

HIGH RESOLUTION CHRONOLOGY FOR LATE MIOCENE MEDITERRANEAN STRATIGRAPHIC EVENTS

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Riassunto. Una accurata biostratigrafia a Foraminiferi planctonici e nanfossili calcarei ha permesso di riconoscere con precisione la posizione di numerosi eventi biostratigrafici nelle successioni mediterranee fittamente campionate di Falconara, Monte Gibliscemi e pozzo 654 (ODP Leg 107). Le successioni studiate coprono un intervallo stratigrafico compreso tra il Tortoniano alto e il Messiniano preevaporitico. La analisi quantitativa della associazione a Foraminiferi planctonici nelle sezioni di Falconara, che contiene il proposto stratotipo del limite Tortoniano-Messiniano, e di Monte Gibliscemi ha messo in evidenza una successione di fluttuazioni di abbondanza relativa di *Globigerinoides* spp. del tutto comparabile con le fluttuazioni di abbondanza relativa di *Globigerinoides* spp. ottenute nel segmento di età corrispondente carotato nel pozzo 654, nel Tirreno. La magnetostratigrafia di questo pozzo è stata re-interpretata secondo la successione di eventi paleomagnetici proposta da Cande & Kent (1992, 1995) per il Miocene superiore. Se anche in questo intervallo stratigrafico la periodicità delle fluttuazioni di abbondanza è di 21 kyr, ossia riferibile alla periodicità dei cicli orbitali della precessione, l'età di ogni fluttuazione può essere valutata. Utilizzando le età ottenute con le fluttuazioni di abbondanza che coincidono con i limiti paleomagnetici nel pozzo 654 è risultato che esse sono più antiche di quelle proposte da Shackleton et al. (1995) e Cande & Kent (1995). La stessa procedura applicata alla parte della successione riferibile al Messiniano nel pozzo 552 (DSDP, Leg 81), carotato nell'Atlantico nord orientale, ha permesso, utilizzando le fluttuazioni di abbondanza nella associazione a nanfossili calcarei riportate da Beaufort & Aubry (1990), di ottenere valori di età per i limiti paleomagnetici del Chron 3An. Anche questi sono risultati di poco più antichi di quelli proposti da Shackleton et al. (1995) e Cande & Kent (1995). La recente re-interpretazione della magnetostratigrafia del pozzo 654 proposta da Kastens (1992) non è stata adottata in quanto essa presuppone una eccessiva diacronità degli eventi biostratigrafici all'interno del bacino mediterraneo.

I dati provenienti dallo studio quantitativo delle associazioni a Foraminiferi planctonici nelle tre successioni mediterranee e i dati quantitativi sulla associazione a nanfossili calcarei riportati da Beaufort & Aubry (1990) per l'intervallo del Miocene superiore nel pozzo 552 permettono di ricostruire una completa successione di fluttuazioni di abbondanza indotte dai cicli astronomici della precessione tra il Tortoniano superiore e lo Zancleano basale. Il confronto con il pozzo 552 ha anche permesso una correlazione tra gli eventi riconosciuti nel bacino mediterraneo e gli eventi paleoceanografici identificati nella successione atlantica durante il Miocene superiore.

La correlazione tra le singole fluttuazioni e i livelli corrispondenti alle principali variazioni litologiche e ai principali bio-eventi ha permesso una loro dettagliata valutazione cronologica. In particolare, l'età della base della Formazione dei Tripoli è valutata a 6.93 MA e la sua sommità è valutata a 6.08 MA. Per correlazione con i dati isotopici del pozzo 552, la sommità della Formazione dei Tripoli precede di circa 0.34 my il più antico massimo glaciale riconosciuto nell'intervallo messiniano.

Abstract. An integrated calcareous plankton biostratigraphy allowed a very detailed biostratigraphic subdivision for the pre-evaporitic Tortonian-Messinian segments at Falconara, at Monte Gibliscemi and at Site 654 (ODP, Leg 107). Quantitative analysis on the planktonic foraminiferal assemblages pointed out a sequence of relative abundance fluctuations in the *Globigerinoides* spp. population. On the assumption that in this stratigraphic interval, as in the overlying Pliocene interval, the abundance fluctuations have a periodicity of 21 kyr, correlatable to the precession astronomical cycles, the age of every fluctuation has been estimated. At Site 654 correlation of the abundance fluctuations with the magnetostratigraphic boundaries, re-interpreted according to the magnetic polarity reversals record proposed by Cande & Kent (1992, 1995), made it possible to identify the ages of these boundaries. They are older than the ages proposed by Shackleton et al. (1995) and by Cande & Kent (1995). The same procedure in the Upper Miocene segment of DSDP Site 552, on the base of the nanofossil abundance fluctuations published by Beaufort & Aubry (1990), allowed to obtain for the paleomagnetic boundaries of Chron 3An ages totally comparable to the ages proposed by Benson et al. (1995) and slightly older than the ages proposed by Shackleton et al. (1995) and Cande & Kent (1995). The re-interpretation of the magnetostratigraphy at Site 654 recently proposed by Kastens (1992) was not adopted since it introduces too large diachroneities for the biostratigraphic events within the Mediterranean basin.

The data coming from the quantitative analysis on the planktonic foraminifera in the three Mediterranean sequences together with quantitative data on the nanofossil assemblage published by Beaufort & Aubry (1990) for the Late Miocene segment of the North-eastern Atlantic Site 552 provide a complete sequence of abundance fluctuations, forced by the astronomical precession cycles, from the middle Late Tortonian to the base of the Zanclean. They allow an accurate correlation of the sedimentary and biostratigraphic events recorded in the Mediterranean basin with the paleoceanographic events recorded in the North Atlantic. The age of each sedimentary and/or biostratigraphic event could be estimated by comparison with the sequence of abundance fluctuations. The base of the Tripoli Formation is estimated at 6.93 MA and its top at 6.08 MA. By correlation with Site 552, the top of the Tripoli Formation at Falconara predates the Messinian older glacial maximum by about 0.34 myr.

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Introduction.

Late Miocene witnessed dramatic changes in the Mediterranean sedimentary and biodynamic evolution. In several localities the Tortonian open marine marly sequence with a diversified calcareous plankton and benthic microfossil assemblage changed into the predominantly finely laminated Messinian sediments of the Tripoli Formation, yielding an abundant and diversified siliceous assemblage with diatoms and silicoflagellates in the laminated intervals. However, a restricted and poorly diversified foraminiferal assemblage, with benthic foraminifera population dominated by only one species, *Bulimina echinata*, is present in the marly intervals. The Calcare di Base, a cavernous limestone which heralds the Lower Evaporite unit (Decima & Wezel, 1971), when the Mediterranean became a sterilized basin, followed the Tripoli Formation. Separated by a tectonic event from the Lower Evaporite cycle, the Upper Evaporite unit (Decima & Wezel, 1971) is generally present in Sicily with seven repeated couplets of gypsum and silty clays. In other localities, as in the Marche Region in central Italy, up to 5 white limestone horizons are present in the Colombacci Formation (Colalongo et al., 1978), coeval with the Upper Evaporite unit of Sicily. Brackish, shallow water fossils, essentially represented by *Ammonia beccarii tepida*, *Cyprideis* spp., *Congerina* spp., *Dreissena* spp. and *Melanopsis* spp. are present in the Upper Evaporite cycle and in the Colombacci Formation (Ruggieri, 1958, 1967; Decima & Sprovieri, 1973; Casati et al., 1978; Colalongo et al., 1978; Cita et al., 1990). Dwarfed planktonic Foraminifera are sometime present in discrete, scattered levels of the Upper Messinian marls (Cita et al., 1990).

In Sicily the Upper Evaporite unit is closed by the topmost lithological Messinian unit, the Arenazzolo. It is an essentially clastic sediment, with faunistic assemblage and sedimentary features testifying deposition in a very shallow, brackish water environment. In Northern Italy blackish to gray clays, sometime rich in *Cardium* spp. or *Phragmites*, are present at the top of the Messinian sequence, just below the deep-water, open marine Pliocene sediments (Sturani, 1973; Ruggieri & Sprovieri, 1976; Colalongo et al., 1978; Casati et al., 1978; Giammarino et al., 1984).

Well established calcareous plankton events allow a good biostratigraphic resolution of the Mediterranean Late Miocene pre-evaporitic sequence (D'Onofrio et al., 1975; Iaccarino, 1985; Theodoridis, 1984). Several second order biostratigraphic events allow further, more detailed subdivisions.

An accurate chronology of all these Late Miocene events is still lacking. The generally poor and often controversial magnetostratigraphy of Late Miocene sequences (Langereis et al., 1984; Hsu, 1985; Channell et al., 1990; Benson et al., 1991) or the inferred magnetostrati-

graphy for the Tripoli Formation (Burckle, 1976, 1977; Gersonde & Schrader, 1984) do not provide a sound basis for an accurate estimate of the age of the several lithostratigraphic and biostratigraphic events recorded in the Mediterranean Tortonian-Messinian geological sequence. Only in a very recent time the papers by Krijgsman et al. (1994) and Hodell et al. (1994) provide reliable magnetostratigraphies for several uppermost Tortonian-Lower Messinian sequences from Crete and from northwestern Morocco. Oxygen and Carbon isotope analyses from Mediterranean sequences (van der Zwaan, 1979, 1982; van der Zwaan & Gudjonsson, 1986; Glacçon et al., 1990) provide only a general picture of the main paleoceanographic changes and are inappropriate for a detailed isotopic stratigraphy. Consequently, it is difficult at the present time to correlate in detail the Late Miocene Mediterranean events with the extra-Mediterranean record, for which the recent papers by Keigwin et al. (1987), Keigwin (1987), Beaufort & Aubry (1990) and Hodell et al. (1994) provide an excellent high resolution chronology of the Late Miocene interval.

Abundance fluctuations in the planktonic foraminiferal assemblages from several Pliocene-Lower Pleistocene Mediterranean sections have been recently identified (Sprovieri, 1992, 1993). Their periodicity is well related to the precession astronomical cycles during the Zanclean and the Early Piacenzian and to the obliquity astronomical cycles during the Late Piacenzian, the Gelasian and Selinuntian. Correlation of the biostratigraphic events with the abundance fluctuations provided the chronological estimates of the several bio-events recorded in these time-intervals (Sprovieri, 1993). A similar approach for the Mediterranean Tortonian - pre-evaporitic Messinian interval is proposed in this paper. Chronological estimates of the recognized lithologic and biostratigraphic events could be attempted and a detailed correlation with paleoceanographic events recorded in the coeval part of the sequence of DSDP Leg 81 Site 552, from the Hatton Drift, in North-eastern Atlantic (56° 2.56' N, 23° 13.88' W, 2301 m).

Materials.

Three sections (Fig. 1) have been investigated: Falconara and Gibliscemi from Sicily and ODP Site 654 from the Tyrrhenian Sea. In the well-known Falconara section a pre-evaporitic segment, with a thickness of about 71 m and referable to the "Marne a Globigerine" Formation (Behrman, 1938; Colalongo et al., 1979a) has been sampled at approximately 15-25 cm interval. In the overlying Tripoli Formation only one sample from each claystone and laminite beds of every lithologic couplet has been studied. A total thickness of about 27 m is present between the base of the Calcare di Base and the base of the Tripoli Formation.

Globigerina angustumbilicata Bolli
Globigerina bulloides d'Orb. s.l.
Globigerina falconensis Blow
Globigerina nepenthes Todd
Globigerinoides bulloideus Crescenti
Globigerinoides obliquus Bolli s.l.
Globigerinoides quadrilobatus (d'Orb.) s.l.
Neogloboquadrina atlantica (Berggren)
Neogloboquadrina acostaensis Blow
Globorotalia conomiozea Kennett
Globorotalia continuosa Blow
Globorotalia menardii (Parker, Jones & Brady) s.l.
Globorotalia miotumida Jenkins
Globorotalia obesa (Bolli)
Globorotalia praehumerosa Natori
Globorotalia scitula (Brady) s.l.
Hastigerina siphonifera (d'Orb.)
Globoquadrina spp.
Orbulina spp.
Globigerinita glutinata (Egger)
Sphaeroidinellopsis spp.
Turborotalita quinqueloba (Natland)

Tab. 1 - List of the planktonic foraminifera taxonomic units adopted for the quantitative analysis of the Falconara, Monte Gibliscemi and Hole 654 sequences.

Biostratigraphic and quantitative results from the planktonic foraminiferal assemblage of the "Marne a Globigerine" segment of Falconara have been correlated and compared with quantitative results from planktonic foraminiferal assemblage obtained in the Late Miocene, pre-evaporitic interval of ODP Site 654, Leg 107, drilled in the Sardinian upper continental slope in the Tyrrhenian basin. Magnetostratigraphy at this Site has been published by Channell et al. (1990) for the Upper Tortonian-Lower Messinian sediments underlying an evaporite bearing Messinian segment. At Site 654 samples have been studied at a mean interval of 20-25 cm.

Data from these two sequences have been correlated and compared with data from the Monte Gibliscemi section, outcropping about 15 km north of Gela and about 30 km east of Falconara, in southern Sicily. The section has been sampled at a mean interval of about 20-25 cm.

Finally, data from these three sequences have been integrated and compared with the data published by Beaufort & Aubry (1990) for the Messinian interval of the North Atlantic Site 552. The sequence studied by Beaufort & Aubry (1990) includes the stratigraphic interval coincident with the Messinian Mediterranean evaporitic sequence, in which quantitative analyses are not possible, since sediments are barren or inadequate for detailed faunistic investigations on calcareous plankton assemblages.

Methodology.

For the analysis of the planktonic foraminifera, samples were washed on a 63 µm sieve. All the residue was studied for biostrati-

graphic analysis. Only the fraction greater than 125 µm has 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 (TU) reported in Tab. 1. In the modern oceans *Globigerinoides* spp. live in tropical and subtropical regions and are considered warm waters indicators (Bè & Tolderlund, 1971; Cifelli & Smith, 1974; Bè & Hutson, 1977; Coulbourn et al., 1980). Variation in their relative abundance essentially reflects variations in sea surface temperature, with high relative abundances correlated with warmer intervals and low relative abundances correlated with cooler intervals. The relative abundance fluctuations of the *Globigerinoides* population have been used to identify short-term climatic fluctuations in the sequence studied at Falconara, Monte Gibliscemi and Site 654. Quantitative values of *Orbulina* spp. have not been considered for the estimate of the percent values of the *Globigerinoides* spp. population.

Calcareous nannofossils have been studied on smear slides using a light microscope at about 1000 magnifications. Smear slides were prepared following standard procedure. The recognition of the biostratigraphic events is based on the analysis of not less than 3000 nannoliths. The same samples used for foraminifera analysis have been studied.

The Falconara section

The Falconara section outcrops on the southern slope of Monte Cantigaglione, about 3.5 km NW of Castello di Falconara (Fig. 1). The local lithologic sequence between the basal tectonized marly complex overlying the "Argille Scagliose" and the Calcare di Base is represented by the "Marne a Globigerine" Formation (Behrman, 1938; Colalongo et al., 1979a), about 90 m thick, and the Tripoli Formation, about 27 m thick. The "Marne a Globigerine" Formation is represented by gray marls with intercalated reddish laminites, each generally topped by a manganese crust. The reddish laminites are about 10-30 cm thick and are not regularly distributed along the sequence. They are more frequent in the lower part of the section, below the *Gt. suterae* FO (First Occurrence). Only the upper 71 m of the marls have been studied. In the underlying

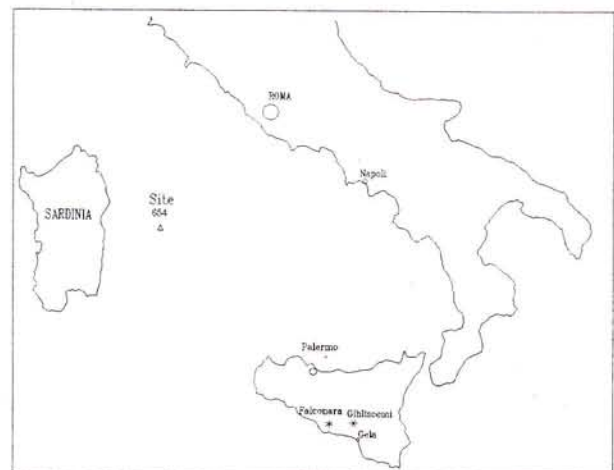


Fig. 1 - Index map of the studied sequences.

segment several faults strongly reduce the thickness of the sequence.

The "Marne a Globigerine" are overlaid, without tectonic or sedimentologic disturbance, by the Tripoli Formation. This Formation includes 41 couplets of alternating laminites and gray to reddish-laminated claystones. Thickness of the composite couplets varies between 20 and 170 cm. In each of the three topmost couplets of the Tripoli Formation a micritic limestone bed about 30 cm thick is intercalated in the claystones. The carbonatic level just below the Calcare di Base has been interpreted by McKenzie et al. (1979) as diagenetically transformed from an original gypsum bed. It is followed by the cavernous limestones of the Calcare di Base, coincident with the base of the Mediterranean Messinian evaporites. The diatomaceous bed included in the lithological cycle 26 is represented by porcellanite, about 25 cm thick.

In this section, first published by Catalano & Sprovieri (1971), the stratotype of the Tortonian-Messinian boundary was proposed in coincidence with the appearance level of *Globorotalia conomiozea* (Colalongo et al., 1979b). Calcareous plankton biostratigraphy concerning this section has been published by D'Onofrio et al. (1975), Colalongo et al. (1979a), van der Zwaan (1982) and Theodoridis (1984). Diatoms from the Tripoli segment were studied by Gersonde (1980) and used for correlation of Lower Messinian deposits in the western Mediterranean by Gersonde & Schrader (1984). Van der Zwaan (1982) and Van der Zwaan & Gudjonsson (1986) published oxygen and carbon stable isotopic data from large spaced samples from the upper part of the marls and from the Tripoli segment. McKenzie et al. (1979) published stable isotopic data from bulk samples essentially from the Tripoli Formation. Several attempts to obtain paleomagnetic results from the section have been unsuccessful (Langereis et al., 1984; Hsu, 1985; Langereis & Dekker, 1992), but Gautier et al. (1994) claim to have obtained paleomagnetic results from the uppermost part of the marls and from the Tripoli segment. According to these Authors a sedimentary gap is present between the "Marne a Globigerine" Formation and the base of the Tripoli Formation.

The marly segment.

Samples have been collected from 2 segments. The stratigraphically younger segment includes the Tripoli Formation at the top. The 2 segments have been correlated with accuracy by the disappearance level of left coiling *Globorotalia menardii* (form 4 of Tjalsma, 1971). This bio-event occurs 41.50 m above the base of segment B and 30.0 m below the lowermost Tripoli level which, in agreement with Benson et al. (1991), is present about 1.75 m below the base of the white wall in which the main part of the Tripoli Formation outcrops.

This correlation is supported by several other biostratigraphic events. In the 2 segments *Globorotalia suterae* appears about 3.0 m below the disappearance level of *Gt. menardii* form 4. *Sphaeroidinellopsis* spp., *Globoquadrina* spp. and *Candeina nitida*, which are rare to absent in the remaining part of the section, are frequent in the level in which the *Gt. suterae* FO has been recorded. The first occurrence of *Globorotalia saphoe* is 3.75 m below the *Gt. suterae* FO. The extinction level of the calcareous nannofossil *M. convallis* is recorded 2 m below the *Gt. suterae* FO. Samples have been collected at an interval of 12-25 cm. A total of 312 samples have been studied.

Calcareous plankton biostratigraphy.

Planktonic foraminifera. Planktonic foraminiferal biostratigraphy for the studied composite section is reported in Fig. 2 and 3, following the biostratigraphic scheme of Iaccarino (1985). The stratigraphic positions of second order biostratigraphic events are also reported. They allow a more detailed biostratigraphic subdivision of the section and represent important control points for an accurate correlation with other sequences. Thickness in meters above the base of the composite section for the planktonic foraminifera events is reported in Tab. 2. Along the studied segment *N. acostaensis* is essentially left coiling, but just above the appearance of *Globigerinoides obliquus extremus*, in coincidence of abundance fluctuation 266, prevailing right coiling specimens of *Neogloboquadrina acostaensis* are present. *Globorotalia menardii* s. l. is more or less continuously present with left coiling specimens (form 4 of Tjalsma, 1971) from the base of the section up to 41.50 m above the base. It is again present in short segments at 49 m and at 60 m above the base. From 56.10 m above the base right coiling specimens of *Gt. menardii* s. l. (*Gt. menardii* form 5 of Tjalsma, 1971) are frequent up to the appearance of *Globorotalia miotumida*.

Calcareous nannofossils. Calcareous nannofossil biostratigraphic scheme proposed by Theodoridis (1984) for the Late Miocene interval has been adopted. In this interval it allows a more detailed biostratigraphic resolution than the standard biostratigraphic scheme proposed by Martini (1971).

Calcareous nannofossil assemblages are rich and well diversified. Preservation is generally good, with evidence of dissolution and/or overgrowth only in some discrete levels. Three calcareous nannofossil events have been identified in the marls below the Tripoli Formation and the recognized biostratigraphic intervals are reported in Fig. 2 and 3. Position in meters above the base of the bio-events are reported in Tab. 2. *Amaurolithus primus* first appears at 54.25 m, below the appearance of dextral population of *Gt. menardii* s.l. (form 5

| FALCONARA SECTION | | | |
|--------------------------------------|--------|-----------|-------------------|
| EVENTS | METERS | CYCLE | ABSOLUTE AGE (MA) |
| Top Tripoli Formation | 98.25 | 72 (M42) | 6.08 |
| FCO <i>Gl. multiloba</i> | 87.30 | 104 (M26) | 6.41 |
| FCO <i>N. acostaensis</i> dx | 86.10 | 107 (T24) | 6.44 |
| LCO <i>N. atlantica</i> | 83.90 | 115 (M20) | 6.53 |
| FO <i>A. amplificus</i> | 84.30 | 121 (T17) | 6.59 |
| Base abundance <i>N. atlantica</i> | 81.10 | 129 (M13) | 6.67 |
| FCO <i>N. atlantica</i> | 77.00 | 139 (T8) | 6.78 |
| LO <i>Gt. nicolae</i> | 76.00 | 141 (T7) | 6.80 |
| LO <i>R. rotaria</i> | 74.50 | 145 (T5) | 6.84 |
| FO <i>Gt. nicolae</i> | 74.05 | 147 (T4) | 6.86 |
| Base Tripoli Formation | 71.20 | 153 (T1) | 6.93 |
| FO <i>Gt. conomiozea</i> | 62.25 | 174 | 7.15 |
| FO <i>R. rotaria</i> | 61.10 | 176 | 7.17 |
| FO <i>Gt. miotumida</i> plexus | 61.60 | 176 | 7.17 |
| FO <i>Gt. mediterranea</i> | 61.60 | 176 | 7.17 |
| FO <i>A. delicatus</i> | 59.00 | 190 | 7.32 |
| FCO <i>Gt. menardii</i> s.l. dx | 56.10 | 193 | 7.35 |
| FO <i>A. primus</i> | 54.25 | 197 | 7.39 |
| Presence <i>Gt. menardii</i> s.l. sx | 49.00 | 203 | 7.45 |
| LCO <i>Gt. menardii</i> s.l. sx | 41.50 | 210 | 7.53 |
| FO <i>Gt. suterae</i> | 39.00 | 218 | 7.61 |
| LO <i>M. convallis</i> | 37.00 | 223 | 7.66 |
| FO <i>Gt. saphoae</i> | 36.25 | 224 | 7.67 |
| FO <i>Gt. praeumerosa</i> | 34.75 | 226 | 7.69 |
| LO <i>Gt. continuaosa</i> | 33.25 | 228 | 7.71 |
| FO <i>Gld. obliquus extremus</i> | 11.00 | 269 | 8.14 |

| SITE 654 | | | |
|--------------------------------------|--------|-------|-------------------|
| EVENTS | MBSF | CYCLE | ABSOLUTE AGE (MA) |
| FO <i>Gt. conomiozea</i> | 369.60 | 174 | 7.15 |
| FO <i>R. rotaria</i> | 369.89 | 176 | 7.17 |
| FO <i>Gt. miotumida</i> plexus | 371.23 | 176 | 7.17 |
| FO <i>A. delicatus</i> | 371.53 | 176 | 7.17 |
| FCO <i>Gt. menardii</i> s.l. dx | 383.50 | 193 | 7.35 |
| FO <i>A. primus</i> | 387.75 | 197 | 7.39 |
| Presence <i>Gt. menardii</i> s.l. sx | 390.10 | 203 | 7.45 |
| LCO <i>Gt. menardii</i> s.l. sx | 396.50 | 210 | 7.53 |
| FO <i>Gt. suterae</i> | 401.17 | 218 | 7.61 |

| GIBLISCEMI | | | |
|----------------------------------|--------|-------|-------------------|
| EVENTS | METERS | CYCLE | ABSOLUTE AGE (MA) |
| Base Tripoli Formation | 116.00 | 153 | 6.93 |
| FO <i>Gt. conomiozea</i> | 102.60 | 174 | 7.15 |
| FO <i>R. rotaria</i> | 101.55 | 176 | 7.17 |
| FO <i>Gt. miotumida</i> plexus | 101.25 | 176 | 7.17 |
| FO <i>Gt. mediterranea</i> | 101.25 | 176 | 7.17 |
| FO <i>A. primus</i> | 94.50 | 197 | 7.39 |
| LCO <i>Gt. menardii</i> s.l. sx | 91.00 | 210 | 7.53 |
| FO <i>Gt. suterae</i> | 86.45 | 218 | 7.61 |
| LO <i>M. convallis</i> | 84.50 | 223 | 7.66 |
| FO <i>Gt. saphoae</i> | 83.85 | 224 | 7.67 |
| FO <i>Gt. praeumerosa</i> | 82.30 | 226 | 7.69 |
| LO <i>Gt. continuaosa</i> | 81.30 | 228 | 7.71 |
| FO <i>Gld. obliquus extremus</i> | 65.00 | 269 | 8.14 |

Tab. 2 - Position in meters above the base (below the sea floor, for Hole 654) of the considered events, their correlation to the abundance fluctuations and their age in the Falconara, Monte Gibliscemi and Hole 654 sequences. For the Tripoli interval, the lithologic level coeval to the abundance fluctuation is indicated.

of Tjalsma, 1971)(Fig. 2 and 3). In the basal samples it is very rare, with a relative abundance below 0.04% and is discontinuously present above. The first, very rare specimens of *Amaurolithus delicatus* have been found at 59 m, below the appearance of the *Gt. miotumida* plexus and above the appearance of *Gt. menardii* form 5 (Fig. 3). From the base of the *Reticulofenestra rotaria* Zone the 2 species increase in abundance, however they represent a small component of the floristic assemblage, with maximum values of 0.2-0.3%. The appearance of *R. rotaria* has been identified at 61.10 m. The species is generally rare, with a maximum relative abundance of 7% on 100 specimens of *Reticulofenestra* spp., and discontinuously present in the samples. In the topmost part of its short range it is present only in the first 5 laminitic intervals of the Tripoli Formation.

Quantitative results. The relative abundance fluctuations of *Globigerinoides* spp. in the studied segment of the "Marne a Globigerine" Formation are reported and labelled in Fig. 3. They are regularly spaced throughout the sequence, with a mean thickness of 130 cm and with a cyclical repetition of low and high relative abundance values. The irregular amplitude of the abundance fluctuations is possibly, at least in part, consequence of not sufficiently close-spaced samples in combination with a slightly irregular sedimentation rate. The brownish laminites, topped by a manganeseiferous crust, coincide with positive fluctuations, but not every positive fluctuation coincides with a brownish laminitic level. Every couplet of positive and negative abundance fluctuation of *Globigerinoides* spp. is considered to represent a cycle. Every positive or negative fluctuation represents a half-cycle.

A total of 130 positive and negative abundance fluctuations of *Globigerinoides* spp. have been identified, but other 10 fluctuations are interpreted in the short sedimentary hiatus at about 61 m above the base (Fig. 3).

The Tripoli segment.

Only 1 sample from each claystone and laminated level has been studied in the Tripoli Formation at Falconara. They represent a too low sample density to identify with accuracy the biostratigraphic distribution of the markers and the environmental evolution in a sequence in which within the same claystone or laminitic level environmental conditions strongly changed. Nevertheless, some results are here discussed. For a better location of the bio-events in the Tripoli segment, they are referred to the lithological levels, which are labelled T1-T41 for the laminites and M1-M42 for the intercalated claystones. The tripolaceous level is arbitrarily considered the upper lithology of each couplet. The semi-quantitative distributions of the most important species of calcareous plankton in the Tripoli segment are reported in Fig. 4 and 5.

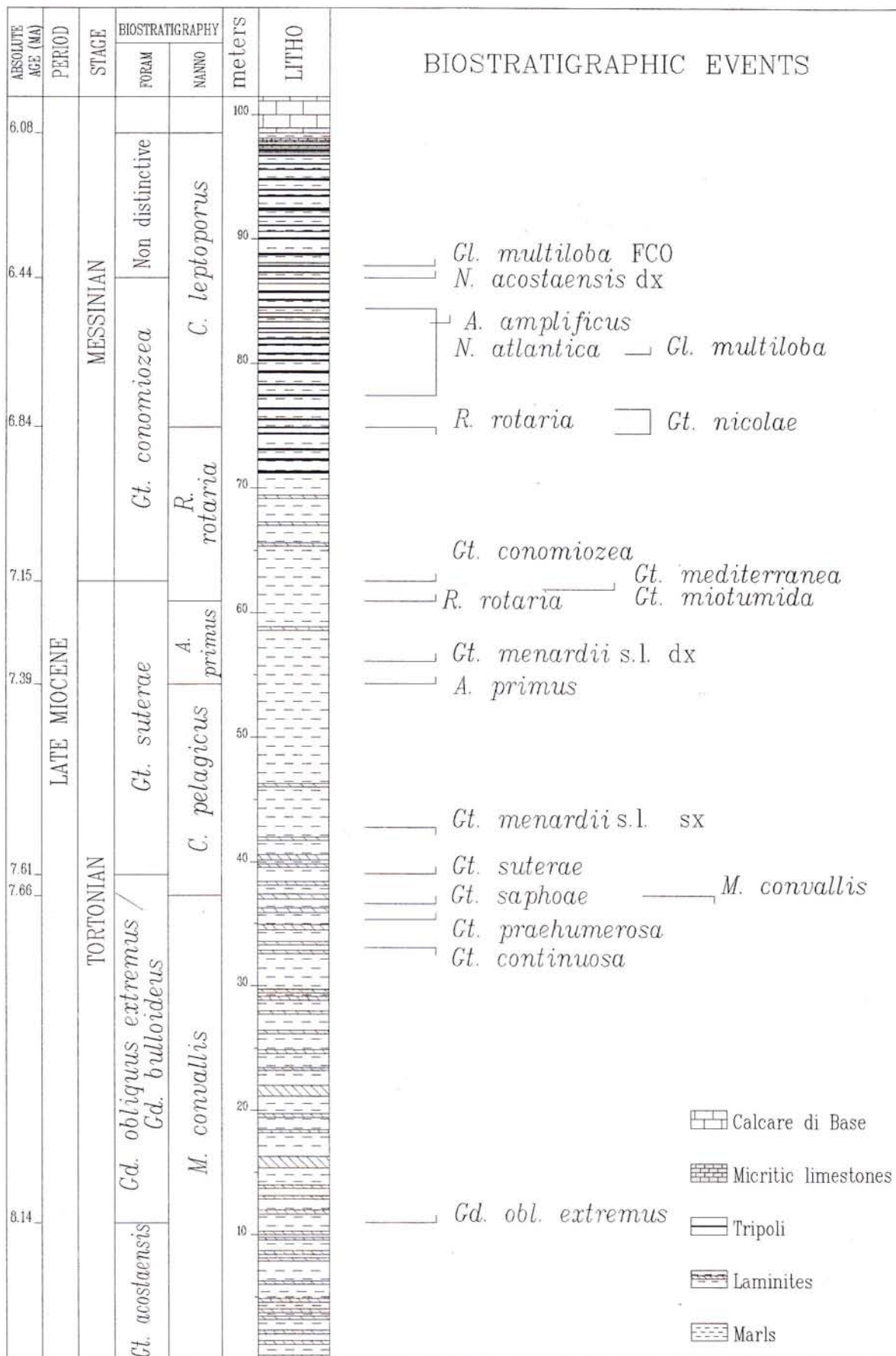


Fig. 2 - Calcareous plankton biostratigraphy of the studied Falconara section. Several second order biostratigraphic events are reported.

All the laminitic levels, but levels T26 (diagenetically transformed into porcellanite), T39, T40 and T41, yield a rich, more or less diversified planktonic foraminiferal assemblage. In the laminated levels T39, T40 and T41 no siliceous assemblage was found and in the last 2 levels only a clastic residue is present. In the claystone beds diversity in the planktonic foraminiferal assemblage is generally lower than in the laminitic levels. In some

claystone levels the foraminiferal assemblage is only represented by the benthic species *Bulimina echinata* and planktonic assemblage is missing in the residue greater than 125 microns. Levels M30, M41 and M42 are barren. Diatoms are abundant in the laminites, but are very rare or absent in the claystones (Gersonde, 1980; Gersonde & Schrader, 1984). Radiolaria are frequent only in the laminites.

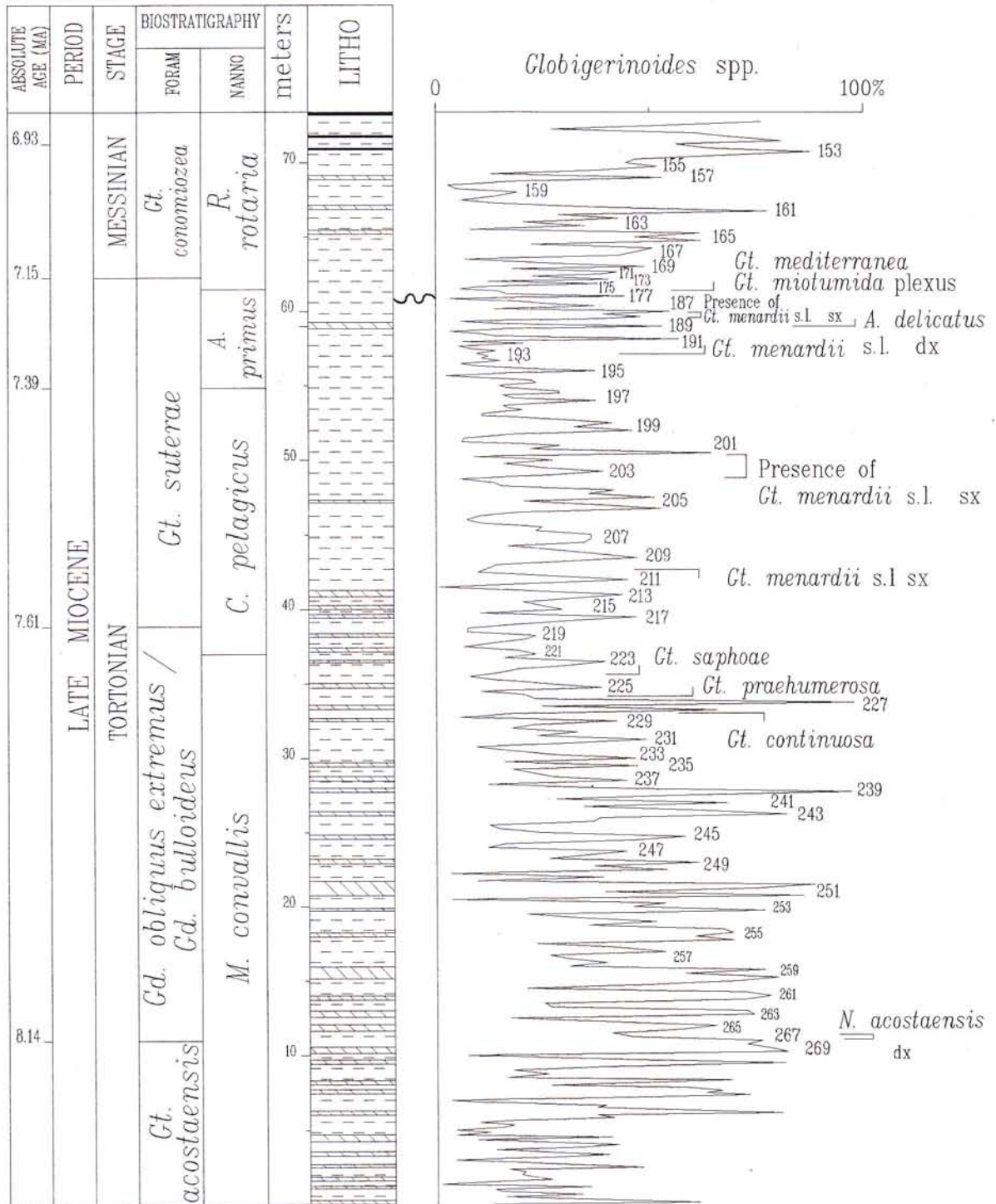


Fig. 3 - Relative abundance fluctuations of the *Globigerinoides* spp. population in the "Marne a Globigerine" Formation at Falconara. Positive fluctuations are labelled and the position of several second order planktonic foraminifera events are reported. See Fig. 2 for lithology. Wavy line indicates hiatus.

Globorotalia nicolae occurs from level T4 to level T7. The *Globorotalia miotumida* plexus and *Globorotalia conomiozea*, which are absent in the claystones, are well represented up to level T7. Above this level they are present only in levels T12 and T13, where they are rare. *Globigerinoides* spp. are abundant up to level T8. Above level T8 *Globigerinoides* spp. are common to abundant only in some discrete laminitic levels between levels T12 and T31 (Fig. 4). *Globigerina multiloba* appears, rare, in level M12 and is common in M21. From level M26 up to level M36 it is more frequently present and more or less abundant. *Neogloboquadrina atlantica*, with frequent to abundant left coiling specimens, is well represented between levels T8 and M20 (Fig. 4), but it is more continuously present above level M13. In the interval between levels T24 and T31 *Neogloboquadrina*

acostaensis is represented by essentially right coiling specimens. It is virtually absent in the interval between M32 and M35, but is frequent and sinistrally coiled in level T33. In level T35 and in levels T38 and T39 frequent to abundant dextral specimens of *N. acostaensis* are present again. The base of the "non distinctive" Zone (Iaccarino, 1985) has been identified in coincidence of level T24, where essentially left coiling specimens of *N. acostaensis* first occur. *Turborotalita quinqueloba* is more frequent in the claystone intervals above level M26. *Bulimina echinata* occurs only in the claystone intervals from level M11, but increases in abundance above level M20. Generally, a warmer planktonic foraminiferal assemblage is present in the samples from the laminitic levels, in good agreement with the diatoms assemblage, dominated by warm species (Gersonde & Schra-

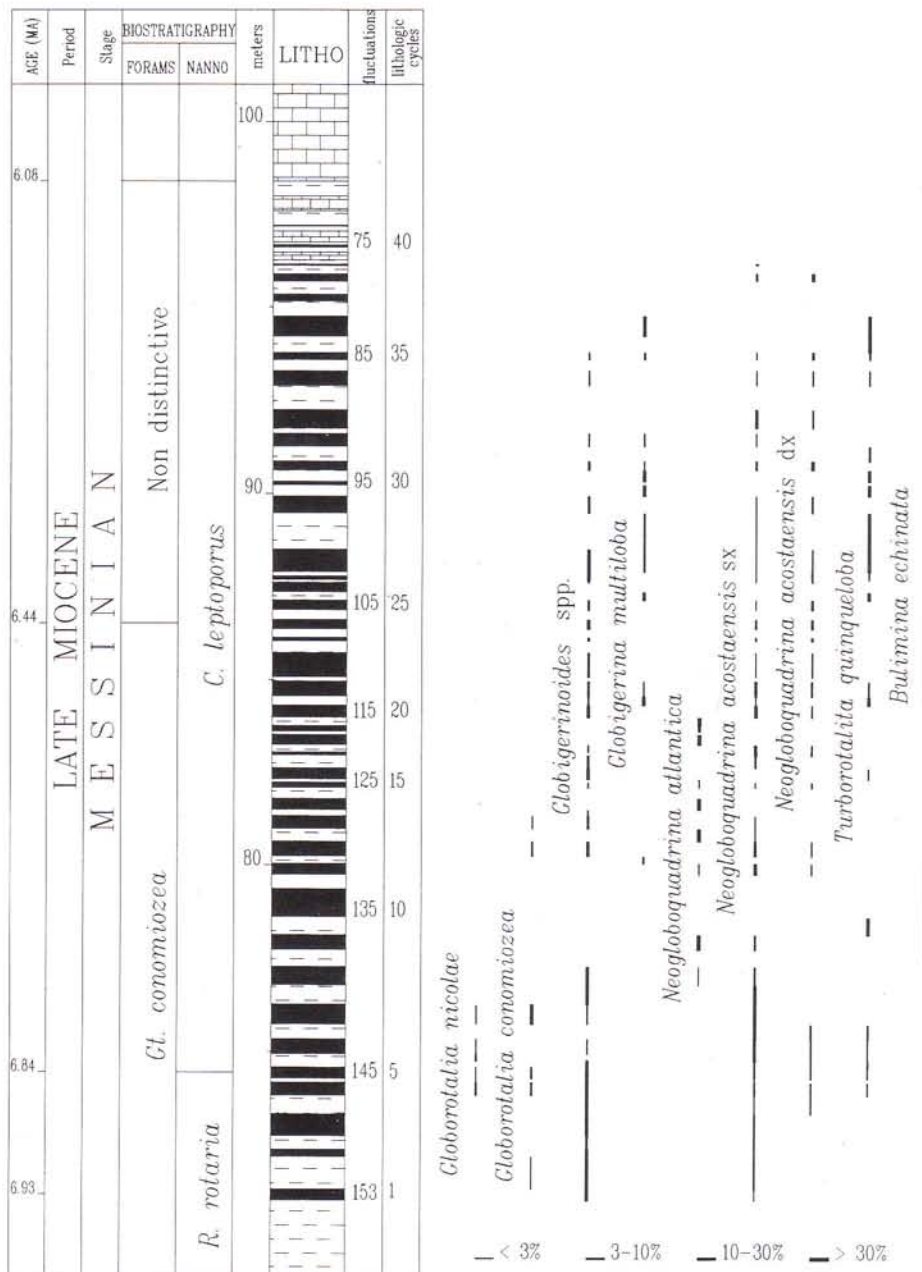


Fig. 4 - Semi-quantitative distribution of the most frequent planktonic foraminifera in the Tripoli segment at Falconara. See Fig. 2 for lithology.

der, 1984). This agrees also with the conclusion of McKenzie et al. (1979), who correlate the laminitic levels with the warmest episodes of interglacial cycles.

In some levels of the Tripoli segment planktonic foraminifera assemblage is very poor or absent at all. Therefore variations in abundance of the *Globigerinoides* spp. population in this segment do not represent a complete and continuous record of the abundance fluctuations. Nevertheless, the 41 lithologic alternations of gray claystones and white laminites and the repetitive presence-absence of siliceous assemblages, respectively in the laminites and in the claystones, testify a regular cyclicity also in this time interval (McKenzie et al., 1979) and are interpreted as representing consecutive half-cycles. The lowermost Tripoli level (T1), in which *Globigerinoides* spp. are abundant, is correlated with cycle 153 (Fig. 3 and 4).

Calcareous nannofossils are generally well preserved. They are more abundant in the lower part of the

Tripoli segment, up to level T26, decrease between level T26 and T39, are extremely rare above and absent in the 2 uppermost cycles. *Reticulofenestra* spp., *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Helicosphaera* spp. and the six rayed *Discoaster* spp. are the prevailing species. A remarkable difference was detected in the floristic assemblages of the claystones and of the laminitic levels, with reduced number of species in the claystones. If *Discoaster variabilis* is the most common species of *Discoaster*, both in the claystones and laminites, *Discoaster pentaradiatus* and *Sphenolithus* spp. are generally present, rare to common, only in the laminites. They are well-known indicators of warm water masses (Bukry, 1981; Perch-Nielsen, 1985). Therefore the laminitic levels may be ascribed to warmer conditions, in agreement with the indications provided by planktonic foraminifera, diatoms (Gersonde & Schrader, 1984) and oxygen isotopic data (McKenzie et al., 1979). *Amaurolithus* spp. are generally rare and scattered, more frequently present in the

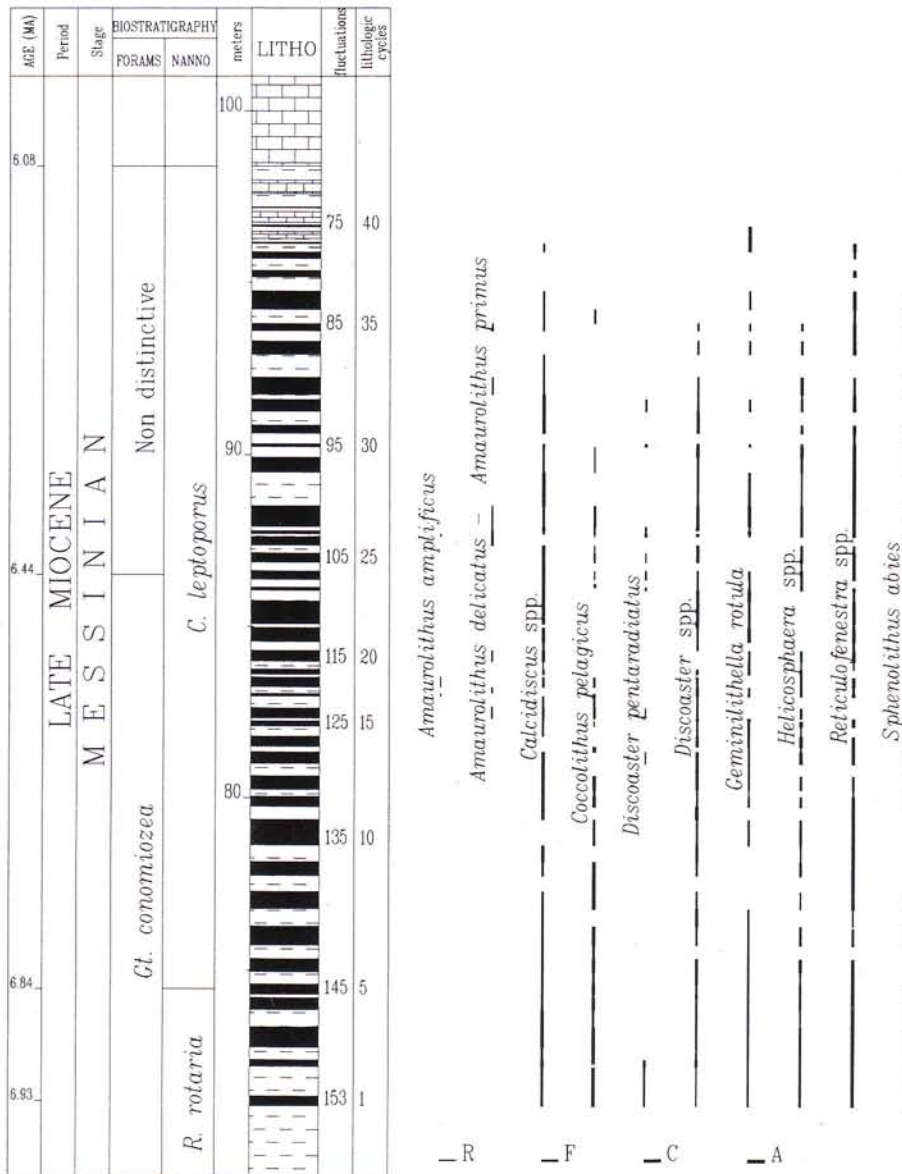


Fig. 5 - Semiquantitative distribution of the main calcareous nannofossil taxonomic units in the Tripoli Formation of Falconara. A = more than 10 specimens in each field; C = 1 to 10 specimens in each field; F = 1 specimen in 1 to 10 fields; R = 1 specimen in more than 10 fields. See Fig. 2 for lithology.

laminites. *A. amplificus* is present, rare and scattered, from level T17 to level T26 (Fig. 5). The presence of this marker in the middle part of the Tripoli Formation may be used to subdivide in more detail this lithological unit on the base of the calcareous nannofossil biostratigraphy. *R. rotaria*, rare and essentially present in the laminites, disappears above level T5. From level M3 upwards dolomitic crystals are generally abundant in the claystone samples, but are not present in levels from M26 to M29. Semiquantitative distributions of the main taxonomic units are reported in Fig. 5.

The Gibliscemi section

This section outcrops along the southern slope of Monte Gibliscemi (14° 16' 05" Long. E; 37° 12' 16" Lat. N) (Fig. 1). As in the Falconara section, 2 main lithological intervals can be distinguished below the Calcare di Base. The lower interval is about 116 m thick and outcrops above a tectonically disturbed marly complex, which includes sediments referable, according to the biostratigraphic schemes of Iaccarino (1985) and Fornaciari et al. (1995), to the Upper Serravallian for the presence of *Globorotalia mayeri* and *Helicosphaera walbersdorfensis* and to the lowermost Tortonian for the presence of *N. acostaensis* and *Helicosphaera stalis* without *Discoaster bellus*. The lower interval is represented by lithologic couplets, with each couplet generally represented by light-gray marls at the base and reddish laminites, each topped by a brownish manganiferous crust in the uppermost part. The reddish laminites are not present in all the couplets, but the manganiferous crust is generally present. Between 90 and 97 m (Fig. 6) no laminites and manganiferous crusts are present and the lithologic couplets cannot be recognized. The mean thickness of the couplets is 1 meter. In the basal part of several couplets darker, bioturbated marls, 5-30 cm thick, are present. These darker marls are not present above cycle 51. Small faults, with reduced displacement, are present in the upper part of this unit, but the sequence can be reconstructed following the lateral extension of the laminitic levels at the top of the couplets. The upper part of this unit is well correlatable with the stratigraphic interval studied at Falconara below the Tripoli Formation and is ascribed to the "Marne a Globigerine" Formation. Each couplet of this unit is considered corresponding to 1 lithologic cycle. In each cycle 5-10 samples have been collected, with at least 1 sample coming from the laminites, if present. The resulting mean interval between the samples is about 20 cm. A total of 525 samples have been studied.

The lithologic cycles identified along the interval 1 have been informally numbered in upwards direction

(Fig. 6), with the local lowermost cycle above the tectonized marly complex labelled with number 12. A total of 84 lithologic cycles have been identified. In the segment between 90 and 97 m a lithologic cyclicity is not present. At about 99.50 m a sandy laminated level, labelled with number 93 in Fig. 6, is present. It is interpreted as a turbiditic event, which gave origine to a short hiatus between lithological cycles 92 and 94. We staked out the top of the cycles, which we made coincident with the top of the laminites. All the stakes have been numbered. Every cycle has been sub-divided into two half-cycles. The upper half-cycles include the laminites. The lower half-cycles include the gray marls. Results on relative abundance of the planktonic foraminiferal assemblages indicate that the upper half-cycles are characterized by a relatively greater abundance of *Globigerinoides* spp. For an easier comparison with Falconara and Site 654 sequences, in Fig. 6 even half-cycles of the *Globigerinoides* spp. abundance fluctuations have been numbered (numbers in italics) from top to bottom. By correlation with Falconara and Site 654, number 153 has been ascribed to the base of the Tripoli and number 174 has been ascribed to the marly level in which *Gt. conomiozea* first occurs. The section has been sampled along 2 segments. The lower segment includes cycles 1 to 52, the upper segment includes cycles from 53 to 106.

The upper interval is represented by the Tripoli Formation. Its upper part is tectonically disturbed by several faults, but the contact between the Tripoli and the underlying marly interval shows no evidence of tectonic or sedimentologic disturbance. On the contrary, the contact with the overlying Calcare di Base is clearly erosive and between the 2 formations an unconformity is present.

The rare benthic foraminiferal assemblages in the marls of the lower interval are indicative of a bathyal environment. According to the bathymetric distribution of benthic foraminifera in the Mediterranean basin (Blanc Vernet, 1969; Parker, 1958; Wright, 1978; Hasegawa et al., 1990), the presence of rare *Parrelloides robertsonianus* and *Siphonina reticulata* and the virtual absence of nodosarids, together with a very high plankton/benthos ratio (about 95% of planktonic foraminifera) is indicative of a minimum depth of about 1000-1300 meters. In some levels, essentially corresponding to the blackish marls at the base of the couplets, the benthic assemblage is dominated by *Cibicidoides pachyderma*. In the same samples pyrite framboides are frequent. Evidence of dissolution is limited to the samples from the blackish marls. Benthic foraminifera are absent in the Tripoli Formation. Only *Bulimina echinata* is present, more or less abundant, in the claystone intervals.

Only data on calcareous plankton biostratigraphy and planktonic foraminifera relative abundance fluctua-

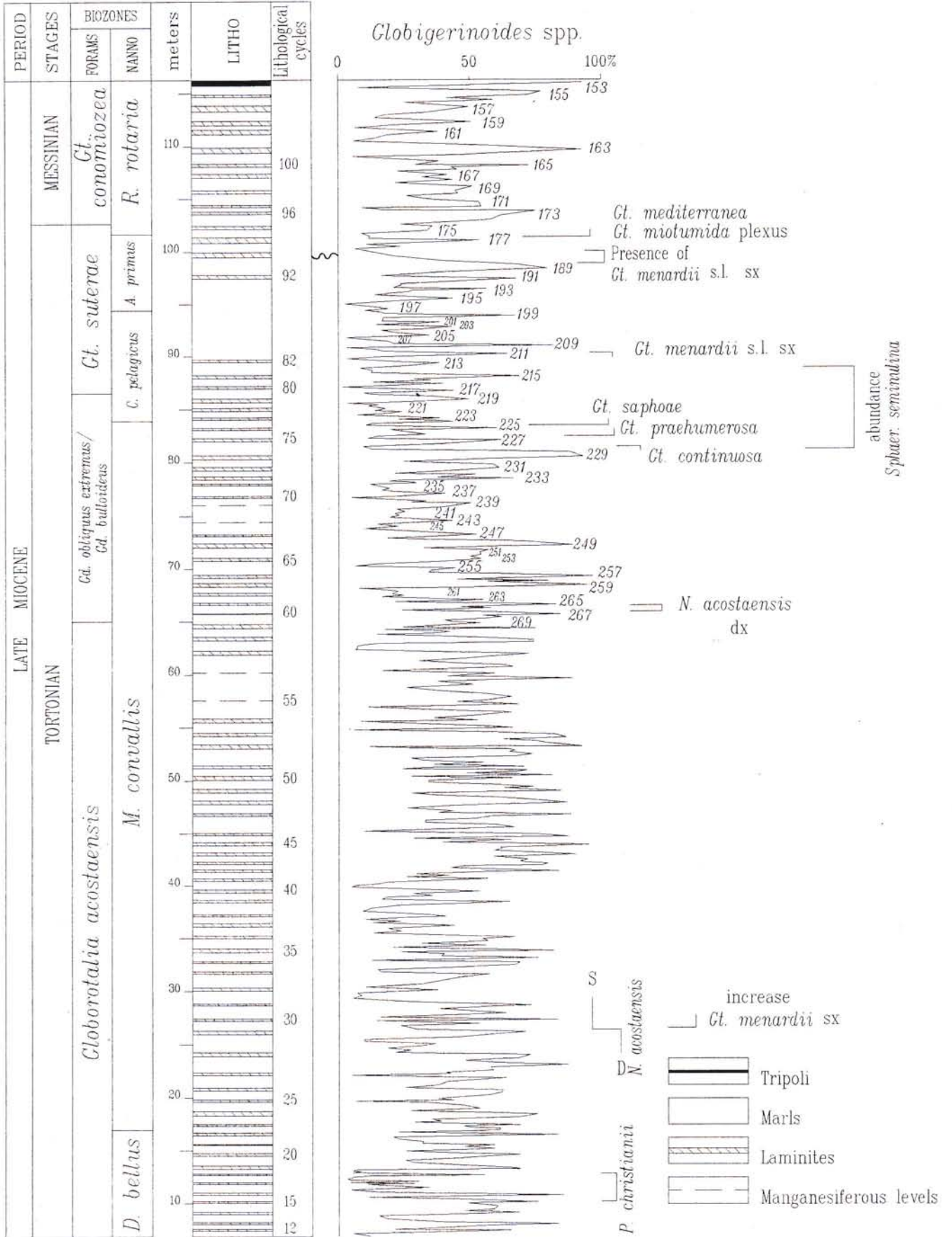


Fig. 6 - Relative abundance fluctuations of the *Globigerinoides* spp. population in the "Marne a Globigerine" Formation of the Monte Gibliscemi section. Positive fluctuations are labelled and the position of several second order planktonic foraminifera events are reported. Wavy line indicates hiatus.

tions from interval 1 are reported in this paper. More detailed and complete analyses on sedimentology, carbonate content, oxygen and carbon stable isotopes and paleoclimatic interpretation for all the section, including the Tripoli Formation will be reported in next papers.

Biostratigraphy.

Planktonic foraminifera. The biostratigraphic subdivision of the studied segment of interval 1 is reported in Fig. 6. The same biostratigraphic zonal scheme adopted for the Falconara section has been used. The stratigraphic position of second order biostratigraphic events is also reported. The segment includes the *Gt. acostaensis* (upper part), *Gld. obliquus extremus*/*Gld. bulloideus*, *Gt. suterae* and *Gt. conomiozea* (lower part) Zones. It is therefore ascribed to the Upper Tortonian and Lower Messinian. Thickness in meters above the base of the section is reported for every planktonic foraminifera event in Tab. 2. From lithological cycle 30 upwards *N. acostaensis* is essentially left coiling, but in the marls of cycle 61 (coincident with abundance fluctuation 266), just above the appearance of *Gld. obliquus extremus*, prevailing right coiling specimens of *N. acostaensis* are present. *Gt. menardii* s.l. is represented essentially by left coiling specimens up to about 90.5 m, coincident with abundance fluctuation 210. The short presence of left coiling *Gt. menardii* s.l., identified at Falconara and Site 654 in coincidence of abundance fluctuation 203, slightly above the interval with an essentially continuous presence of left coiling *Gt. menardii* s.l., has not been identified. The appearance of right coiling specimens of *Gt. menardii* s.l. (form 5 of Tjalsma, 1971) is not recorded in the section, but a short interval with frequent and well preserved left coiling specimens of *Gt. menardii* s.l. is present just below the sandy level labelled with number 93 (Fig. 6), above the first occurrence of *Amaurolithus primus*. The presence of left coiling *Gt. menardii* s.l. at this level is recorded in coincidence of the same fluctuation in the other 2 studied sequences of Falconara and Site 654.

Calcareous nannofossils. Calcareous nannofossil assemblages are rich and well diversified. Preservation is generally good and evidence of dissolution and/or overgrowth is present only in some scattered levels. Four calcareous nannofossil events have been recorded in the studied segment and the identified biostratigraphic intervals are reported in Fig. 6. They belong to the uppermost part of the *Discoaster bellus* Zone (according to Fornaciari et al., 1995, but with its upper boundary identified by the FO of *M. convallis*), *M. convallis*, *C. pelagicus*, *A. primus* and *R. rotaria* Zones. Also in this section the markers are extremely rare in coincidence of their appearance levels and increase in abundance upsection.

Quantitative analysis. The relative abundance fluctuations of *Globigerinoides* spp. are reported in Fig. 6. At least one positive and one negative abundance fluctuation (half-cycles) are present in every lithologic couplet, with the former which generally straddles the laminitic level. The correlation between every biostratigraphic event and the corresponding half-cycle is shown in Fig. 6 and is reported in Tab. 2. According to the calcareous plankton biostratigraphic results the upper part of the interval 1 is well correlatable with the segment studied at Falconara. The same number of half-cycles occurs in the same stratigraphic interval in the 2 sections and the biostratigraphic events coincide with the same abundance fluctuations. Therefore the identified biostratigraphic events are isochronous within the resolution of the adopted cyclostratigraphic method.

ODP Leg 107 Site 654

ODP Leg 107 Site 654 was rotary drilled in the upper part of the Sardinian continental margin, in the Tyrrhenian sea (10°41.80' Long. Est; 40°34.76' Lat. Nord) (Fig. 1). Below the 243 m thick Plio-Pleistocene sequence (Unit 1), a 72 meters thick sequence of Messinian evaporites (Unit 2) were drilled. About 36.3 meters of organic claystone, dolomitic calcareous siltstone (Unit 3) are present below the evaporites. They are followed downwards by about 55 meters of open marine nannofossil chalk (Unit 4) and about 12 meters of glauconitic sandstone (Unit 5). Below the glauconitic sandstone Hole 654A bottomed in gravel-bearing reddish mudstones (Unit 6), of continental environment, drilled for about 13 meters (Kastens et al., 1987; Borsetti et al., 1990). Only the Miocene segment of open marine nannofossil chalk is studied in this paper. Seven samples have been studied from each section, at a mean interval of about 20 cm, with a total of 171 samples.

Biostratigraphy.

Planktonic foraminifera. The identified planktonic foraminifera biozones for the studied segment are reported in Fig. 7. The stratigraphic positions of second order biostratigraphic events are also reported in order to allow a more detailed correlation with the other studied sequences. Depth (mbsf) of the relevant biostratigraphic events are reported in Tab. 2.

Calcareous nannofossil. The same calcareous nannofossil Zones adopted for the Falconara section have been used in the studied segment of Site 654. They allow a more detailed biostratigraphic resolution than the zonation adopted by Mueller (1990). The identified biostratigraphic Zones are reported in Fig. 7. Two calca-

reous nannofossil zonal marker events are present. *A. primus* appears, extremely rare, in sample 44-1, 25-27, at 387.05 mbsf. No samples were available for calcareous nannofossil analysis between this level and sample 44-1, 95-97 (at 387.75 mbsf), in which *A. primus* is not present. Therefore the appearance of *A. primus* occurs within the short interval between 387.05 and 387.75 mbsf. This is in good agreement with Mueller (1990), but predates the level in which Flores et al. (1992) and Sierro et al. (1993) reported the first occurrence of *A. primus* at Site 654. *A. delicatus* appears, rare, in sample 42-3, 114-116, at 371.53 mbsf, practically coincident with the appearance of the *Gt. miotumida* plexus, in agreement with Sierro et al. (1993). Both species slightly increase in abundance above 372.14 mbsf. *R. rotaria* first appears at 369.89 mbsf, just below the appearance of *Gt. conomiozea* (Fig. 7). It is extremely rare in this sample and is present only in scattered samples above. Depth in meter

of the identified biostratigraphic events is reported in Tab. 2.

Quantitative analysis. The same quantitative approach adopted for the Falconara and Monte Gibliscemi sections has been adopted for the sequence of ODP Site 654. Even if the relative abundance of *Globigerinoides* spp. is lower than in the other two studied sections, the quantitative analysis along the studied segment of Hole 654 produced the sequence of abundance fluctuations of *Globigerinoides* spp. reported and labelled in Fig. 7. The appearance of the *Gt. miotumida* plexus occurs in the negative abundance fluctuation just below the appearance of *Gt. conomiozea*. Between the appearance of the *Gt. miotumida* plexus and of the dextral *Gt. menardii* s.l. population 16 positive and negative fluctuations occur. Between the appearance level of right coiling specimens of *Gt. menardii* s.l. and the first occurrence of *Gt. suterae* 25 positive and negative abundance fluctuations of

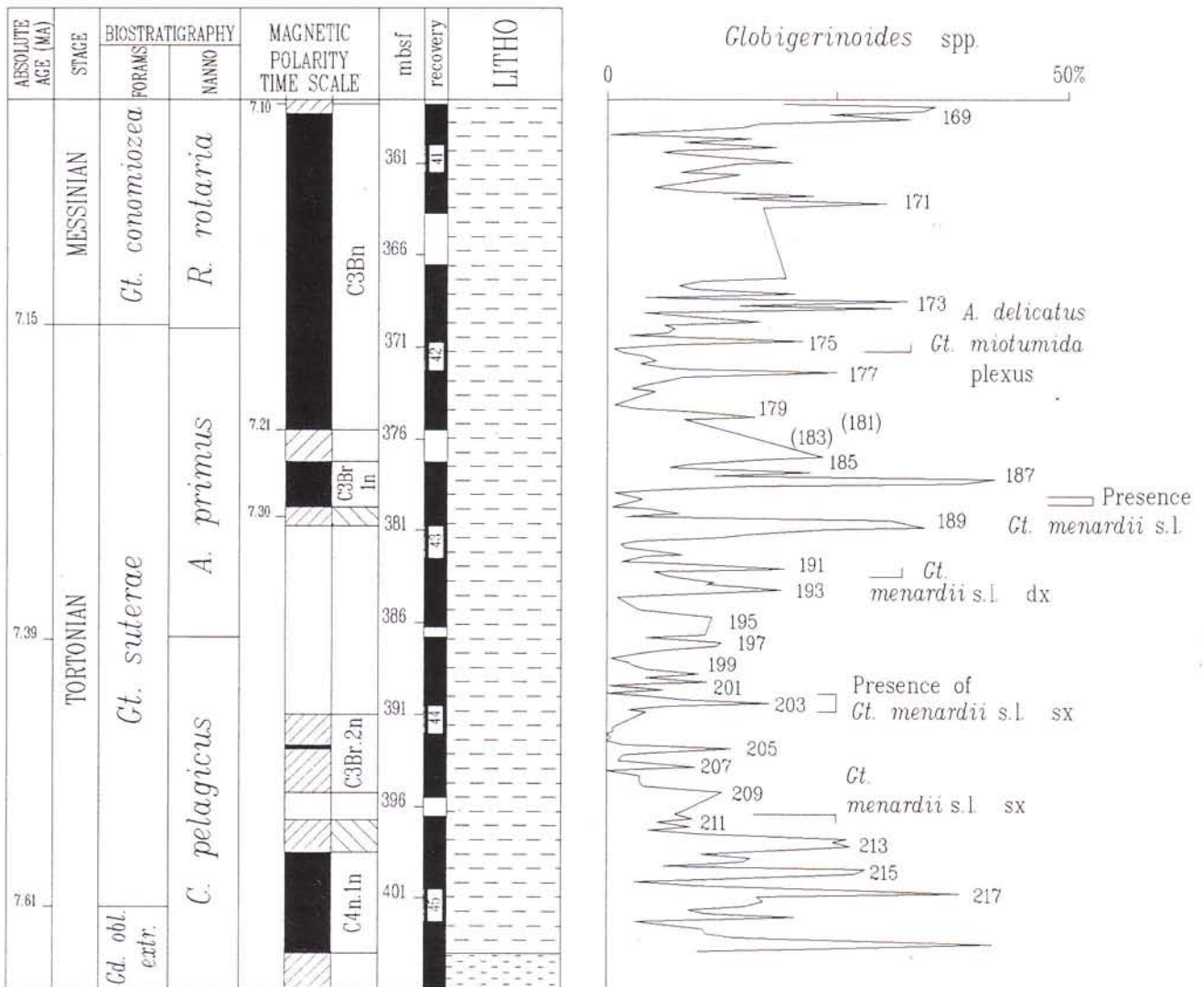


Fig. 7 - Relative abundance fluctuations of the *Globigerinoides* spp. population in the pre-evaporitic segment of Hole 654. Magnetic Polarity Time Scale is from Channell et al. (1990), re-interpreted according to the Geomagnetic Polarity Time Scale of Cande & Kent (1995). Small black vertical bars indicate recovered intervals.

Globigerinoides spp. can be counted. The first occurrence of *A. primus* is also recorded in coincidence of the same relative abundance fluctuation of *Globigerinoides* spp. (fluctuation 197) in which in the other studied sections *A. primus* appears. The first occurrence of *R. rotaria* at Site 654 is recorded just below the appearance of *Gt. conomiozea* and above the appearance of the *Gt. miotumida* plexus, in coincidence of abundance fluctuation 174. At Falconara and Monte Gibliscemi *R. rotaria* first occurs below the *Gt. conomiozea* FO, in coincidence of abundance fluctuation 176. According to the present data the first occurrence of *R. rotaria* is slightly diachronous between the Tyrrhenian basin and the southern Mediterranean sections. Detailed analyses of other sections outcropping in Northern Italy are needed to trace this biostratigraphic boundary between the 2 geographic areas.

The coiling change in the *Globorotalia scitula* plexus.

Sierro et al. (1993) propose the change in coiling direction of the *Gt. scitula* plexus as a useful biostratigraphic tool in the Late Miocene interval. According to these Authors, a coiling change from predominantly sinistral to predominantly dextral forms in this group, identified as PF-Event A, approximately coincides with the *A. primus* FO in the NE Atlantic and Mediterranean sequences, included Site 654. Event PF-A predates the appearance of the *Gt. miotumida* plexus and dextral population of *Gt. scitula* is continuously present up to the coiling change from sinistral to dextral forms of *Neogloboquadrina acostaensis* (PF-Event 4). The only exception in this interval is an isolated peak of sinistral specimens of the *Gt. scitula* group (PF-Event B and C) coincident with the replacement of dextral *Gt. menardii* by the *Gt. miotumida* plexus (PF-Event 3).

In Fig. 8 we report the relative abundance of dextral specimens of *Gt. scitula* counted in each sample of the Falconara marly segment and at Site 654 in the interval between slightly below the *Gt. suterae* FO and above the *Gt. conomiozea* FO. In Fig. 9 the relative abundance of dextral specimens of *Gt. scitula* is reported for the Monte Gibliscemi section from a longer interval, from the upper part of the *Gt. acostaensis* Zone to the base of the Tripoli Fm. Occurrences of the main calcareous plankton events are also reported in the figures.

In the three sequences from fluctuation 177 upwards, *Gt. scitula* is present with several short peaks in which dextral specimens dominate. Dominance of dextral population of *Gt. scitula* is intercalated by short intervals with sinistral population. The base of this interval with frequent peaks of dextral population of *Gt. scitula* post-dates the appearance of right coiling population of *Gt. menardii* s.l. and pre-dates the appearance of the *Gt.*

miotumida plexus, which is recorded in an interval with prevailing sinistral population of *Gt. scitula* (Fig. 8, 9). At Site 654 the base of the interval with dextral population of *Gt. scitula* is just below the base of C3Bn, according to the re-interpretation of the paleomagnetic stratigraphy proposed in this paper for Site 654 (see below).

These results are in good agreement with the data reported by Sierro et al. (1993). However, the stratigraphic position of the first occurrence of *A. primus* is not comparable with the data reported by Flores et al. (1992) and by Sierro et al. (1993). In our sections *A. primus* appears, extremely rare but with well identified specimens, in coincidence of fluctuation 197, below the appearance of dextral population of *Gt. menardii* s.l. and well below the base of the interval with several peaks of dextral population of *Gt. scitula*. It slightly increases in abundance just below the appearance of *Gt. conomiozea*. Possibly the extremely rare presence of these two species at their appearance level may explain the younger identification of this bio-event as reported by Sierro et al. (1993).

The base of the above discussed interval with repeated peaks of dextral population of *Gt. scitula* may be consistently correlated with Event A of Sierro et al. (1993). Nevertheless, in the Monte Gibliscemi section frequent peaks of dextral population of *Gt. scitula* are also present below, approximately between the appearance of *Globorotalia saphoae* (fluctuation 225) and fluctuation 189 (Fig. 8, 9). Below fluctuation 225 *Gt. scitula* is represented by essentially sinistral population and only isolated spikes of prevailing dextral population of *Gt. scitula* can be identified (Fig. 9). In conclusion, a strong instability in the *Gt. scitula* population, with frequent shifts of prevailing dextral and sinistral populations, begins from fluctuation 225. In the interval above this level only in short segments sinistral populations of *Gt. scitula* prevail. On the contrary, sinistral specimens of *Gt. scitula* prevail in the stratigraphic interval below the level coincident with fluctuation 225.

Relative abundance fluctuations at Site 552.

Beaufort & Aubry (1990) record variations in ratio between *Coccolithus pelagicus* (a cold water calcareous nannofossil) and *Reticulofenestra pseudoumbilicus* (a mid latitude abundant calcareous nannofossil during the Neogene, according to Haq, 1980) in the Messinian segment, between 104 and 150 mbsf, of the North Atlantic Hole 552 (Fig. 10). Variations in relative abundance between *C. pelagicus* and *R. pseudoumbilicus* during the Late Miocene, even if not linked exclusively with temperature, are related by the Authors to climatic variations, with an high *C. pelagicus*/*R. pseudoumbilicus* (Cp/Rp) ratio indicative of cold water mass and a low

Cp/Rp ratio indicative of a more temperate water mass. We regard the *C. pelagicus*/*R. pseudoumbilicus* variations in ratio comparable, in the lower latitude subtropical regions, with the relative abundance fluctuations in the *Globigerinoides* spp. population, with the low Cp/Rp ratio correlated to high (positive) abundance fluctuations and viceversa.

Keigwin et al. (1987) and Keigwin (1987) published an high resolution magnetostratigraphy and isotopic stratigraphy for the Upper Miocene sedimentary interval of this Hole (Fig. 11). The initial uncertainty as to the identification of Chron 5 (C3An of Cande & Kent, 1992) was resolved by the isotopic stratigraphy (Keigwin, 1987), so that the record can be confidently interpreted as part of Chron 6 (C3Bn of Cande & Kent, 1992) and the entire Chron 5.

Milankovitch periodicities are present in the time-series of the Cp/Rp ratio. Even if the periodicity of the ec-

centricity cycles dominates between 104 and 135 mbsf and the precession cycles are more easily recognizable below 135 mbsf (Beaufort & Aubry, 1990), the 21-kyr cycles can be also identified in the upper part of the segment (Fig. 10). A total of 168 positive and negative variations in the Cp/Rp ratio (half-cycle) are present between 105 and 150 mbsf. If the fluctuation between 105 and 106 mbsf, coincident with the Miocene-Pliocene boundary, is labelled with number 1, the C3An.1n/C3r boundary coincides with half-cycle 59, the C3An.1n/C3An.r boundary with half-cycle 83, the C3An.r/C3An.2n boundary with half-cycle 99, the C3An.2n/C3Ar boundary with half-cycle 129, and the C3Ar/C3Bn boundary with half-cycle 169 (Fig. 9). The age of the Miocene/Pliocene boundary has an age of 5.32-5.33 MA (Hilgen, 1991; Sprovieri, 1993). If at Site 552 a mean periodicity of 21 kyr is adopted for each cycle composed by a negative and positive variation of

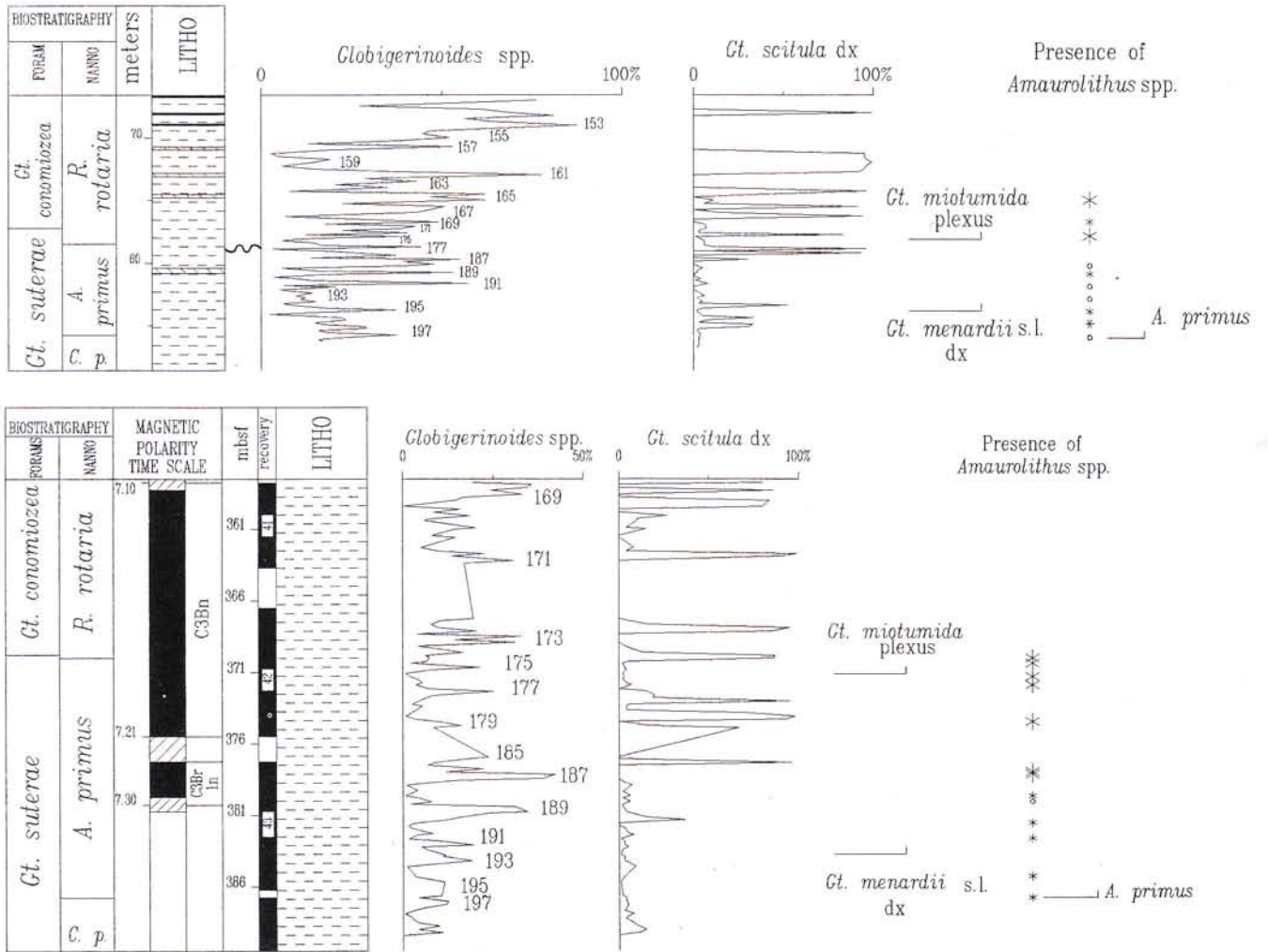


Fig. 8 - Coiling changes of the *Gt. scitula* group in the Falconara and Site 654 sequences. Abundance fluctuations of *Globigerinoides* spp. and the appearance levels of other second order planktonic foraminifera bio-events are reported for comparison. On the right, the presence of *Amaurolithus* spp. is reported: o = 1 specimens in more than 21 fields of view; * = 1 specimens in 21 fields of view; X = more than 1 specimens in 21 fields of view. Above: Falconara section; below: Site 654. Paleomagnetic data of Site 654 are from Channell et al. (1990). Only the numbers of the even cycles are reported. See Fig. 2 for lithology.

the Cp/Rp ratio, ages of 5.94 MA, 6.19 MA, 6.36 MA, 6.67 MA and 7.10 MA respectively result for the identified paleomagnetic boundaries (Tab. 3). The ages obtained for the paleomagnetic boundaries of C3An.1n are totally comparable with the ages proposed for this paleomagnetic subchron by Benson et al. (1995) in the Morocco sections. All the ages obtained for Chron C3An are older than the ages proposed by Shackleton et al. (1995) and Cande & Kent (1995) for the same paleomagnetic boundaries.

Late Miocene magnetostratigraphy at ODP Site 654.

With reference to the biostratigraphic resolution proposed for the 3 studied sections and to the sequence of lithological cycles and/or abundance fluctuations of *Globigerinoides* spp. included in every biostratigraphic interval, the magnetostratigraphy of the Miocene interval of Site 654 is discussed. The nomenclature of Cande & Kent (1992) and the ages obtained for the paleomagnetic boundaries are the other main references for the discussion.

The magnetic polarity stratigraphy for the Late Miocene interval of ODP Site 654 was documented by Channell et al. (1990). The 2 proposed interpretations are reported in Fig. 12, but the Authors favored the correlation of the polarity sequence identified between 420 and 360 mbsf to Chrons 6 and 7 (C3Bn and C4n). Glaçon et al. (1990) followed this interpretation in their paper on planktonic foraminifera events and stable isotope records in the Upper Miocene interval of Site 654.

In the stratigraphic interval referred by Channell et al. (1990) to the normal polarity event between about 358 and 381 mbsf 21 positive and negative abundance fluctuations of *Globigerinoides* spp. are interpreted (Fig. 7). The top of this normal polarity segment is ascribed to the top of Chron 6 (top of C3Bn of Cande & Kent, 1992) by Channell et al. (1990). It is slightly above the first occurrence of *Gt. conomiozea*, as also recorded in northwestern Morocco by Hodell et al. (1994). The top of Chron C3Bn is just below fluctuation 168 at Site 552 (Fig. 10). Therefore the abundance fluctuation of *Globi-*

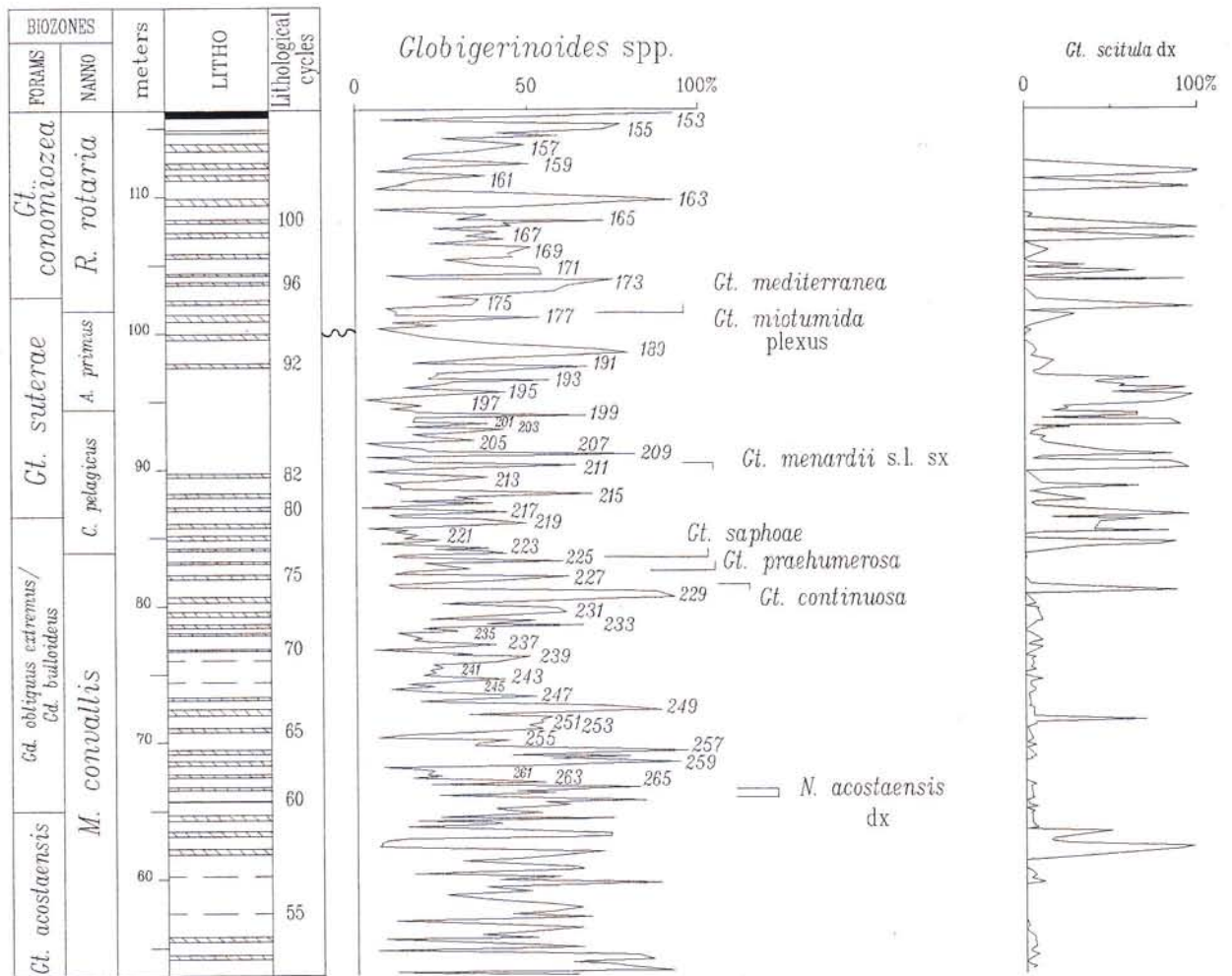


Fig. 9 - Coiling changes of the *Gt. scitula* group in the Monte Gibliscemi section. Abundance fluctuations of the *Globigerinoides* spp. population and the appearance levels of other second order bio-events are reported for comparison. Only the number of the even cycles are reported. See Fig. 6 for lithology.

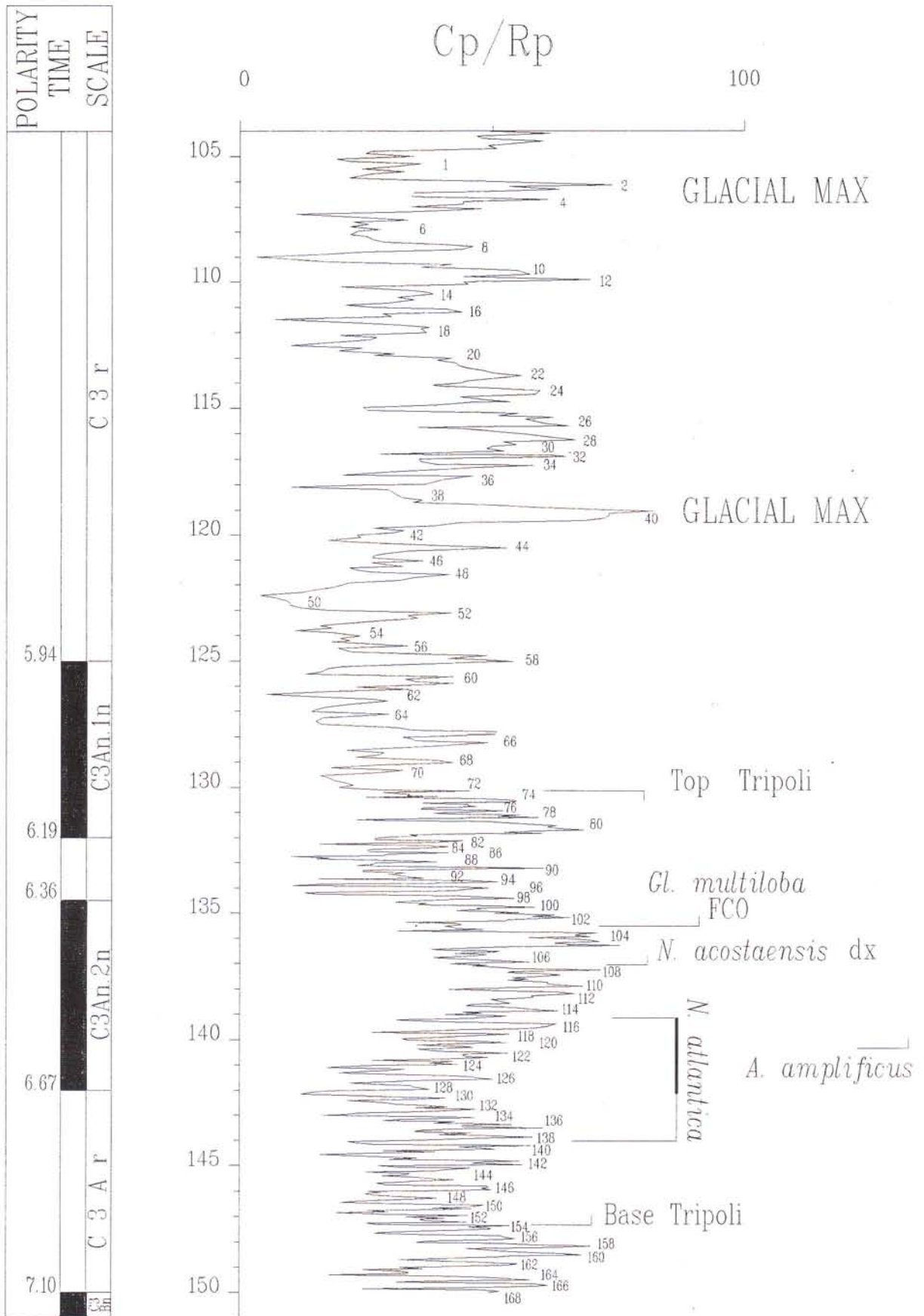


Fig. 10 - Abundance fluctuations of the *C. pelagicus/R. pseudoumbilicus* ratio in the Late Miocene segment at Site 552 (from Beaufort & Aubry, 1990). Position of the main lithologic and biostratigraphic Mediterranean events is indicated by correlation with the studied sections. Fluctuations referred to the periodicity of the precession astronomical cycles are numbered. Odd numbers indicate cool fluctuations. The cycles correlated with the interval in which, in the Tripoli Formation at Falconara, *N. atlantica* is abundant are marked by a thicker line.

gerinoides spp. at 358 mbsf, coincident with the top of C3Bn, is labelled with number 169. The age of the top of C3Bn is 7.10 MA if the age of the abundance fluctuation 169 is used (Tab. 3). The base of the normal polarity segment ascribed to C3Bn is here proposed at 375.5 mbsf and coincides with fluctuation 180 (Fig. 7), with an age of 7.21 MA. The short normal polarity segment between the not recovered interval at about 377 mbsf and 381 mbsf is ascribed to C3Br.1n. Its base coincides with abundance fluctuation 189 (Fig. 7), with an age of about 7.30 MA. The top of the normal polarity interval identified by Channell et al. (1990) below about 398

mbsf is the top of C4n.1n. It straddles abundance fluctuations 210-213 and its age is estimated at 7.53-7.56 MA. The short normal polarity event at about 393 mbsf is referred to C3Br.2n (pars). The here proposed interpretation of the magnetostratigraphy of Site 654 is in good agreement with the magnetostratigraphy reported by Hodell et al. (1994) for the Sale' Briqueterie in Northwestern Morocco, where about 3 obliquity cycles of $\delta^{18}\text{O}$ were identified in C3Bn (in which the first occurrence of *Globorotalia conomiozea* was recognized) and about 8 obliquity cycles were identified between the base of C3Bn and the top of C4n.1n.

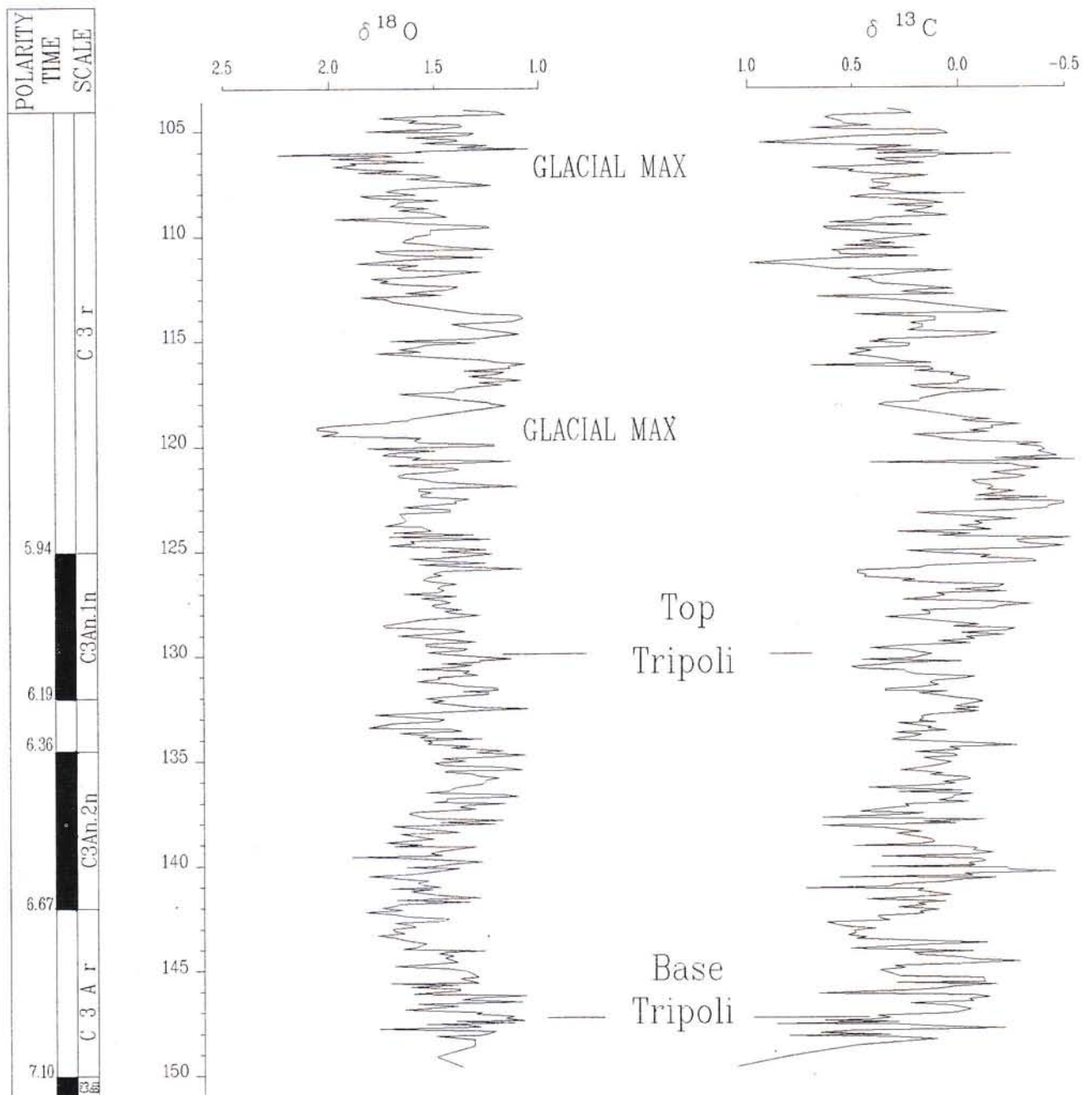


Fig. 11 - Oxygen (on the left) and Carbon isotopic records for Site 552 (from Keigwin, 1987). Position of the base and top of the Tripoli Formation is indicated by correlation with the relative abundance fluctuations recognized in the Falconara sequence and the coeval segment at Site 552.

| | ESTIMATED AGE (MA) | | ESTIMATED AGE (MA) | | ESTIMATED AGE (MA) | | ESTIMATED AGE (MA) | | ESTIMATED AGE (MA) | |
|----|--------------------|-----|--------------------|-----|--------------------|-----|--------------------|-----|--------------------|-----|
| 1 | 5.33 | 57 | 5.92 | 113 | 6.51 | 169 | 7.09 | 202 | 7.44 | 235 |
| 2 | 5.34 | 58 | 5.93 | 114 | 6.52 | 170 | 7.11 | 203 | 7.45 | 236 |
| 3 | 5.35 | 59 | 5.94 | 115 | 6.53 | 171 | 7.12 | 204 | 7.46 | 237 |
| 4 | 5.36 | 60 | 5.95 | 116 | 6.54 | 172 | 7.13 | 205 | 7.47 | 238 |
| 5 | 5.37 | 61 | 5.96 | 117 | 6.55 | 173 | 7.14 | 206 | 7.48 | 239 |
| 6 | 5.38 | 62 | 5.97 | 118 | 6.56 | 174 | 7.15 | 207 | 7.49 | 240 |
| 7 | 5.39 | 63 | 5.98 | 119 | 6.57 | 175 | 7.16 | 208 | 7.50 | 241 |
| 8 | 5.40 | 64 | 5.99 | 120 | 6.58 | 176 | 7.17 | 209 | 7.51 | 242 |
| 9 | 5.41 | 65 | 6.00 | 121 | 6.59 | 177 | 7.18 | 210 | 7.53 | 243 |
| 10 | 5.43 | 66 | 6.01 | 122 | 6.60 | 178 | 7.19 | 211 | 7.54 | 244 |
| 11 | 5.44 | 67 | 6.02 | 123 | 6.61 | 179 | 7.20 | 212 | 7.55 | 245 |
| 12 | 5.45 | 68 | 6.03 | 124 | 6.62 | 180 | 7.21 | 213 | 7.56 | 246 |
| 13 | 5.46 | 69 | 6.04 | 125 | 6.63 | 181 | 7.22 | 214 | 7.57 | 247 |
| 14 | 5.47 | 70 | 6.06 | 126 | 6.64 | 182 | 7.23 | 215 | 7.58 | 248 |
| 15 | 5.48 | 71 | 6.07 | 127 | 6.65 | 183 | 7.24 | 216 | 7.59 | 249 |
| 16 | 5.49 | 72 | 6.08 | 128 | 6.66 | 184 | 7.25 | 217 | 7.60 | 250 |
| 17 | 5.50 | 73 | 6.09 | 129 | 6.67 | 185 | 7.26 | 218 | 7.61 | 251 |
| 18 | 5.51 | 74 | 6.10 | 130 | 6.69 | 186 | 7.27 | 219 | 7.62 | 252 |
| 19 | 5.52 | 75 | 6.11 | 131 | 6.70 | 187 | 7.28 | 220 | 7.63 | 253 |
| 20 | 5.53 | 76 | 6.12 | 132 | 6.71 | 188 | 7.29 | 221 | 7.64 | 254 |
| 21 | 5.54 | 77 | 6.13 | 133 | 6.72 | 189 | 7.30 | 222 | 7.65 | 255 |
| 22 | 5.55 | 78 | 6.14 | 134 | 6.73 | 190 | 7.32 | 223 | 7.66 | 256 |
| 23 | 5.56 | 79 | 6.15 | 135 | 6.74 | 191 | 7.33 | 224 | 7.67 | 257 |
| 24 | 5.57 | 80 | 6.16 | 136 | 6.75 | 192 | 7.34 | 225 | 7.68 | 258 |
| 25 | 5.58 | 81 | 6.17 | 137 | 6.76 | 193 | 7.35 | 226 | 7.69 | 259 |
| 26 | 5.59 | 82 | 6.18 | 138 | 6.77 | 194 | 7.36 | 227 | 7.70 | 260 |
| 27 | 5.60 | 83 | 6.19 | 139 | 6.78 | 195 | 7.37 | 228 | 7.71 | 261 |
| 28 | 5.61 | 84 | 6.20 | 140 | 6.79 | 196 | 7.38 | 229 | 7.72 | 262 |
| 29 | 5.62 | 85 | 6.21 | 141 | 6.80 | 197 | 7.39 | 230 | 7.74 | 263 |
| 30 | 5.64 | 86 | 6.22 | 142 | 6.81 | 198 | 7.40 | 231 | 7.75 | 264 |
| 31 | 5.65 | 87 | 6.23 | 143 | 6.82 | 199 | 7.41 | 232 | 7.76 | 265 |
| 32 | 5.66 | 88 | 6.24 | 144 | 6.83 | 200 | 7.42 | 233 | 7.77 | 266 |
| 33 | 5.67 | 89 | 6.25 | 145 | 6.84 | 201 | 7.43 | 234 | 7.78 | 267 |
| 34 | 5.68 | 90 | 6.27 | 146 | 6.85 | | | | | |
| 35 | 5.69 | 91 | 6.28 | 147 | 6.86 | | | | | |
| 36 | 5.70 | 92 | 6.29 | 148 | 6.87 | | | | | |
| 37 | 5.71 | 93 | 6.30 | 149 | 6.88 | | | | | |
| 38 | 5.72 | 94 | 6.31 | 150 | 6.90 | | | | | |
| 39 | 5.73 | 95 | 6.32 | 151 | 6.91 | | | | | |
| 40 | 5.74 | 96 | 6.33 | 152 | 6.92 | | | | | |
| 41 | 5.75 | 97 | 6.34 | 153 | 6.93 | | | | | |
| 42 | 5.76 | 98 | 6.35 | 154 | 6.94 | | | | | |
| 43 | 5.77 | 99 | 6.36 | 155 | 6.95 | | | | | |
| 44 | 5.78 | 100 | 6.37 | 156 | 6.96 | | | | | |
| 45 | 5.79 | 101 | 6.38 | 157 | 6.97 | | | | | |
| 46 | 5.80 | 102 | 6.39 | 158 | 6.98 | | | | | |
| 47 | 5.81 | 103 | 6.40 | 159 | 6.99 | | | | | |
| 48 | 5.82 | 104 | 6.41 | 160 | 7.00 | | | | | |
| 49 | 5.83 | 105 | 6.42 | 161 | 7.01 | | | | | |
| 50 | 5.85 | 106 | 6.43 | 162 | 7.02 | | | | | |
| 51 | 5.86 | 107 | 6.44 | 163 | 7.03 | | | | | |
| 52 | 5.87 | 108 | 6.45 | 164 | 7.04 | | | | | |
| 53 | 5.88 | 109 | 6.46 | 165 | 7.05 | | | | | |
| 54 | 5.89 | 110 | 6.48 | 166 | 7.06 | | | | | |
| 55 | 5.90 | 111 | 6.49 | 167 | 7.07 | | | | | |
| 56 | 5.91 | 112 | 6.50 | 168 | 7.08 | | | | | |

Tab. 3 - Number and age of the identified positive ("warm") and negative ("cold") abundance fluctuations between the Miocene/Pliocene boundary at Site 552 and the base of the studied sections at Falconara and Monte Gibliscemi.

Kastens (1992) reports a re-interpretation of the magnetostratigraphy of Hole 654. She concludes giving preference to the interpretation B of Channell et al. (1990) (Fig. 12) and she ascribes the 2 normal magnetic intervals between 358 and 395 mbsf to Chron 5 and the normal polarity segment below 398 mbsf to Chron 6. This interpretation introduces very large diachronies

for the calcareous plankton bio-events recognized at Hole 654A and in other correlative sequences within the Mediterranean basin. For instance, the *Gt. conomiozea* FO is tied to Chron 3Bn but at Hole 654 it would be in the upper part of subchron C5.n1 (C3An.1n of Cande & Kent, 1992) according to Kastens (1992), with a diachrony of about 1 myr. The appearance of *Amaurolithus* spp. is on fluctuation 197 at Falconara, Monte Gibliscemi and Site 654 (Fig. 3, 6 and 7), below the base of C3Bn. Also in Morocco (Benson et al., 1991) and in the Equatorial Pacific ocean (Raffi, 1992) it occurs below Chron C3Bn. This nannofossil event would be within Chron C3r according to Kastens (1992), with a diachrony of about 1 myr. In the Tripoli Formation *A. amplificus* is present in some samples from level T17 (= fluctuation 121) in the Falconara section (Fig. 5). At Site 552 fluctuation 121 is above the base of Chron 3An.2n (Fig. 10). Raffi (1992) reports the distribution of *A. amplificus* from just below the base of Chron C3An.2n to just below the top of Chron C3An.1n in the Equatorial Pacific. Since the distribu-

tion of *A. amplificus* is restricted to Chron C3An, its presence in the Tripoli Formation strongly supports the attribution to Chron C3An of the lithological couplets of the Tripoli Formation. According to Kastens (1992) and by correlation between Hole 654 and Falconara, the base of the Tripoli Formation (and the distribution of

A. amplificus) would occur somewhere in Chron C3r. But this is inconsistent with the stratigraphic range of *A. amplificus*, which disappears close to the top of Chron 3An.1n and is therefore not present in Chron C3r. It is unlikely that *A. amplificus* survived in the Mediterranean basin its oceanic extinction event.

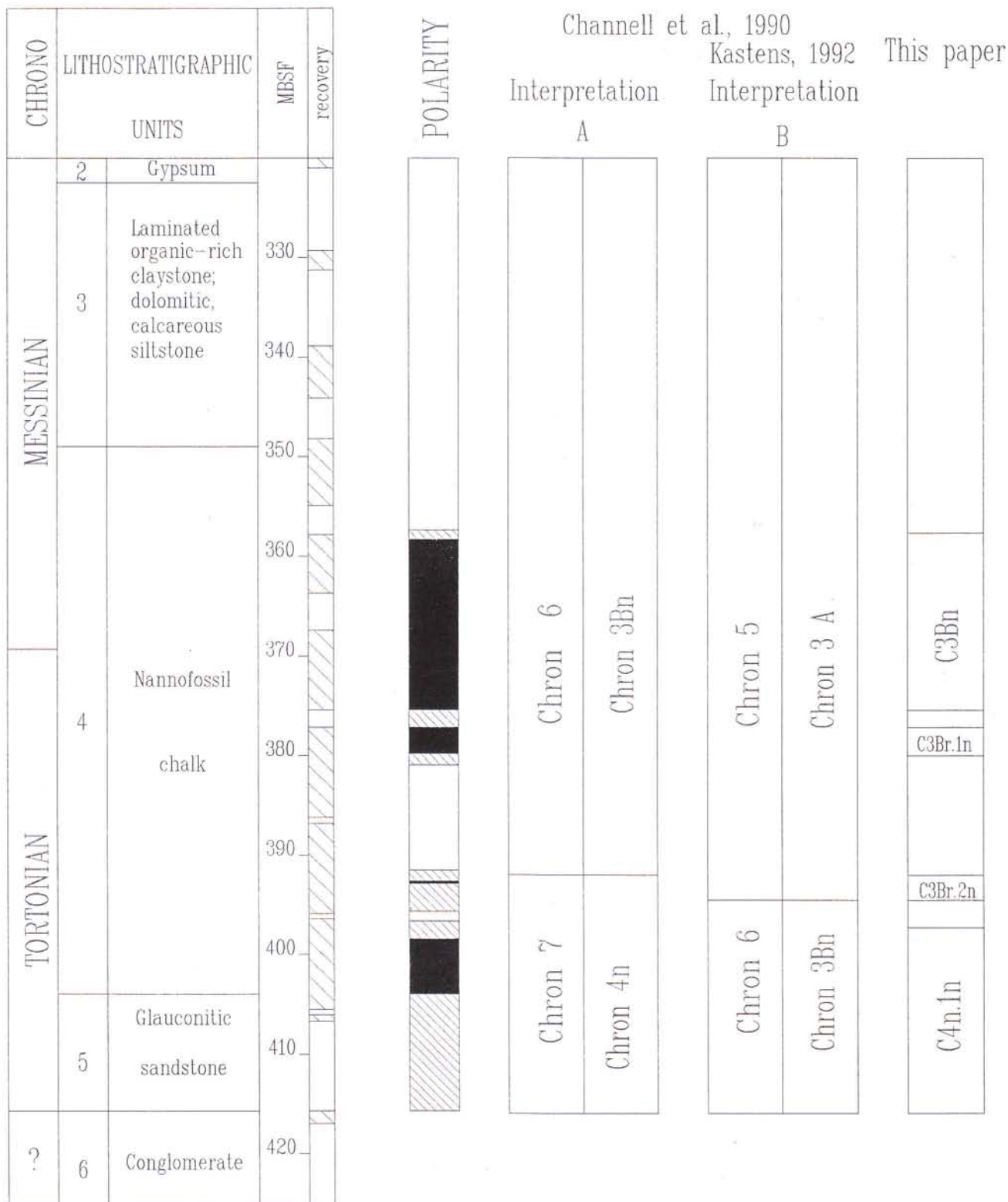


Fig. 12 - Magnetostratigraphic interpretations of the Upper Miocene segment at Site 654 according to Channell et al. (1990) and this paper. Vertical black bars of column 2 indicate normal polarity field.

Correlation of the considered sections

At Site 552 and Site 654 the C3Bn/C3Ar boundary was detected with accuracy (Fig. 7 and 10). Therefore the two sequences can be easily correlated by this magnetostratigraphic event (Fig. 13).

As reported above, the appearance of *Gt. saphoea*, *Gt. suterae*, of the *Gt. miotumida* plexus and of *Gt. conomiozea* in the planktonic foraminiferal assemblage, the extinction levels of *M. convallis* and the appearance of *A. primus* in the calcareous plankton assemblage coincide with the same relative abundance fluctuations of *Globigerinoides* spp. at Falconara, at Monte Gibliscemi and Site 654. We have used these biostratigraphic events to correlate the Falconara, Monte Gibliscemi and Site 654 sequences (Fig. 13).

Chronology of Late Miocene Mediterranean biostratigraphic and lithostratigraphic events.

The new proposed magnetostratigraphic interpretation of the Miocene interval at Site 654 and the age of the abundance fluctuations of the *Globigerinoides* spp. population represent the main constraint to obtain the chronology for every event. Furthermore, the abundance fluctuations are well correlated at Monte Gibliscemi with the lithologic cycles. Their ages are estimated on the assumption that the periodicity of the precession astronomical cycles recognizable at Site 552 in the latest Miocene time interval was also present during the Early Messinian and during the Middle and Late Tortonian and modulated the origin of the lithological couplets and the relative abundance fluctuations in the planktonic foraminifera assemblage. The sequence of positive and negative fluctuations are labelled in Fig. 3, 6 and 7 and their estimated ages are reported in Tab. 3. Even numbers are used for positive fluctuations and odd numbers for negative fluctuations. Correlations of the abundance fluctuations with the identified events and their absolute ages are reported in Tab. 2.

Along the Tripoli segment at Falconara abundance fluctuations of the planktonic foraminiferal assemblage cannot be continuously recorded since some samples from the claystone and laminitic levels do not yield planktonic foraminifera. Nevertheless the lithologic alternations of the laminitic-claystone couplets have already been referred to the waxing and waning of the Antarctic ice-cap (McKenzie et al., 1979) during the Late Miocene, when the periodicity of the precession astronomical cycles is recognized in the time-series (Keigwin, 1987; Beaufort & Aubry, 1990). Therefore a mean periodicity of 21 kyr is adopted for the 41 cycles of the laminitic-claystone couplets. The laminitic levels, in which a warmer assemblage in the planktonic foraminiferal and calcareous nannofossil population is generally present, are equated with the positive fluctuations of the *Globigerinoides* spp. assemblage.

feral and calcareous nannofossil population is generally present, are equated with the positive fluctuations of the *Globigerinoides* spp. assemblage.

The *Gt. conomiozea* FO occurs at Site 654 in coincidence of an abundance half-cycle that is 5 positive and negative abundance fluctuations of *Globigerinoides* spp. below the top of C3Bn. Since the top of C3Bn coincides with fluctuation 169, this bio-event coincides with half-cycle 174 and the age of the *Gt. conomiozea* FO is estimated at 7.15 MA. It is younger of about 0.15 myr than the age recently proposed by Vai et al. (1993).

Between the *Gt. conomiozea* FO and the base of the Tripoli Formation at Falconara and Monte Gibliscemi (Fig. 3 and 6) 21 positive and negative fluctuations of the *Globigerinoides* spp. population or lithological half-cycles are present. Therefore the base of the Tripoli Formation coincides with fluctuations 153. At Site 552 fluctuation 153 is 24 positive and negative fluctuations below the base of C3An.2n (Fig. 10). An age of 6.93 MA is estimated for the base of the Tripoli Formation at Falconara and Monte Gibliscemi. The topmost claystone level of the Tripoli Formation at Falconara is 83 half-cycles above the base of the Tripoli Formation (Fig. 4). It is correlated with fluctuation 72 at Site 552 and has an age of 6.08 MA.

The extinction of *R. rotaria* is recorded in the Falconara (Fig. 4 and 5) and Gibliscemi sections in the fifth laminitic level above the base of the Tripoli Formation. This laminitic level is correlated at Falconara with relative abundance fluctuation 145. It has an age of 6.84 MA. *A. amplificus* first occurrence is recorded in coincidence of level T17 (Fig. 5), which is correlated with fluctuation 121. Its absolute age at Falconara is 6.59 MA. In the interval between levels T8-M20 *N. atlantica* is frequent to abundant and it is more continuously present between M13 and M20, respectively correlated with fluctuation 129 and 115 at Site 552. This segment with frequent *N. atlantica* spans a time interval of about 150 kyr, between 6.53 MA and 6.67 MA. *N. atlantica* is a cold water mass species (Poore & Berggren, 1975) and its abundance indicates that cold water masses occupied the Mediterranean basin in this time interval. The interval between fluctuations 129 and 115 at Site 552 includes the coldest interval recognized in C3An according to the oxygen isotope stratigraphy reported by Keigwin (1987).

An essentially dextral population of *N. acostaensis* is present from level T24. Level T24 is correlated with fluctuation 107 at Site 552 (Fig. 4 and 10), which is in the middle-upper part of C3An.2n, with an age of 6.44 MA (Tab. 3). The appearance of predominantly dextral *N. acostaensis* at Falconara is possibly correlatable with the appearance of dextral *N. acostaensis* at DSDP Site 397, drilled in the Northwest African continental margin. At this Site dextral population of *N. acostaensis* ap-

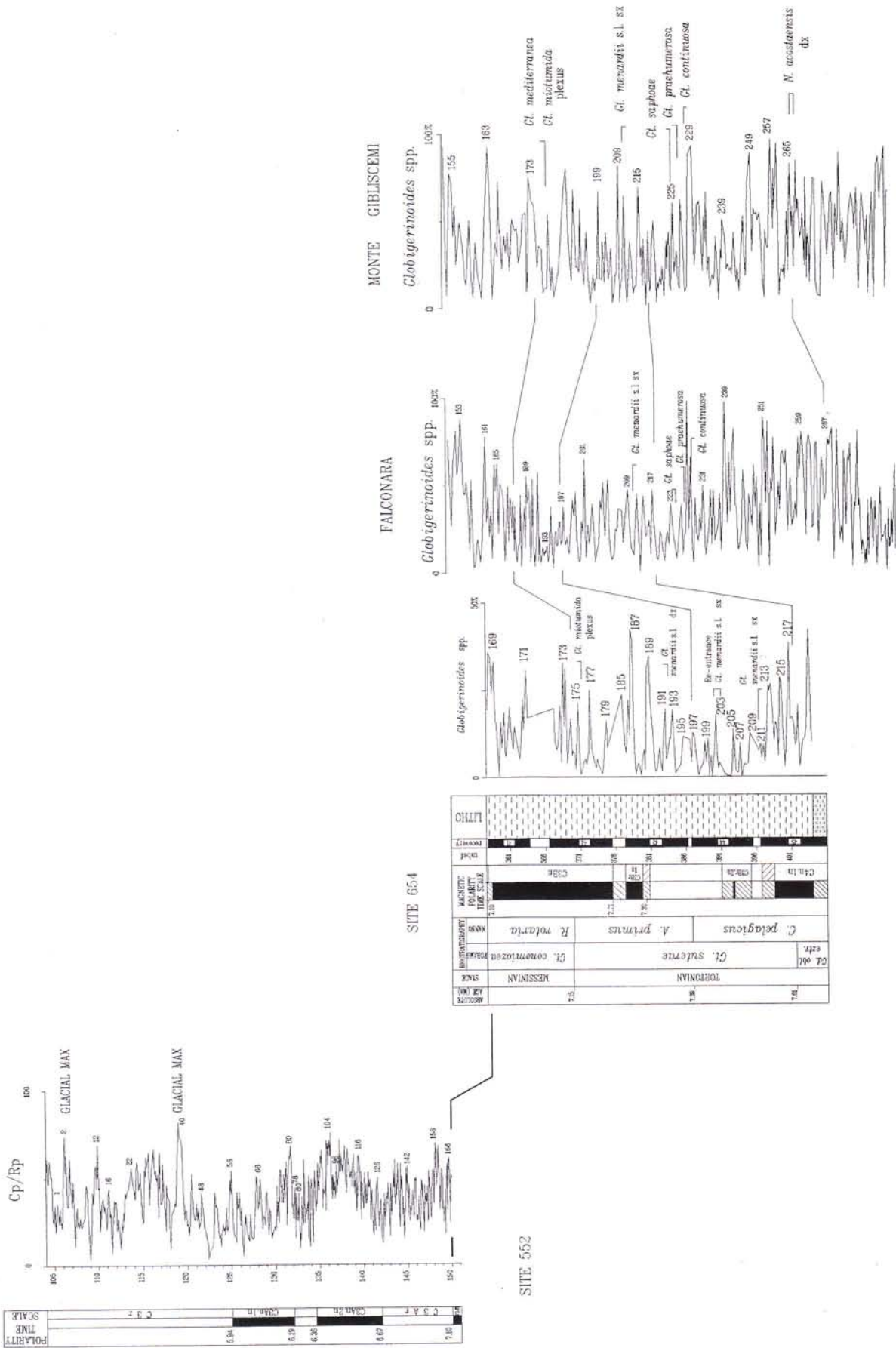


Fig. 13 - Correlation of the considered sequences. Thick line between Site 552 and Site 654 indicates paleomagnetic correlation; thin lines between Site 552 and Site 654 indicate biostratigraphic correlations. Cp/Rp = *C. pelagicus*/*R. pseudoumbilicus*.

pears at approximately 440 mbsf (Mazzei et al., 1979), in a normal polarity interval interpreted as C5.2n (C3An.2n). In the Equatorial Pacific core RC 12-66 (Saito et al., 1975) a shift from sinistral to dextral *N. acostaensis* population also occurs in C5.2n (C3An.2n).

Globigerina multiloba appears in level M12, below the appearance of dextral population of *N. acostaensis*. It is rare and discontinuous in the lower part of its range and increases in abundance from level M26 (Fig. 4), identified in Tab. 2 as the *Gl. multiloba* FCO. This level is above the appearance of dextral population of *N. acostaensis* and has an age of 6.41 MA. Colalongo et al. (1979a) report the *Gl. multiloba* FO above the appearance of dextral population of *N. acostaensis*. Possibly this level can be correlated with the level here identified as the first common occurrence of *Gl. multiloba* at Falconara.

The base of the Calcare di Base is just above level M42, which has an age of 6.08 MA (Fig. 4). This is the age of the top of the Tripoli Formation. If no hiatus is present between the base of the Calcare di Base and the immediately underlying claystone at the top of the Tripoli Formation at Falconara, an age of 6.08 MA may be proposed for this main lithological boundary in the Mediterranean basin, which corresponds to the base of the Messinian evaporites.

Several calcareous plankton bio-events have been identified in the studied sequences below the *Gt. conomiozea* FO and have been correlated to the recognized lithologic or faunistic cycles (Fig. 3, 6 and 7). In all the sections they coincide with the same half-cycle. This implies that they are well correlatable and isochronous and allow to propose an accurate chronology for these bio-events. The first appearance of *A. delicatus* and *R. rotaria* are apparently diachronous between the Falconara section and Site 654, in which their appearance level is recorded in younger levels. Possibly the extremely rare presence of these 2 forms at Site 654 may explain this delayed first occurrence and other sections must be studied to verify this diachroneity. The chronology of all the identified bio-events is reported in Tab. 2.

The top of the Tripoli Formation: Correlation with Site 552.

The age estimated for the top of the Tripoli Formation at Falconara and the identification of its position in the sequence of precession cycles allow to export this level outside the Mediterranean. An accurate correlation is possible with Site 552, where a detailed quantitative analysis evidenced fluctuations in the *C. pelagicus/R. pseudoumbilicus* ratio induced by precession astronomical cycles (Beaufort & Aubry, 1990). At Falconara the top of the Tripoli Formation is recognized in coinci-

dence of level M42. It is correlated at Site 552 with fluctuation 72, which occurs at about 130 mbsf (Fig. 10). Keigwin et al. (1987) and Keigwin (1987) published a detailed oxygen and carbon isotopic stratigraphy for Site 552. The isotopic results based on the analysis of *Globigerina bulloides* are plotted in Fig. 11. The periodicity in the fluctuations of the oxygen isotope values can be well compared with the periodicity of the precession astronomical cycles, as discussed by Beaufort & Aubry (1990). Fluctuation number 40, correlated with the Messinian lower glacial maximum (Keigwin, 1987; Beaufort & Aubry, 1990) is identified just above 120 mbsf and fluctuation 72, correlated with the top of the Tripoli Formation at Falconara, is at 130 mbsf (Fig. 10). In this interval (Fig. 11) the values of $\delta^{13}\text{C}$ gradually decrease. In the oxygen isotopic record (Fig. 11) the strong peak to heavier values identified at 119 mbsf and correlated with the lower glacial maximum post-dates the level correlated with the top of the Tripoli Formation of about 0.34 myr.

Correlation of the Tripoli Formation to the Paleomagnetic reversals record.

Burckle (1976, 1977), Harper (1977) and Gersonde & Schrader (1984) correlated the Sicilian Tripoli Formation to the paleomagnetic reversals record. Their proposed correlations were based on the occurrence in the Tripoli sequence of diatoms species whose ranges were previously defined by Burckle (1972, 1979) in deep-sea Pacific sections, many of which were placed in a paleomagnetic framework by Opdyke (1972).

Two possibly global calcareous plankton biostratigraphic events have been recognized within the Tripoli Formation at Falconara, the presence of *A. amplificus* and the coiling change from sinistral to dextral in the *N. acostaensis* population. The appearance of *A. amplificus* is correlated with the C3An/C3Ar paleomagnetic boundary by Raffi (1992) in the Eastern Equatorial Pacific. The latter event is recorded in C3An.2n by Saito et al. (1975) and Mazzei et al. (1979) in the Equatorial Pacific and eastern North Atlantic DSDP 397 respectively. Gersonde & Schrader (1984) report the distribution of *Thalassiosira praeconvexa* in the Tripoli Formation at Falconara, where the species disappears in the lower part. The extinction level of *T. praeconvexa* is within C3An.2n according to Burckle (1978). The age of the base and top of the Tripoli Formation at Falconara has been obtained by correlation with Site 552, where the abundance fluctuations (Cp/Cr ratio) are directly compared to the paleomagnetic reversal boundaries (Fig. 10). Therefore the base and top of the Tripoli Formation at Falconara can be chronologically positioned. All these

biostratigraphic and chronologic data allow to calibrate the stratigraphic placement of the Tripoli Formation outcropping at Falconara to the sequence of paleomagnetic reversals record of Cande & Kent (1992). The lowermost diatomitic level is correlated with fluctuation 153 at Site 552. Since the base of C3An.2n is coincident at this Site with fluctuation 129 (Fig. 10), the base of the Tripoli Formation at Falconara pre-dates the base of C3An.2n of about 0.34 myr. The top of the Tripoli Formation is correlated with fluctuation 72 at Site 552 (Fig. 10). The top of C3An.1n is coincident with fluctuation 59 at Site 552 (Fig. 10). Therefore the top of the Tripoli Formation pre-dates the top of C3An.1n of about 140 kyr. The correlation of the Tripoli Formation to the paleomagnetic reversals record proposed by previous Authors and in this paper is reported in Fig. 14.

Conclusions

Quantitative analysis on planktonic foraminiferal assemblages of close-spaced samples from the Upper Miocene Falconara and Monte Gibliscemi sections and from Hole 654 resulted in a sequence of short-term positive and negative abundance fluctuations of the *Globigerinoides* spp. population. They are interpreted as indicative of short-term climatic fluctuations induced by the precession astronomical cycles. On the base of the correlation with the sequence of the abundance fluctuations, a new interpretation is proposed for the magnetostratigraphy at Site 654 with reference to the paleomagnetic polarity stratigraphy of Cande & Kent (1992, 1995). The ages of the so interpreted paleomagnetic boundaries are older than the ages proposed by Shack-



Fig. 14 - Stratigraphic position of the Tripoli Formation at Falconara (hatched areas) calibrated to the paleomagnetic reversals record according previous Authors and this paper.

ton et al. (1995) and Cande & Kent (1995). The interpretation of the magnetostratigraphy of Site 654 recently proposed by Kastens (1992) introduces too large diachronies of the several calcareous plankton bio-events within the Mediterranean basin.

By correlation of the datum levels of the several calcareous plankton bio-events with the sequence of abundance fluctuations, the age of every bio-events could be proposed. The base of the Tripoli Formation at Falconara coincides with fluctuation 153. By correlation with Site 552, it has an age of 6.93 MA. The top of the Tripoli Formation at Falconara coincides with fluctuation 72 and its age is 6.08 MA. At Site 552 a decrease of the carbon isotopic values begins just above the level correlated with the top of Tripoli Formation. Since the base of the Pliocene has an age of 5.33 MA, the top of the Tripoli Formation, deposited in a time interval of about 0.85 myr between 6.93 and 6.08 MA, is 0.65 myr older than the re-establishment of normal marine environment in the Mediterranean basin. Consequently, the Messinian "salinity crisis" covers a time interval of about 0.65 myr.

The results reported in this paper, based on a detailed integrated calcareous plankton biostratigraphy and on cyclostratigraphy from 4 sequences (one of which

from the North Atlantic ocean) are comparable with the results recently obtained by Hodell et al. (1994) in northwestern Morocco. As far as the results reported by Gautier et al. (1994), evidences from the three sections concerning the sequence of lithologic features and field observations, of calcareous plankton bio-events, of relative abundance fluctuations of *Globigerinoides* spp. and of the obtained ages for lithologic and biostratigraphic events prove that no hiatus exists in the Falconara section between the marly and Tripoli segments and that the magnetostratigraphy proposed by Gautier et al. (1994) is questionable.

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REFERENCES

- Bè A. W. H. & Hutson W. H. (1977) - Ecology of planktonic foraminifera and biogeographic patterns of life and fossil assemblages in the Indian Ocean. *Micropaleont.*, v. 23, pp. 369-414, New York.
- Bè A. W. H. & Tolderlund D. S. (1971) - Distribution and ecology of living planktonic foraminifera in surface waters of the Atlantic and Indian Oceans. In Funnel B. M. & Riedel W. R. (Eds.) - *Micropaleontology of the Oceans*, Cambridge Univ. Press, pp. 105-149, London.
- Beaufort L. & Aubry M.P. (1990) - Fluctuations in the composition of Late Miocene calcareous nannofossil assemblages as a response to orbital forcing. *Paleoceanography*, v. 5, pp. 845-865, Washington.
- Behrman R. B. (1938) - Appunti sulla geologia della Sicilia centro-meridionale. Tip. Cuggiani, 60 pp., Roma.
- Benson R., Rakic-El Bied K. & Bonaduce G. (1991) - An important current reversal (influx) in the Rifian corridor (Morocco) at the Tortonian-Messinian boundary: the end of the Tethys ocean. *Paleoceanography*, v. 6, pp. 164-192, Washington.
- Benson R., Hayek L. C., Hodell D. & Rakic-El Bied K. (1995) - Extending the climatic precession curve back into the late Miocene by signature template comparison. *Paleoceanography*, v. 10, pp. 5-20, Washington.
- Blanc-Vernet L. (1969) - Contribution à l'étude des Foraminifères de Méditerranée. Relations entre la microfauna et le sédiment. Biocoenoses actuelles, thanathocoenoses pliocènes et quaternaires. *Rec. Trav. Stat. Mar. Endoume*, v. 64-48, 281 pp., Marseille.
- Borsetti A. M., Curzi P., Landuzzi V., Mutti M., Ricci Lucchi F., Sartori R., Tomadin L. & Zuffa G. (1990) - Messinian and pre-Messinian sediments from ODP Leg 107 Sites 652 and 654 in the Tyrrhenian sea. Sedimentologic and petrographic study and possible comparison with Italian sequences. In Kastens K. A. & Mascle J. (1990) - *Proc. ODP, Sc. Res.*, v. 107, pp. 169-186, College Station, TX (Ocean Drilling Program).
- Bukry D. (1981) - Cenozoic coccoliths from the Deep Sea Drilling Project. In Warme J. E., Douglas R. C. & Winterer E. L. (Eds.) - *The Deep Sea Drilling Project: A decade of Progress. SEPM Spec. Publ.*, v. 32, pp. 335-353, Washington.
- Burckle L. H. (1972) - Late Cenozoic planktonic diatom zones from eastern Equatorial Pacific. *Nova Hedwigia*, v. 39, pp. 217-246, Berlin.
- Burckle L. H. (1976) - Time-relations of diatoms in the neostatotype Messinian. *Messinian Seminar* N. 2, Abstract, p. 30, Gargnano.

- Burckle L. H. (1977) - Diatom analysis of the pre-evaporitic facies in the neostatotype area of the Messinian. *Messinian Seminar* N. 3, Abstract, p. 2, Malaga.
- Burckle L. H. (1979) - Validation of middle Pliocene to Pleistocene paleomagnetic reversals record using diatom and silicoflagellate datum levels. In von Rad U., Ryan W.B.F. et al. (Eds.) - *Init. Rpts. DSDP, Project 47, Pt. 1*, pp. 480-497, Washington.
- Cande S. & Kent D. (1992) - A New Geomagnetic Polarity Time Scale for the Late Cretaceous and Cenozoic. *Journ. Geoph. Res.*, v. 97, pp. 13,917-13,951, La Jolla, California.
- Cande S. & Kent D. (1995) - Revised calibration of the geomagnetic polarity timescale for the late Cretaceous and Cenozoic. *Journ. Geoph. Res.* In press.
- Casati P., Bertozzi P., Cita M. B., Longinelli A. & Damiani V. (1978) - Stratigraphy and paleoenvironment of the Messinian "Colombacci" Formation in the periadriatic trough. A pilot study. In Catalano R. et al. (Eds.) - *Messinian Evaporites in the Mediterranean*, *Mem. Soc. Geol. It.*, v. 16, pp. 173-195, Roma.
- Catalano R. & Sprovieri R. (1971) - Biostratigrafia di alcune serie saheliane (Messiniano inferiore) in Sicilia. In Farnacci A. (Ed.) - *Proc. II Planktonic Conf., Roma 1970*, pp. 211-249, Roma.
- Channell J. T., Torii M. & Hawthorne T. (1990) - Magnetostratigraphy of sediments recovered at Sites 650, 651, 652 and 654 (Leg 107, Tyrrhenian Sea). In Kastens K. A. & Mascle J. (Eds.) - *Proc. ODP, Sc. Res.*, v. 107, pp. 335-346, College Station, TX (Ocean Drilling Program).
- Cifelli R. & Smith R. K. (1974) - Distribution patterns of planktonic foraminifera in the Western North Atlantic. *Journ. Foram. Res.*, v. 4, pp. 112-125, Washington.
- Cita M. B., Santambrogio S., Melillo B. & Rogate F. (1990) - Messinian Paleoenvironments: new evidences from the Tyrrhenian sea (ODP Leg 107). In Kastens K. & Mascle J. (Eds.) - *Proc. ODP, Sc. Res.*, v. 107, pp. 211-227.
- Colalongo M. L., Di Grande A., D'Onofrio S., Giannelli L., Iaccarino S., Mazzei R., Romeo M. & Salvatorini G. (1979a) - Stratigraphy of Late Miocene Italian sections straddling the Tortonian/Messinian boundary. *Boll. Soc. Paleont. It.*, v. 18, pp. 258-302, Modena.
- Colalongo M. L., Di Grande A., D'Onofrio S., Giannelli L., Iaccarino S., Mazzei R., Brigatti M F., Romeo M., Rossi A. & Salvatorini F. (1979 b) - A proposal for the Tortonian/Messinian boundary. *Ann. Géol. Pays Hell.*, Tome hors serie, v. 1, pp. 285- 294, Athènes.
- Colalongo M. L., Cremonini G., Farabegoli E., Sartori R., Tampieri R. & Tomadin L. (1978) - Paleoenvironmental study of the "Colombacci" Formation in Romagna (Italy): the Cella section. In Catalano R. et al. (Eds.) - *Messinian Evaporites in the Mediterranean*, *Mem. Soc. Geol. It.*, v. 16, pp. 197-216, Roma.
- Coulbourn W. T., Parker F. L. & Berger W. H. (1980)- Faunal and solution patterns of planktonic foraminifera in surface sediments of the North Pacific. *Mar. Micropaleont.*, v. 5, pp. 329-399, Amsterdam.
- Decima A. & Sprovieri R. (1973) - Comments on Late Messinian microfaunas in several sections from Sicily. In Drooger (Ed.) - *Messinian Events in the Mediterranean*, *Kon. Ned. Ak. Wet.*, pp. 229-234, Amsterdam.
- Decima A. & Wezel F. (1971) - Osservazioni sulle evaporiti messiniane della Sicilia centro-meridionale. *Riv. Min. Sic.*, nn. 130-132, pp. 172-187, Palermo.
- D'Onofrio S., Giannelli L., Iaccarino S., Morlotti E., Romeo M., Salvatorini F., Sampò M. & Sprovieri R. (1975) - Planktonic foraminifera of the Upper Miocene from some Italian sections and the problem of the lower boundary of the Messinian. *Boll. Soc. Paleont. It.*, v. 14, pp. 177-196, Modena.
- Flores J. A., Sierro F. J. & Glaçon G. (1992) - Calcareous plankton analysis in the preevaporitic sediments of the ODP Site 654 (Tyrrhenian Sea, Western Mediterranean). *Micropaleont.*, v. 38, pp. 269-288, Washington.
- Fornaciari E., Di Stefano A., Rio D. & Negri A. (1995) - Middle Miocene Quantitative Calcareous Nannofossil Biostratigraphy in the Mediterranean Region. *Micropaleont.* Submitted.
- Gautier F., Clauzon G., Suc J.P., Cravatte J. & Violanti D. (1994) - Age et durée de la crise de salinité messinienne. *C. R. Acad. Sci. Paris*, v. 318, pp. 1103-1109, Paris.
- Gersonde R. (1980) - Study of the paleoecology and biostratigraphy of diatom assemblages from the lower Messinian "Tripoli" Formation in the Caltanissetta basin (Sicily). In 6th Intern. Symp. on living and fossil Diatoms, Abstract, 2 pp., Budapest.
- Gersonde R. & Schrader H. (1984) - Marine Planktonic Diatom correlation of lower Messinian deposits in the western Mediterranean. *Mar. Micropaleont.*, v. 9, pp. 93-110, Amsterdam.
- Giammarino S., Sprovieri R. & Di Stefano E. (1984) - La sezione pliocenica di Castel d'Appio (Ventimiglia). *Atti Soc. Tosc. Sc. Nat.*, Mem., v. 91, pp. 1-26, Pisa.
- Glaçon G., Vergnaud-Grazzini C., Iaccarino S., Rehault J. P., Randrianasolo A., Sierro J. F., Weaver P., Channell J. E. T., Torii M. & Hawthorne T. (1990) - Planktonic foraminiferal events and stable isotope records in the upper Miocene Site 654. In Kastens K. A. & Mascle J. (Eds.) - *Proc. ODP, Sc. Res.*, v. 107, pp. 415-428, College Station, TX (Ocean Drilling Program).
- Haq B. H. (1980) - Biogeographic history of Miocene calcareous nannoplankton and paleoceanography of the Atlantic ocean. *Micropaleont.*, v. 26, pp. 414-443, Washington.
- Harper H. E. (1977) - Diatom Biostratigraphy of the Miocene Pliocene Boundary in Marine Strata of the Circum North Atlantic. Ph. D. dissertation, Harvard Univ., 122 pp.
- Hasegawa S., Sprovieri R. & Poluzzi A. (1990) - Quantitative analysis of benthic foraminiferal assemblages from Pliocene-Pleistocene sequences in the Tyrrhenian sea, ODP Leg 107. In Kastens K. & Mascle J. (Eds.) - *Proc. ODP, Sc. Res.*, v. 107, pp. 461-478, College Station, TX (Ocean Drilling Program).
- Hilgen F. J. (1991) - Extension of the astronomically calibrated (polarity) time scale to the Miocene/Pliocene

- boundary. *Earth Planet. Sc. Lett.*, v. 107, pp. 349-368, Amsterdam.
- Hodell D. A., Benson R. H., Kennett J. P. & Rakic-El Bied K. (1989) - Stable isotope stratigraphy of latest Miocene sequences in northwest Morocco: The Bou Regreg section. *Paleoceanography*, v. 4, pp. 407-482, Washington.
- Hodell D. A., Benson R. H., Kent D. V., Boersma A. & Rakic-El Bied K. (1994) - Magnetostratigraphic, biostratigraphic and stable isotope stratigraphy of an Upper Miocene drill core from the Sale' Briqueterie (northwestern Morocco): A high-resolution chronology for the Messinian stage. *Paleoceanography*, v. 9, pp. 835-855, Washington.
- Hsu K. J. (1985) - Unresolved problem concerning the Messinian salinity crisis. *Giorn. Geol.*, v. 47, pp. 203-212, Bologna.
- Iaccarino S. (1985) - Mediterranean Miocene and Pliocene planktic foraminifera. In Bolli H. M., Saunders J. B. & Perch-Nielsen K. (Eds.) - *Plankton Stratigraphy*, Cambridge Univ. Press, v. 1, pp. 283-314, Cambridge.
- Kastens K. A. (1992) - Did Glacio-Eustatic sea level drop trigger the Messinian Salinity Crisis? New evidence from Ocean Drilling Program Site 654 in the Tyrrhenian sea. *Paleoceanography*, v. 7, pp. 333-356, Washington.
- Kastens K. A., Mascle J. et al. (1987) - *Proc. ODP, Init. Repts.*, Part. A, v. 107, 1013 pp., College Station, TX (Ocean Drilling Program).
- Keigwin L. D. (1987) - Towards a high-resolution chronology for latest Miocene paleoceanographic events. *Paleoceanography*, v. 2, pp. 639-660, Washington.
- Keigwin L. D., Aubry M. P. & Kent D. V. (1987) - North Atlantic Late Miocene stable isotope stratigraphy, biostratigraphy, and magnetostratigraphy. In Ruddiman W. F. et al. (Eds.) - *Init. Rpts. DSDP*, v. 94, pp. 935-963, Washington (U. S. Gov. Printing Office).
- Krijgsman W., Hilgen F. J., Langereis C. G. & Zachariasse W. J. (1994) - The age of the Tortonian/Messinian boundary. Preprint.
- Langereis C. & Dekker M. J. (1992) - Paleomagnetism and rock magnetism of the Tortonian-Messinian boundary stratotype at Falconara, Sicily. *Physics of the Earth and Planet. Interiors*, v. 71, pp. 100-111, Amsterdam.
- Langereis C. G., Zachariasse W. J. & Zijdeveld J. D. A. (1984) - Late Miocene magnetostratigraphy of Crete. *Mar. Micropaleont.*, v. 8, pp. 261-281, Amsterdam.
- Martini (1971) - Standard Tertiary and Quaternary calcareous nannoplankton zonation. In Farinacci A. (Ed.) - *Proc. II Planktonic Conf., Roma 1970*, v. 2, pp. 738-785, Roma.
- Mazzei R., Raffi I., Rio D., Hamilton N. & Cita M. B. (1979) - Calibration of Late Neogene calcareous plankton datum planes with the paleomagnetic record of Site 397 and correlation with Moroccan and Mediterranean sections. In von Rad U., Ryan W. B. F. et al. (Eds.) - *Init. Rpts. DSDP*, v. 47, pp. 375-389, Washington (U. S. Gov. Printing Office).
- McKenzie J. A., Jenkyns H. C. & Bennet G. C. (1979) - Stable isotope study of the cyclic diatomite-claystones from the Tripoli Formation, Sicily: a prelude to the Messinian salinity crisis. *Palaeogeog., Palaeoclim., Palaeoecol.*, v. 29, pp. 125-141, Amsterdam.
- Mueller C. (1990) - Nannoplankton biostratigraphy and paleoenvironmental interpretations from the Tyrrhenian Sea. In Kastens K. & Mascle J. (Eds.) - *Proc. ODP, Sc. Res.*, v. 107, pp. 495-512, College Station, TX.
- Opdyke N. D. (1972) - Paleomagnetism of deep-sea cores. *Rev. Geophys. Space Phys.*, v. 10, pp. 213-249, New York.
- Parker F. L. (1958) - Eastern Mediterranean foraminifera. *Rept. Swed. Deep-Sea Expedition*, v. 8, pp. 217-283, Goteborg.
- Perch-Nielsen K. (1985) - Cenozoic calcareous nannofossils. In Bolli H. M., Saunders J. B. & Perch-Nielsen K. - *Plankton Stratigraphy*, Cambridge Univ. Press, v. 1, pp. 427-554, Cambridge.
- Poore R. Z. & Berggren W. A. (1975) - The morphology and classification of *Neogloboquadrina atlantica* (Berggren). *Journ. Foram. Res.*, v. 5, pp. 692-694, New York.
- Raffi I. (1992) - Nannofossil Biochronology of middle Miocene to lowermost Pliocene in low-latitude environment: results from ODP Leg 138 (Eastern Equatorial Pacific). In Montanari A. et al. (Eds.) - *Interdisciplinary Geological Conference on the Miocene Epoch with emphasis on the Umbrian-Marche sequence*, Abstract, pp. 92-93, Ancona.
- Ruggieri G. (1958) - Gli esotici neogenici della colata gravitativa della Val Marecchia. *Atti Acc. Sc. Lett. Arti*, v. 17, pp. 1-170, Palermo.
- Ruggieri G. (1967) - The Miocene and later evolution of the Mediterranean sea. In *Aspects of Tethyan Biogeography*. *Syst. Ass. London*, v. 7, pp. 283-290, London.
- Ruggieri G. & Sprovieri R. (1976) - Messinian salinity crisis and its paleogeographical implications. *Palaeogeog. Palaeoclim. Palaeoecol.*, v. 20, pp. 13-21, Amsterdam.
- Saito T., Burckle L. N. & Hay J. D. (1975) - Late Miocene to Pleistocene biostratigraphy of Equatorial Pacific sediments. In Saito T. & Burckle L. (Eds.) - *Late Neogene Boundaries*, *Micropaleont. Press*, pp. 226-244, New York.
- Shackleton N. J., Crowhurst S., Hagelberg T., Pisias N. & Schneider D. A. (1995) - A new Late Neogene timescale: Application to ODP leg 138 sites. In Pisias N., Mayer L., Janacek T. et al. (Eds.) - *Proc. ODP, Sc. Res.*, v. 138, College Station, TX. In press.
- Sierro F. J., Flores J. A., Civis J. A., Gonzales D. & Frances G. (1993) - Late Miocene globorotaliid event-stratigraphy and biogeography in the NE-Atlantic and Mediterranean. *Mar. Micropaleont.*, v. 21, pp. 143-169, Amsterdam.
- Sprovieri R. (1992) - Mediterranean Pliocene biochronology: an high resolution record based on quantitative planktonic foraminifera distribution. *Riv. It. Paleont. Strat.*, v. 98, n.1, pp. 61-100, Milano.
- Sprovieri R. (1993) - Pliocene-Early Pleistocene astronomically forced planktonic foraminifera abundance fluctuations and chronology of Mediterranean calcareous plankton bio-events. *Riv. It. Paleont. Strat.*, v. 99, n.3, pp. 371-414, Milano.
- Sturani C. (1973) - A fossil Eel (*Anguilla* sp.) from the Messinian of Alba (Tertiary Piedmontese Basin). *Paleoenviron.*

- ronmental and paleogeographic implications. In Drooger C. W. (Ed.) - Messinian Events in the Mediterranean, *Kon. Ned. Ak. Wet.*, pp. 243-255, Amsterdam.
- Theodoridis S. (1984) - Calcareous nannofossil biozonation of the Miocene and revision of the helicoliths and discoasters. *Utrecht Micropaleont. Bull.*, v. 32, pp. 1-271, Utrecht.
- Tjalsma R. C. (1971) - Stratigraphy and foraminifera of the Neogene of the Eastern Guadalquivir Basin (southern Spain). *Utrecht Micropaleont. Bull.*, v. 4, pp. 1-161, Utrecht.
- Vai G.B., Villa I. M. & Colalongo M. L. (1993) - First direct radiometric dating of the Tortonian/Messinian boundary. *C. R. Acad. Sci. Paris*, s. 2, v. 316, pp. 1407-1414, Paris.
- Van der Zwaan G. J. (1979) - The pre-evaporitic Late Miocene environment of the Mediterranean; stable isotopes of planktonic foraminifera from section Falconara, Sicily. *Proc. Kon. Ned. Ak. Wet.*, v. 82, pp. 379-397, Amsterdam.
- Van der Zwaan G. J. (1982) - Paleocology of Late Miocene Mediterranean foraminifera. *Utrecht Micropaleont. Bull.*, v. 25, pp. 1-201, Utrecht.
- Van der Zwaan G. J. & Gudjonsson L. (1986) - Middle Miocene-Pliocene stable isotope stratigraphy and paleoceanography of the Mediterranean. *Mar. Micropaleont.*, v. 10, pp. 71-90, Amsterdam.
- Wright R. (1978) - Neogene paleobathymetry of the Mediterranean based on benthic foraminifers from DSDP Leg 42A. In Hsu K. J. & Montadert L. (Eds.) - *Init. Repts DSDP*, v. 42, pp. 837-846, Washington.

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