieri (1992) coincident with fluctuation 113, is now correlated with fluctuation 115.

Comparison with other Mediterranean and extra-Mediterranean (Site 607, DSDP Leg 94) calibrations evidences that some discrepancies exist in the uppermost part of the Pliocene. At Site 607 (Raymo et al., 1989; Raffi et al., 1993) the extinction level of *Discoaster brouweri* is reported on isotopic stage 71 and above the base of the Olduvai (Fig. 10). The same event occurs below the base of Olduvai, and is coincident with the top of isotopic stage 73 in the "Upper Singa section" (Fig. 11) (Lourens et al., 1992). By lithological correlation and according to Rio et al. (1993) also in the Vrica section

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1	2	3	3	4	4
61		1.74825	1.75	1.71594	1.72
62		1.76912	1.77	1.73646	1.74
63		1.79000	1.79	1.75700	1.76
64		1.81000	1.81	1.78525	1.79
65		1.83000	1.83	1.81350	1.81
66		1.85000	1.85	1.84175	1.84
68		1.89000	1.89	1.89825	1.90
70		1.93000	1.93	1.95475	1.95
71		1.95000	1.95	1.98300	1.98
72		1.97000	1.97	2.00198	2.00
73		1.99000	1.99	2.02097	2.02
74		2.01000	2.01	2.03995	2.04
76		2.05000	2.05	2.07792	2.08
77		2.07000	2.07	2.09691	2.10
78		2.09000	2.09	2.13487	2.13
80		2.13000	2.13	2.17284	2.17
82		2.17000	2.17	2.21081	2.21
84		2.21000	2.21	2.24878	2.25
86		2.25000	2.25	2.28675	2.29
88		2.29000	2.29	2.32472	2.32
90		2.33000	2.33	2.36269	2.36
92		2.37000	2.37	2.40066	2.40
94		2.41000	2.41	2.43863	2.44
96		2.45000	2.45	2.47660	2.48
98		2.49000	2.49	2.51456	2.51
99		2.51000	2.51	2.53355	2.53
100		2.53000	2.53	2.55253	2.55
102		2.57000	2.57	2.57152	2.57
104		2.60000	2.60	2.60000	2.60
106		2.64000	2.64	2.63797	2.64
108		2.68000	2.68	2.67594	2.68
110		2.72000	2.72	2.71391	2.71
112		2.76000	2.76	2.75188	2.75
113		2.78000	2.78	2.77086	2.77
114		2.80000	2.80	2.78985	2.79
116		2.84000	2.84	2.82781	2.83
118		2.88000	2.88	2.86578	2.87
120		2.92000	2.92	2.90375	2.90
121		2.94000	2.94	2.92274	2.92
	108	2.97333	2.97	2.96649	2.97
	107	2.99556	3.00	2.99566	3.00
	106	3.01778	3.02	3.02483	3.02
	105	3.04000	3.04	3.05400	3.05
	104	3.06333	3.06	3.07833	3.08
	103	3.08667	3.09	3.10267	3.10
	102	3.11000	3.11	3.12700	3.13
	101	3.13200	3.13	3.14560	3.15
	100	3.15400	3.15	3.16420	3.16
	99	3.17600	3.18	3.18280	3.18
	98	3.19800	3.20	3.20140	3.20
	97	3.22000	3.22	3.22000	3.22
	96	3.24200	3.24	3.24100	3.24

Tab. 4 a

2	3	3	4	4
95	3.26400	3.26	3.26200	3.26
94	3.28600	3.29	3.28300	3.28
93	3.30800	3.31	3.30400	3.30
92	3.33000	3.33	3.32500	3.33
91	3.35083	3.35	3.34400	3.34
90	3.37167	3.37	3.36300	3.36
89	3.39250	3.39	3.38200	3.38
88	3.41333	3.41	3.40100	3.40
87	3.43417	3.43	3.42000	3.42
86	3.45500	3.45	3.43900	3.44
85	3.47583	3.48	3.45800	3.46
84	3.49666	3.50	3.47700	3.48
83	3.51750	3.52	3.49600	3.50
82	3.53833	3.54	3.51500	3.52
81	3.55916	3.56	3.53400	3.53
80	3.58000	3.58	3.55300	3.55
79	3.60105	3.60	3.56984	3.57
78	3.62211	3.62	3.58668	3.59
77	3.64316	3.64	3.60353	3.60
76	3.66421	3.66	3.62037	3.62
75	3.68527	3.69	3.63721	3.64
74	3.70632	3.71	3.65405	3.65
73	3.72737	3.73	3.67089	3.67
72	3.74842	3.75	3.68774	3.69
71	3.76948	3.77	3.70458	3.70
70	3.79053	3.79	3.72142	3.72
69	3.81158	3.81	3.73826	3.74
68	3.83264	3.83	3.75510	3.76
67	3.85369	3.85	3.77195	3.77
66	3.87474	3.87	3.78879	3.79
65	3.89580	3.90	3.80563	3.81
64	3.91685	3.92	3.82247	3.82
63	3.93790	3.94	3.83931	3.84
62	3.95895	3.96	3.85616	3.86
61	4.00106	4.00	3.88984	3.89
60	4.02211	4.02	3.90668	3.91
59	4.04317	4.04	3.92352	3.92
58	4.06422	4.06	3.94037	3.94
57	4.08527	4.09	3.95721	3.96
56	4.10633	4.11	3.97405	3.97
55	4.12738	4.13	3.99089	3.99
54	4.14843	4.15	4.00773	4.00
53	4.16948	4.17	4.02458	4.02
52	4.19054	4.19	4.04142	4.04
51	4.21054	4.21	4.05688	4.06
50	4.23054	4.23	4.07235	4.07
49	4.25054	4.25	4.08782	4.08
48	4.27054	4.27	4.10329	4.10
47	4.29054	4.29	4.11875	4.12
46	4.31054	4.31	4.13422	4.13
45	4.33054	4.33	4.14969	4.15
44	4.35054	4.35	4.16515	4.17

Tab. 4 b

2	3	3	4	4
43	4.39054	4.39	4.19609	4.20
42	4.41054	4.41	4.21156	4.21
41	4.43054	4.43	4.22702	4.23
40	4.45054	4.45	4.24249	4.24
39	4.47054	4.47	4.25796	4.26
38	4.49473	4.49	4.28047	4.28
37	4.52018	4.52	4.31083	4.31
36	4.54564	4.55	4.34119	4.34
35	4.57109	4.57	4.37156	4.37
34	4.59654	4.60	4.40192	4.40
33	4.62200	4.62	4.43228	4.43
32	4.64317	4.64	4.45334	4.45
31	4.66435	4.66	4.47440	4.47
30	4.68552	4.69	4.49546	4.50
29	4.70670	4.71	4.51651	4.52
28	4.72788	4.73	4.53757	4.54
27	4.74905	4.75	4.55863	4.56
26	4.77023	4.77	4.57969	4.58
25	4.79140	4.79	4.60075	4.60
24	4.81258	4.81	4.62180	4.62
23	4.83508	4.84	4.64255	4.64
22	4.85758	4.86	4.66330	4.66
21	4.88008	4.88	4.68405	4.68
20	4.90258	4.90	4.70480	4.70
19	4.92058	4.92	4.72840	4.73
18	4.93858	4.94	4.75200	4.75
17	4.95658	4.96	4.77560	4.78
16	4.97458	4.97	4.79920	4.80
15	4.99258	4.99	4.82280	4.82
14	5.01480	5.01	4.84360	4.84
13	5.03702	5.04	4.86440	4.86
12	5.05925	5.06	4.88520	4.89
11	5.08147	5.08	4.90600	4.91
10	5.10369	5.10	4.92680	4.93
9	5.12591	5.13	4.94760	4.95
8	5.14813	5.15	4.96840	4.97
7	5.17036	5.17	4.98920	4.99
6	5.21480	5.21	5.03000	5.03
5	5.23702	5.25	5.05080	5.05
4	5.25924	5.26	5.07160	5.07
3	5.28147	5.28	5.09240	5.09
2	5.30369	5.30	5.11320	5.11
1	5.32591	5.33	5.13400	5.13

Tab. 4 c

Tab. 4a, 4b, 4c - Obtained and rounded ages for Pliocene abundance fluctuations. 1) Obliquity fluctuations; 2) precession fluctuations; 3) absolute and rounded ages (MA) according to the polarity time scale of Hilgen (1991); 4) absolute and rounded ages (MA) according to the polarity time scale of Cande & Kent (1992).

Events	Hilgen MA	CK MA	Cycle	
G. oceanica s.l.	1.75	1.72		61
N. pachyderma left FCO	1.81	1.79		64
Base Pleistocene	1.83	1.81		65
D. brouweri LO	1.99	2.02	top	73
Gt. truncatulinoides FO	2.07	2.10	top	77
Gt. inflata FO	2.13	2.17	base	80
Gt. bononiensis LO	2.45	2.48	mid	96
D. pentaradiatus LO	2.51	2.53	mid	99
D. tamalis LCO	2.82	2.81	mid	115
N. atlantica left FO	2.83	2.82	top	116
Top paracme *D. tamalis*	2.86	2.85	mid	117
Base glacial regime	2.94	2.92	base	121
Base paracme *D. tamalis*	2.99	2.98	top	*107*
Sphaeroidinellopsis spp. LO	3.22	3.22	top	*97*
Gt. bononiensis FO	3.31	3.30	top	*93*
Top paracme *D. pentaradiatus*	3.56	3.53	base	*81*
Gt. puncticulata LO	3.57	3.55	top	*80*
Sphenolithus spp. LO	3.73	3.67	top	*73*
Gt. margaritae LO	3.75	3.69	base	*72*
R. pseudoumbilicus LO	3.85	3.77	base	*67*
Base paracme *D. pentaradiatus*	3.90	3.81	mid	*65*
Gt. margaritae LCO	3.94	3.84	top	*63*
D. asymmetricus FCO	4.11	3.99	base	*56*
Gt. puncticulata FO	4.52	4.31	base	*37*
Gt. margaritae FCO	5.10	4.93	top	*10*
Base Pliocene	5.33	5.13	base	*1*

Tab. 5 - Absolute ages (MA) of the Pliocene Mediterranean calcareous plankton events and their correlation to the abundance fluctuations. Numbers in Italic style indicate precession fluctuations; numbers in Roman style indicate obliquity fluctuations. CK = Cande & Kent (1992); Hilgen = Hilgen (1991).

this event occurs below the base of the Olduvai. In the Mediterranean sequences the *D. brouweri* extinction level always occurs on the upper part of fluctuation 73 (Fig. 3, 7 and 9) and therefore this event predates its extinction level in the mid-high North Atlantic latitudes.

At Monte S. Nicola (Sprovieri, 1992) and at Capo Rossello (Di Stefano et al., 1993) the *D. brouweri* LO and the *Globorotalia truncatulinoides* FO, both of which are recorded at the top of a "warm" fluctuation, are separated by 1 "warm" fluctuation, with the *Gt. truncatulinoides* FO correlated with the top of fluctuation 77 (Fig. 3 and 7). In the "Upper Singa section" the *D. brouweri* LO occurs at about 109.5 m, at the top of isotopic stage 73 and the first occurrence of *Gt. truncatulinoides* is recorded at 100.95 m (Driever, 1988; Zijderveld et al., 1991; Lourens et al., 1992). This latter
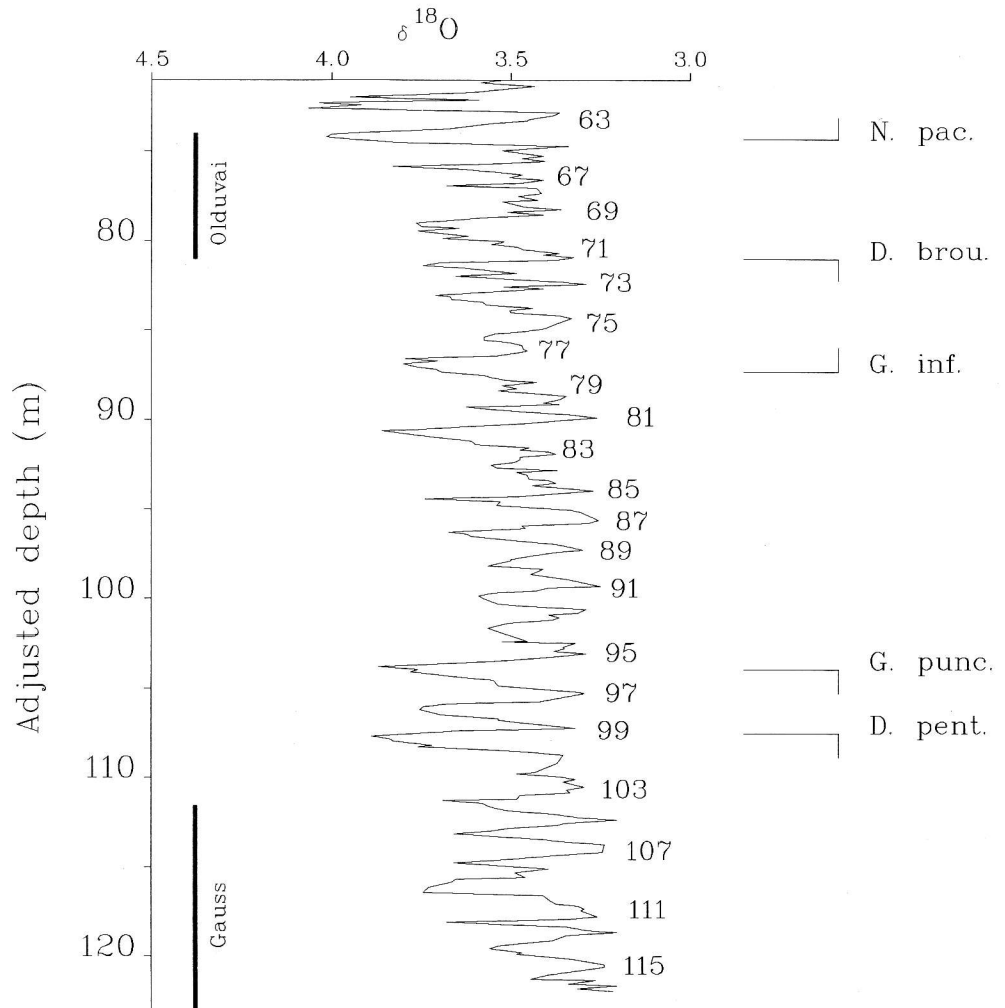
Fig. 10 - Correlation between oxygen isotopic Stages and biostratigraphic events in the Pliocene interval of
Site 607. From Raymo et al. (1989).

event, coincident with the top of a "warm" fluctuation which is labelled with number
75 by Lourens et al. (1992) (Fig. 11), apparently occurs in coincidence of the "warm"
cycle immediately below that where the *D. brouweri* LO is recorded. Compared with
the results from the other Mediterranean sections, in which a "warm" fluctuation is
present between the 2 bio-events , a discrepancy exists. If a sedimentary gap is ruled
out at this level in the "Upper Singa section", two possibilities may be considered. The
first one implies that the *Gt. truncatulinoides* FO is delayed in the Singa section. But
this level also yields *Sphaeroidinella dehiscens* which is not recorded above and it is just
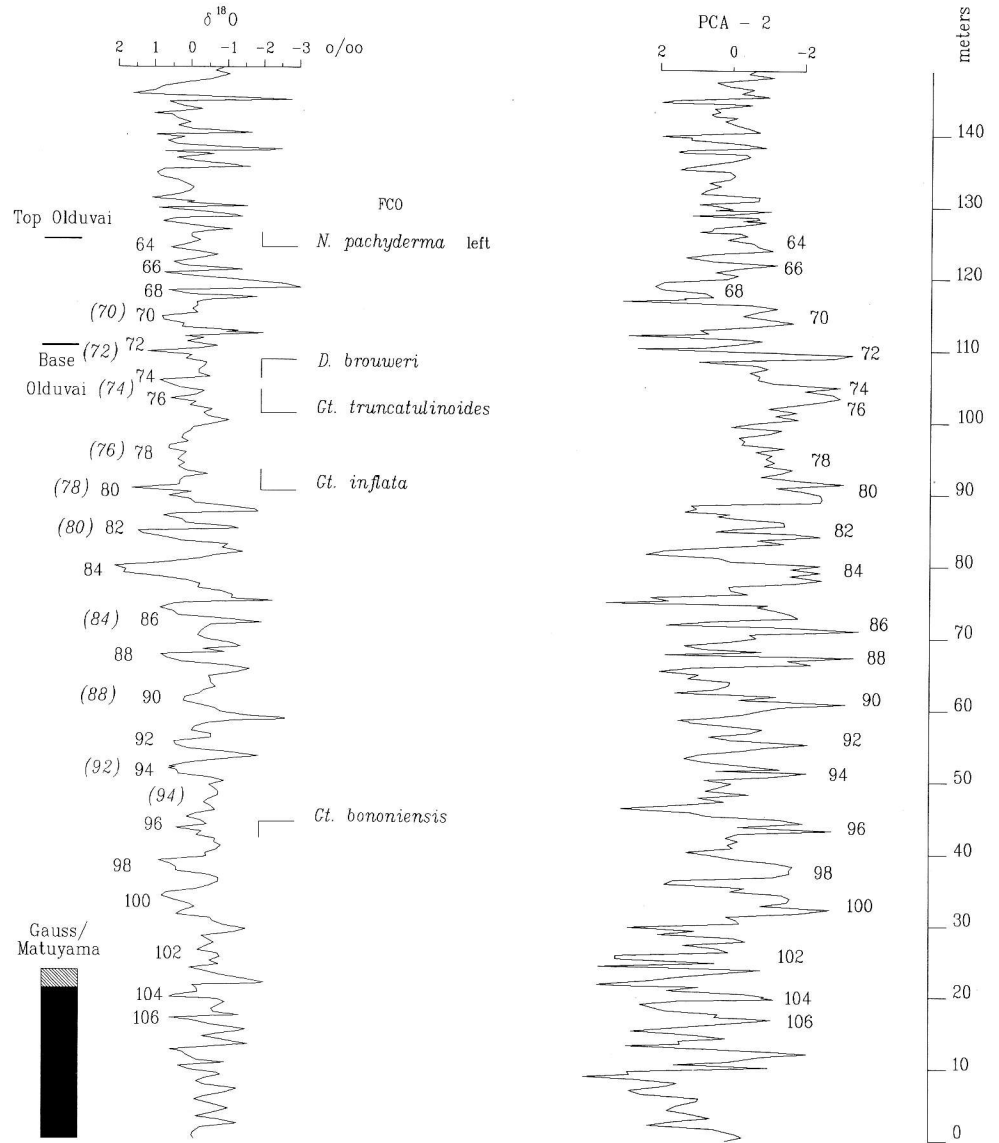
Fig. 11 - Abundance fluctuations of the oxygen isotope (planktonic foraminifera) and PCA-2 records from the Singa section. Modified from Lourens et al. (1992). *Discoaster brouweri* extinction level is from Driever (1988).

below the re-entrance of *Gt. inflata* (Zijderveld et al., 1991) as in the other Mediterranean sequences. It is therefore well comparable with the level in which *Gt. truncatulinoides* appears in the other Mediterranean sequences and it seems correlatable with the level in which this bio-event has been detected.

The second possibility is that the 2 oxygen isotope peaks with heavier values at 105.45 m and 102.95 m, both of which are ascribed to isotopic Stage 74 by Lourens et al. (1992), actually represent 2 discrete peaks, separated by the negative fluctuation at 103.95 m, and ascribed to isotopic Stage 74 and 76 respectively (Fig. 11). This second possibility is here preferred. According to this interpretation, since an additional peak is introduced at this level, between the base of Olduvai and the Gauss/Matuyama boundary a fluctuation results in excess. The segment between 45 and 50 m is ascribed to isotopic Stage 94 by Lourens et al. (1992). But in this segment the isotopic signal does not show clear evidence of a shift to heavier values and the PCA-2 curve clearly shows a gradual transition to the underlying "warm" end-member. Therefore all this segment may be well ascribed to a "warm" isotopic Stage, labelled with number 95 (Fig. 11). Consequently the recognized number of oxygen isotopic Stages between the base of the Olduvai and the Gauss/Matuyama boundary (Raymo et al., 1989) is obtained.

At Site 653 the level of the *Gt. truncatulinoides* FO is apparently different. Frequent specimens of *Gt. truncatulinoides*, without *Sphaeroidinella dehiscens*, are present in the sample at 95.75 mbsf (Sprovieri, 1992, fig. 5). In the detailed set of samples studied at this stratigraphic interval with one sample each 25 cm (Glaçon et al., 1990; Sprovieri, 1992), *Gt. truncatulinoides* is absent in the following samples and is again present in the samples between 93.75 and 93.20 mbsf, together with *Sphaeroidinella dehiscens*. The sample at 95.75 mbsf coincides with the top of the *Gd. ruber* TU abundance fluctuation labelled with number 79, the sample at 93.75 mbsf coincides with the top of the abundance fluctuation 77. Therefore at Site 653 the *Gt. truncatulinoides* FO apparently predates the first occurrence of this bio-event as recorded in all the studied Mediterranean land-sections, where it always occurs at the top of fluctuation 77. On the base of the available data, it is difficult to evaluate the results from Site 653. The presence of *Gt. truncatulinoides* in only 1 sample at its appearance level is suspect and this presence may be an arctifact, consequence of contamination during drilling procedure or during laboratory manipulations of the samples. On the base of the available informations, the better controlled data from the studied land-sections are here retained and the first appearance level of *Gt. truncatulinoides* is correlated with fluctuation 77.

At Site 607 *Gt. truncatulinoides* first appears (Weaver & Clement, 1986) between 74 and 77 mbsf (corrected depth), within the Olduvai subchron and where isotopic Stages 66 and 68 are reported by Raymo et al. (1989). Therefore the *Gt. truncatulinoides* FO is delayed at the North Atlantic latitude of Site 607 with respect to the same Mediterranean biostratigraphic event.

The *Globorotalia inflata* FO is recorded in all the Mediterranean sections in coincidence of the second "cold" fluctuation below the *Gt. truncatulinoides* FO, and therefore it occurs in coincidence of fluctuation 80. In the "Upper Singa section" this event is reported in coincidence of the oxygen isotopic Stage 78 by Lourens et al. (1992), but according the above discussed revision of the numbers of the isotopic fluc-

tuations, also in this section the *Gt. inflata* FO coincides with isotopic Stage 80. At Site 607 it is recorded on isotopic Stage 78 (Raymo et al., 1989) (Fig. 10). Therefore at the mid-high North Atlantic latitudes also this event is diachronous with the Mediterranean region. The latitudinal difference between Site 607 and the Gibraltar portal through which the faunistic interchange between the Mediterranean and the Atlantic ocean occurs may be the origin of the difference in time of these bio-events.

Early Pleistocene.

Results.

Site 653.

The relative abundance fluctuations of the 4 most frequent and significant taxonomic units in the Pleistocene segment of Site 653 are plotted against depth and calcareous plankton biostratigraphy (Glaçon et al., 1990; Rio et al., 1990) in Fig. 12. The analysis of additional samples allowed to slightly amend the level in which *Globorotalia truncatulinoides excelsa* appears. It is now recorded at 63.65 mbsf. Relative abundance fluctuations of *N. pachyderma* are reported and numbered in Fig. 13. The 20.5 cycles in the interval between 53 and 85.50 mbsf have been labelled from the base upwards starting with number 61 in coincidence of the fluctuation in which the FO of *Gephyrocapsa oceanica* s.l. occurs, at 85.50 mbsf (Fig. 13). In both the Capo Rossello and Monte S. Nicola Pliocene-Early Pleistocene sections (Di Stefano et al., 1993; Channell et al., 1992; Sprovieri, 1992) the FO of *Gephyrocapsa oceanica* s.l. is coincident with fluctuation 61. *Calcidiscus macintyrei* extinction level is coincident with fluctuation 55, the base of the Large *Gephyrocapsa* Zone is coincident with fluctuation 49, the base of the Small *Gephyrocapsa* Zone (S1) is coincident with fluctuation 37, the base of the *Globorotalia truncatulinoides excelsa* Zone is coincident with fluctuation 35 and the top of the Small *Gephyrocapsa* Zone (S2) is coincident with fluctuation 27. Fluctuations 27 and 25 include a small, short positive fluctuation of *N. pachyderma*, which identifies a short, cold event within these interglacial intervals.

Ficarazzi.

The relative abundance fluctuations of the *N. pachyderma* TU in the Pleistocene sequence of the Sicilian type locality are reported in Fig. 14, from Scarantino (1993). The base of the Small *Gephyrocapsa* Zone is recorded at 28.70 m and the top of this biozone is recorded at 12.40 m. *Globorotalia truncatulinoides excelsa* appears at 25.70 m. At 3.5 m below the top of the sequence, in coincidence of a biocalcarenitic bed rich in *Arctica islandica* and proposed as definition of the top of the Sicilian (Ruggieri et al., the cold pteropod *Limacina retroversa* is abundant (Buccheri, 1984). Other 2 levels with rare *L. retroversa* are present at about 9 m (Buccheri, personal communica-

tion). Between the top of the sands and conglomerates at the base and the top of the sequence 11 main relative abundance fluctuations are present. If the base of the Small *Gephyrocapsa* Zone is correlated with fluctuation 37, the base of the *Globorotalia truncatulinoides excelsa* Zone is coincident with fluctuation 35 and the top of the Small *Gephyrocapsa* Zone is coincident with fluctuation 27. Therefore in the Ficarazzi sequence the same correlation between biostratigraphic events and relative abundance fluctuations of *N. pachyderma* recognized at Site 653 can be identified. The biocalcarenitic bed, and the abundance of *Limacina retroversa*, is coincident with fluctuation 22. The other 2 levels with *Limacina retroversa* coincide with fluctuation 26. Finally, the base of the local Pleistocene, represented by a 16 meters thick sequence of sands and conglomerate, is possibly coincident with fluctuation 43. Within fluctuations 25 and 27 a small positive fluctuation of *N. pachyderma* is recorded.

Croce Valanidi.

The calcareous plankton biostratigraphy and relative abundance fluctuations of the *N. pachyderma* TU recognized in the Croce Valanidi section are reported in Fig. 15, from Scarantino (1993). *Globorotalia truncatulinoides excelsa* is present throughout the section. The top of the Small *Gephyrocapsa* Zone is recorded 11 m above the base. In the level at 31 m a rich assemblage of *Limacina retroversa* is present, and 2 other levels with rare *L. retroversa* occur at 15 and 15.50 m (Fig. 15). Four main relative abundance fluctuations have been identified. If fluctuation coincident with the top of the Small *Gephyrocapsa* Zone is labelled with number 27, the base of the section is coincident with fluctuation 29 and the sample in which *Limacina retroversa* is abundant is coincident with fluctuation 22. The other 2 levels with *Limacina retroversa* coincide with fluctuation 26. Within fluctuations 25 and 27 a short positive abundance fluctuation of *N. pachyderma* occurs, as at Site 653 and Ficarazzi.

Vrica.

Relative abundance data of the *N. pachyderma* TU from the lower part of the sequence studied at Site 653 have been compared with the relative abundance data of the same TU from the Pleistocene segment of the Vrica section (Selli et al., 1977). They are plotted and labelled in Fig. 16 in which thick line indicates the relative abundance fluctuations of the total population of *N. pachyderma* (left and right coiling specimens) and thin line indicates the relative abundance fluctuations of left coiling specimens. The calcareous plankton biostratigraphy is reported, with the calcareous nannofossil zonation based on data from Rio et al. (1993). In the lithologic log sapropelitic levels are reported from Selli et al. (1977). The top of the Olduvai subchron is from Zijderveld et al. (1991).

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Fig. 12 - Relative abundance fluctuations of the most frequent taxonomic units in the Pleistocene interval at Site 653. N. pac.= *Neogloboquadrina pachyderma*; Gt. inf. = *Globorotalia inflata*; T. qui. = *Turborotalita quinqueloba*; Gd. rub. = *Globigerinoides ruber*.
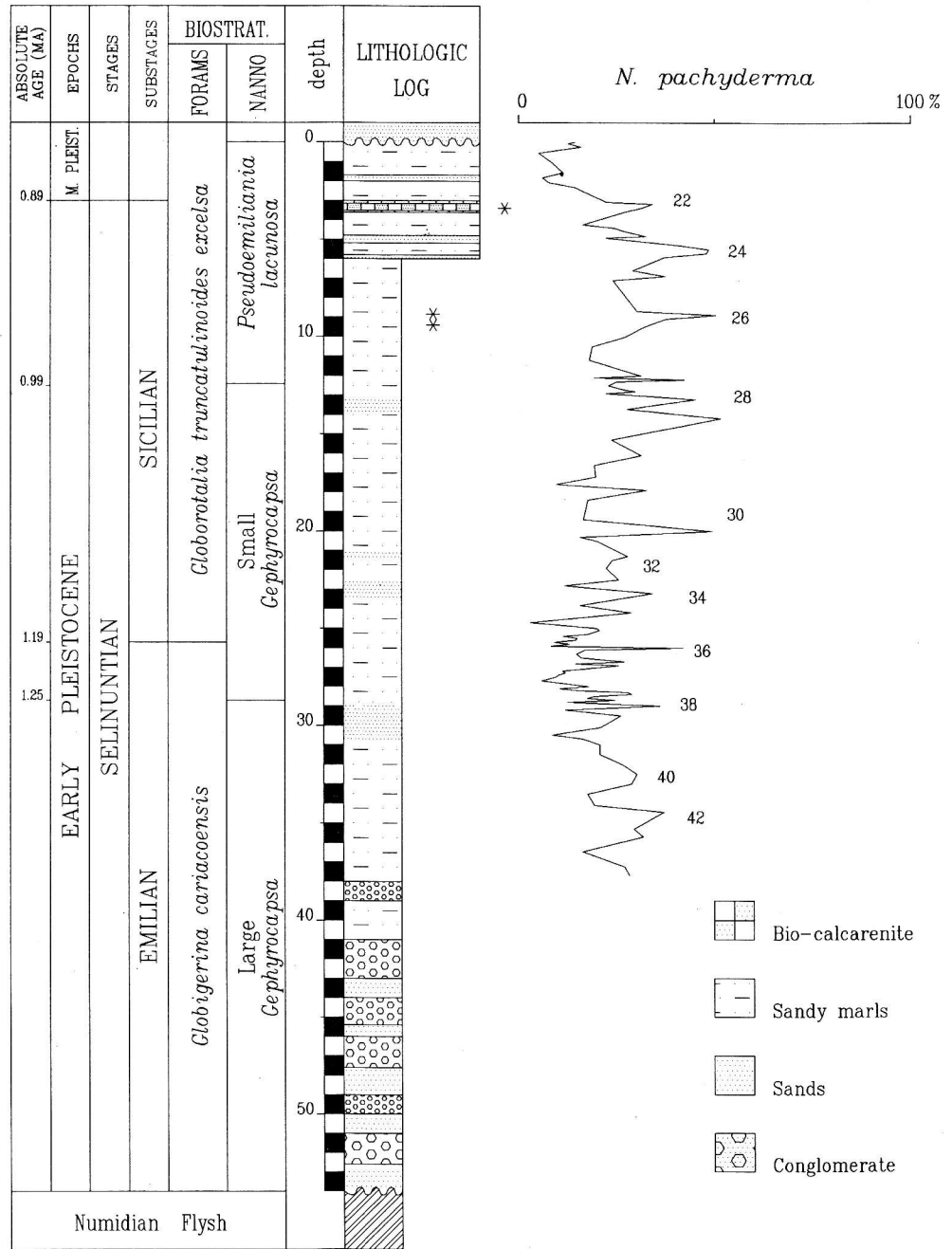
Fig. 13 - Relative abundance fluctuations of *Neogloboquadrina pachyderma* in the Pleistocene interval at Site 653. Number of fluctuations are reported for the Early Pleistocene segment.

Fig. 14 - Relative abundance fluctuations of *Neogloboquadrina pachyderma* in the Pleistocene segment at Ficarazzi (Cava Puleo well). From Scarantino (1993). Asterisks indicate the presence of *Limacina retroversa*.
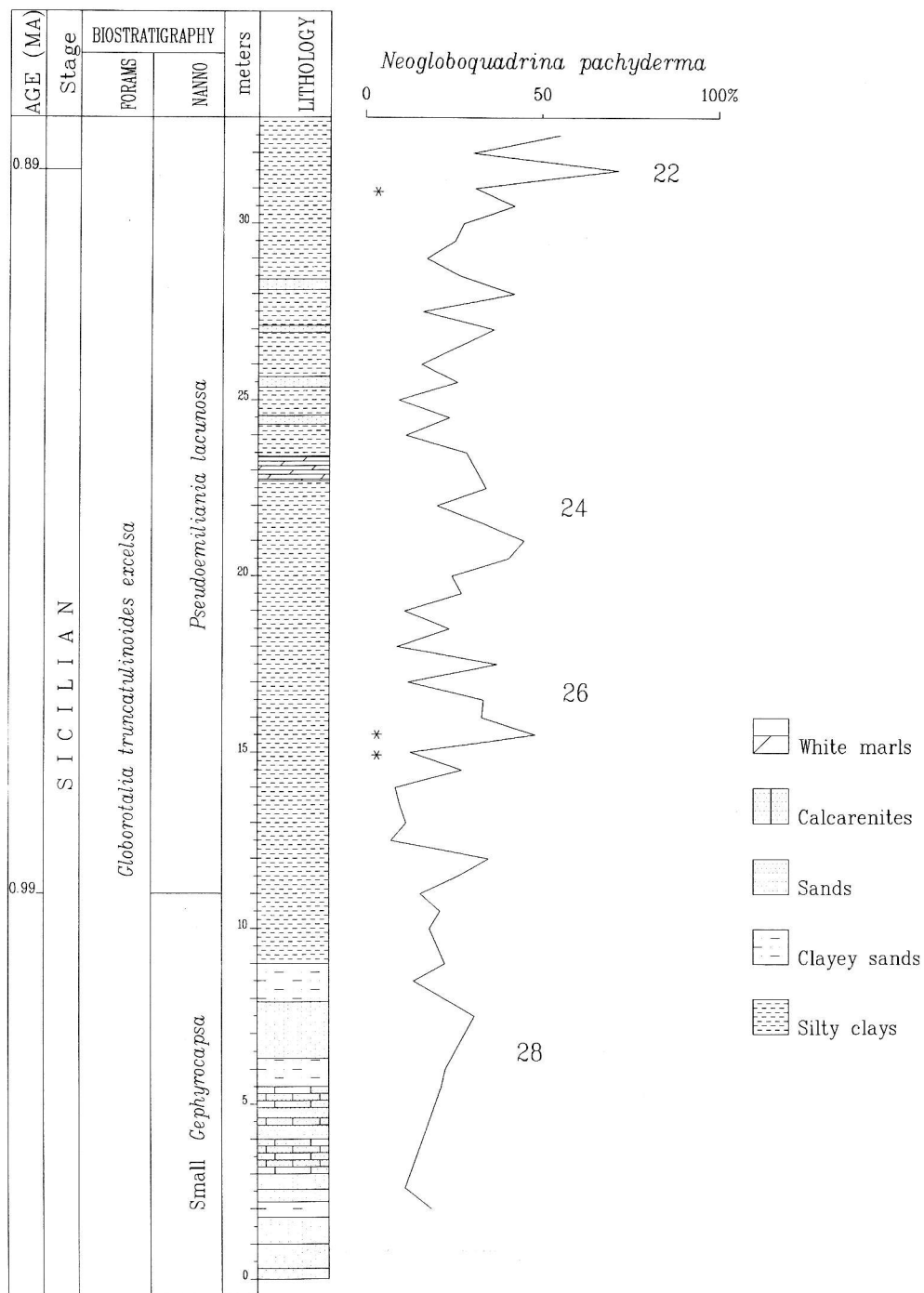
R. Sprovieri

Fig. 15 - Relative abundance fluctuations of *Neogloboquadrina pachyderma* in the Croce Valanidi section. From Scarantino (1993). Asterisks indicate the presence of *Limacina retroversa*.
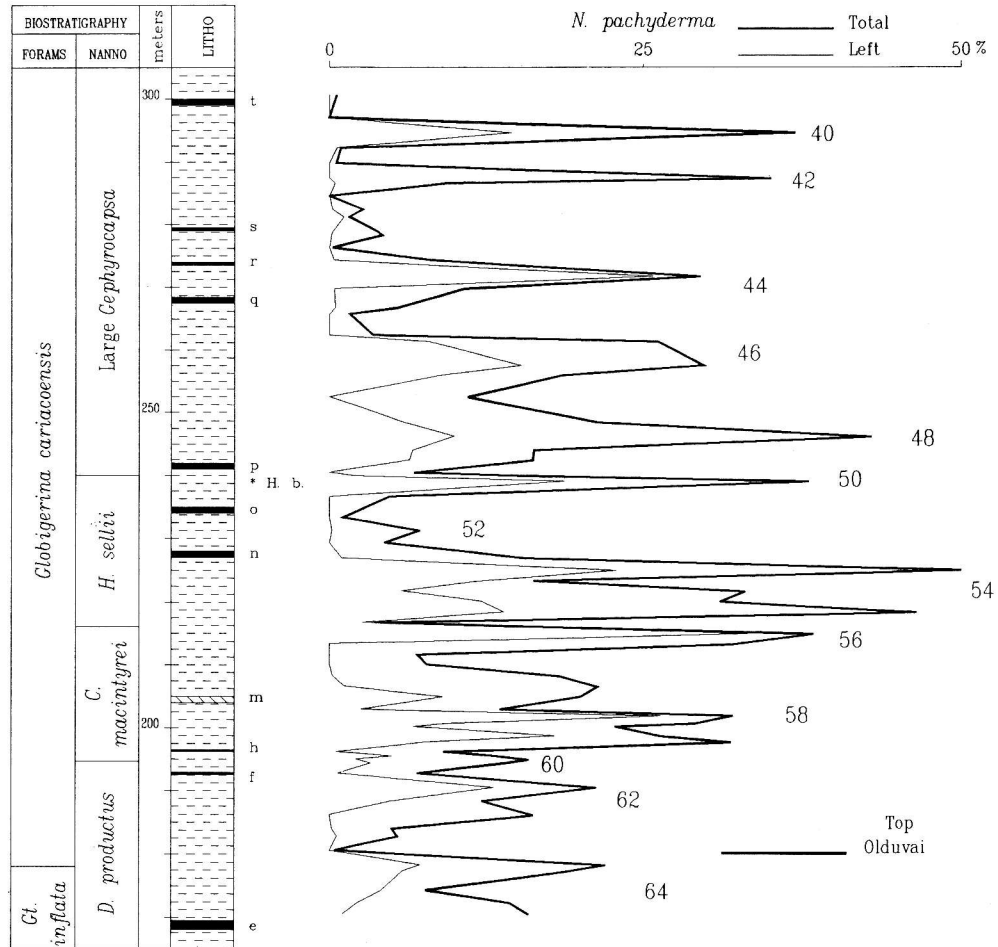
Fig. 16 - Relative abundance fluctuations of *Neogloboquadrina pachyderma* in the Vrica section. H. b. =
Hyalinea baltica FO; letters indicate the coded sapropelitic levels according to Selli et al. (1977).
Top of Olduvai is from Zijderveld et al. (1991).

Throughout the studied segment 13 fluctuations of the relative abundance data of *N. pachyderma* are present. If the level of the first occurrence of *G. oceanica* s.l. is made coincident with fluctuation labelled with number 61 the *C. macintyrei* extinction level coincides with fluctuation 55 and the base of the Large *Gephyrocapsa* Zone coincides with fluctuation 49. The top of the sequence coincides with fluctuation 39. Level "e" is coincident with fluctuation 65. Finally the base of the *Globigerina cariacoensis* Zone, coincident with the first common occurrence of left coiling specimens of *N. pachyderma*, is recorded 8 meters above the top of level "e" and is coincident with fluctuation 64.

Capo Rossello.

The calcareous plankton biostratigraphy and the relative abundance fluctuations of the *Gd. ruber* TU in the upper part of the Capo Rossello section are reported in Fig. 3, from Di Stefano et al. (1993). The FCO of left coiling specimens of *N. pachyderma* occurs at 160 m, the FO of *Gephyrocapsa oceanica* s.l. is at 178 m, the LO of *C. macintyrei* is at 198 m and the base of the Large *Gephyrocapsa* Zone is at 214 m, where also the first occurrence of *Hyalinea baltica* is recorded. In the Pleistocene segment 8 relative abundance fluctuations of *Gd. ruber* are present. According to the sequence of the underlying Pliocene fluctuations, number 64 is ascribed to the fluctuation coincident with the FCO of left coiling specimens of *N. pachyderma*. Consequently the FO of *Gephyrocapsa oceanica* s.l. is coincident with fluctuation 61, the LO of *C. macintyrei* is coincident with fluctuation 55 and the base of the Large *Gephyrocapsa* Zone is coincident with fluctuation 49. Reference is made to Di Stefano et al. (1993) for discussion about the reduced thickness of positive fluctuations 57, 53 and 51. The first occurrence of *H. baltica* is recorded on fluctuation 49. Finally, the reddish, laminated level, 150 cm thick, outcropping at about 141 m above the base and about 20 m below the FCO of left coiling specimens of *N. pachyderma* is coincident with fluctuation 67.

Monte S. Nicola.

The calcareous plankton biostratigraphy and the *Gd. ruber* TU relative abundance fluctuations recognized in the upper part of this section, studied by Channell et al. (1992), are reported in Fig. 7. The FCO of left coiling specimens of *N. pachyderma* is recorded at 140 m, the FO of *Gephyrocapsa oceanica* s.l. is at 150 m. *C. macintyrei* is present in the top sample and therefore the top of this section predates the base of the *H. sellii* Zone. In the Pleistocene segment 5 relative abundance fluctuations of the *Gd. ruber* TU are present. If they are numbered above the sequence of the Pliocene fluctuations, the FCO of left coiling specimens of *N. pachyderma* is on fluctuation 64 and fluctuation 61 is coincident with the FO of *Gephyrocapsa oceanica* s.l. The top of the sequence is coincident with fluctuation 56. The reddish, laminitic level outcropping at 127 m and below the FCO of left coiling *N. pachyderma* (Channell et al., 1992; Sprovieri, 1992; Fig. 7) is coincident with fluctuation 67.

Discussion.

Three paleomagnetic reversal boundaries have been identified in some of the considered Early Pleistocene Mediterranean sections. The top of the Olduvai subchron, which is at the base of the oxygen isotope Stage 63 (Shackleton et al., 1990), is reported in the Vrica and Singa sections (Zijderveld et al., 1991; Lourens et al., 1992), above the FCO of *N. pachyderma* left. It is between oxygen isotope Stage 64 and 63 in the Singa section (Fig. 17) and between fluctuations 64 and 63 in the Vrica section (Fig. 16). The top of the Jaramillo is reported by Ruddiman et al. (1986, 1989) and by Shackleton et al. (1990) in coincidence of oxygen isotope Stage 27. In the Croce

Valanidi section the top of Jaramillo has been identified (Aifa et al., 1987; Barrier, 1987) about 5 meters above the base of the marly interval that follows the basal calcarenitic sands and coincides with a negative fluctuation of the *N. pachyderma* relative abundance. The top of the Small *Gephyrocapsa* Zone, is recorded by Scarantino (1993) in this section 2 meters above this lithological boundary (Fig. 15), within the same negative fluctuation of the *N. pachyderma* relative abundance in which the top of Jaramillo is reported. Therefore this fluctuation is labelled with number 27 and the top of the Small *Gephyrocapsa* Zone can be used to identify fluctuation 27. At Site 653 the top of the Small *Gephyrocapsa* Zone is recorded at 58.92 mbsf (Rio et al., 1990), in coincidence of a negative fluctuation of the *N. pachyderma* relative abundance, to which label 27 is ascribed. Therefore at Site 653 the top of Jaramillo is implied in coincidence of this fluctuation. By the same correlation, the top of Jaramillo can be implied at about 12.7 m in the Ficarazzi section.

Between the top of Olduvai and the FO of *Gephyrocapsa oceanica* s.l. 1.25 fluctuation is present in the Singa and Vrica sections. At Site 653 17 fluctuations are present between the FO of *Gephyrocapsa oceanica* s.l., coincident with fluctuation 61, and the top of the Small *Gephyrocapsa* Zone, coincident with fluctuation 27. Therefore a total of 18.25 fluctuations occur between the top of Olduvai and the top of Jaramillo, in a time interval of 0.8 my (Shackleton et al., 1990). The same number of oxygen isotopic Stages are recorded in the same stratigraphic interval by Ruddiman et al. (1986, 1989) at Site 607. If 2 obliquity cycles are included in fluctuation/Stage 35 (Shackleton et al., 1990), a periodicity of about 41 kyr, well correlatable to the obliquity astronomical cycles, is obtained for these fluctuations. Authors agree (Ruddiman et al., 1986, 1989; Shackleton et al., 1990) that in the lower part of the Pleistocene interval oxygen isotope fluctuations were dominated by the obliquity astronomical cycles. If this periodicity is applied to the sequence of abundance fluctuations starting from fluctuation 63, whose base is coincident with the top of Olduvai, the ages of the other fluctuations can be obtained. They are reported in Tab. 6. In all the considered sequences the identified bio-events are always coincident with the same fluctuation and the same number of fluctuations is present in the same biostratigraphic interval. Accordingly, the age of biostratigraphic events recorded in this stratigraphic interval in coincidence with abundance fluctuations can be estimated and are reported in Tab. 7.

In the Monte S. Nicola and Capo Rossello sections a laminitic level outcrops a few meters below the FCO of left coiling specimens of *N. pachyderma*. In these sections this level is coincident with the same abundance fluctuation (67), whose age is estimated at 1.87 MA (Tab. 4). Therefore the two laminitic levels are strictly correlatable. In the Singa section the laminated bed outcropping in coincidence of cycle 67 (Lourens et al., 1992), and therefore correlatable with the laminites discussed above in the Capo Rossello and Monte S. Nicola sections, corresponds to level "C" reported in the Vrica section by Selli et al. (1977). No evidence of laminites "d" and "e", outcropping in the Vrica and Singa sections between this laminite and the FCO of *N. pachyderma* left was found in the 2 Sicilian sections.

1	2	2	3	3
22	0.890000	0.89	0.890000	0.89
24	0.930000	0.93	0.930000	0.93
26	0.970000	0.97	0.970000	0.97
27	0.990000	0.99	0.984000	0.99
28	1.010000	1.01	1.000250	1.01
30	1.050000	1.05	1.032750	1.05
31	1.070000	1.07	1.049000	1.07
32	1.101304	1.10	1.079781	1.10
34	1.143043	1.14	1.120824	1.14
35	1.184782	1.18	1.161867	1.18
36	1.226521	1.23	1.202910	1.22
37	1.24739	1.25	1.223431	1.24
38	1.268260	1.27	1.243953	1.26
40	1.309999	1.31	1.284996	1.30
42	1.351738	1.35	1.326039	1.34
44	1.393477	1.39	1.367082	1.38
46	1.435216	1.44	1.408125	1.43
48	1.476955	1.48	1.449168	1.47
49	1.497824	1.50	1.469689	1.49
50	1.518694	1.52	1.490210	1.51
52	1.560433	1.56	1.531253	1.55
54	1.602172	1.60	1.572296	1.59
55	1.623041	1.62	1.592817	1.61
56	1.643911	1.64	1.613338	1.63
58	1.685650	1.69	1.654381	1.67
60	1.727389	1.73	1.695424	1.71
61	1.748258	1.75	1.715945	1.73
62	1.769128	1.77	1.736466	1.75
63	1.790000	1.79	1.757000	1.77
64	1.810000	1.81	1.785250	1.79
65	1.830000	1.83	1.813500	1.82
66	1.850000	1.85	1.841750	1.84
68	1.890000	1.89	1.898250	1.88
70	1.930000	1.93	1.954750	1.93
71	1.950000	1.95	1.983000	1.95

Tab. 6 - Obtained and rounded ages for the Early Pleistocene abundance fluctuations. 1) Number of fluctuation; 2) absolute and rounded ages according to the paleomagnetic time scale of Shackleton et al. (1990); 3) absolute and rounded ages according to the paleomagnetic time scale of Cande & Kent (1992). Age of the Pliocene fluctuations are obtained according to the paleomagnetic time scale of Hilgen (1991).

Relative abundance data of *N. pachyderma* from the Pleistocene segment of the Vrica section have been recently published by Zijderveld et al. (1991). Their quantitative data of *N. pachyderma* are well comparable with the data plotted in Fig. 16. The only difference is the abundance peak labelled with number 56 in this figure and

Events	1 MA	2 MA	Cycle	
Top Sicilian	0.89	0.89	mid	22
Gephyrocapsa sp. 3 FO	0.99	0.98	mid	27
Gt. truncatulinoides excelsa FO	1.19	1.17	base	35
Base Small *Gephyrocapsa*	1.25	1.22 ·	mid	37
Base Large *Gephyrocapsa*	1.50	1.47	mid	49
C. macintyrei LO	1.62	1.59	mid	55
G. oceanica s.l. FO	1.75	1.72	mid	61
N. pachyderma left FCO	1.81	1.79	mid	64
Base Pleistocene	1.83	1.81	mid	65
D. brouweri LO	1.99	2.02	top	73
Gt. truncatulinoides FO	2.07	2.10	top	77
Gt. inflata FO	2.13	2.17	base	80

Tab. 7 - Absolute age of relevant bio- and chrono-stratigraphic events in the Mediterranean Early Pleistocene stratigraphic interval and their correlation to the numbered cycles. 1) According to the polarity time scale of Shackleton et al. (1990); 2) according to the polarity time scale of Cande & Kent (1992). Age of the Pliocene bio-events are obtained according to the polarity time scale of Hilgen (1991).

which occurs about 10 meters above the "m" level. It is by far more consistent than the small fluctuation reported by Zijderveld et al. (1991) also about 10 meters above level "m". Small differences in the sample intervals may explain this discrepancy.

In the Ficarazzi sequence the bio-calcarenitic level rich in *A. islandica* and *L. retroversa* is coincident with fluctuation 22. Therefore an absolute age of about 0.89 MA is proposed for this level, and for the top of the Sicilian. If the basal sands and conglomerate at the base of the local Pleistocene sequence is correlated with fluctuation 43, the age of the local base of the Pleistocene can be estimated at about 1.37 MA.

Lourens et al. (1992) report oxygen isotope, SST (Sea Surface Temperature) and PCA-2 fluctuations from the "Upper Singa section", outcropping on the Jonian side of the Calabrian region, Southern Italy. In the Pleistocene segment oxygen isotope data are tentatively correlated with the oxygen isotope stratigraphy reported by Ruddiman et al. (1989) for Site 607. The oxygen isotope and PCA-2 data from the Pleistocene segment of the Upper Singa section are reported in Fig. 17, according to the analytical data of Lourens et al. (1992). Only 2 calcareous plankton biostratigraphic events are recorded by Lourens et al. (1992) in the Pleistocene segment, the increase of *N. pachyderma* left and the LO of *C. macintyrei*. The latter event is reported by Driever (1988) between samples JT9640 and JT9641, about 2 meters below sapropel C10. In Fig. 17 other nannofossil biostratigraphic events are reported, whose position is implied by correlation with the Vrica section, for which Rio et al. (1993) report the FO of *Gephyrocapsa oceanica* s.l. between sapropel "f" and "h", and the base of the Large *Gephyrocapsa* Zone just below the "p" level, practically coincident with the FO of *Hyalinea*
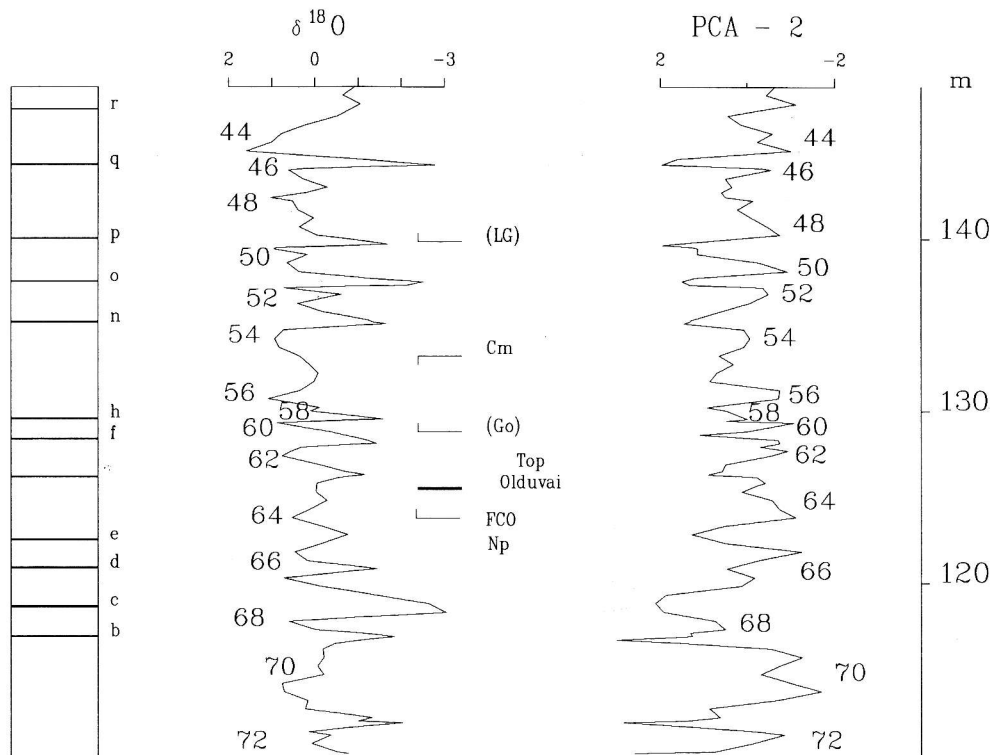
Fig. 17 - Correlation of biostratigraphic events to the oxygen isotopic and PCA-2 curves in the Singa section (from Lourens et al., 1992). LG = Base Large *Gephyrocapsa* Zone; Cm = *C. macintyrei* LO; Go = *G. oceanica* s.l. FO; FCO Np = *N. pachyderma* left FCO. Biostratigraphic events implied from the Vrica section (Rio et al., 1993) are reported in brackets. Laminitic levels are labelled by correlation with the Vrica section.

baltica. In Fig. 17 isotopic Stages are labelled according to the here proposed interpretation, taking into account these biostratigraphic datums and the results from the other Mediterranean sequences discussed above, including the Vrica section which outcrops some tens of kilometers North of the Singa section. All the bio-events recorded or implied in the Singa section coincide with the same fluctuation recorded in the other sections. Fluctuation labelled with number 58, at about 132 m, can be better identified on the PCA-2 and SST curves in which at this level a truncated fluctuation is well identified (Fig. 17), but it is very weak in the oxygen isotope curve. If this small fluctuation identified at about 132 m is not considered, the extinction level of *C. macintyrei* would coincide with fluctuation 57. But the extinction level of *C. macintyrei* is clearly well identified by Driever (1988) with the same distribution pattern recorded in the other Mediterranean sections. Therefore it can be correlated with the same biostratigraphic event at Site 653 (Rio et al., 1990), at Capo Rossello (Di Stefano et al., 1993) and Vrica (Rio et al., 1993) and that is coincident with fluctuation 55.

Comparison with extra-Mediterranean sequences.

Several oxygen isotope data from Pleistocene sequences in the oceanic regions have been published since the pioneer paper by Shackleton and Opdyke (1976). On the contrary still rare are papers in which oxygen isotope fluctuations in this interval are directly compared with calcareous plankton biostratigraphic and paleomagnetic data.

Ruddiman et al. (1986, 1989) and Raymo et al. (1989) report oxygen and carbon isotope, calcium carbonate and sea-surface temperature (SST) data from Site 607 (DSDP, Leg 94), drilled in the mid-high latitudes North Atlantic ocean. Paleomagnetic data at this Site are available and represent the basic reference for biostratigraphic evaluations. Raffi et al. (1993) report position of Early Pleistocene nannofossil biostratigraphic events at this Site and Raymo et al. (1989) report the position of the FCO (first common occurrence) of *Neogloboquadrina pachyderma* left (Fig. 18). According to
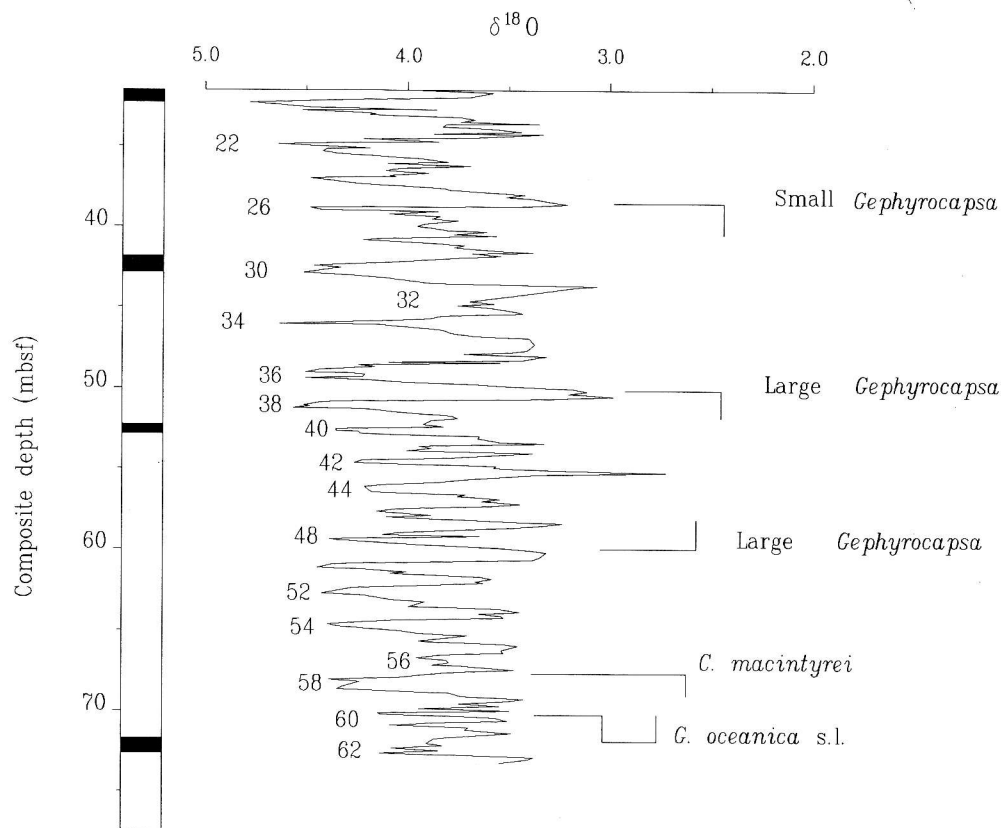

Fig. 18 - Oxygen isotope curve at Site 607. From Ruddiman et al. (1989). Calcareous nannofossil events are from Raffi et al. (1993).

these data the *N. pachyderma* left FCO, the base of the Large *Gephyrocapsa* interval and the base of the Small *Gephyrocapsa* Zone are perfectly correlatable between the Mediterranean basin and the mid-high North Atlantic latitudes. But the appearance level of *Gephyrocapsa oceanica* s.l. is on fluctuation 61 in the Mediterranean sequences and on isotopic Stage 60 at Site 607, the *C. macintyrei* LO is on isotopic Stage 57 at Site 607 and on fluctuation 55 in the Mediterranean record and the top of the Small *Gephyrocapsa* Zone is on fluctuation 27 in the Mediterranean and on isotopic stage 25 at Site 607. Therefore, on the assumption that the abundance fluctuations respond in phase with the oxygen isotopic stages as discussed above, these three nannofossil events are slightly diachronous between the Mediterranean basin and the mid-high North Atlantic latitudes.

The age of the Early Pleistocene chronostratigraphic boundaries.

The Pliocene/Pleistocene boundary stratotype is defined in the Vrica section (Calabria, Italy) in coincidence of the base of the marls overlying the sapropelitic level "e" (Aguirre & Pasini, 1985). According to the recent paper by Zijderveld et al. (1991) this level is about 8.5 m below the top of Olduvai subchron if their second (preferred) proposal for the identification of this paleomagnetic event is accepted.

The base of the Pleistocene is generally approximated in the Mediterranean sections by the FCO of left coiling specimens of *Neogloboquadrina pachyderma* if planktonic foraminifera are used (Sprovieri, 1978; Colalongo et al., 1982; Glaçon et al., 1990; Sprovieri, 1992; Channel et al., 1992) and by the First Occurrence of *Gephyrocapsa oceanica* s.l. if calcareous nannofossils are used (Raffi & Rio, 1979; Rio et al., 1984; Rio et al., 1990; Rio et al., 1991). In the Vrica section the former event is recorded 8 m above the top of level "e" (Fig. 16), and is therefore just below the top of the Olduvai subchron. The latter event is recorded in this section 27 m above the top of level "e" (Rio et al., 1993; Fig. 16). Level "e" is coincident with fluctuation 65, the FCO of left coiling *N. pachyderma* is coincident with fluctuation 64 and the FO of *G. oceanica* s.l. is coincident with fluctuation 61. The same bio-events are recorded, in the same order, in the Capo Rossello and Monte S. Nicola sections (Fig. 3 and 7), where the FCO of left coiling *N. pachyderma* is coincident with fluctuation 64, and the FO of *G. oceanica* s.l. is recorded in coincidence of fluctuation 61.

With reference to the adopted time scale the age of fluctuations 61, 64 and 65 is 1.75, 1.81 and 1.83 MA (Tab. 7) respectively. Therefore the age of the Pliocene/Pleistocene boundary, as defined by the base of the marls overlying level "e" in the Vrica section is 1.83 MA. The recognition of this boundary by the FCO of left coiling *N. pachyderma* is about 20 kyr younger and its recognition by the FO of *G. oceanica* s.l. is about 80 kyr younger.

Since abundant left coiling specimens of *N. pachyderma* are discontinuously recorded in the Mediterranean Pleistocene sequences (Fig. 16), the very first common occurrence of this form may be difficult to be detected if a detailed, continuous set of

samples is not available or if scattered samples are studied for field-geology investigations. Therefore the presence in the samples of *G. oceanica* s.l., which is generally recorded in the samples belonging to Early Pleistocene stratigraphic levels above its appearance level, represents a more useful and reliable reference to identify Early Pleistocene sediments, even if its FO is recorded only about 80 kyr above the Pliocene/Pleistocene boundary.

The base of the Emilian substage is recognized by the FO of *Hyalinea baltica*, practically coincident with the base of the Large *Gephyrocapsa* Zone (Glaçon et al., 1990; Rio et al., 1991). This calcareous nannofossil event is coincident with fluctuation 49 and therefore its absolute age is about 1.50 MA. Consequently the Santernian stratigraphic interval is about 0.33 my long. The base of the Sicilian is recognized by the FO of *Globorotalia truncatulinoides excelsa*, which occurs at the base of fluctuation 35, 1 fluctuation above the base of the Small *Gephyrocapsa* Zone. Therefore the absolute age of the base of the Sicilian is at 1.19 MA. If the recognition of this chronostratigraphic boundary is approximated by the base of the Small *Gephyrocapsa* Zone, an error of about 40 kyr is introduced. Finally, the top of the Sicilian (and of the Early Pleistocene), defined by the bio-calcarenitic bed, rich in *Arctica islandica* and *Limacina retroversa*, outcropping at Cava Puleo (Palermo, Sicily) (Ruggieri et al., 1984), is coincident with fluctuation 22. The top of the Early Pleistocene is therefore coincident with the world-wide recognized Pleistocene change in climate regime and isotopic periodicity (Ruddiman et al., 1986, 1989; Shackleton et al., 1990). Its absolute age is 0.89 MA.

Conclusions.

The re-evaluation of the age of the abundance fluctuations within paleomagnetic intervals whose upper and lower reversal boundaries ages are updated according to the new time scale proposed by Hilgen (1991) allows to update the estimated age of the calcareous plankton events recorded in the Pliocene Mediterranean record. The new proposed ages of the Pliocene bio-events are reported in Tab. 5.

The abundance fluctuations have a periodicity of about 40 kyr, well correlatable with the periodicity of the obliquity astronomical cycles, in the upper part of the Pliocene, from a level below the *D. tamalis* LCO. Since this level, at the beginning of the Glacial regime (Sprovieri, 1992), is coincident with fluctuation 121, its absolute age is estimated at 2.94 MA. In the underlying part of the Pliocene the periodicity of the abundance fluctuations can be correlated with the precession astronomical cycles.

In the uppermost Pliocene, Mediterranean calcareous plankton events are diachronous if compared with the mid-North Atlantic Site 607. *D. brouweri* LO is recognized on oxygen isotopic Stage 71 and just above the base of Olduvai at Site 607, but it is recorded on oxygen isotopic Stage and fluctuation 73, just below the base of Olduvai, in the Mediterranean sequences. The first occurrence of *Gt. inflata* is recorded on isotopic Stage 78 at Site 607, but it is present on fluctuation 80 in the

Mediterranean basin. The proposed re-evaluation of the number of isotopic stages (and PCA-2 fluctuations) in the "Upper Singa section", in which according to Lourens et al. (1992) the *Gt. truncatulinoides* FO is reported on the "warm" oxygen isotopic stage (and PCA-2 fluctuation) immediately below the "warm" stage on which the *D. brouweri* LO is reported, reconciles the data from the Singa section with the results obtained from the other Mediterranean sequences.

The labels of lithological cycles proposed by Langereis & Hilgen (1991) and Hilgen (1991) in the Capo Rossello composite section is slightly revised, according to the results from the Capo Spartivento section. In particular, 4 cycles are included in the Sidufjall interval. A total number of 79 abundance fluctuations are recognized between the base of the Pliocene and the Gilbert/Gauss boundary, which occurs between fluctuations 79 and 80.

By extrapolation of the periodicity of 22.2 kyr of the abundance fluctuations within the Thvera interval down to the base of the Pliocene (Cita, 1975b), the age of this chronostratigraphic boundary is estimated at 5.33 MA.

Periodicity of the relative abundance fluctuations of the *N. pachyderma* and *Gd. ruber* taxonomic units in several Mediterranean sequences referable to the Early Pleistocene, among which the Pleistocene segment of Site 653 is included, were controlled by the obliquity astronomical cycles. Correlation of calcareous plankton biostratigraphic datums to these fluctuations in all the studied Mediterranean sequences evidences that they are isochronous and allows a detailed estimate of the absolute age for these bio-events.

According to the data from Pleistocene segment of Site 607 reported by Ruddiman et al. (1989) and Raffi et al. (1993) some calcareous nannofossil events are diachronous between the mid-high North Atlantic region and the Mediterranean. A revised interpretation of the labels of the isotopic Stages reported by Lourens et al. (1992) in the Pleistocene segment of the Singa section results in the same correlation between the biostratigraphic datums and the abundance fluctuations recognized in the other Mediterranean sequences.

The age of the Pliocene/Pleistocene boundary is estimated at 1.83 MA. The recognition of this chronostratigraphic boundary by the FCO of left coiling *N. pachyderma* or by the FO of *G. oceanica* s.l. is younger than about 20 kyr and 80 kyr respectively. Due to the discontinuous presence of abundant left coiling specimens of *N. pachyderma* in the Mediterranean Early Pleistocene sequences, which makes this marker sometime unreliable for the recognition of Early Pleistocene sediments, it is suggested that the recognition in the samples of the more continuously present calcareous nannofossil *G. oceanica* s.l. is a more reliable reference, even if its FO is recorded only about 80 kyr above the Pliocene/Pleistocene boundary. The Santernian-Emilian boundary is estimated at 1.50 MA. The Emilian-Sicilian boundary is estimated at 1.19 MA. If this chronostratigraphic boundary is recognized by the base of the Small *Gephyrocapsa* Zone an error of about 40 kyr is introduced. Finally, the top of the Sicilian is coincident with isotopic Stage/fluctuation 22, with an absolute age of 0.89 MA.
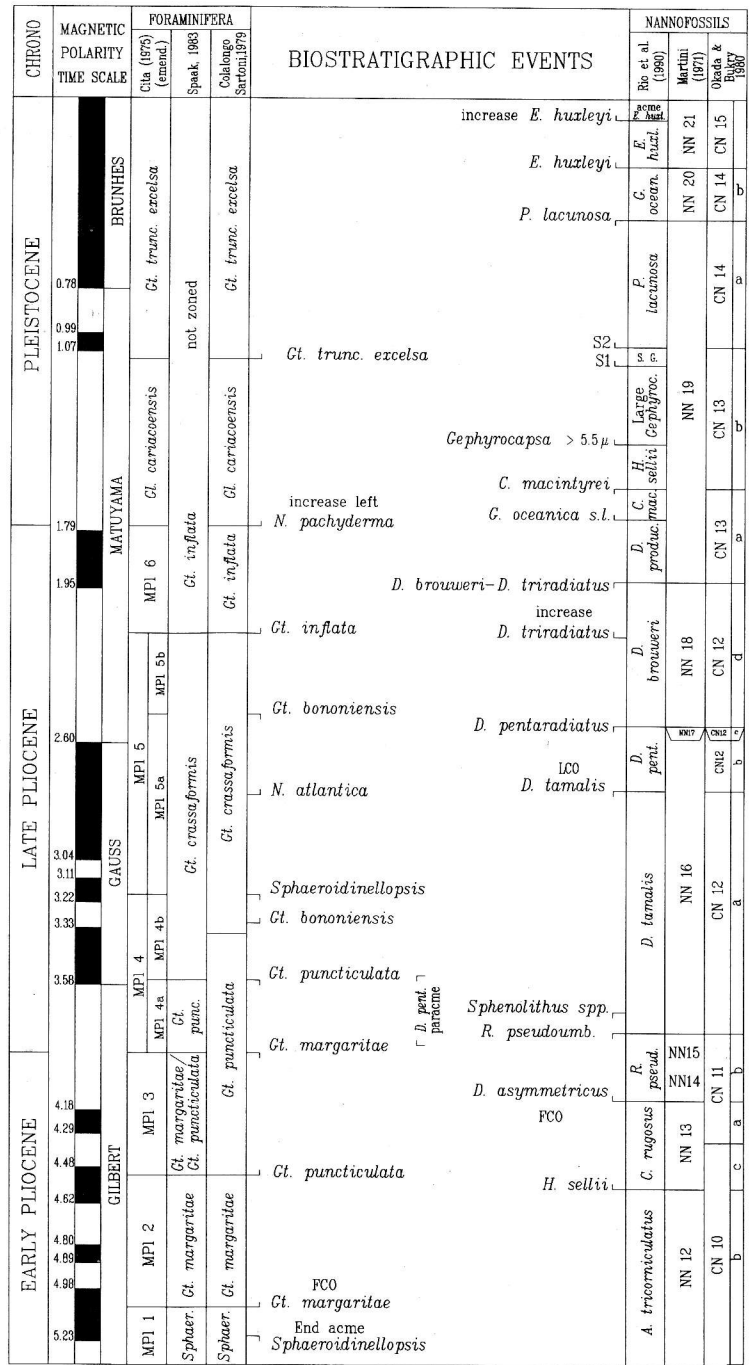
Fig. 19 - Calcareous plankton integrated biostratigraphic scheme for the Plio-Pleistocene Mediterranean interval.

According to the obtained chronological data for the Pliocene-Early Pleistocene bio-events the calcareous plankton biostratigraphic scheme proposed by Sprovieri (1992) for the Mediterranean Plio-Pleistocene stratigraphic interval is updated and reported in Fig. 19, in which the ages of the Pliocene reversal boundaries are from Hilgen (1991) and the ages of the Pleistocene reversal boundaries are from Shackleton et al. (1990).

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