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Original Citation:

Middle Eocene to Middle Miocene planktonic foraminiferal biostratigraphy for internal basins (Monferrato and Northern Appennines, Italy) / MANCIN N.; PIRINI C.; BICCHI E.; FERRERO E.; G. VALLERI. - In: MICROPALEONTOLOGY. - ISSN 0026-2803. - STAMPA. - 49 (4):(2003), pp. 341-358.

Availability:

Publisher:

Sheridan Press:PO Box 465:Hanover, PA 17331:(717)632-3535, EMAIL: pubsvc@tsp.sheridan.com, Fax:

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Source: *Micropaleontology*, Vol. 49, No. 4 (Winter, 2003), pp. 341-358
Published by: The Micropaleontology Project, Inc.
Stable URL: http://www.jstor.org/stable/3648452
Accessed: 28/10/2010 07:31

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Middle Eocene to Middle Miocene planktonic foraminiferal biostratigraphy for internal basins (Monferrato and northern Appennines, Italy)

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ABSTRACT: A planktonic foraminiferal zonal scheme is proposed for the internal basinal successions of the Monferrato and Northern Appennines (late Bartonian-early Serravallian). This scheme is based on a synthesis of quantitative analyses performed on the foraminiferal assemblages from 30 stratigraphic sections, cropping out over a distance of 300 km, between the Piedmont and the Northern Appennines. The proposed zonal scheme represents the synthesis, with minor changes, of the biozonations proposed by Novaretti et al. (1995) and Mancin and Pirini (2001) with the addition of unpublished data from some new sections, spanning a broader temporal and geographical range. With respect to the previous regional and standard biozonations, this scheme shows a better biostratigraphical resolution resulting from the replacement of missing or unreliable standard bioevents with new "reproducible" and reliable regional biohorizons. These new events are: LO of muricate species, which identifies the top of the *Acarinina* spp., *Globigerinatheka* spp. and *Turborotalia cerroazulensis* Assemblage Zone because *Truncorotaloides rohri* is very rare to absent; LO of *Turborotalia cerroazulensis* lineage, which marks the top of the *Turborotalia cerroazulensis* Interval Zone because the *Hantkenina* group is absent; LO of psuedohastigerinids, which marks the upper boundary of the *Pseudohastigerina* spp. Interval Zone because *Cassigerinella chipolensis* and *Pseudohastigerina micra* do not co-occur; the former appears later, in the *Globigerina ampliapertura* Zone, whereas the latter often disappears near the Eocene/Oligocene boundary; FCO of *Paragloborotalia opima opima*, which identifies the *Paragloborotalia opima opima* Subzone boundary (IFP21a/IFP21b) because the LO of *Chiloguembelina cubensis* is a weakly reliable event; FO of *Globoquadrina dehiscens*, which marks the *Paragloborotalia kugleri* Subzone boundary (IFN1a/IFN1b) because the FCO of the *Globigerinoides* group occurs later; LO of *Paragloborotalia kugleri*, which identifies the top of the *P. kugleri* Total Range Zone because the FO of *Globigerinoides altiaperturus* occurs later and finally, the FO of *Globigerinoides trilobus,* used to subdivide the interval between the LO of *P. kugleri* and the LO of *Catapsydrax dissimilis,* because *Globigerinatella insueta* is absent.

Other homotaxial biohorizons have also been recognized and introduced among the primary bioevents. These "secondary events" can help in better placing zonal and subzonal boundaries when the primary events cannot be used and in the refinement of the correlations among the different sections.

The validity of this proposal, in our view, consists in the general correspondence between the adopted bioevents and the standard zonal boundaries and therefore in an easy correlation with the various standard schemes. Moreover, the area of applicability of this biozonation could be extended to the surrounding basins and also to coeval Mediterranean successions.

INTRODUCTION

The late Eocene to middle Miocene interval was a time of dynamic geological and paleoceanographical evolution in the Mediterranean region. Since the late Oligocene, the collision of the European and Adriatic plates resulted in final closure of the Tethyan Ocean, the birth of the modern Mediterranean Sea, and the structuring of peri-mediterranean thrust-fold belts like the Alps and Appennines (Boccaletti et al.1980, Abbate and Sagri 1982, Boccaletti et al. 1990). The global climate underwent rapid cooling associated with the expansion of the Antarctic ice sheet (Boersma and Premoli Silva 1986, Hallock et al. 1991) and the Mediterranean Sea gradually became independent from the Atlantic Ocean and from the Indo-Pacific Tethys. As a consequence foraminiferal assemblages rapidly evolved and diversified, becoming provincial to internal basins like the Mediterranean Sea and, above all, like the episutural and perisutural basins related to the Alpine and Appenninic orogenesis.

It is known, that some of the tropical and Mediterranean zonal markers are, in fact, very rare to absent throughout "non-oceanic" internal basins, or show a different chronostratigraphic range preventing the use of the so-called "standard planktonic foraminiferal zonations". Therefore, clearly there is a need to identify new regional bioevents valid for internal basins and to propose an up-to-date planktonic foraminiferal biostratigraphy that can easily be correlated with the standard zonations.

The present paper takes into consideration the middle Eocene-middle Miocene successions in the Monferrato and Torino Hill areas (Tertiary Piedmont Basin-TPB) and in the central-western Northern Appennines (Epiligurids). The most recent papers dealing with planktonic foraminiferal biozonations in the studied areas are by Novaretti (1990, 1993), Bicchi et al. (1994), Ferrero et al. (1994), and Novaretti et al. (1995) for the Monferrato and by Mancin and Pirini (2001, with references therein), for the Epiligurids. A revision of these studies and ongoing research, with the identification of new regional bioevents, pointed out that a more detailed biostratigraphy was achievable.

The aim of this paper is to show that the synthesis of the scheme proposed by Novaretti et al. (1995) and Mancin and Pirini (2001), with minor changes, results in a new biozonation valid for the whole studied area and also for different tectonostratigraphic contexts. Moreover, the area of applicability of this scheme could also be extended to adjacent successions and to other coeval basins.

GEOLOGICAL SETTING

The middle Eocene-middle Miocene successions, that crop out in the Epiligurian Basin and in the Tertiary Piedmont Basin (TPB, text-fig. 1), are related to a large episutural basin (Tertiary Epi-mesoalpine Basin, Mutti et al. 1995) formed along the internal margin of the Western Alps after the Ligurian (Mesoalpine) collision event.

The Epiligurian succession, that crops out in isolated bodies along the Northern Appennines chain unconformably overlying the Ligurid Units ("piggy back basins"; Ori and Friend 1984, Ricci Lucchi 1990), is composed of turbiditic sandstones and conglomerates and of hemipelagic marls mainly deposited in deep-water basins. It includes (from base to top): the Monte Piano Marls, the Ranzano Sandstones, the Antognola Marls and the Contignaco Formation (text-fig. 2a). These sediments, late Bartonian to early Burdigalian in age, are characterized by sharp lateral variations in the depositional geometry related to the original complex internal topography of the sedimentary basins (Bettelli et al. 1987, Martelli et al. 1993, 1998).

The Monferrato succession, to the west, is very similar to the Epiligurian one and can be considered the NW termination of the Appenninic chain. It is composed of a mainly terrigenous Eocene-Miocene succession, deposited into complex internal basins (Biella et al. 1987, Piana and Polino 1995, Gelati and Gnaccolini 1998), resting unconformably on upper Cretaceous-Eocene Ligurian Flysch.

According to recent stratigraphic and structural studies (Falletti 1994, Clari et al. 1994, 1995, Piana and Polino 1995) the Monferrato area consists of two stratigraphic successions, related to different tectonostratigraphic domains, and cropping out, respectively, in the eastern and western portions (text-fig. 2b). The Eastern Monferrato succession, consisting of Oligocene to lower Miocene terrigenous sediments of variable depths (Clari et al. 1987) and followed unconformably by shallow-water shelf carbonates, includes (from base to top): the "Cardona Unit", the Antognola Marls and finally the "Pietra da Cantoni Group". The Western Monferrato succession, consisting of Oligocene to lower Miocene coarse terrigenous sediments deposited both in strongly subsiding basins and on adjacent structural highs, includes (from base to top): the Ranzano Sandstones, the Antognola Marls, and finally the Pteropod Marls and its lateral equivalents. Both in the Eastern and Western Monferrato, the succession ends with Langhian to Serravallian calcarenites and marls ("Tonengo Calcarenites" and "Micengo Marls").

To the west, the Rio Freddo transpressional deformation zone separates the Monferrato area from the adjoining Torino Hill, belonging to the Alpine domain (Piana and Polino 1994, 1995) and consisting of Oligocene to Miocene terrigenous sediments deposited in a subsiding basin (Ferrero 1987, Novaretti 1990, Clari et al. 1995). This succession includes (from base to top): the Ranzano Sandstones, the Superga Formation, the Lower Pteropod Marls and finally the Termofourà and Baldissero Complexes.

MATERIALS AND METHODS

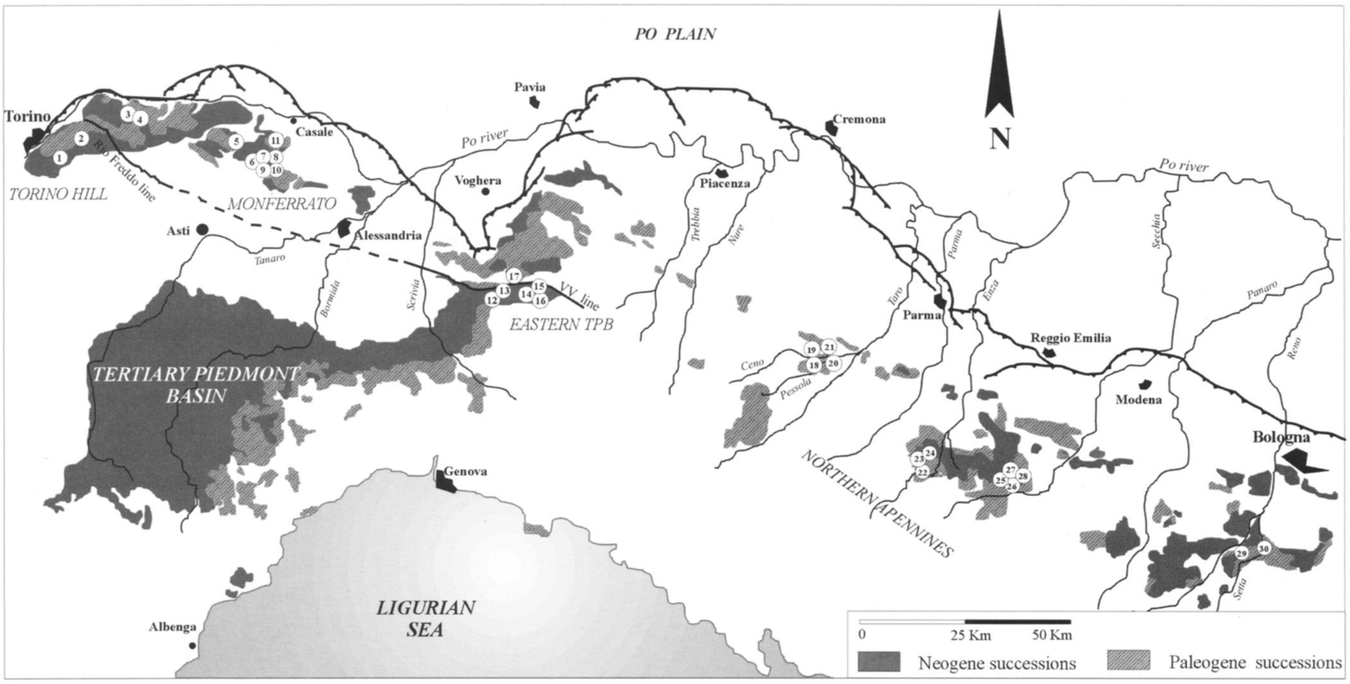
This study is based on quantitative and semiquantitative analyses performed on the planktonic foraminiferal assemblages from about 30 stratigraphic sections (four of them, Colombaia, Lovaro, Santa Caterina 1 and Santa Caterina 2, unpublished), late Bartonian to early Serravallian in age, cropping out over a distance of about 300 km (text-fig. 1). These analyses allowed to identify several primary and secondary bioevents and to verify their reliability. Table 1 and 1B list and summarize primary and secondary events, reference sections, lithostratigraphic units and the reliability of the bioevents considered in the present work. Primary and secondary bioevents include classic first occurrence (FO) and last occurrence (LO) together with abundance fluctuations of marker species such as first common occurrence (FCO) and last common occurrence (LCO). For testing the reproducibility and reliability of primary and secondary bioevents, the distribution patterns of several marker species have been established by means of quantitative methods (abundance curves) in coeval sediments from both the studied areas. Stratigraphic sections and quantitative data are reported and discussed in detail in the papers by Mancin and Pirini (2001) for the Northern Appennines and by Bicchi et al. (1994), Novaretti et al. (1995) and Bicchi et al. (in press) for the Monferrato and Torino Hill areas, to which the reader is referred. Discussions about "reproducibility" and reliability of primary and secondary bioevents follow the methodological approach and criteria suggested by Fornaciari and Rio (1996).

Correlation of the zonal boundaries to the geomagnetic polarity time scale (GPTS) is essentially obtained by assuming that primary biohorizons identified in the studied sections are coeval with standard bioevents and therefore, that the ages of these biohorizons are approximately the same ages as those reported in the GSSPs sections and in the oceanic realm, where primary events are also correlated to the sequence of the paleomagnetic reversals. In particular, the reader can refer to the papers by Nocchi et al. (1986), Premoli Silva and Boersma (1988), Bice and Montanari (1988), Berggren and Miller, (1988), Miller et al. (1991), Berggren et al. (1995); Iaccarino et al. (1996) and Coccioni et al. (1999), for more information about the ages of primary and secondary bioevents. Age calibration of the geomagnetic polarity time scale is referred to Cande and Kent (1992, 1995).

An informal numerical notation codifies each zone; IFP and IFN indicate the Internal Basin Foraminifera Paleogene and the Internal Basin Foraminifera Neogene, respectively.

"Reproducibility" and reliability of the utilized bioevents

A bioevent can be considered "reproducible" when the index species is an easily and clearly recognizable taxon, whose distribution patterns show a clear abrupt change. Moreover, a bioevent can be considered reliable when it shows the same range in distant sections developed in various facies maintain-



TORINO HILL: ***1.*** Superga; ***2.*** Rivalba; ***WESTERN MONFERRATO:*** ***3.*** Bric Carrassa; ***4.*** Moransengo;
EASTERN MONFERRATO: ***5.*** Patro; ***6.*** Castel d'Uviglie; ***7.*** Colma; ***8.*** Rosignano; ***9.*** Moleto occidentale; ***10.*** Moleto centrale; ***11.*** Ozzano;
EASTERN TPB: ***12.*** Fontanelle; ***13.*** Ca' Bella N; ***14.*** Valle di Nivione; ***15.*** Nivione; ***16.*** San Michele;
NORTHERN APENNINES: ***17.*** Monteacuto; ***18.*** Rio delle Lubbie; ***19.*** Rio Molinetto; ***20.*** Fosio; ***21.*** Rio Boccolo; ***22.*** Antognola; ***23.*** Campora; ***24.*** Mussatico; ***25.*** Colombaia;
26. Santa Caterina 1; ***27.*** Santa Caterina 2; ***28.*** Lovaro; ***29.*** Torrazza; ***30.*** Cava dell'Albergana.

TEXT-FIGURE 1
Location of the studied sections in the Torino Hill, Monferrato, Eastern Tertiary Piedmont Basin (TPB) and Northern Appennine areas, (modified from Bigi et al. 1983).

ing its position relative to other bioevents (Fornaciari and Rio 1996).

On the basis of these definitions we have identified 16 primary events, considered as reliable and used to define the zonal and subzonal boundaries. Some of these primary events are new regional biohorizons because they have been introduced for the first time (*e.g.* the FCO of *P. opima opima* and the FO of *G. trilobus*) or because they have been used with a different meaning respect to the standard biozonations (*e.g* the LO of muricate species, the LO of *T. cerroazulensis* group, the LO of *Pseudohastigerina* spp., the FO of *G. dehiscens* and the LO of *P. kugleri*).

Nine secondary homotaxial bioevents, inserted among primary bioevents and maintaining their stratigraphic position relative to the primary bioevents, have also been recognized (Table 1 and 1B).

Secondary events have previously been used by Mancin and Pirini (2001) for the Paleogene Epiligurian succession and in the present scheme they have been extended to the Neogene Monferrato and Torino Hill sequences. These secondary events, helping to place the zonal and subzonal boundaries better when primary events are missing, have mainly been used to correlate the various portions of the entire middle Eocene-middle Miocene stratigraphic succession in the studied areas. Other recognized events can instead help only in the biostratigraphic resolution for restricted areas. They, in fact, do not preserve their relative position in the stratigraphic succession on a regional scale and the marker taxa are often difficult to recognized, usually rare to very rare and discontinuously present.

All the identified bioevents are listed and reported according to their regional distribution in text-figs. 3 and in Table 1 and 1B. A brief discussion on the reliability of the primary and secondary homotaxial events, essentially on the basis of their quantitative distribution, is reported below.

FO of *Globigerinatheka semiinvoluta* (secondary event)

This event has been proposed by Berggren and Miller (1988) to define the upper boundary of Zone P14. In the oceanic record the horizon falls in the upper part of Chronozone C18n (about 39.2-38.4 Ma; Berggren and Miller, 1988; Berggren et al. 1995).

The FO of *G. semiinvoluta* can be considered a moderately good reliable bioevent as the zonal marker, easily recognizable, is discontinuously present and increasing slowly in abundance in its initial range. Therefore we prefer to use the abrupt extinction of muricate species to identify the upper boundary of the *Acarinina* spp., *Globigerinatheka* spp. and *Turborotalia cerroazulensis* Assemblage Zone (IFP16 Zone). However, because the FO of *G. semiinvoluta* occurs slightly before the LO of muricate species, it can be used, as a secondary event, to correlate the proposed scheme with the Berggren and Miller (1988) one.

TABLE 1
List of planktonic foraminiferal bioevents used in the literature or proposed in the present paper for biostratigraphical subdivision and correlation in the studied time interval (late Bartonian to early Serravallian). Also reported: studied sections and lithostratigraphic units where bioevents have been recognized with observations on their biostratigraphic reliability.

FORAMINIFERAL BIOEVENTS	TYPE OF BIOEVENT	PROPONENTS	REFERENCE SECTIONS (meters from the base)	LITHOSTRATIGRAPHIC UNITS	RELIABILITY
FO of *P. pseudokugleri*	Secondary	Present paper	Torrazza (14 m), Santa Caterina 2 (74 m), Antognola (50 m), Nivione (70 m)	Antognola and Rigoroso Marls	Unreliable, limited applicability because the speses is rare to absent and difficult to detect
LO of *P. opima opima*	**Primary**	Bolli & Saunders (1985) Berggren & Miller (1988) Spezzaferri (1994)	Torrazza (7 m), Santa Caterina 2 (66 m), Antognola (42 m), Nivione (68 m)	Antognola and Rigoroso Marls	**Fairly to moderately reliable**
LO of *C. cubensis*	Secondary homotaxial	Berggren & Miller (1988) Spezzaferri (1994)	Santa Caterina 2 (28 m), Antognola (36 m) San Michele (70 m)	Antognola and Rigoroso Marls	Weakly reliable, difficult to detect
FCO of *P. opima opima*	**Primary**	Present paper	Santa Caterina 2 (17 m), Antognola (6m), Rio Boccolo (38 m), San Michele (45 m)	Antognola and Rigoroso Marls	**Good, reliable**
LO of *G. ampliapertura*	**Primary**	Berggren & Miller (1988) Spezzaferri (1994)	Cava dell'Albergana (63 m), Santa Caterina 2 (10 m), Antognola (1m), Rio Boccolo (29 m), San Michele (25 m)	Antognola and Rigoroso Marls	**Good, reliable**
LO of *T. pseudoampliapertura*	Secondary	Present paper	Santa Caterina 2 (8 m), Rio Boccolo (13 m), San Michele (2 m)	Antognola and Rigoroso Marls	Unreliable, probably diachronous
FO of *G. rohri*	Secondary	Present paper	Santa Caterina 2 (5m), Rio Boccolo (26 m), San Michele (25 m)	Antognola and Rigoroso Marls	Unreliable, probably diachronous
FO of *G. ciperoensis*	Secondary	Present paper	Santa Caterina 1 (46 m), Rio Boccolo (12 m), San Michele (35 m)	Antognola and Rigoroso Marls	Unreliable, difficult to detect and probably diachronous
FO of *G. sellii*	Secondary	Blow (1969)	Santa Caterina 1 (6 m), Mussatico (250 m), Rio Boccolo (9 m), San Michele (6 m)	Ranzano Fm., Antognola and Rigoroso Marls	Unreliable, probably diachronous
FO of . *P. opima opima*	Secondary homotaxial	Bolli & Saunders (1985)	Cava dell'Albergana (60 m), Santa Caterina 1 (8 m), Mussatico (245 m)	Ranzano Fm. and Antognola Marls	Less reliablenot sufficiently tested in the Mediterranean area
LO of pseudohastigerinids	**Primary**	Berggren & Miller (1988) Mancin & Pirini (2001)	Cava dell'Albergana (63 m), Lovaro (68 m)	Ranzano Fm.	**Good, reliable**
LO of *P. micra*	Secondary	Bolli (1957b, 1966a)	Lovaro (40 m), Monteacuto (84 m)	Ranzano Fm. and .Monte Piano Marls	Unreliable, probably diachronous
LO *T. cerroazulensis* lineage	**Primary**	Bolli (1957a; 1972)	Lovaro (21 m), Monteacuto (84 m), Fontanelle (13 m)	Ranzano Fm. and .Monte Piano Marls	**Fairly good**
FO of *P. naguewichiensis*	Secondary	Present paper	Lovaro (40 m), Monteacuto (80 m)	Ranzano Fm. and .Monte Piano Marls	Unreliable, probably diachronous
LO of *G. semiinvoluta*	**Primary**	Bolli (1957a) Proto Decima & Bolli (1970)	Lovaro (21 m), Campora (116), Monteacuto (72 m), Fontanelle (9 m)	Monte Piano Marls and Ranzano Fm.	**Fairly to moderately reliable**
LO of *G. subconglobata luterbacheri*	Secondary homotaxial	Present paper	Lovaro (12 m), Campora (116m), Fosio (70 m) Monteacuto (18 m), Fontanelle (7 m)	Monte Piano Marls and Ranzano Fm.	Good, reliable
LO of muricate species	**Primary**	Mancin & Pirini (2001)	Lovaro (21 m) , Campora (53 m), Fosio (70 m) Monteacuto (10 m)	Monte Piano Marls	**Excellent reliable**
LO of *T. cerroazulensis pomeroli*	Secondary	Toumarkine and Luterbacherr (1985)	Fosio (57 m), Monteacuto (30 m), Fontanelle (5 m)	Monte Piano Marls and Ranzano Fm.	Unreliable, probably diachronous
LO of *P. pseudoscitulus*	Secondary	Present paper	Fosio (65 m), Monteacuto (6 m)	Monte Piano Marls	Unreliable, difficult to detect and probably diachronous
FO of *G. semiinvoluta*	Secondary homotaxial	Berggren & Miller (1988)	Colombaia (2 m), Campora (44 m), Fosio (48 m), Monteacuto (6 m)	Monte Piano Marls	Moderately reliable

LO of muricate species (primary event)

This event, as proposed by Mancin and Pirini (2001), identifies the upper boundary of the *Acarinina* spp., *Globigerinatheka* spp. and *Turborotalia cerroazulensis* Assemblage Zone (IFP16 Zone). It approximates also the Bartonian/Priabonian boundary, as already proposed by Proto Decima (1975) and Berggren et al. (1985, 1995). This event lies at the uppermost part of Chronozone C18n (about 38.7 Ma) in the pelagic sediments of the "Umbria-Marche" Basin (Nocchi et al. 1986). The LO of muricate species is coeval with the LO of *Truncorotaloides rohri* in the oceanic record (Bolli 1957a, Toumarkine and Luterbacher 1985); however, we cannot use this latter bioevent to define the top of the IFP16 Zone because *T. rohri* is always very rare to absent in the studied sections (Mancin and Pirini 2001) and in other coeval Mediterranean successions (Nocchi et al. 1986).

The LO of muricate species can be considered an excellent reliable bioevent firstly because, this group of planktonic foraminifera is easily and clearly recognizable even in rapid analyses. Moreover, this event is easily detectable for a sharp decrease in abundance and abrupt disappearance, always preceded by a marked reduction in size (<125 μm) of the marker species, still frequent to common in the underlying levels. Finally, it has been detected in most of the outcropping areas (text-fig. 4).

In the GSSP Massignano section, the LO of some small muricate species (e.g. *Acarinina medizzai*, *Acarinina rugosoaculeata*, *Acarinina rotundimarginata*) occurs higher in the overlying levels, just above the LO of *Turborotalia cerroazulensis pomeroli* and just below the FO of *Turborotalia cerroazulensis cunialensis* (Coccioni et al. 1988; Spezzaferri et al. in press). In the studied sections, no muricate taxa have been observed above this bioevent, which appears to be abrupt.

LO of *Globigerinatheka subconglobata luterbacheri* (secondary event)

This event is here proposed as a secondary biohorizon. In temperate oceanic areas it falls in the upper part of Chronozone C16n (about 35.8 Ma, Berggren and Miller, 1988).

The LO of *G. subconglobata luterbacheri* appears as a good reliable biohorizon since this species, is easily recognizable by its very large size (400 to 600μm) and subglobular shape. Moreover, this event is easily detectable by the abrupt decrease in

TABLE 1B
List of planktonic foraminiferal bioevents used in the literature or proposed in the present paper for biostratigraphical subdivision and correlation in the studied time interval (late Bartonian to early Serravallian). Also reported: studied sections and lithostratigraphic units where bioevents have been recognized with observations on their biostratigraphic reliability.

FORAMINIFERAL BIOEVENTS	TYPE OF BIOEVENT	PROPONENTS	REFERENCE SECTIONS (meters from the base)	FORMATIONS	RELIABILITY
FO of *O. universa*	**Primary**	Iaccarino (1985)	Colma (38 m), Castel d'Uviglie (25 m)	Pietra da Cantoni gr., Termofourà and Baldissero Complexes	**Moderately reliable**
FO of *G. praemenardi*	Secondary homotaxial	Iaccarino (1985)	Colma (36 m))	Pietra da Cantoni gr.	Weakly reliabledifficult to detec and not sufficiently testedt
FO of *O. suturalis*	**Primary**	Iaccarino (1985)	Colma (34 m), Castel d'Uviglie (22 m), Rivalba (384 m, Superga (480 m)	Pietra da Cantoni gr., Termofourà and Baldissero Complexes	**Fairly reliable**
FO of *P. glomerosa curva*	Secondary homotaxial	Blow (1959) Bolli (1966) Iaccarino (1985)	Colma (27 m), Moransengo (440 m), Rivalba (136 m), Superga (406 m)	Pietra da Cantoni gr., Pteropod Marls, Termofourà and Baldissero Complexes	Weakly to fairly reliable
FO of *P. sicana*	**Primary**	Bicchi et al. (1994)	Colma (25 m), Rosignano (28 m), Castel d'Uviglie (19 m), Moleto Occidentale (64 m), Ozzano (43 m), Patro (1 m), Moransengo (288 m)	Pietra da Cantoni gr., Pteropod Marls, Termofourà and Baldissero Complexes	**Fairly to moderately reliable**
FO of *G. bisphaericus*	**Primary**	Bicchi et al. (1994)	Colma (16 m), Rosignano (24 m), Castel d'Uviglie (5 m), Moleto Occidentale (36 m), Ozzano (39 m), Moransengo (240 m), Rivalba (102 m), Superga (235 m)	Pietra da Cantoni gr., Pteropod Marls, Termofourà and Baldissero Complexes	**Good, reliable**
FCO of *Globigerinoides* gr.	Secondary homotaxial	Spezzaferri (1994)	Colma (14 m), Rosignano (9 m), Castel d'Uviglie (1 m), Moleto Occidentale (24 m), Ozzano (32 m), Bric Carrassa (550 m) , Moransengo (190 m), Rivalba (100 m)	Pietra da Cantoni gr., Pteropod and Antognola Marls, Termofourà Complex	Weakly reliable, not sufficiently tested in the Mediterranean area. Probably diachronous.
LO of *C. dissimilis*	**Primary**	Bolli & Saunders (1985) Berggren & Miller (1988) Spezzaferri (1994)	Colma (0,5 m), Rosignano (7 m), Ozzano (8 m), Bric Carrassa (470 m), Moransengo (179 m), Rivalba (70 m)	Pietra da Cantoni gr., Pteropod and Antognola Marls	**Good, reliable**
LO of *G. primordius*	Secondary	Present paper	Valle di Nivione (110 m), Bric Carrassa (140 m), Moransengo (173 m)	Antognola Marls, Castagnola Fm.	Unreliable, probably diacrhonous
FO of *G. trilobus*	**Primary**	Present paper	Santa Caterina 2 (112 m), Antognola (100 m), Valle di Nivione (68 m), Moransengo (193 m)	Antognola Marls, Castagnola Fm.	**Weakly reliable**
LO of *P. kugleri*	**Primary**	Bolli (1957b) Berggren & Miller (1988) Spezzaferri (1994)	Santa Caterina 2 (90 m), Antognola (98 m), Valle di Nivione (68 m), Bric Carrassa (133m), Moransengo (155m)	Antognola Marls, Castagnola Fm.	**Fairly to moderately reliable**
LO of *G. rohri*	Secondary	Present paper	Antognola (110 m), Valle di Nivione (65 m), Bric Carrassa (65 m)	Antognola Marls, Castagnola Fm.	Unreliable, probably diachronous
LO of *P. pseudokugleri*	Secondary	Present paper	Santa Caterina 2 (88 m), Antognola (94 m), Valle di Nivione (65 m), Bric Carrassa (120 m), Moransengo (140 m)	Antognola Marls, Castagnola Fm.	Unreliable, difficult to detec
FO of *G. dehiscens*	**Primary**	Srinivasan & Kennett (1983) Iaccarino (1985)	Santa Caterina 2 (78 m), Antognola (82 m), Nivione (108 m), Valle di Nivione, (62 m), Bric Carrassa (98 m)	Antognola Marls, Castagnola Fm.	**Good, reliable**
LO of *G. sellii*	Secondary homotaxial	Present paper	Torrazza (26 m), Santa Caterina 2 (78 m), Antognola (88 m), Nivione (105 m), Bric Carrassa (70 m)	Antognola and Rigoroso Marls, Anconella Sandstones	Good, reliable
FO of *P. kugleri*	**Primary**	Bolli (1957b) Berggren & Miller (1988) Spezzaferri (1994)	Torrazza (24 m), Santa Caterina 2 (76 m), Antognola (78 m) Nivione (100 m), Valle di Nivione (50 m), Bric Carrassa (5 m), Moransengo (60 m)	Antognola and Rigoroso Marls, Castagnola Fm.	**Fairly reliable**
LO of *G. angulisuturalis*	Secondary	Baldi Becke et al. (1978)	Torrazza (20 m), Santa Caterina 2 (76 m),Antognola (76 m), Nivione (98 m)	Antognola and Rigoroso Marls	Unreliable, limited applicability because the species is rare or absent, not yet sufficiently tested in the Mediterranean area
FO of *G. primordius*	Secondary homotaxial	Present paper	Torrazza (18 m), Santa Caterina 2 (74 m), Antognola (60 m), Nivione (86 m), Valle di Nivione (24 m)	Antognola and Rigoroso Marls	Fairly reliable

abundance of the marker species, that is still frequent to common and continuously present in the underlying levels. However, we prefer to use the LO of *G. semiinvoluta* and not the LO of *G. subconglobata luterbacheri* as zone boundary, because this last bioevent is not easily correlatable with standard biohorizons. The LO of *G. subconglobata luterbacheri* slightly precedes the LO of *G. semiinvoluta* and it can replace this event in temperate regions or in areas, such as the Alps and the southern Atlantic, where *G. semiinvoluta* might be absent or represented by specimens considerably smaller than those of fully developed tropical assemblages.

LO of *Globigerinatheka semiinvoluta* (primary event)

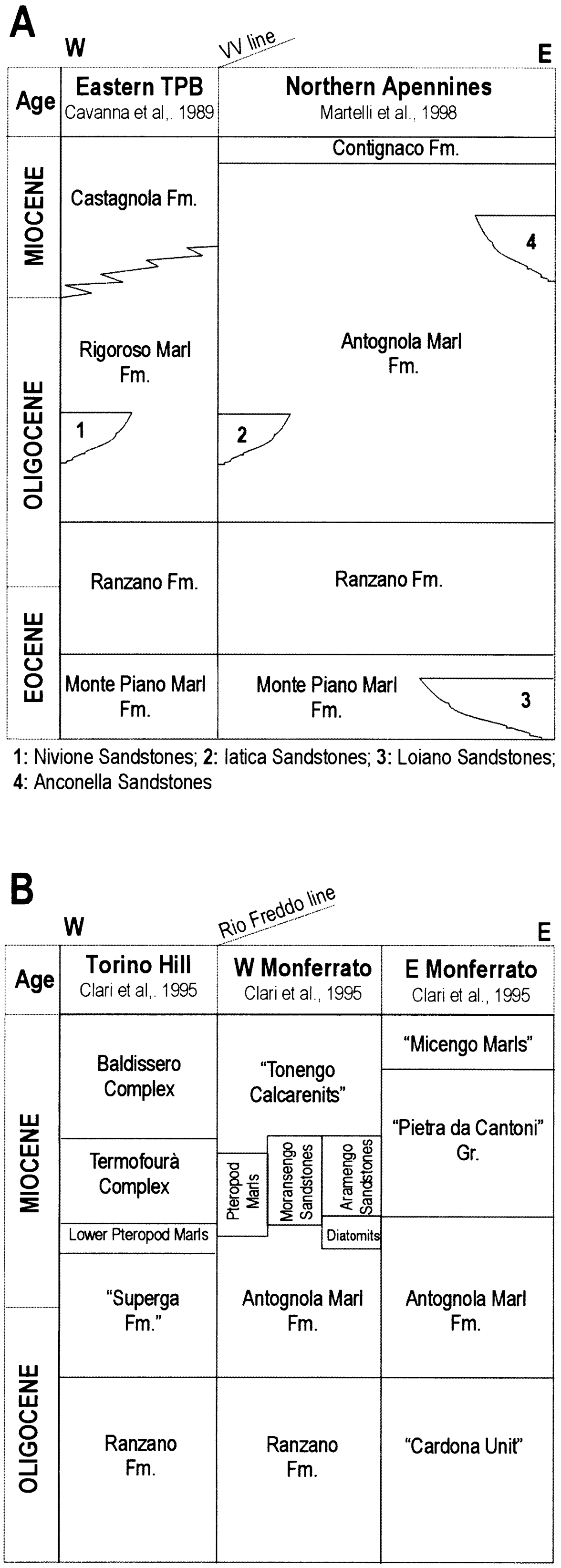
This event, as proposed by Bolli (1957a) and by Proto Decima and Bolli (1970), defines the upper boundary of the *G. semiinvoluta* Interval Zone (IFP17 Zone). In the GSSP Massignano section (Marche-Umbria Basin) this event falls in the uppermost part of Chronozone C16n.2n (about 35.8 Ma, Nocchi et al. 1986), whereas it falls in the Chronozone C15r (about 35.3 Ma; Berggren and Miller, 1988; Berggren et al. 1995) in the oceanic record.

The LO of *G. semiinvoluta* can be considered a fairly to moderately reliable bioevent. The zonal marker is easily recognizable, with an abrupt decrease in abundance and becoming discontinuously present in its final range. Therefore, in sections with reworking, it can be quite difficult to judge whether the low rate of occurrence represents genuine productivity or reworking. However we used the LO (not the LCO) of *G. semiinvoluta* because this event correlates better with other Mediterranean successions. Moreover, the correct position of *G. semiinvoluta* LO can be easily identified by the just preceding LCO level and LO of *G. subconglobata luterbacheri.*

LO of *Turborotalia cerroazulensis* lineage (primary event)

This event, as proposed by Bolli (1957a, 1972), defines the upper boundary of the *T. cerroazulensis* Interval Zone (IFP18 Zone), in place of the LO of *Hatkenina* spp. The *Hantkenina* group, in fact, is always very rare to absent in the studied sections. In the GSSP Massignano section, the LO of *T. cerroazulensis* lineage falls about 40cm below the Priabonian/Rupelian boundary, in the lowermost part of Chronozone 13r1, just above the thin normal interval C13n1 (about 33.6-33.8 Ma, Coccioni et al. 1988, Bice and Montanari 1988; Beggren et al. 1995).

The LO of *T. cerroazulensis* lineage can be considered a fairly reliable bioevent because the number of marker species, in the Northern Appennine sections, is usually less abundant than in the tropical areas. For example *T. cerroazulensis cunialensis* is continuously present and abundant in the Fontanelle section only (text-fig. 1, n°12). However this event is rather easy to



TEXT-FIGURE 2
Stratigraphical relations of the studied lithostratigraphic units. Lateral correlations are schematically simplified as reported in Bettelli et al. (1987) and Novaretti et al. (1995). A: Eastern Tertiary Piedmont Basin (TPB) and Northern Appennine successions; B: Torino Hill and Monferrato (Western and Eastern sectors, respectively) successions.

identify, in fact, the uppermost presence of the rare specimens of this lineage is preceded by a marked reduction in size of the pseudohastigerinids group (<125μm), sometimes with the FO of *Pseudohastigerina naguewichiensis*. In deep-water successions, this event coincides with an abrupt change in the benthic assemblage, with an increase in abundance of infaunal taxa, such as buliminids and bolivinids. Both these features have been reported by some authors from successions from central Italy and oceanic areas (Keller 1983, Boersma and Premoli Silva 1986, Nocchi et al. 1986).

LO of pseudohastigerinids (primary event)

This event, as proposed by Mancin and Pirini (2001) and by Berggren and Miller (1988), identifies the upper boundary of the *Pseudohastigerina* spp. Interval Zone (IFP19 Zone) and of the P18 Zone, because *Cassigerinella chipolensis* and *Psuedohastigerina micra* do not co-occur. The former, in fact, appears later in the *Globigerina ampliapertura* Zone, whereas the latter often disappears near the Eocene/Oligocene boundary. Moreover, *Chiloguembelina cubensis* is usually very rare to absent. In the oceanic record this event falls in the lower portion of Chronozone C12r (about 32.7-32.0 Ma, Berggren and Miller 1988; Berggren et al. 1995).

The LO of the pseudohastgerinid group appears as a reliable biohorizon since these taxa, although very small (<125 μm), are easily recognizable by their planispiral and biumbilicate shape. Moreover, this event is quite easily detectable by the gradual decrease in abundance of the marker species.

FO of *Paragloborotalia opima opima* (secondary event)

This event, proposed here as a secondary event, has been used by Bolli and Saunders (1985) to identify the upper boundary of the *Globigerina ampliapertura* Interval Zone. In the oceanic Hole 558, this bioevent lies in the middle portion of Chronozones C12n (about 30.6 Ma; Berggren et al. 1995).

The FO of *P. opima opima* can be considered a less reliable biohorizon because the marker species is usually very rare to rare in its initial range. Moreover this event has not yet been sufficiently tested for the Mediterranean area, where it may occur diachronously.

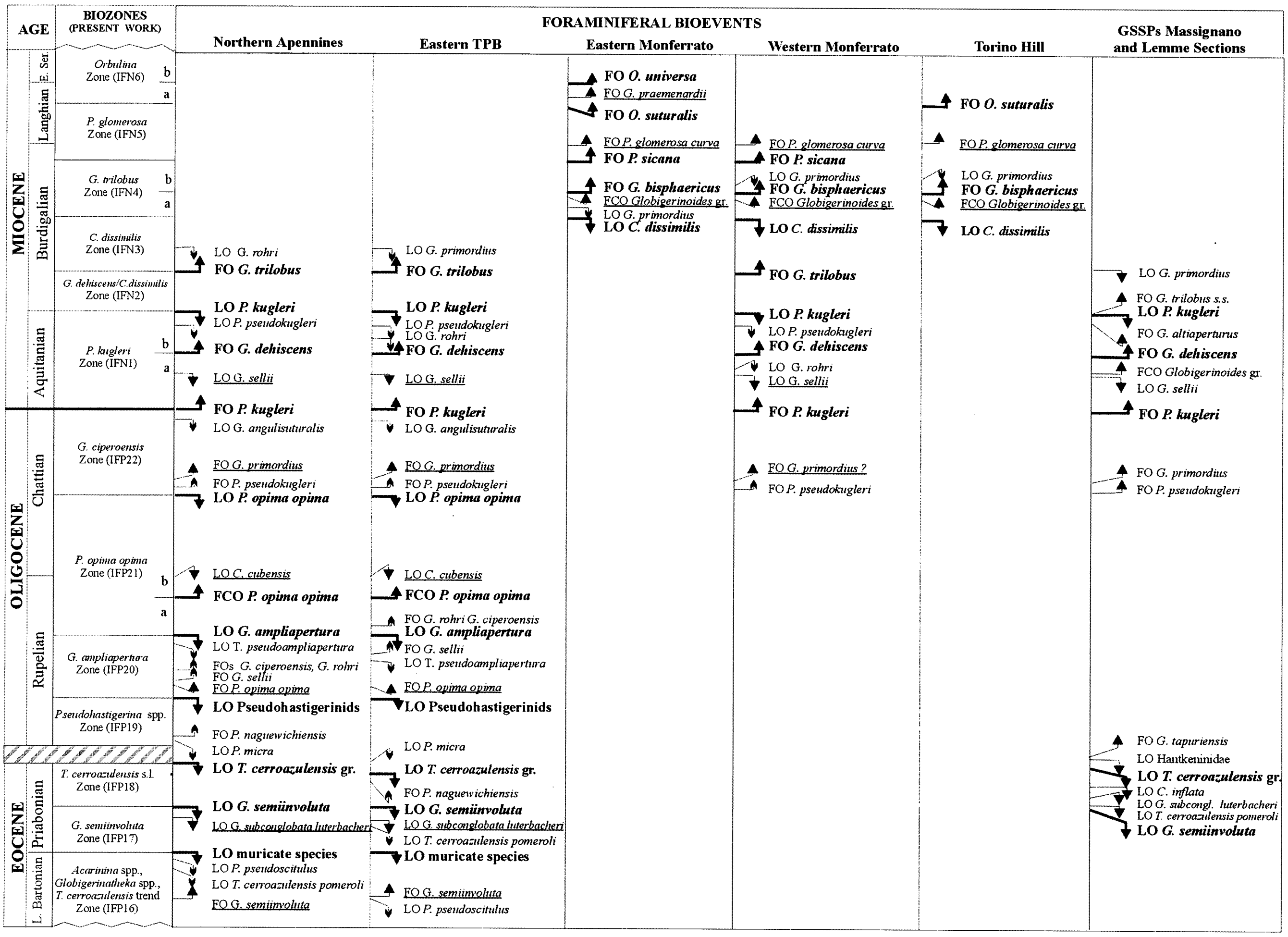
LO of *Globigerina ampliapertura* (primary event)

This event, as proposed by Berggren and Miller (1988) and by Spezzaferri (1994), defines the upper boundary of the *Globigerina ampliapertura* Interval Zone (IFP20 Zone). In the oceanic record this event falls in the lower portion of Chronozone C11r (about 30.3 Ma, Berggren et al. 1995).

The LO of *G. ampliapertura* can be considered a reliable bioevent for zonal boundary definition because the marker species is easily recognizable. *G. ampliapertura* shows a wide intraspecific variability and a rare to very rare distribution, but it is continuously present throughout its range; its last occurrence is abrupt.

FCO of *Paragloborotalia opima opima* (primary event)

This event is here proposed to subdivide the *P. opima opima* Interval Zone (IFP21 Zone) into two subzones (a and b) in place of the LO of *C. cubensis*. In the Cagnero and Pieve d'Accinelli sections, both located in the Umbria-Marche Appennines and proposed as possible GSSPs sections, this event lies in the upper



TEXT-FIGURE3
Planktonic foraminiferal bioevents recorded in the studied areas and in the GSSPs Massignano and Lemme sections. Primary events are in bold; secondary homotaxial events are underlined.

portion of Chronozone C9r (about 28.2 Ma) just below the LO of *Chiloguembelina cubensis* (Coccioni et al. 1999).

The FCO of *P. opima opima* can be considered a good reliable event for correlations in the studied areas. This species, easily recognizable by its peculiar subquadrangular shape, first occurs in low abundance just before the LO of *G. ampliapertura,* and becomes well established and abundant (>5% of the planktonic assemblages) only above. Since the position of the first common and continuous occurrence of this taxon is easily correlatable among the various sections (text-fig. 4), it has been used for subzonal boundary definition.

LO of *Chiloguebelina cubensis* (secondary event)

This event has been used by Berggren and Miller (1988), by Spezzaferri (1994) and by Mancin and Pirini (2001) to subdivide the *P. opima opima* Interval Zone into two subzones. It also marks the Rupelian/Chattian boundary in the Cagnero and Pieve d'Accinelli sections, where this event lies in the lower portion of Chronozone C9n (about 27.8 Ma; Coccioni et al. 1999).

The LO of *C. cubensis* can be considered a weakly reliable biohorizon for zonal boundary definition since the marker species is not easy to recognize for its small size (40-80 µm) and its taxonomic features, visible with a SEM microscope only. Moreover this taxon is usually poorly preserved in the studied sections, making it difficult to distinguish between the genera *Chiloguembelina* and *Streptochilus*. Finally *C. cubensis* is also rare to very rare. For these reasons we prefer to use the FCO of *P. opima opima* to define the boundary between the Subzones a and b (IFP21 Zone) and to consider the LO of *C. cubensis* as a secondary event.

LO of *Paragloborotalia opima opima* (primary event)

This event, as proposed by numerous authors (Bolli and Saunders 1985, Berggren and Miller 1988, Spezzaferri 1994, Mancin and Pirini 2001), defines the upper boundary of the *P. opima opima* Interval Zone (IFP21 Zone). In the oceanic record it falls in the uppermost part of Chronozone C9n (about 27.1 Ma, Berggren and Miller 1988; Berggren et al. 1995).

The LO of *P.opima opima* can be considered a fairly to moderately reliable bioevent because the easily recognizable zonal marker, becomes abruptly rare and discontinuous in its final range. However we prefer to use the LO of *P. opima opima* and not the just preceding LCO, because this event correlates better with other Mediterranean successions.

FO of *Globigerinoides primordius* (secondary event)

This event, utilized here as a secondary event, has been used by Blow (1969) to identify the lower boundary of the *Globigerinoides quadrilobatus primordius/Globorotalia kugleri* Zone. In the GSSP Lemme section, this bioevent lies in the upper portion of Chronozone C7n (about 24.7 Ma, Iaccarino et al. 1996).

The FO of *G. primordius* can be considered a fairly reliable bioevent because the marker species, even if usually very rare to rare in its initial range, is easily recognizable by a single secondary opening, located on the spiral side of the last chamber. However this event, that slightly follows the LO of *P. opima opima*, can help in placing this latter bioevent correctly, when *P. opima opima* is reworked. Moreover the LO of *G. primordius* has been detected in most of the outcropping areas (text-fig. 4).

FO of *Paragloborotalia kugleri* (primary event)

This event, as proposed by various authors (Bolli 1957b, Srinivasan and Kennett 1983, Berggren and Miller 1988, Spezzaferri 1994, Novaretti et al. 1995, Mancin and Pirini 2001), defines the upper boundary of the *Globigerina ciperoensis* Interval Zone (IFP22 Zone). It also approximates the Oligocene/Miocene boundary in the GSSP Lemme section, where this event lies about 2 m above the boundary, in the lowermost part of Chronozone C6Cn2n (about 23.8 Ma, Iaccarino et al. 1996).

The FO of *P. kugleri* appears as a fairly reliable biohorizon since the marker species is continuously present throughout its range even if usually very rare to rare and not easily recognizable. This is due to its small size (<125 μm) and its taxonomic features, different from those of the oceanic specimens. In particular, *P. kugleri* is here characterized by fewer chambers in the last whorl (6 rarely 7), moderately subacute peripheral margin and less prominent dorsal side with gently curved sutures (see Mancin and Pirini 2001, plate 5, fig. 3). However, the FO of *P. kugleri* is the only planktonic foraminiferal bioevent that closely approximates the Oligocene/Miocene boundary in Mediterranean and oceanic successions and can be consistently used to define the upper boundary of Zone P22.

LO of *Globoquadrina sellii* (secondary event)

This event is here utilized as a secondary biohorizon. No paleomagnetic data are available for this bioevent.

The LO of *G. selli* appears as a reliable biohorizon since this species is quite easily recognizable for its large size and subcircular shape with three subspherical chambers in the last whorl. Moreover, this event is easily detectable for the abrupt decrease in abundance and extinction of the marker species, which is frequent to common and continuously present in the underlying levels. However, this event has not been detected in all the outcropping areas (text-fig. 4).

The LO of *G. sellii* can help in placing the Oligocene/Miocene boundary in areas, such as the Alps and Appennines region, where *P. kugleri* may be absent or represented by specimens quite different from those of fully developed tropical forms.

FO of *Globoquadrina dehiscens* (primary event)

This event is used, as proposed by Srinivasan and Kennett (1983), Novaretti et al. (1995) and Mancin and Pirini (2001), to subdivide the *P. kugleri* Total Range Zone (IFN1 Zone) into two subzones, in place of the differentiation level of the *Globigerinoides* genus. This group, in fact, first common occurs later in the studied sections, after the LO of *Catapsydrax dissimilis*. The FO of *G. dehiscens* also defines the lower boundary of the *G. dehiscens-C. dissimilis* Interval Zone in the scheme of Iaccarino (1985). In the GSSP Lemme section this horizon lies in the lowermost portion of Chronozone C6Br (about 22.5 Ma, Iaccarino et al. 1996).

The FO of *G. dehiscens* can be considered a reliable bioevent for zonal boundary definition, since the zonal marker is easily and clearly recognizable and shows a sharp increase in abundance just after its FO. Moreover it has been detected in all the outcropping areas (text-fig. 4).

LO of *Paragloborotalia kugleri* (primary event)

This event, as proposed by various authors (Bolli 1957b, Srinivasan and Kennett 1983, Berggren and Miller 1988, Spezzaferri 1994, Novaretti et al. 1995, Mancin and Pirini 2001), defines the upper boundary of the *P. kugleri* Total Range Zone (IFN1 Zone). It also approximates, as in Mancin and Pirini (2001), the Aquitanian/Burdigalian boundary, because *Globigerinoides altiapertus* first occurs later. In the GSSP Lemme section, this event falls in the lower part of Chronozone C6AAr1r (about 20 Ma, Iaccarino et al. 1996).

This event is a fairly to moderately reliable biohorizon as the marker species is usually rare and becomes discontinuously present in its final range.

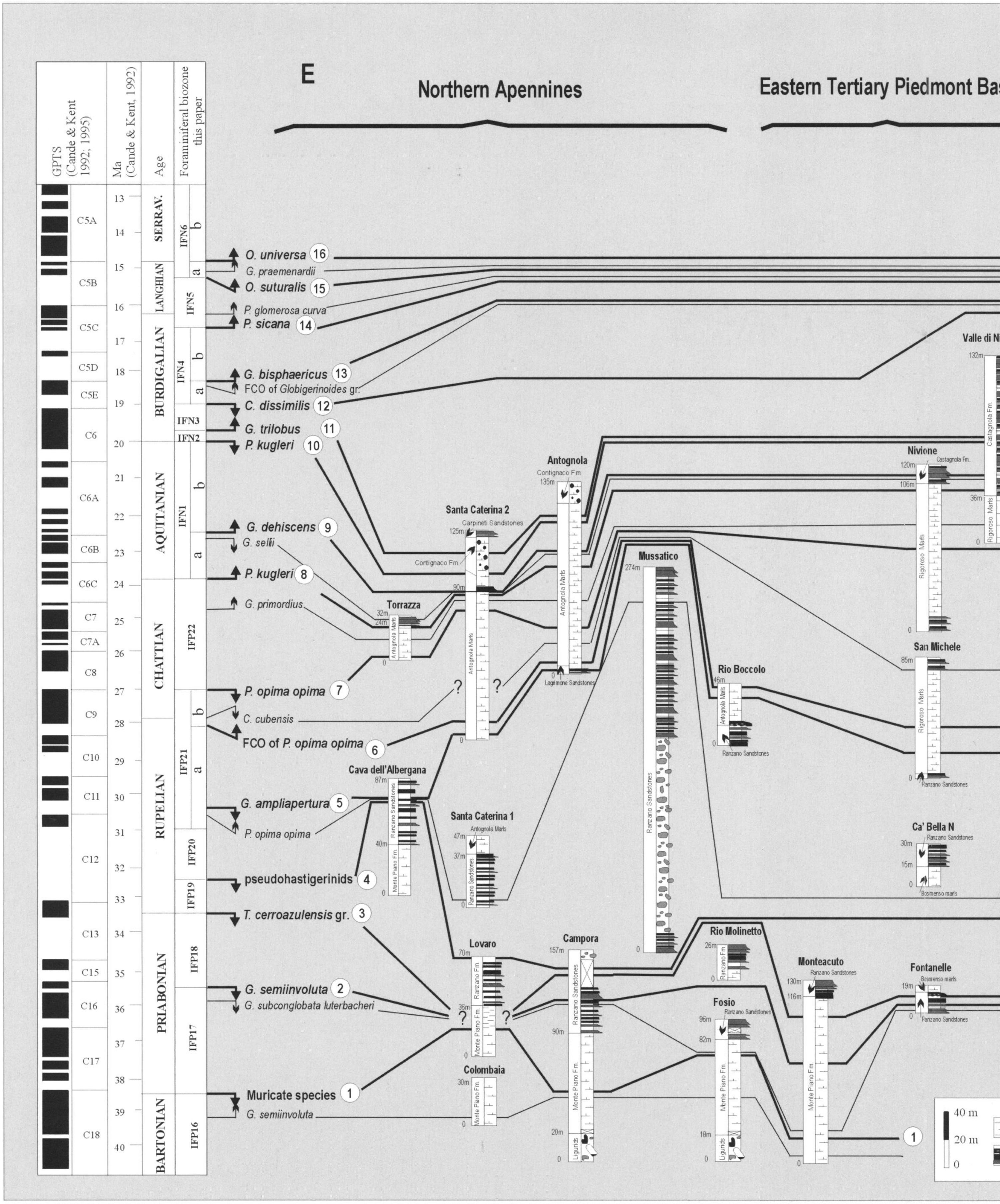
FO of *Globigerinoides trilobus* (primary event)

This event is here proposed as zonal boundary to subdivide the interval between the LO of *P. kugleri* and the LO of *C. dissimilis* (= N5/N6 Zones of Blow, 1969), because *Globigerinatella insueta* is absent. This event, in spite of its weak reliability, is in fact the only biohorizon that can approximate said boundary. *G. trilobus* slowly increases in abundance after its FO, sometimes discontinuously. Moreover it has not been detected in all our sections and, in the Mediterranean area, can occur diachronously.

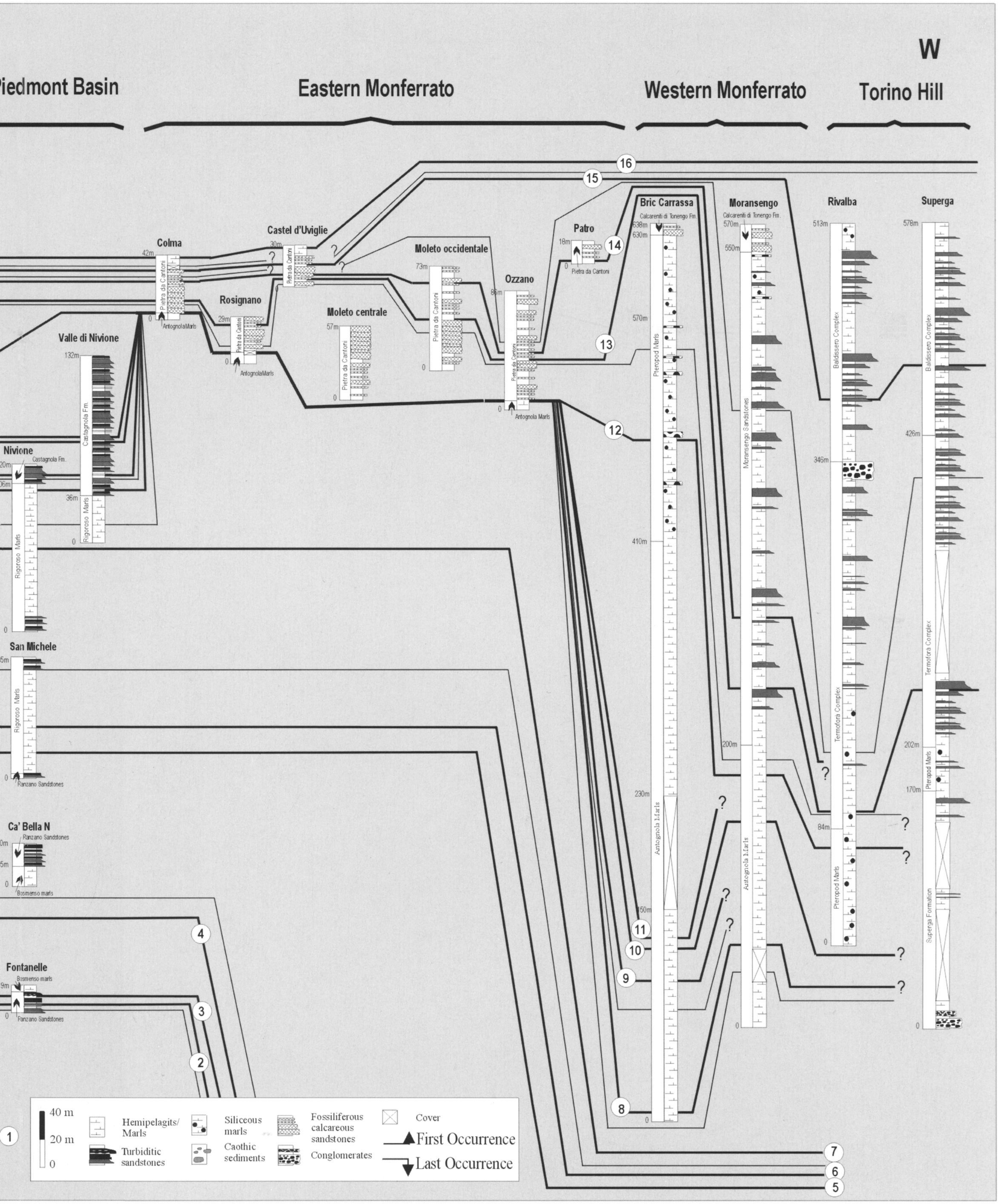
In the studied sections it occurs between the LO of *P. kugleri* and the LO of *C. dissimilis* as reported for adjacent Appennine successions, such as in the Serra di Porta section (Bonazzi and Fregni 1987). In the GSSP Lemme section, this horizon coincides with the LO of *P. kugleri* in the upper part of Chronozone C6AAr1R (about 20 Ma, Iaccarino et al. 1996). In the same section, however, some ancestor specimens (*Globigerinoides* cfr. *trilobus*, see Iaccarino et al. 1996), very difficult to differentiate from *G. immaturus,* first occur in the *P. kugleri* Total Range Zone, whereas typical specimens (*G. trilobus* s.s., see Iaccarino et al. 1996) first occur only later, after the LO of *P. kugleri*. Studies still ongoing in the area, can better test the reliability of this event.

LO of *Catapsydrax dissimilis* (primary event)

This event, as proposed by numerous authors (Srinivasan and Kennett 1983, Bolli and Saunders 1985, Berggren and Miller 1988, Spezzaferri 1994, Bicchi et al. 1994, Novaretti et al. 1995), identifies the upper boundary of the *C. dissimilis* Interval Zone (IFN3 Zone). In the Mediterranean area and in adjacent Monferrato sections (Villadeati-Godio) this event falls in the lowermost part of Chronozone C5E (about 19 Ma, Foresi et al. 1998, d'Atri et al. 2001). In the high latitude oceanic record the LO of *C. dissimilis* occurs later, above the FO of *Globigerinoides bisphaericus* and just below the FO of



TEXT-FIGURE 4
Biostratigraphical correlation scheme of the upper Bartonian-lower Serravallian Monferrato and Epiligurian successions. Primary events are numbered and in bold.



ed and in bold.

Praeorbulina sicana, in the lower part of Chronozone C5Dn (about 17.3 Ma, Miller et al. 1991; Berggren et al. 1995).

The LO of *C. dissimilis* can be considered a reliable biohorizon because the marker species is easily recognizable from its taxonomic features even if it gradually decreases in abundance before its LO.

FCO of *Globigerinoides* group (secondary event)

This event, proposed here as a secondary event, has been used by Spezzaferri (1994) to subdivide the *P. kugleri* Zone into two subzones.

In the oceanic realm, this bioevent lies in the upper part of Chronozone C6C, above the FO of *P. kugleri* (Spezzaferri 1994). In the studied sections it occurs just below the FO of *Globigerinoides bisphaericus* and above the LO of *C. dissimilis*. For this reason it has been correlated to the upper portion of Chronozone C5E (about 18.4 Ma).

The FCO of the *Globigerinoides* gr. can be considered a weakly reliable bioevent. In fact, although planktonic foraminiferal assemblages quickly become dominated by *Globigerinoides* in most of the studied areas (text-fig. 4), it has not yet been sufficiently tested for the Mediterranean area, where it may occur diachronously. For this reason, we prefer to use the FO of *G. bisphaericus* to subdivide the *Globigerinoides trilobus* Interval Zone (IFN4 Zone).

FO of *Globigerinoides bisphaericus* (primary event)

This event is used, as proposed by Bicchi et al. (1994), to subdivide the *G. trilobus* Interval Zone (IFN4 Zone) into two subzones. In the oceanic record (DSDP Site 608, North Atlantic; Miller et al. 1991) this event lies in the upper part of Chronozone C5E (about 18.2 Ma).

The FO of *G. bisphaericus* can be considered a reliable bioevent because the zonal marker, easily and clearly recognized for a largely enveloping last chamber almost completely hiding the umbilicus, sharply increases in abundance after its FO. Moreover, this event has been recognized in most of the studied areas (text-fig. 4) and also in adjacent outcrops, like that of the Bismantova Group in the Northern Appennines (Bonazzi and Fregni 1987; Fregni and Panini 1995) .

FO of *Praeorbulina sicana* (primary event)

This event, as proposed by Bicchi et al. (1994), defines the upper boundary of the *G. trilobus* Interval Zone (IFN4 Zone), in place of the weakly to fairly reliable FO of *Praeorbulina glomerosa curva*. In the Langhian stratotype section (Tertiary Piedmont Basin) this event falls in the middle part of Chronozone C5Cn2n (about 16.6 Ma, Fornaciari et al. 1997).

The FO of *P. sicana* represents the first occurrence of the genus *Praeorbulina*, the ancestor of the *Orbulina* lineage; for this reason we prefer to use this biohorizon as zonal boundary, in place of the FO of. *P. glomerosa curva,* proposed as a secondary event.

This event can be considered a fairly to moderately reliable bioevent because the marker species, is sometimes poorly preserved in the studied sections, making it difficult to identify the four supplementary apertures, peculiar to this species, around the base of the last chamber.

FO of *Praeorbulina glomerosa curva* (secondary event)

This event, proposed here as a secondary event, has been used by various authors (Bolli 1966, Blow 1969, Iaccarino 1985) to define the upper boundary of the *G. trilobus* Zone and the Burdigalian/Langhian boundary. In the oceanic realm this event lies in the uppermost part of Chronozone C5Cn (about 16.1-16.3 Ma, Miller et al. 1991; Berggren et al. 1995).

The FO of *P. glomerosa curva* can be considered a weakly to fairly reliable bioevent, because, in the studied sections, the marker species is usually poorly preserved, making it difficult to identify the seven very small supplementary apertures, peculiar to this species, around the base of the last chamber.

FO of *Orbulina suturalis* (primary event)

This event, as proposed by Iaccarino 1985, defines the upper boundary of the *P. glomerosa* Interval Zone (IFN5 Zone) in spite of its fair reliability, because it is the only biohorizon that marks said boundary. It has been also used by Berggren et al. (1985, 1995) to approximate the Langhian/Serravallian boundary. In the oceanic record this event falls in the middle part of Chronozone C5Bn (about 15.1 Ma; Berggren et al. 1995) whereas in the Mediterranean area (Foresi et al. 1998) it lies at the C5ADr/C5Bn Chronozone boundary (about 14.7 Ma). In the Mediterranean area the Langhian/Serravallian boundary is drawn at the FO of *O. universa*, following the proposal of Bizon et al. (1979) and Iaccarino (1985), because the FO of *O. suturalis* is not used in extra-Mediterranean biostratigraphic zonations (Fornaciari et al. 1997; with references therein).

In some studied sections, *O. suturalis* is locally poorly preserved preventing distinction between it and other *Praeorbulina* species, for example from *P. glomerosa circularis*, which differs in having all the apertures confined to the sutures only.

FO of *Globorotalia praemenardii* (secondary event)

This event, here proposed as a secondary biohorizon, has been used by Iaccarino (1985) and Foresi et al. (1998) to define the upper boundary of the *Orbulina universa* Subzone (Subzone b). In the Mediterranean area (Foresi et al. 1998) this event lies in the lowermost portion of Chronozone 5ACn (about 14.1 Ma), above the FO of *O. universa*. In the Colma section (text-fig. 1, n° 7) the FO of *G. praemenardii* precedes the FO of *O. universa*, preventing the use of the biozonation of Iaccarino (1985).

The FO of *G. praemenardi* can be considered a weakly reliable biohorizon since this event has been detected in one section only, and because this species is not easily distinguished from its younger *G. menardii* specimens, sometimes also with transitional forms between the two taxa. Moreover, the species abundance is very variable above all in its initial range, where it is rare to very rare and discontinuously present.

FO of *Orbulina universa* (primary event)

This event, as proposed by Iaccarino (1985) and Foresi et al. (1998), defines the lower boundary of the *O. universa* Subzone. It also marks the Langhian/Serravallian boundary as proposed by Bizon et al. (1979) and Iaccarino (1985). According to some authors (Vervolet, 1966, Blow, 1969, Rio et al. 1997, Foresi et al. 1998, 2002, Sprovieri 2002) the foraminiferal bioevent that closely approximates the Langhian/Serravalian boundary is the LO of *Globorotalia peripheroronda*. This species, however, is always rare to absent and discontinuously present in its final range in the Mediterranean area and therefore, the same authors proposed the FO of *O. universa* as substitute event to mark the

Langhian/Serravallian boundary. In the Tremiti Islands the FO of *O. universa* occurs in the lowermost part of Chronozone 5ADn (about 14.3 Ma, Foresi et al. 1998).

In the studied sections this event can be considered a moderately reliable biohorizon since the marker species is easily recognizable by its completely spherical test, which only shows the early chambers when broken. However, it has not yet been sufficiently tested for the Mediterranean area, where it probably occurs diachronously (Casolari et al. 2000)

Other events

Other bioevents, unreliable but utilized locally in the biostratigraphic resolution for restricted areas have also been recognized (Table 1 and 1B). These events are: LOs of *Planorotalites pseudoscitulus*, *Turborotalia cerroazulensis pomeroli* and *Pseudohastigerina micra*, FOs of *Pseudohastigerina naguewichiensis*, *Globoquadrina sellii*, *Globigerina ciperoensis* and *Globoquadrina rohri*, LO of *Turborotalia pseudoampliaperura*, FO and LO of *Paragloborotalia pseudokugleri*, LO of *Globigerina angulisuturalis*, LO of *Globoquadrina rohri,* and finally LO of *Globigerinoides primordius*.

PROPOSED PLANKTONIC FORAMINIFERAL ZONAL SCHEME

The zonal scheme proposed here represents the synthesis, with minor changes, of the biozonations of Novaretti et al. (1995) and Mancin and Pirini (2001) with the addition of new unpublished sections located in the Secchia valley. This synthesis consists in an extension of the area of applicability from the Northern Appennines to the Monferrato and Torino Hill successions, spanning also a broader temporal range (late Bartonian to early Serravallian), (text-figs. 5,6).

The main changes are: the FCO of *P. opima opima,* used to subdivide the *P. opima opima* Interval Zone (IFP21 Zone) in place of the weakly reliable LO of *C. cubensis* and the FO of *G. trilobus,* used to subdivide the interval between the LO of *P. kugleri* and the LO of *C. dissimilis* (=N5/N6 of Blow 1969) because *G. insueta* is absent. A very short description is reported for the biostratigraphic zones established in the present paper.

Acarinina spp., *Globigerinatheka* spp. and *Turborotalia cerroazulensis* Assemblage Zone (IFP16 p.p.)

Authors: Mancin and Pirini (2001)

Definition: interval, with the zonal markers, defined at the top by the LO of muricate species. The base of this zone never crops out in the studied areas.

Age: Late Bartonian.

Reference sections (text-figs. 1and 4): Colombaia (25), Lovaro (28), Campora (23), Fosio (20), Monteacuto (17).

Remarks: G. semiinvoluta first appears in the upper part of this zone. *Planorotalites pseudoscitulus* and *Globigerina senni* last occur in the middle-upper part of this zone.

This interval corresponds to the *T. rohri* Zone (Bolli 1957a) and is correlated to the P14 Zone and the lower portion of the P15 Zone of Berggren and Miller (1988).

Globigerinatheka semiinvoluta Interval Zone (IFP17)

Authors: Bolli (1957a), modified by Proto Decima and Bolli (1970)

Definition: interval from the LO of muricate species to the LO of *G. semiinvoluta.*

Age: Early Priabonian.

Reference sections (text-figs. 1and 4): Lovaro (28), Campora (23), Fosio (20), Monteacuto (17), Fontanelle (12).

Remarks: G. subconglobata luterbacheri last occurs in the uppermost part of this zone.

This interval corresponds to the upper portion of the P15 Zone and the lower part of the P16 Zone of Berggren and Miller (1988).

Turborotalia cerroazulensis Interval Zone (IFP18)

Authors: Bolli (1957a), modified by the same author in 1972.

Definition: interval from the LO of *G. semiinvoluta* to the LO of *T. cerroazulensis* lineage.

Age: Late Priabonian.

Reference sections (text-figs. 1and 4): Lovaro (28), Campora (23), Rio Molinetto (19), Monteacuto (17), Fontanelle (12).

Remarks: The pseudohastigerinid group markedly reduces in size (<125μm) and sometimes, *P. naguewichiensis* first occurs just before the LO of *T. cerroazulensis* lineage.

This interval corresponds to the P16 p.p. and P17 Zones of Berggren and Miller (1988).

Pseudohastigerina spp. Interval Zone (IFP19)

Authors: Mancin and Pirini (2001)

Definition: interval from the LO of *T. cerroazulensis* lineage to the LO of pseudohastigerinids.

Age: Early Rupelian.

Reference sections (text-figs. 1 and 4): Cava dell'Albergana (30), Lovaro (28), Campora (23), Monteacuto (17), Fontanelle (12).

Remarks: The genus *Chiloguembelina* and the species *Cassigerinella chipolensis* are absent in the studied sections. *C. chipolensis* characterizes this interval in tropical oceanic areas but, in the Northern Appennines, it first occurs only in the lower part of the *Paragloborotalia opima opima* Zone (Late Rupelian). Locally, *Globigerina ampliapertura* first appears in the upper part of the zone.

This interval corresponds to the *C. chipolensis/P. micra* and to the lower portion of the *Globigerina ampliapertura* Zones in the scheme of Bolli and Saunders (1985).

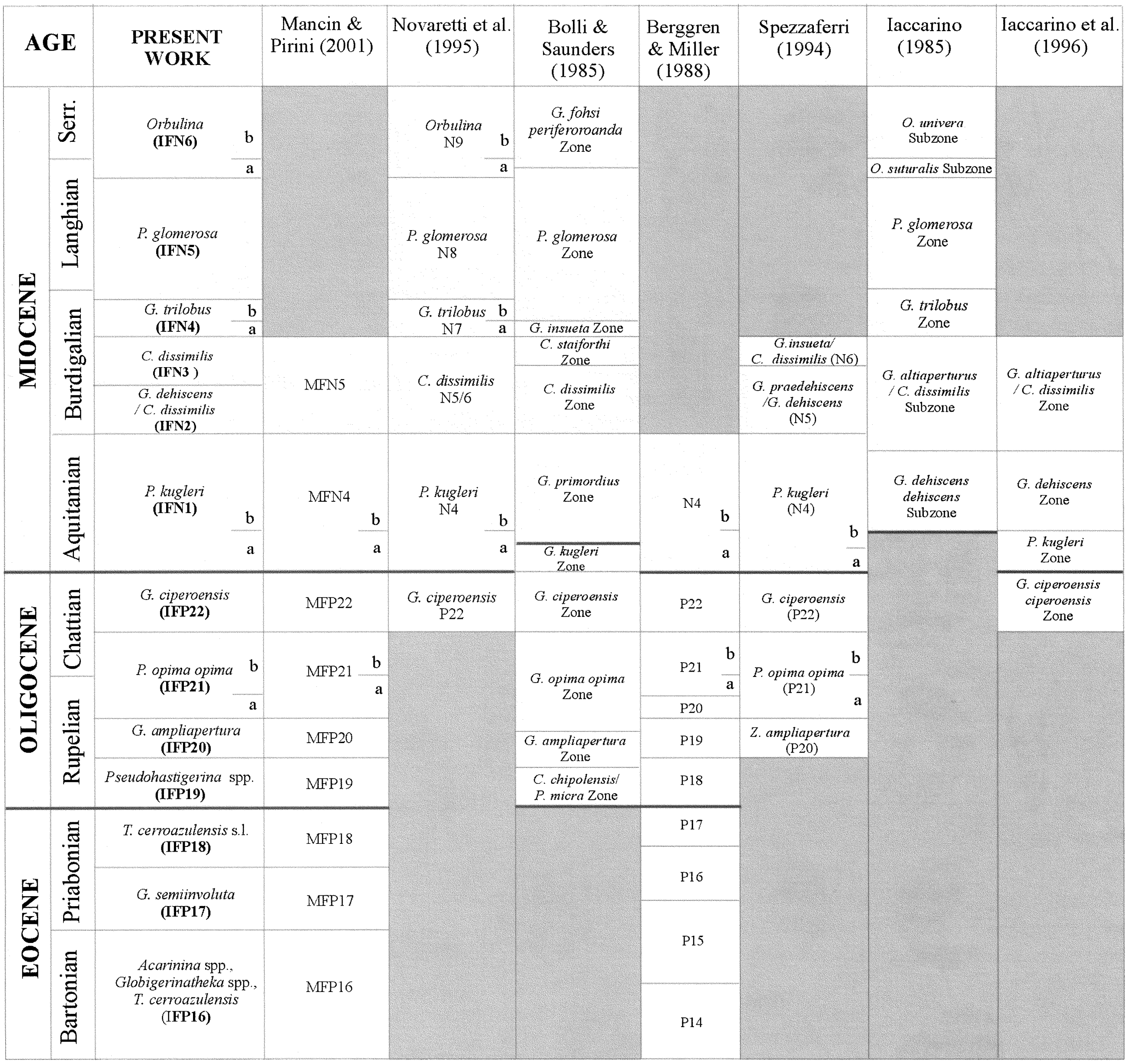
Globigerina ampliapertura Interval Zone (IFP20)

Authors: Bolli (1957b), amended by Spezzaferri (1994).

Definition: interval from the LO of pseudohastigerinids to the LO of *G. ampliapertura.*

Age: Late Rupelian.

Reference sections (text-figs. 1 and 4): Cava dell'Albergana (30), Santa Caterina 1 and 2 (26,27), Antognola (22), Mussatico (24), Rio Boccolo (21), Ca' Bella N (13) San Michele (16).



TEXT-FIGURE 5
Summary of middle Eocene to middle Miocene planktonic foraminiferal zonal schemes. In bold lines are the Eocene/Oligocene and the Oligocene/Miocene boundaries according to the various authors.

Remarks: P. opima opima and *Globoquadrina sellii* first appear in the middle-upper part of this zone. *Turboratalia pseudoampliapetura* last occurs just before the upper boundary.

This interval corresponds to the *G. ampliapertura* p.p. Zone and to the lower portion of the *P. opima opima* Zone in the scheme of Bolli and Saunders (1985) and to the P19 Zone of Berggren and Miller (1988).

Paragloborotalia opima opima Interval Zone (IFP21)

Authors: Bolli (1957b), amended by Spezzaferri (1994).

Definition: Interval from the LO *G. ampliapertura* to the LO of *P. opima opima*. As in Spezzaferri (1994) two subzones are recognized.

Subzone a (IFP21a)

Authors: Spezzaferri (1994), amended in this paper.

Definition: interval from the LO *G. ampliapertura* to the FCO of *P. opima opima* (replacing the LO of *C. cubensis*)

Age: Late Rupelian.

Reference sections (text-figs. 1 and 4): Santa Caterina 2 (27), Antognola (22), Rio Boccolo (21), San Michele (16).

Description: The marker species is usually rare (<5% of the planktonic assemblage) but continuously present. The planktonic assemblage is characterized by *Catapsydrax* (above all *C. dissimilis*), *Globigerina* (*G. venezuelana*, *G. euapertura*, *G. ouachitaensis*, *G. ciperoensis* and *G. angulisuturalis*), *Globoquadrina* (*G. selli*, *G. tripartita* and *G. rohri*). Frequent tenuitellids and rare *Chiloguembelina* spp. and *C. chipolensis* characterized the small size fractions.

Remarks: Locally, *Globoquadrina rohri* and *Globigerina ciperoensis* first appear in the lower-middle part of the subzone.

This interval corresponds to the P20 and P21 p.p. Zones of Berggren and Miller (1988).

Subzone b (IFP21b)

Authors: Spezzaferri (1994), amended in this paper

Definition: interval from the FCO to the LO of *P. opima opima.*

Age: Latest Rupelian-Early Chattian.

Reference sections (text-figs. 1 and 4): Torrazza (29), Santa Caterina 2 (27), Antognola (22), Rio Boccolo (21), San Michele (16), Nivione (15).

Description: P. opima opima is frequent to common and continuously present, however it usually becomes rare and discontinuous towards the top. Planktonic assemblage is similar to that of the previous subzone.

Remarks: C. cubensis disappears in the lowermost part of the subzone.

This interval corresponds to the P21 p.p. Zone of Berggren and Miller (1988).

***Globigerina ciperoensis* Interval Zone (IFP22)**

Authors: Cushman and Stainforth (1945), amended by Bolli (1957b).

Definition: Interval from the LO of *P. opima opima* to the FO of *P. kugleri.*

Age: Late Chattian.

Reference sections (text-figs. 1 and 4): Torrazza (29), Santa Caterina 2 (27), Antognola (22), Nivione (15), Valle di Nivione (14), Colma (7), Rosignano (8), Ozzano (11), Bric Carrassa (3).

Remarks: Paragloborotalia pseudokugleri and *Globigerinoides primordius* first appear in the middle-upper part of this zone, whereas *Globigerina angulisuturalis* last occurs just before the FO of *P. kugleri*. In the Moransengo section (Western Monferrato) *G. primordius* and *P. kugleri* first occur together; however missing stratigraphy (about 20m) prevents the relative placing of these two bioevents. *G. primordius,* in fact, probably first occurs earlier, just above the FO of *P. pseudokugleri* as also recorded for other adjacent sections.

This interval corresponds to the P22 Zone of Berggren and Miller (1988) and Spezzaferri (1994).

***Paragloborotalia kugleri* Total range Zone (IFN1)**

Authors: Bolli (1957b).

Definition: Interval defined by the total range of the zonal marker. As in Srinivasan and Kennett (1983), two subzones are recognized.

Remarks: In the Eastern Monferrato sections the interval between the IFP22 p.p.-IFN3 p.p. Zones is absent, corresponding to the discontinuity surface between the fine-grained Antognola sediments and the overlying carbonatic facies of the "Pietra da Cantoni" Group (text-fig. 4).

Subzone a (IFN1a)

Authors: Srinivasan and Kennett (1983).

Definition: interval from the FO of *P. kugleri* to the FO of *G. dehiscens.*

Age: Early Aquitanian.

Reference sections (text-figs. 1 and 4): Torrazza (29), Santa Caterina 2 (27), Antognola (22), Nivione (15), Valle di Nivione (14), Bric Carrassa (3), Moransengo (4).

Remarks: G. sellii disappears in the upper part of the subzone. Radiolaria first appear in the finer grain size (< 125μm) within this subzone.

This interval corresponds to the *G. kugleri* Zone and the lower part of the *G. primordius* Zone in the scheme of Bolli and Saunders (1985), to the N4a Subzone of Berggren and Miller (1988), to the N4a and N4b p.p. Subzones of Spezzaferri (1994), and finally to the *P. kugleri* Zone of Iaccarino et al. (1996).

Subzone b (IFN1b)

Authors: Srinivasan and Kennett (1983).

Definition: interval from the FO of *G. dehiscens* to the LO of *P. kugleri.*

Age: Aquitanian.

Reference sections (text-figs. 1 and 4): Santa Caterina 2 (27), Antognola (22), Nivione (15), Valle di Nivione (14), Bric Carrassa (3), Moransengo (4).

Remarks: P. pseudokugleri disappears in the upper part of the subzone. Radiolaria group shows an increase in size (>125μm) and becomes frequent to common within this subzone.

This interval corresponds to the *G. primordius* p.p. Zone in the scheme of Bolli and Saunders (1985), to the N4b Subzone of Berggren and Miller (1988), to the N4b p.p. Subzone of Spezzaferri (1994) and finally, to the *G. dehiscens* and lower part of the *G. altiaperturus/C. dissimilis* Zones of Iaccarino et al. (1996).

***Globoquadrina dehiscens/Catapsydrax dissimilis* Interval Zone (IFN2)**

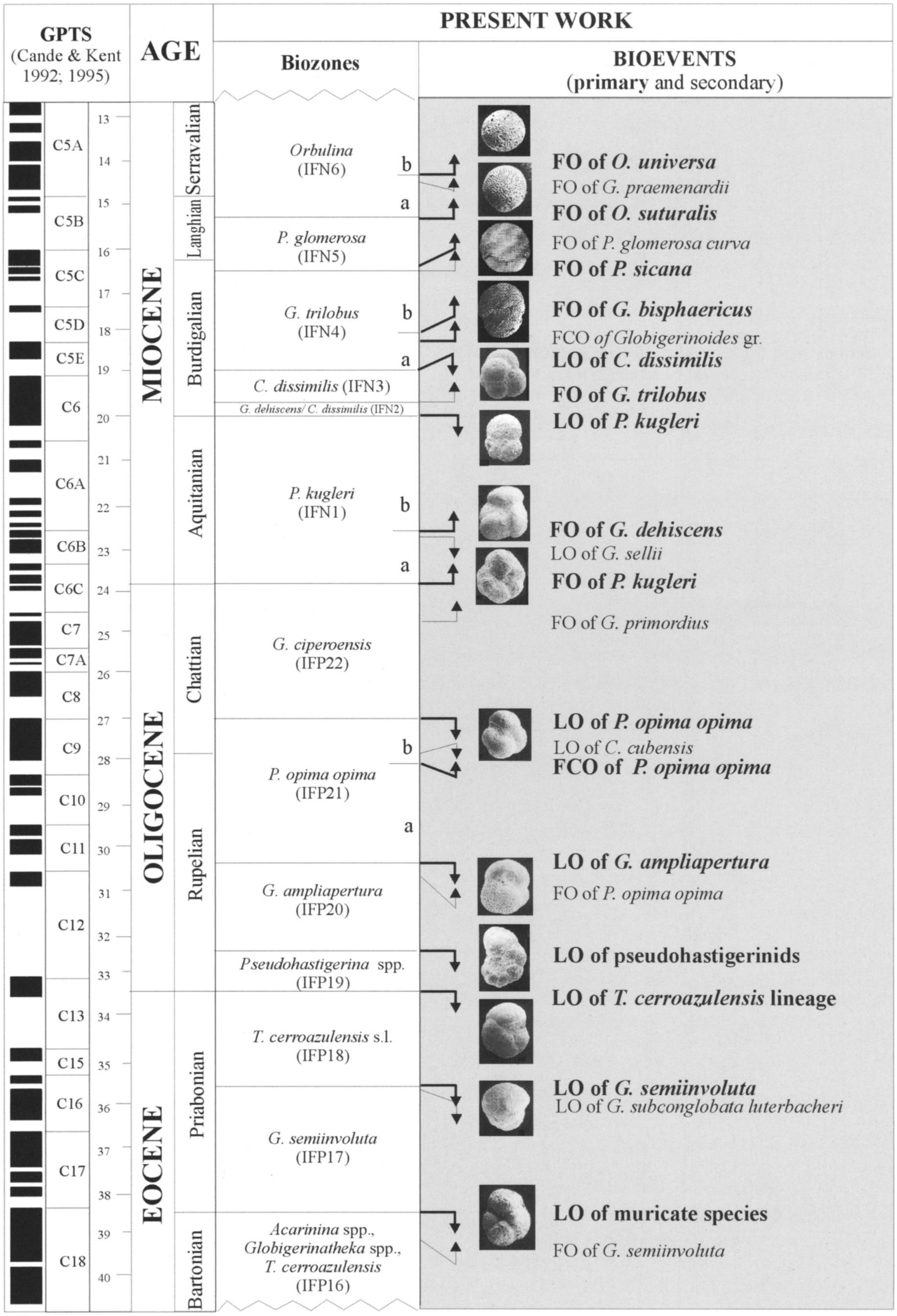
Authors: present paper.

Definition: interval from the LO of *P. kugleri* to the FO of *G. trilobus.*

Age: Early Burdigalian.

Reference sections (text-figs. 1 and 4): Santa Caterina 2 (27), Antognola (22), Valle di Nivione (14), Bric Carrassa (3), Moransengo (4).

Description: the zonal markers are continuously present throughout the interval with typical specimens. The planktonic assemblage is characterized by abundant *Globigerina venezuelana*, *G. euapertura*, *Globoquadrina dehiscens*, rare *Globigerinoides* (*G. primordius*, *G. immaturus*) *Paraglobo-*



TEXT-FIGURE 6
Proposed biostratigraphical zonal scheme. Main events are in bold.

rotalia semivera, *P. siakensis*, *Zeaglobigerina woodi* and common radiolaria.

Remarks: Locally *G. primordius* disappears within this interval. *G. altiaperturus*, *G. praedehiscens* and *G. insueta* are absent from the studied sections and therefore the standard biozonations of Iaccarino (1985), Bolli and Saunders (1985), Spezzaferri (1994) and Iaccarino et al. (1996) are not applicable. In the previous schemes of Novaretti et al. (1995) and Mancin and Pirini (2001) the interval between the LO of *P. kugleri* and the LO of *C. dissimilis* (=MFN5-MFN6 Zones) had not been subdivided.

This interval corresponds to the *Globigerinoides altiaperturus/Catapsydrax dissimilis* p.p. Zone of Iaccarino et al. (1996), to the N5 p.p. Zone of Spezzaferri (1994) and to the lower portion of the *C. dissimilis* Zone and *C. dissimilis/G. dehiscens* Zone in the schemes of Novaretti et al. (1995) and Mancin and Pirini (2001), respectively.

***Catapsydrax dissimilis* Interval Zone (IFN3)**

Authors: present paper.

Definition: Interval from the FO of *G. trilobus* to the LO of *C. dissimilis.*

Age: Early Burdigalian.

Reference sections (text-figs. 1 and 4): Santa Caterina 2 (27), Antognola (22), Valle di Nivione (14), Bric Carrassa (3), Moransengo (4), Rivalba (2).

Description: The planktonic assemblage is similar to that of the previous zone except for the presence of *G. trilobus* and for the rarity of the foraminiferal fauna, usually poorly preserved.

Remarks: This interval corresponds to the upper part of the *Globigerinoides altiaperturus/Catapsydrax dissimilis* Zone of Iaccarino et al. (1996), to N5 p.p. and N6 Zones of Spezzaferri (1994) and to the upper portion of the *C. dissimilis* Zone and *C. dissimilis/G. dehiscens* Zone in the schemes of Novaretti et al. (1995) and Mancin and Pirini (2001), respectively.

***Globigerinoides trilobus* Interval Zone (IFN4)**

Authors: Bizon and Bizon (1972), amended by Bicchi et al. (1994).

Definition: interval from the LO of *C. dissimilis* to the FO of *Praeorbulina sicana*. As in Bizon (1979) two subzones are recognized.

Subzone a (IFN4a)

Authors: Bizon (1979).

Definition: interval from the LO of *C. dissimilis* to the FO of *G. bisphaericus.*

Age: Burdigalian.

Reference sections (text-figs. 1 and 4): Colma (7), Rosignano (8), Castel d'Uviglie (6), Moleto centrale and Moleto occidentale (9,10), Ozzano (11), Bric Carrassa (3), Moransengo (4), Rivalba (2) and Superga (1).

Remarks: This interval corresponds to the lower portion of the *G. trilobus* Zone in the scheme of Iaccarino (1985).

Subzone b (IFN4b)

Authors: Bizon (1979), amended by Bicchi et al. (1994).

Definition: interval from the FO of *Globigerinoides bisphaericus* to the FO of *P. sicana.*

Age: Late Burdigalian.

Reference sections (text-figs. 1 and 4): Colma (7), Rosignano (8), Castel d'Uviglie (6), Moleto occidentale (9), Ozzano (11), Patro (5), Moransengo (4), Rivalba (2) and Superga (1).

Remarks: G. altiaperturus first appears in the lower part of the subzone.

This interval corresponds to the *G. trilobus* p.p. Zone in the scheme of Iaccarino (1985).

***Praeorbulina glomerosa* s.l. Interval Zone (IFN5)**

Authors: Bizon and Bizon (1972).

Definition: interval from the FO of *P. sicana* to the FO of *Orbulina suturalis.*

Age: Late Burdigalian-Langhian.

Reference section (text-figs. 1 and 4): Colma (7), Rosignano (8), Castel d'Uviglie (6), Moleto occidentale (9), Ozzano (11), Patro (5), Moransengo (4), Rivalba (2) and Superga (1).

Remarks: the evolutionary trend of the *Praeorbulina* genus (*P. glomerosa glomerosa*, *P. glomerosa curva*, *P. circularis*) takes place within this zone. The appearance of *O. suturalis* represents the next step in the evolutionary lineage. This zone corresponds to the uppermost portion of the *G. trilobus* and *P. glomerosa* Zones in the scheme of Iaccarino (1985).

***Orbulina* Interval Zone (IFN6)**

Authors: Bizon and Bizon (1972), amended by Bicchi et al. (1994).

Definition: interval identified at the base by the first occurrence of *O. suturalis*. In the studied sections the upper zone boundary has not been defined. On the basis of the FO of *O. universa*, the first two subzones of Iaccarino (1985) have been recognized.

Subzone a (IFN6a)

Authors: Iaccarino and Salvatorini (1982).

Definition: interval from the FO of *O. suturalis* to the FO of *O. universa.*

Age: Latest Langhian.

Reference sections (text-figs. 1 and 4): Colma (7), Castel d'Uviglie (6), Superga (2) and Rivalba (1).

Remarks: Globorotalia praemenardii first occurs within this subzone.

Subzone b p.p. (IFN6b p.p.)

Authors: to be amended.

Definition: interval defined at the base by the FO of *O. universa*. The top has not been identified. However the FO of *G. praemenardii* within the previous subzone prevents the application of the biozonation by Iaccarino (1985).

Age: Early Serravallian.

Reference sections (text-figs. 1 and 4): Colma (7), Castel d'Uviglie (6).

CONCLUSIONS

Detailed analyses were performed on the planktonic foraminiferal assemblages from 30 stratigraphic sections, cropping out between the Monferrato and Torino Hill areas and the Northern Appennines. The data allowed to propose a new regional biostratigraphic zonal scheme, late Bartonian to early Serravallian in age, valid for the whole studied area. With respect to the previous regional and standard schemes, the proposed biozonation shows better biostratigraphic resolution. The distribution pattern of several species, in fact, established by quantitative methods, allowed to identify about forty bioevents. The testing of these events enabled to recognize that some of these are regional reproducible and reliable and so usable as primary or secondary biohorizons. Other events, valid for other areas or standard biozonations, have been instead recognized as unreliable.

Primary and secondary biohorizons have also been utilized for chronostratigraphic subdivision. In particular, the Bartonian/Priabonian boundary has been approximated by the abrupt extinction of the muricate species of *Acarinina*, *Trucorotaloides* and *Morozovella*. Secondary events recorded just below the boundary are the FO of *G. semiinvoluta* and, locally, the LO of *P. pseudoscitulus*.

The Priabonian/Rupelian boundary has been approximated by the LO of *T. cerroazulensis* lineage. Secondary events recorded near the boundary are the FO of *P. naguewichiensis* and an abrupt reduction in size of the *Pseudohastigerina* group (<125μm) from the boundary up.

The Rupelian/Chattian boundary has been marked by the LO of *C. cubensis*, postdating the FCO of *P. opima opima*. The Chattian/Aquitanian boundary has been approximated by the FO of *P. kugleri*. Secondary events recorded near the boundary are the FO of *G. primordius* below the boundary and the LO of *G. sellii* and the FO of *G. dehiscens*, just above.

The Aquitanian/Burdigalian boundary has been approximated by the LO of *P. kugleri*. *P. pseudokugleri* last occurs just below the boundary, whereas *G. trilobus* first occurs just above.

The Burdigalian/Langhian boundary has been approximated by the FO of *P. glomerosa curva*. The secondary event recorded just below the boundary is the FO of *P. sicana*.

Finally, the Langhian/Serravalian boundary has been approximated by the FO of *O. universa*. Secondary events recorded just below the boundary are the FO of *O. suturalis*, and locally, the FO of *G. praemenardii*.

The proposed scheme is easily correlatable with the standard subdivisions (text-fig. 5) and therefore the area of applicability of this biozonation, with the use of secondary homotaxial events, could be extended to the surrounding basins (Langhe and Paleogene-Neogene foredeep) and also to coeval Mediterranean successions. Moreover this biozonation could help in better defining the stratigraphic and evolutionary history of the studied areas, providing the basis for a better understanding of the geohistory of a sedimentary basin during this time interval (Di Giulio et al. 2002).

Finally, we hope that this work can also add important pieces to the complex biostratigraphical puzzle of the Paleogene and Neogene Mediterranean realm as recently augured by Iaccarino (2002).

ACKNOWLEDGMENTS

Thanks are due to A. Cherchi, M. Cobianchi and S. Radrizzani, for careful review and significant improvement in the initial version of the manuscript. The authors are grateful to H.P. Luterbacher and K. G. Miller for text review and for useful suggestions.

This work was presented at "Cinematiche collisionali: tra esumazione e sedimentazione" 81^ Riunione estiva della Società Geologica Italiana (Torino, 10-12 Settembre 2002) and was financially supported by "Fondi FAR" Prof. M. Cobianchi, Università di Pavia, "Fondi Progetti di ricerca di Ateneo" Prof. C. Pirini, Università di Genova, "Fondi MIUR" Prof. E. Ferrero, Università di Torino and "Fondi MIUR" Prof. G. Valleri, Università di Firenze.

REFERENCES

ABBATE, E. AND SAGRI, M., 1982. Le unità torbiditiche cretaciche dell'Appennino Settentrionale ed i margini continentali della Tetide. Memorie della Società Geologica Italiana, 24: 115-126.

BALDI BECKE, M., GELATI R., RADOVICH, A. and ROBBA, E., 1978. The problem of the Oligocene/Miocene boundary, some relevant biological events. Rivista Italiana di Paleontologia e Stratigrafia, 84(2): 443-455.

BERGGREN, W.A., KENT, D.V. and FLYNN, J.J., 1985. Jurassic to Paleogene: Part 2. Paleogene geochronology and chronostratigraphy. In: Snelling, N.J., Ed., The Chronology of the geological record. Memories of the Geological Society of London. London., 10: 141-195.

BERGGREN, W.A., AND MILLER, K. G., 1988. Paleogene tropical planktonic foraminiferal biostratigrphy and magnetobiochronology. Micropaleontology, 34: 362-378.

BERGGREN, W.A., KENT, D.V., SWISHER, C.C. III and AUBRY, M.P., 1995. A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W.A., Kent, D.V., Aubry, M.P. and Hardenbol, J., Eds., Geochronology, time scales and global stratigraphic correlation. Society of Economic Paleontology and Mineralogy, Special Publication, 54(5), 212 p.

BETTELLI, G., BONAZZI, U., FAZZINI, P. and PANINI, F., 1987. Schema introduttivo alla geologia delle Epiliguridi dell'Appennino modenese e delle aree limitrofe. Memorie della Società Geologica Italiana, 39: 215-244.

BICCHI, E., NOVARETTI, A., FERRERO, E., PIRINI, C. and VALLERI G., 1994. Biostratigrafia della successione oligomiocenica della Collina di Torino e del Monferrato. Atti Ticinensi di Scienze della Terra, Serie Speciale 1: 215-225.

BICCHI, E., DELA PIERRE, F., FERRERO, E., MAIA, F., NEGRI, A., PIRINI, C., RADRIZZANI, S. and VALLERI, G., (in press). Evolution of the Miocene carbonate shelf of Monferrato (North-western Italy). Palaios.

BICE, D.M. and MONTANARI, A., 1988. Magnetostratigraphy of the Massignano section (Ancona, Italy). In: Premoli Silva, I., Coccioni, R. and Montanari, A., Eds., The Eocene - Oligocene boundary in the

Marche - Umbria basin (Italy). Ancona, October 1987, International Subcommission on Paleogene Stratigraphy: 111-118.

BIELLA, G.C., GELATI, R., MAISTRELLO, M., MANCUSO, R., MASSIOTTA, P. and SCARASCIA, S., 1987. The structure of the upper crust in the Alps-Appennine boundary region deduced from refraction seismic data. Tectonophysic, 142: 71-85.

BIGI, G., COSENTINO, D., PAROTTO, M., SARTORI, R. and SCANDONE, P., 1983. Structural model of Italy. Consiglio Nazionale delle Ricerche, progetto finalizzato geodinamica.

BIZON, G., 1979. Planktonic foraminifera. In: Bizon, G. et al. Report of the Working group on Micropaleontology; 7th International Congress on the Mediterranean Neogene, Athens: 3-1340.

BIZON, G. and BIZON, J.J., 1972. Atlas des principaux foraminifères planctoniques du bassin méditerranéen. Oligocène à Quaternaire. Editions Technip, Paris, 316 p.

BIZON, G. and MÜLLER, C., 1979. Report of the working group on micropaleontology; 7th International Conference on the Mediterranean Neogene, Athens: 64-1335.

BLOW, W.H., 1969. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. Proceeding on the First International Conference on Planktonic Microfossils. Genève 1967, 1: 199-422.

BOCCALETTI, M., COLI, M., DECANDIA, F., GIANNINI, E. and LAZZAROTTO, A., 1980. Evoluzione dell'Appennino Settentrionale secondo un nuovo modello strutturale. Memorie della Società Geologica Italiana, 21: 359-373.

BOCCALETTI, M., CALAMITA, F., DEIANA, G., GELATI, R., MASSARI, F., MORATTI, G. and RICCI LUCCHI, F., 1990. Migrating fore deep-thrust belt system in the Northern Appennines and Alps. Palaeogeography, Palaeoclimatology, Palaeoecology, 77: 3-14

BOERSMA, A. and PREMOLI SILVA, I., 1986. Terminal Eocene events: planktonic Foraminifera and isotopic evidence. In: Pomerol, Ch. and Premoli Silva, I., Eds., Terminal Eocene Events: development in Paleontology and Stratigraphy. Amsterdam: Elsevier, 213-224.

BOLLI, H.M., 1957a. Planktonic foraminifera from the Eocene Navet and San Fernando Formations of Trinidad. B.W.I. Bulletin U.S. Natural Museum, 215: 72-155.

———, 1957b. Planktonic foraminifera from the Oligocene-Miocene Cipero and Lengua Formations of Trinidad. B.W.I. Bulletin U.S. Natural Museum, 215: 97-123.

———, 1966. Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera. Boletin Informativo, Asociacion Venezolana de Geologia, mineria y petroleo, 9: 3-32.

———, 1972. The genus *Globigerinatheka* Brönnimann. Journal of Foraminiferal Research, 2(3): 109-136.

BOLLI, H.M. and SAUNDERS, J.B., 1985. Oligocene to Holocene low latitude planktic foraminifera. In: Bolli, H.M., Saunders, J.B. and Perch Nielsen, K., Eds., Plankton Stratigraphy. London, Cambridge: University Press, 155-262.

BONAZZI, U. and FREGNI, P., 1987. La discontinuità di Serra di Porta tra le Formazioni di Antognola e di Bismantova (Pavullo nel Frignano, Appennino Modenese). Memorie della Società Geologica Italiana, 39: 285-295.

CANDE, S.C. and KENT, D.V., 1992. A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. Journal of Geophysical Research, 97: 13917-13951.

———, 1995. Revised calibration of the geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. Journal of Geophysical Research, 100: 6093-6095.

CASOLARI, E., NEGRI, A., PICOTTI, V. and BERTOTTI, G., 2000. Neogene stratigraphy and sedimentology of the Gargano promontory (Southern Italy). Eclogae Geologicae Helvetiae, 93: 7-23.

CAVANNA, F, DI GIULIO, A., GALBIATI, B., MOSNA, S., PEROTTI, C.R. and PIERI, M. 1989. Carta Geologica dell'estremità orientale del Bacino Terziario Ligure Piemontese. Atti Ticinensi di Scienze della Terra, 32.

CLARI, P., PROTO DECIMA, F., RICCI, B. and SAMPÒ, M., 1987. Facies di piattaforma nell'Oligocene medio del Monferrato. Bollettino della Società Paleontologica Italiana, 26 (1-2): 109-118.

CLARI, P., DELA PIERRE, F., NOVARETTI, A. and TIMPANELLI, M., 1994. La successione oligo-miocenica del Monferrato occidentale: confronti e relazioni con il Monferrato orientale e la Collina di Torino. Atti Ticinensi di Scienze della Terra, Serie Speciale 1: 191-203.

———, 1995. Late Oligocene-Miocene sedimentary evolution of the critical Alps/Appennines junction: the Monferrato area, Northwestern Italy. Terra Nova, 7: 144-152.

COCCIONI, R., MONACO, P., MONECHI, S., NOCCH,I S. and PARISI, G., 1988. Biostratigraphy of the Eocene - Oligocene boundary at Massignano (Ancona, Italy). In: Premoli Silva, I., Coccioni, R. and Montanari, A., Eds., The Eocene - Oligocene boundary in the Marche - Umbria basin (Italy). Ancona, october 1987, Elsevier: 59-80.

COCCIONI, R., BICE, D., BRINKHIUS, H, CHAN, L.S., CHURCH, N, D'ATRI, A., DEINO, A., DELLISANTI, F., LIRER, F., MACALADY, A., MAIORANO, P., MCDANIEL, A., MONECHI, S., MONTANARI, A., NINI, C., NOCCHI, M., PROSS, J., ROCHETTE, P., RUFFINI, R., SAGNOTTI, L., TATEO, F., TOUCHARD, Y. and WILLIAMS, G.L., 1999. Preliminary results of the Oligocene integrated stratigraphy (Olis) working group. FIST Geoitalia, Bellaria 20-23 Settembre 1999, abstract, fascicolo 1: 81-82.

D'ATRI, A., DELA PIERRE, F., RUFFINI, R., NOVARETTI, A., COSCA, M.A. AND HUNZIKER, J. C., 2001. Calcareous plankton biostratigraphy and ^{40}Ar/^{39}Ar dating of Miocene volcanoclasting layers from Monferrato (NW Italy). Eclogae Geologicae Helveticae, 94: 137-144.

DI GIULIO, A., MANCIN, N. and MARTELLI, L., 2002. Geohistory of the Ligurian orogenic wedge: first inferences from paleobathymetric data of the Epiligurian sediments. Bollettino della Società Geologica Italiana, Volume Speciale 1: 375-384.

FALLETTI, P., 1994. Caratteri stratigrafici della successione oligo-miocenica nel settore orientale del Monferrato. Atti Ticinensi di Scienze della Terra, Serie Speciale 1: 269-282.

FERRERO, E., 1987. Miogypsinidi della serie oligo-miocenica della Collina di Torino. Bollettino della Società Paleontologica Italiana, 26: 119-150.

FERRERO, E., MAIA, F. and TONON, M. 1994. Biostratigrafia dei livelli bioclastici del Monferrato. Atti Ticinensi di Scienze della Terra, Serie Speciale 1: 227-230.

FORESI, L.M., IACCARINO, S., MAZZEI, R. and SALVATORINI, G., 1998. New data on middle to late Miocene calcareous plankton biostratigraphy in the Mediterranean area. Rivista Italiana di Paleontologia e Stratigrafia, 104(1): 95-114.

FORNACIARI, E. and RIO, D., 1996. Latest Oligocene to Early Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. Micropaleontology, 42 (1): 1-36.

FORNACIARI, E. and RIO, D., GHIBAUDO, G., MASSARI, F. and IACCARINO, S., 1997. Calcareous plankton biostratigraphy of the Serravallian (Middle Miocene) stratotype section (Piedmont Tertiary Basin, NW Italy). Memorie di Scienze Geologiche dell'Università di Padova, 49: 127-144.

FREGNI, P. and PANINI, F., 1995. Dati biostratigrafici sulla Formazione di Cigarello (Gruppo di Bismantova) di Pavullo nel Frignano (Appennino Modenese). In: Polino, R. and Sacchi, R. (Eds). Atti del Convegno "Rapporti Alpi-Appennino e guide alle escursioni". Peveragno (CN), 31 maggio-1 giugno 1994. Roma, Accademia Nazionale delle Scienze:87-111.

GELATI, R. and GNACCOLINI, M., 1998. Synsedimentary tectonics and sedimentation in the Tertiary Piedmont Basin, Northwestern Italy. Rivista Italiana di Paleontologia e Stratigrafia, 104(2): 193-214.

HALLOCK, P., PREMOLI SILVA, I. and BOERSMA, A., 1991. Similarities between planktonic and larger foraminiferal evolutionary trends trough Paleogene paleoceanographic changes. Palaeogeography, Palaeoclimatology, Palaeoecology, 83: 49-64.

IACCARINO, S., 1985. Mediterranean Miocene and Pliocene planktic foraminifera. In: Bolli, H.M., Saunders, J.B. and Perch Nielsen, K., Eds., Plankton Stratigraphy. London: Cambridge University Press, 283-314.

———, 2002. Foreword. Rivista Italiana di Paleontologia e Stratigrafia, 108(2): 175-178.

IACCARINO, S. AND SALVATORINI, G. (1982) – A framework of planktonic foraminiferal biostratigraphy for Early Miocene to Late Pliocene Mediterranean area. Paleontol. Stratigr. Evol., 2: 25-115.

IACCARINO, S., BORSETTI, A.M. and RÖGL, F., 1996. Planktonic foraminifera of the Neogene Lemme-Carrosio GSSP Section (Piedmont, Northern Italy). In: Steininger, F.F., Iaccarino, S. and Cati, F., Eds., In search of the Paleogene/Neogene boundary. Part III: The global stratotype section and point the GSSP for the base of the Neogene (The Paleogene/Neogene Boundary). Roma, Giornale di Geologia, 58(1-2): 35-49.

KELLER, G., 1983. Paleoclimatic analyses of middle Eocene through Oligocene planktonic foraminiferal faunas. Palaeogeography, Palaeoclimatology, Palaeoecology, 43: 73-94.

MANCIN, N. and PIRINI, C., 2001. Middle Eocene to Early Miocene foraminiferal biostratigraphy in the Epiligurian Succession (Northern Appennines, Italy).Rivista Italiana di Paleontologia e Stratigrafia, 107(3): 371-393.

MARTELLI, L., CIBIN, U., DI GIULIO, A., CATANZARITI, R. and RIO, D., 1993. Revisione litostratigrafica della Formazione di Ranzano, proposta di legenda per la carta geologica d'Italia alla scala 1:50000. 3° Convegno del Gruppo Informale di sedimentologia, Salice Terme 1993, abstract: 13-14.

———, 1998 Litostratigrafia della Formazione di Ranzano (Priaboniano sup.-Rupeliano, Appennino settentrionale e Bacino Terziario Ligure Piemontese. Bollettino della Società Geologica Italiana, 117: 151-185.

MICULAN, P., 1994. Planktonic foraminiferal biostratigraphy of the Middle Miocene in Italy. Bollettino della Società Paleontologica Italiana, 33(3): 299-339.

MILLER, K.G., FEIGENSON, M.D., WRIGHT, J.D. and CLEMENT, B.M., 1991. Miocene isotope reference section, DSP Site 608: an evaluation of isotope and biostratigraphic resolution. Paleoceanography, 6: 33-52.

MUTTI, E., PAPANI, L., DI BIASE, D., DAVOLI, G., MORA, S., SEGADELLI, S. and TINTERRI, R., 1995. Il bacino terziario epimesoalpino e le sue implicazioni sui rapporti su Alpi ed Appennino. Memorie di Scienze Geologiche dell'Università di Padova, 47: 217-244.

NOCCHI, M., PARISI, G., MONACO, P., MONECHI, S., MADILE, M., NAPOLEONE, G., RIPEPE, M., ORLANDO, M., PREMOLI SILVA, I. and BICE, B.M., 1986. The Eocene- Oligocene boundary in the Umbrian pelagic sequences, Italy. In: Pomerol, Ch. and Premoli Silva, I., Eds., Terminal Eocene Events: developments in Paleontology and Stratigraphy. Amsterdam: Elsevier, 25-40.

NOVARETTI, A., 1990. Studio biostratigrafico dell'area di raccordo fra la Collina di Torino e il Monferrato. Bollettino del Museo Regionale di Scienze Naturali di Torino, 8(1): 1-21.

———, 1993. Biostratigrafia delle Marne di Antognola nel Monferrato occidentale. Bollettino del Museo Regionale di Scienze Naturali di Torino, 11(2): 423-444.

NOVARETTI, A., BICCHI, E., CONDELLO, A., FERRERO, E., MAIA, F., TONON, M. and TORTA, D., 1995. La successione oligo-miocenica del Monferrato: sintesi dei dati biostratigrafici. In: Polino, R. and Sacchi, R., Eds., Atti del Convegno " Rapporti Alpi-Appennino e guide alle escursioni". Peveragno (CN), 31 maggio-1 giugno 1994. Roma. Accademia Nazionale delle Scienze: 39-59.

ORI, G. and FRIEND, P.F., 1984. Sedimentary basin formed and carried piggy-back on active thrust sheet. Geology, 12: 475-478.

PIANA, F. and POLINO, R., 1994. La zona transpressiva di Rio Freddo e l'evoluzione convergente della Collina di Torino e del Monferrato durante il Terziario. Atti Ticinensi di Scienze della Terra, Serie Speciale 1: 167-180.

———, 1995. Tertiary structural relationships between Alps and Appennines: the critical Torino Hill and Monferrato area, Northwestern Italy. Terra Nova, 7: 138-143.

PREMOLI SILVA, I. and BOERSMA, A., 1988. Atlantic Eocene planktonic foraminiferal historical biogeography and paleohydrographic indices. Paleogeography, Palaeoclimatology, Palaeoecology, 67: 315-356.

PREMOLI SILVA, I. and SPEZZAFERRI, S., 1991. Paleogene planktonic foraminiferal biostratigraphy and paleoenvironmental remarks on Paleogene sediments from Indian Oceans sites, leg 115. In: Beckman, J. et al., Eds., Proceedings of the Ocean Drilling Project, volume 15: 277-314. Washington.

PROTO DECIMA, F. and BOLLI, H.M., 1970. Evolution and variability of *Orbulinoides beckmanni* (Saito). Eclogae Geologicae Helvetiae, 63: 883-905.

PROTO DECIMA, F., ROTH, P.H. and TODESCO, L., 1975. Nannoplancton calcareo del Paleocene e dell'Eocene della sezione di Possagno. Schwei. Palaeont. Abh., 97: 35-161.

RICCI LUCCHI, F., 1990. Turbidites in foreland and on-thrust basin of the Northern Appennines. Palaeogeography, Palaeoclimatology, Palaeoecology, 77: 51-66.

SPEZZAFERRI, S., 1994. Planktonic foraminiferal biostratigraphy and taxonomy of the Oligocene and Lower Miocene in the oceanic record: an over view. Palaeontographia Italica, 81: 1-87.

SPEZZAFERRI, S., BASSO, D. and COCCIONI, R., in press. Eocene planktonic foraminiferal response to an extraterrestial impact at Massignano GSSP (Northeastern Appennines). Journal of Foraminiferal Research..

SRINIVASAN, M. and KENNETT, J.P., 1983. The Oligocene-Miocene boundary in the South Pacific. American Bulletin of the Geological Society, 94: 798-812.

TOUMARKINE, M. and LUTERBACHER, H., 1985. Paleocene and Eocene planktic foraminifera. In: Bolli, H.M., Saunders, J.B and Perch Nielsen, K., Eds., Plankton Stratigraphy. London: Cambridge University Press, 87-154.

Manuscript received April 15, 2003
Manuscript accepted October 21, 2003