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PROPOSAL OF THE GLOBAL BOUNDARY STRATOTYPE SECTION AND POINT (GSSP) OF THE PIACENZIAN STAGE (MIDDLE PLIOCENE)

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BACKGROUND AND MOTIVATIONS

One urgent task of the Subcommission on Neogene Stratigraphy (SNS) is to propose to the International Commission on Stratigraphy (ICS) the GSSP's of Pliocene and Miocene stages, none of which is at present formally defined. Much progress has been made during the last years in the Pliocene stratigraphy (Berggren *et al.*, 1995a) and the time is ripe for submitting a formal proposal of the GSSP of the base of the Piacenzian to the ICS. Agreement seems to exist to define the Piacenzian GSSP in the Punta Piccola subsection of the Rossello composite section, located in Caltanisetta basin in southern Sicily. Here we present the preliminary version of the proposal to be commented and voted by members of the SNS.

The Piacenzian stage: brief historical review

The Piacenzian stage was introduced by Mayer-Eymar in 1858 as the *Piacenzische Stufe* to indicate the marly-clayey facies ("*Argille azzurre*") with *Nassa semistriata* outcropping in Northern Italy. It was originally distinguished as a substage of the Astian, which had been erected by De Rouvillle (1853, p. 185) to replace the term "*Deposito subappennino*" used by Brocchi (1814). Mayer (1858) listed several localities in Italy and Europe as typical of the Piacenzian, including the village of Castell'Arquato, located some 25-30 Km from the town of Piacenza, from which he apparently derived the stage name. The term Piacenzian was soon adopted by Pareto (1865), who clearly indicated the fossiliferous sediments of the blue clays outcropping along the Arda Valley between Castell'Arquato and Lugagnano as typical of the unit. Note that Pareto considered the Piacenzian as an upper substage of the Tortonian, considered by him as a Pliocene stage. Since then the term Piacenzian has been widely used in the stratigraphic literature, although with different meanings as summarized in Table 1 and further discussed below. Reviewing the literature, one gains the impression that it was often used to indicate a lithostratigraphic unit, *i.e.* the "*Argille azzurre*" of the Italian Pliocene (see Gignoux, 1950). An important step in the clarification of the Piacenzian stage was the designation of a stratotype in the Castell'Arquato section (Fig. 1) by Barbieri (1967) following the indications of Pareto (1865). The base of the Piacenzian was defined at the lithofacies change (from slope-basin to outer shelf sediments) coincident with the local disappearance of the planktonic foraminifer *Globorotalia margaritae* (Figs. 2 and 3). The top of the Piacenzian stratotype was indicated to coincide with a prominent calcarenitic bed containing *Amphistegina* spp. on top of which the village of Castell'Arquato is built (Fig. 1). Subsequently, the Piacenzian has been adopted in all recent and widely used geologic time scales and the last occurrence (LO) of *G. margaritae* - or other time-equivalent stratigraphic events - have been used to mark its base (*i.e.*, Cita, 1973; Berggren and Van Couvering, 1974; Berggren *et al.*, 1985; Haq and Van Eysinga, 1987; Haq *et al.*, 1988; Harland *et al.*, 1982; 1990; Berggren *et al.*, 1995b).

The Piacenzian stage: present status

An integrated calcareous plankton biostratigraphic study of the historical Piacenzian stratotype in the Castell'Arquato section carried out by Rio *et al.* (1988) and Raffi *et al.* (1989) has shown that a depositional gap is present right at the base of the Piacenzian stratotype, and that the local disappearance of *G. margaritae* is not the true LO of the species (Figs. 2 and 3). The base of the Piacenzian is actually located in an undeterminated point between the LO of the calcareous nannofossil *Reticulofenestra pseudoumbilicus* at about 3.89 Ma (Lourens *et al.*, 1994) and the temporary disappearance in the Mediterranean of the planktonic foraminifer *Globorotalia puncticulata* at about 3.57 Ma (Lourens *et al.*, 1994). Hence, the base of the Piacenzian cannot be recognized with precision in any other section except in the stratotype and, hence, the Castell'Arquato section is not suitable to define the GSSP of the Piacenzian because of the hiatus at its base. Clearly, a redefinition of the base of the Piacenzian is needed in a continuous section at a point that is better constrained in time and more suitable to global correlation.

Position of the Piacenzian Stage in the Pliocene Series

As summarized in Table 1, the position of the Piacenzian within the Pliocene Series has varied over the years. It has been used by many authors for indicating the lower Pliocene using a twofold subdivision of the Pliocene (*e.g.* Mayer, 1858; Gignoux, 1913) or the middle Pliocene using a threefold subdivision of the Pliocene (*e.g.* Seguenza, 1968; Doderlein, 1872). In the type area, some 40-60 meters of yellowish sandy sediments are present between the calcarenitic bed with *Amphistegina* spp. representing the top of the Piacenzian stratotype and the local appearance of *Arctica islandica* (= base of the Pleistocene) which have been ascribed in the past to the Astian (*e.g.* Pareto, 1865). However, the type Astian, located in Piedmont region (Mayer, 1868; Ferrero, 1971) has been abandoned because it is represented by shallow water sandy sediments, difficult to frame in time, and most probably correlative to the Zanclean or to the lower Piacenzian (Sampò *et al.*, 1968). Hence, Barbieri (1967) proposed to extend the Piacenzian to include the interval of time above the stratotype up to the base of the Pleistocene. Consequently, a twofold subdivision of the Pliocene into a lower (Zanclean) and upper (Piacenzian) stages was proposed which became widely accepted (*e.g.* Berggren and Van Couvering, 1974; Cita, 1973; Berggren *et al.*, 1985), although most italian geologists continued to use an informal threefold subdivision (*i.e.* Colalongo *et al.*, 1974) following the proposal of Ruggieri and Selli (1950).

The above quoted recent studies in Castell'Arquato section have indicated that the top of the Piacenzian stratotype falls in the short calcareous nannofossil Zone NN17 of Martini (1971; Zone CN12c of Okada and Bukry, 1980), at a critical point of the evolution of the Earth climatic system, *i.e.* close to the final build-up of the northern hemisphere glaciation, at the Gauss-Matuyama transition. Rio *et al.* (1990b; 1991) argued against the practice of extending the top of the Piacenzian to the Pliocene-Pleistocene boundary because of the position in time of the top of the historical Piacenzian close to the Gauss-Matuyama boundary (where a multitude of signals are present in both the continental and marine stratigraphic records to make the top of the Piacenzian in prospect correlatable on global base). They proposed instead the Piacenzian Stage be limited only to the stratigraphic interval present in the stratotype section and that a new stage be introduced to cover the time-interval between the top of the Piacenzian and the base of the Pleistocene. This proposal results is a three-fold subdivision of the Pliocene Series, easily recognizable on a global base, with the Piacenzian representing the middle Pliocene. Recently, the Gelasian has been proposed as the third upper Pliocene stage and defined in Monte San Nicola section, near the town of Gela, in the eastern Caltanissetta basin, on southern Sicily (Rio *et al.*, 1994). The threefold subdivision of the Pliocene and the GSSP of the Gelasian have been recently approved by the majority of the Subcommission on Neogene Stratigraphy (SNS) and adopted in the recent Cenozoic Time Scale of Berggren *et al.*(1995b). It is being submitted to the ICS for the final approval.

The critical time span for selecting the GSSP

The critical time interval for selecting the GSSP of the Piacenzian is constrained by 1) the position in time of the physical base in the stratotype and 2) the time correlation criteria which have been used for its recognition worldwide. The first point has been discussed above, whereas the second point deserves some comments: indeed, there has been almost unanimous consensus in the literature to follow Barbieri's (1967) proposal and consider the LO of *G. margaritae* as a guide for global correlation of the Zanclean-Piacenzian boundary. However, the last occurrence of this form is diachronous between high and low latitude areas (Baldauf *et al.*, 1986) and also between the Mediterranean and open ocean (Langereis and Hilgen, 1991). In low latitude open ocean, the LO of *G. margaritae* occurs close to the Gilbert-Gauss boundary , at about 3.6 Ma (Hays *et al.*, 1969; Weaver *et al.*, 1989; Berggren *et al.*, 1995a; 1995b). In the Mediterranean the last common and continuous occurrence (LCO) of *G. margaritae* occurs at about 3.98 Ma, but the species remains rare and discontinuous present up to about 3.81 Ma (Langereis and Hilgen, 1991). From the previous discussion, it becomes clear that the critical interval for defining the Piacenzian GSSP falls between 3.98 Ma (the age of the LCO of *G. margaritae* in the Mediterranean) and about 3.6 Ma, the age of the LO of *G. margaritae* in tropical oceanic areas.

Selecting the area of the GSSP of the Piacenzian: the Rossello composite section

The critical time interval for defining the boundary is widely represented in the Italian Pliocene stratigraphic record, which is the type for the Series (Berggren, 1971; Berggren and Van Couvering, 1974). For historical reasons it would be preferable to select the GSSP in the type area of the Piacenzian, *i.e.* in the *"Argille azzurre"* outcropping in the foothills of the Northern Apennines, in the provinces of Piacenza and Parma. The *"Argille azzurre"* contains an abundant malacofauna but generally yields poor calcareous plankton assemblages (marker species are often sporadic and reworking is strong; Rio *et al.*, 1982). Moreover, it does not show any obvious physical cyclicity in the field, which would facilitate the development of a high resolution chronostratigraphic framework. In addition, a major tectonic reorganization (the so-called *"puncticulata-phase"* of Sartori, 1990) affected the Apenninic margin in the time interval critical for the definition of the Piacenzian base, and the resultant hiatus - as observed in the Castell'Arquato section - seems to be widespread (see Channell *et al.*, 1994). In contrast, the Pliocene stratigraphic record on central southern Sicily (Fig. 4) has excellent outcropping conditions, good calcareous plankton contents and an impressive cyclic organization, which facilitates field correlation and the reconstruction of a complete stratigraphic record; consequently, it has become a reference standard for the Pliocene Time Scale. Specifically, Hilgen and coworkers (Hilgen, 1987; Hilgen 1991b; Langereis and Hilgen, 1991) succeeded in construcing a composite section near the town of Agrigento in the Caltanissetta Basin (Figs. 5 and 6), which contains a complete succession of open, deep-marine sediments extending from below the Thvera Subchron into the Matuyama Chron. This Rossello composite section has played a critical role in establishing a global astronomically calibrated time-scale (Berggren *et al.*, 1995a). In this section Cita and Gartner (1973) defined the Zanclean stratotype and Cita (1975a) defined the base of the Pliocene. Because of its superior quality we propose to locate the GSSP of the Piacenzian in the composite Rossello section. Specifically, the Punta Piccola subsection of the Rossello composite (Figs. 5, 6, and 7) is proposed here as the best candidate section to define the Piacenzian GSSP, *i.e.* the Zanclean (Lower Pliocene) - Piacenzian (Middle Pliocene) boundary.

Selecting the boundary level

In agreement with previous suggestions of Rio *et al.* (1991), Langereis and Hilgen (1991), Cita *et al.* (in press), it is proposed that the widely correlatable Gilbert-Gauss magnetic reversal be the guiding criterion in selecting the boundary level for defining the Piacenzian. The traditional alternative criterion, the LO of *G. margaritae*, is disregarded because of the apparent diachroneity of this biohorizon between Mediterranean and open ocean.

Motivations

The motivations in proposing the Gilbert-Gauss polarity reversal as the boundary level for selecting the GSSP of the Piacenzian are its global correlation potential, historical appropriateness and stability of the stratigraphic literature. The Gilbert-Gauss is already being used for recognizing the base of the Piacenzian (*i.e.* Berggren *et al.* 1985; Haq *et al.*, 1988) and the historical Piacenzian stratotype at Castell'Arquato, although poorly constrained in time, appears to be consistent with the redefinition proposed here.

THE PROPOSED GSSP OF THE BASE OF THE PIACENZIAN (MIDDLE PLIOCENE)

Name of the boundary: Base of the Piacenzian.

Rank of the boundary: Stage/Age.

Position of the unit: Middle part of the Pliocene Series, between the Zanclean (below) and Gelasian (above) stages.

Type locality of the Global Stratotype section and point: the Punta Piccola section, southern Sicily, Italy, Europe. The Punta Piccola section forms the upper part of the Rossello composite section, a global reference standard for the Pliocene Time Scale (Hilgen, 1987; Langereis and Hilgen, 1991)

Geographic location: The Punta Piccola section outcrops in a "calanco" along the road from Porto Empedocle to Realmonte, 4 km East of Capo Rossello, about 3 km N-NW of Porto Empedocle, in Agrigento Province (Fig. 7).

Latitude: 37°17' 20" North; Longitude: 13°29'36" East of Greenwich (and 1°02'25" East of Monte Mario).

Map: The area is represented on the "Carta Topografica d'Italia" at 1:25000, Tavoletta Porto Empedocle, Foglio 271, IV NO.

Accessibility: The section is located in state demesne along a main road and it is freely and easily accessible (by public and private transportations) to scientists interested in visiting and sampling the section.

Conservation: Necessary steps for conservation of the section as an international geologic point of prime interest have been undertaken.

GSSP definition: The base of the beige marl bed of the small-scale carbonate cycle 77 in the Punta Piccola section (Fig. 10) is proposed as the GSSP of the base of the Piacenzian Stage and of the Lower Pliocene - Middle Pliocene boundary. The Gilbert-Gauss boundary has been identified within this bed. The small-scale cycle 77 has been correlated with the precessional cycle 347 and it has been assigned an astronomically derived age of 3.600 Ma (Lourens *et al.*, 1992).

Identification in the field: The base of the beige bed of the small-scale cycle 77 is marked by a metal tag in the section. Identification in the field and resampling of the section are greatly facilitated by the characteristic succession of sedimentary cycles.

Completeness of the section: The Punta Piccola section contains an excellent and continuous faunal and polarity record across the Gilbert-Gauss boundary. In addition the presence of astronomically controlled sedimentary cycles, faunistic and isotopic variations can further be employed to provide highly accurate age constraints for the GSSP. All the known biostratigraphic events, precessional sedimentary cycles, obliquity forced faunistic cycles are present. If hiatuses occur, their duration is below the resolution provided by astrocyclostratigraphy (of the order of a few ky). Sediment accumulation rates, which can be accurately determined by using astrochronology, varied from 4.5 to 5.5 cm/ky.

Global correlation: The global correlation of the GSSP of the Piacenzian is assured by different tools, applicable in different sedimentary environments and biogeographic realms. Specifically, the Gilbert-Gauss magnetic reversal provides the primary tool for global correlation being both applicable in marine as well as in continental stratigraphy. Because of the strong climatic gradients characterizing the Pliocene, most biostratigraphic events appear to be diachronous in the various areas (Dowsett, 1988; Hills and Thierstein, 1989) and, hence, the time-significance of a single biohorizon in a specific region must be ascertained before it can be used with confidence. However, biostratigraphic events which can be used in the various marine biogeographic regions for approximating the base of the Piacenzian are numerous. In the Mediterranean region the proposed base of the Piacenzian can be accurately recognized by the temporary disappearance of *Globorotalia puncticulata* (3.57 Ma), by the first (influx) of *Globorotalia crassaformis* (3.60 Ma) and by the end of the absence interval (paracme) of *Discoaster pentaradiatus* (3.61 Ma) and by the LO of *Sphenolithus* spp. (3.66 Ma). The LO of *G. margaritae* is difficult to determine consistently and occurs at 3.81 Ma, and therefore it is a poor tool for recognizing the newly defined Piacenzian base.

In low and mid latitude marine sediments, the LADs of the calcareous nannofossil genus *Sphenolithus* (occurring at 3.66 ± 0.04 Ma; Shackleton *et al.*, 1995) and of the planktonic foraminifers *Globorotalia margaritae* (occurring at about 3.58 Ma; Berggren *et al.*, 1995a) and of *Pulleniatina primalis* (occurring at about 3.65 Ma, Berggren *et al.*, 1995a) provide good approximations of the base of the Piacenzian.

SUMMARY OF BACKGROUND STUDIES ON PUNTA PICCOLA SECTION

The Punta Piccola section was first described by Brolsma (1978) and thereafter it has been the object of numerous stratigraphic studies (Sprovieri and Barone, 1982; Spaak, 1983; Rio *et al.*, 1984; Guerrera *et al.*, 1985; Zachariasse *et al.*, 1989; 1990); Driever, 1988; Bertoldi *et al.*, 1989; Sprovieri, 1992; 1993) which are summarized below.

Geologic setting

Punta Piccola section is located in the Caltanissetta basin (Fig. 4), a broad depositional area developed above and adjacent to evolving thrusts and folds of the central Maghrebian chain. From a structural point of view, the section belongs to a major tectonic element known as the "Gela nappe" or Gela thrust system (Ogniben, 1969; Butler *et al.*, 1995). The Maghrebian chain (Catalano and D'Argenio, 1982) formed by plate convergence between the Calabrian block (in the North) and portions of the North Africa margin (the Pelagian block, in the South).

The stratigraphic succession

The Punta Piccola section (Figs. 8, 9 and 10) consists of marine marls which show a distinct cyclicity in both $CaCO_3$ content and weathering (induration) profile. The strata dip 330°-10°. The lenght of the exposure allows the investigations of a continuous profile and to check the lateral continuity of the individual beds. The section is un-affected by tectonic disturbance apart from an easily recognizable NW-SE running fault, and without any detectable sedimentary discontinuities. The topographic top of the section is formed by unconformably overlying Pleistocene marine terrace deposits (Figs. 7 and 8).

The lithologic column of the Punta Piccola section is reported in Fig. 10. The total thickness is 55 m. The lower part of the section consists of some 20 m of cyclically bedded marls of the "Trubi" (Cita and Gartner, 1973). The "Trubi" marls are overlain by the marly-silty "Monte Narbone Formation" (total thickness 35 m). The transition between the two lithostratigraphic units is gradual. Noteworthy is the presence of brownish to black manganesiferous levels and of brownish-red laminated levels (reported in Fig. 10) in the Monte Narbone Formation. The latter are referred to as "sapropels" in the most recent Mediterranean literature (Lourens *et al.*, 1992). Both manganesiferous levels and "sapropels" are of prime importance for regional stratigraphic correlations.

Depositional environment

The depositional environment of the Punta Piccola section is inferred to be an open marine slope-basin setting (Brolsma, 1978; Sprovieri and Barone, 1982), with water depth in the range of about 800-1000 m. This interpretation is suggested by the abundance of the planktonic foraminifera (92 to 97% of the total foraminifera assemblage; Sprovieri and Barone, 1982), the presence of rare psychrospheric ostracods (*Agrenocythere pliocenica*) and the composition of the benthic foraminifera assemblages, which contain *Parrelloides robertsonianus*, *Dentalina subsoluta*, *Eggerella bradyi*, *Laticarinina pauperata*, *Nuttalides rugosus convexus*, *Cibicides wuellerstorfi* (which have an upper depth range at about 500-800 m; Parker, 1958; Wright, 1978) and of *Planulina ariminensis*, *Siphonina reticulata* and of common Nodosariidae like *Lenticulina* spp., *Marginulina* spp., *Vaginulina* spp. (which have a lower depth limit of common presence at about 1000 m; Blanc-Vernet, 1965).

Chronology of the Punta Piccola section

During the last years it has been shown that the chronological resolution (in the order of a few hundred ky) in the Mediterranean

Pliocene obtained by integrating calcareous plankton biostratigraphy and magnetostratigraphy (Rio *et al.*, 1990) can further be enhanced to a few ky by using paleontological, lithological and geochemical proxy indicators of astronomically controlled variations in the Earth's climatic system. In particular, variations in the abundance of planktonic foraminifera (Sprovieri, 1992; 1993), in the oxygen and carbon stable isotopes (Lourens *et al.*, 1992), in cyclic colour variations in lithology (Hilgen, 1991a, b) and in the distribution of "sapropels" show a distinct cyclicity related to the quasi-periodic oscillations of the Earth's orbital parameters. The cyclostratigraphy developed in the Mediterranean on the base of the previous proxies has been calibrated to the astronomical record thus allowing the construction of an astronomically calibrated time-framework for the entire Pliocene (Hilgen, 1991). The main elements of the Mediterranean Pliocene time framework are reported in Figure 11. They have been applied for developing the chronology of Punta Piccola section.

Calcareous nannoplankton biostratigraphy

Calcareous nannofossils are abundant and well preserved. They have been studied by Rio *et al.* (1984), and Driever (1988). With reference to the Mediterranean zonal scheme of Rio *et al.* (1990a) the section is referred to Zones MNN16 and MNN 16a-17. In terms of the standard calcareous nannofossil zonation of Martini (1971) the entire section is referred to Zone NN16. With reference to the zonal scheme of Okada and Bukry (1980) it is referred to Zone CN12 (Subzones CN12a and CN12b). The proposed GSSP does not correspond to a calcareous nannofossil zonal boundary with reference to most used zonal schemes. However, on a gobal scale the lower limit of the Piacenzian is remarkably close to the extinction of *Sphenolithus* spp. (at about 3.66 Ma; Shackleton *et al.*, 1995). In the Mediterranean the base of the Piacenzian is close to the end of a prominent absence-interval (paracme) of *Discoaster pentaradiatus* as shown by Driever (1988), and dated at 3.61 Ma.

Planktonic foraminifera biostratigraphy

Planktonic foraminifera are abundant and well preserved. They have been studied by Brolsma (1978), Spaak (1983), Sprovieri in Rio *et al.* (1984), Zachariasse *et al.* (1989; 1990) and Sprovieri (1992; 1993). All biohorizons normally recognized in the Mediterranean (Fig. 11) are present in the section and they maintain their known relative position (ranking) and show the same position with respect to the magnetostratigraphy and cyclostratigraphy of other Mediterranean sections. With reference to the Mediterranean zonations of Cita (1973; 1975b), as emended by Sprovieri (1992), the Punta Piccola section extends from Zone MPL4a to Zone MPL5a (Fig. 10). In terms of the Mediterranean zonal scheme of Spaak (1983; Fig. 11), the section is referred to Intervals IV to VII (Fig. 10).

Magnetostratigraphy

The Punta Piccola section provided an excellent magnetostratigraphy which allowed a straightforward correlation to the geomagnetic polarity time scale (Zachariasse *et al.*, 1989; 1990) and which are shown in Figure 10. Three reversed and three normal polarity magnetozones have been recognized. The lower reversed part of the section correlates with the upper part of the Gilbert Chron (2Ar in the nomenclature of Cande and Kent, 1992), while the rest of the section correlates with the Gauss Chron (C2An) apart from the reversed topmost part which corresponds to the base of the Matuyama Chron (Subchron C1r.2r).

Physical cyclicity and astrochronology

The basic sedimentary rhythm in the Trubi succession is represented by quadruplets: 1) a basal grey soft marl, 2) a white more indurated carbonate bed, 3) a beige marl and 4) a white more indurated carbonate bed. The same rhythmites can also be recognized in the overlying Monte Narbone Formation, in which sapropelitic interbeds start to be intercalated in the grey marls. In addition to these basic rhythmites ("small scale cycles" of Hilgen, 1991b), larger-scale variations in carbonate content can be recognized in the Trubi succession as prominent and more indurated marl levels (carbonate units of Hilgen, 1991b).

All sedimentary rhythmites are related to (climatic variations induced by) the Earth's orbital cycles (Hilgen, 1987). The geochronometric applicability of an astronomical control on the sedimentary cyclicity was realised soon afterwards (Hilgen and Langereis, 1988). Hilgen (1991a, b) correlated all sedimentary cycles in the Rossello composite section to the time series of precession (small-scale cycles) and eccentricity (larger-scale cycles) using 1) the Ber90 astronomical solution (Berger and Loutre, 1991) and 2) late Pleistocene sapropels to establish phase relations with the orbital parameters. Recently, this astronomical calibration has been slightly modified (Lourens, 1994; Lourens *et al.*, 1996) using a more realistic target curve (*i.e.* 65 Nlat summer insolation) and astronomical solutions other than Ber90 (*i.e.* QTD90: Quinn *et al.*, 1991; and La90: Laskar, 1990; Laskar *et al.*, 1993). The new target curve clearly reflects the observed additional influence of obliquity on the sedimentary cycle patterns (Fig. 12). The astronomical calibration allows all sedimentary cycles, calcareous plankton datum planes and geomagnetic polarity reversals in the Rossello composite section to be (absolutely) dated with an unprecedented accuracy (Hilgen, 1991b; Lourens *et al.*, 1996). Ages of the grey beds of cycles 77 and 78 (as numbered from the base of the Trubi Formation) are 3.608 and 3.590 Ma respectively and the age of the base of the beige bed of cycle 77 (*i.e.* the proposed Piacenzian GSSP) is 3.600 Ma (Lourens *et al.*, 1996). The age of the Gilbert/Gauss boundary arrives slightly younger at 3.596 Ma.

Faunal fluctations and stable isotopes

High-resolution quantitative planktonic foraminiferal and stable isotope records have been established for the entire Rossello composite section (Lourens *et al.*, 1996). Sprovieri (1992) used the percentage of *Globigerinoides* spp. of the total planktonic foraminiferal fauna to reconstruct temporal variations in sea surface water temperature (SST). Lourens *et al.* (1996) calculated the ratio of warm versus cool water species to derive a SST record while they established a planktonic stable isotopic record in addition. The influence of the astronomical cycles of precession and obliquity is clearly manifested in these records.

Lourens *et al.* (1996) used the astronomical calibration of the sedimentary cycles in combination with refined statistical techniques ((cross-)spectral analysis and band-pass filtering) to unravel the orbital control on high-frequency variations in SST and $\delta^{18}O$ records for the entire Mediterranean Pliocene. Obliquity controlled variations could be correlated in detail to ODP site 659 in the eastern tropical Atlantic and to ODP site 846 in the eastern equatorial Pacific. At Punta Piccola, both the proposed GSSP of the Piacenzian as well as the Gilbert/Gauss reversal boundary fall within the same obliquity related shift in SST and $\delta^{18}O$, labelled O-178 by Lourens *et al.* (1996). The G/G boundary is recorded in the correlative $\delta^{18}O$ minimum in ODP site 659 and 846.

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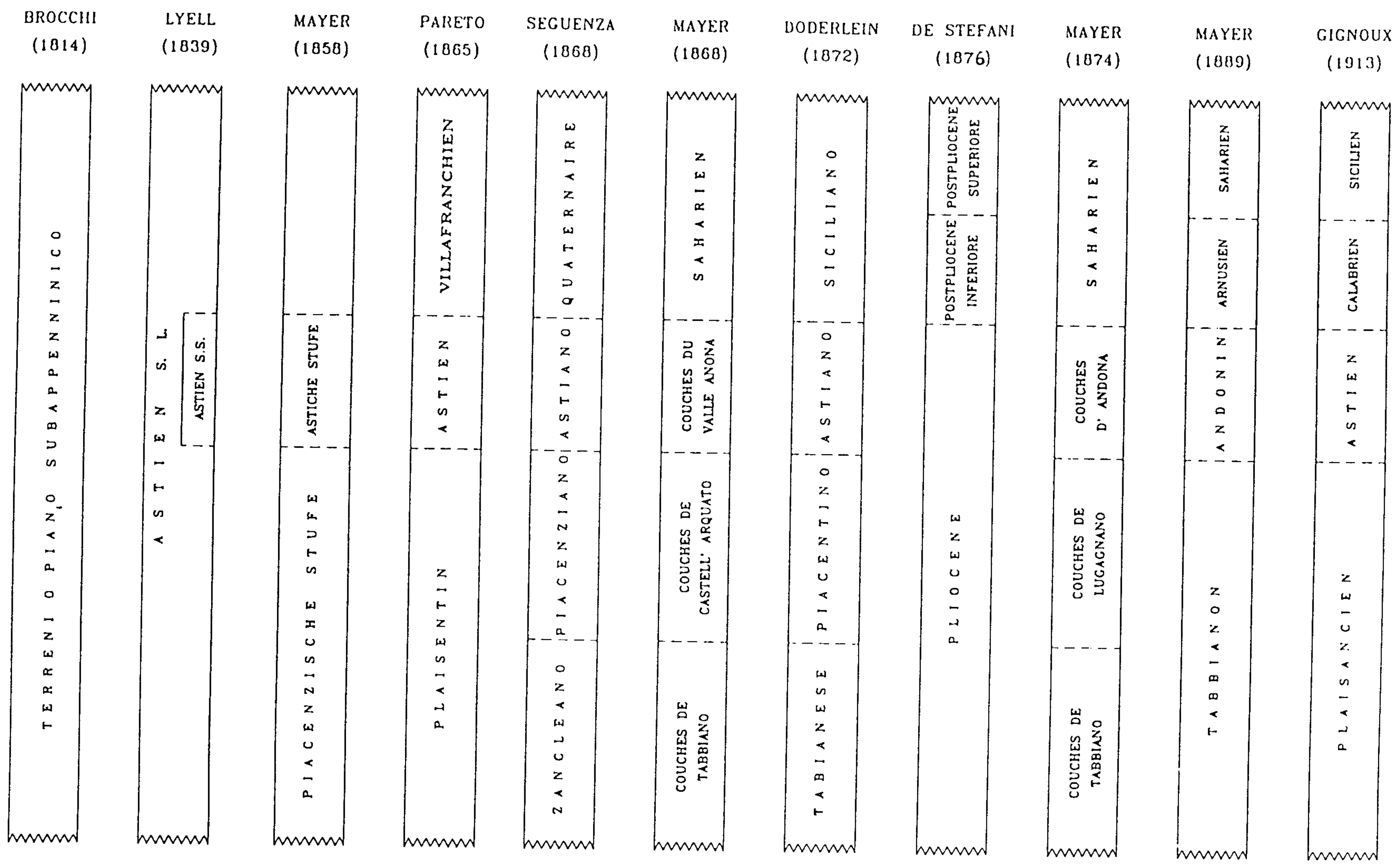

Table 1 - Historical review of the Pliocene chronostratigraphic subdivision before the development of calcareous plankton biostratigraphy and magnetostratigraphy.

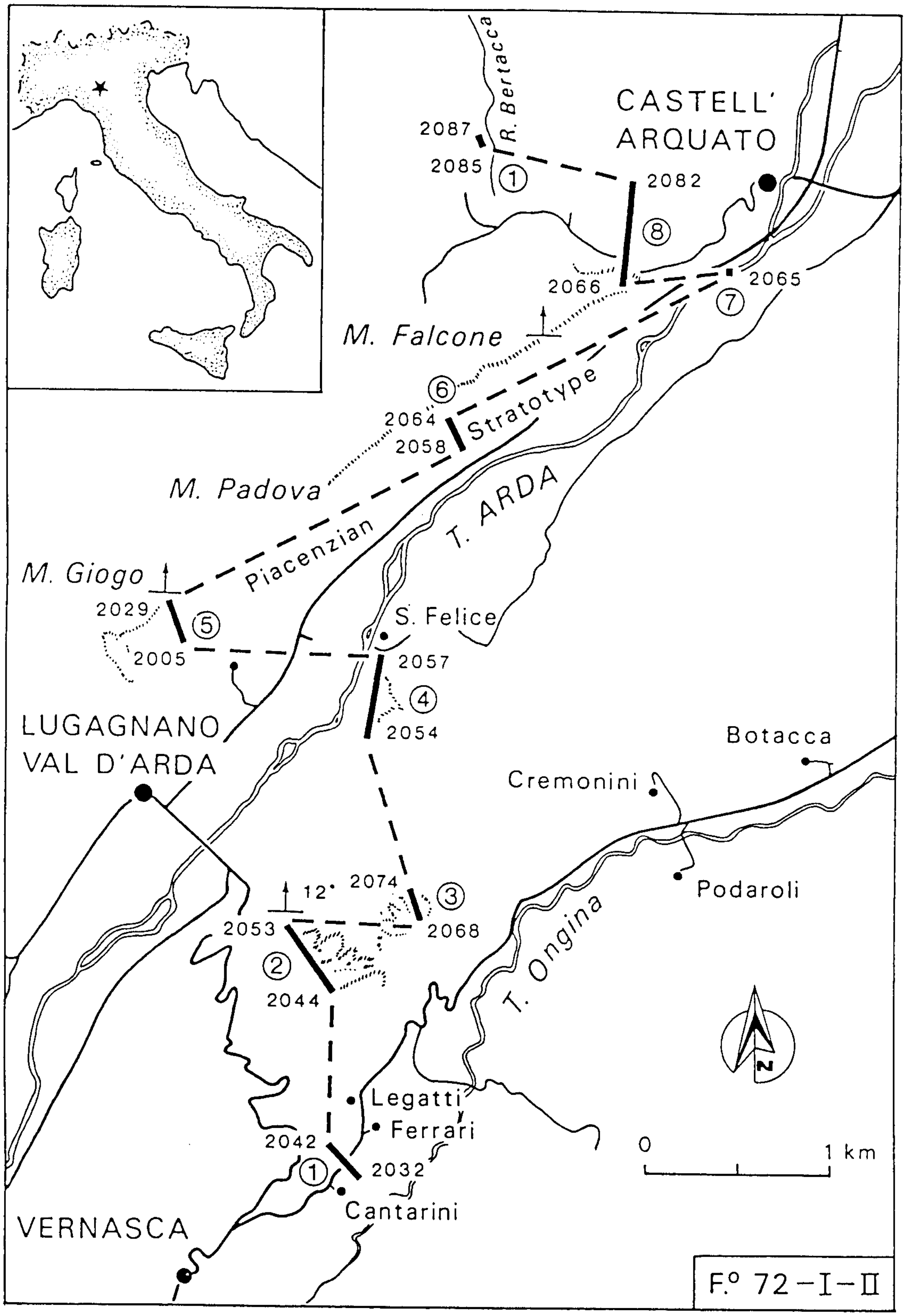

Fig. 1 - The composite Castell'Arquatq (Val d'Arda) section of Barbieri (1967). Segments 5, 6, 7 represent the Piacenzian stratotype (After Barbieri, 1967).

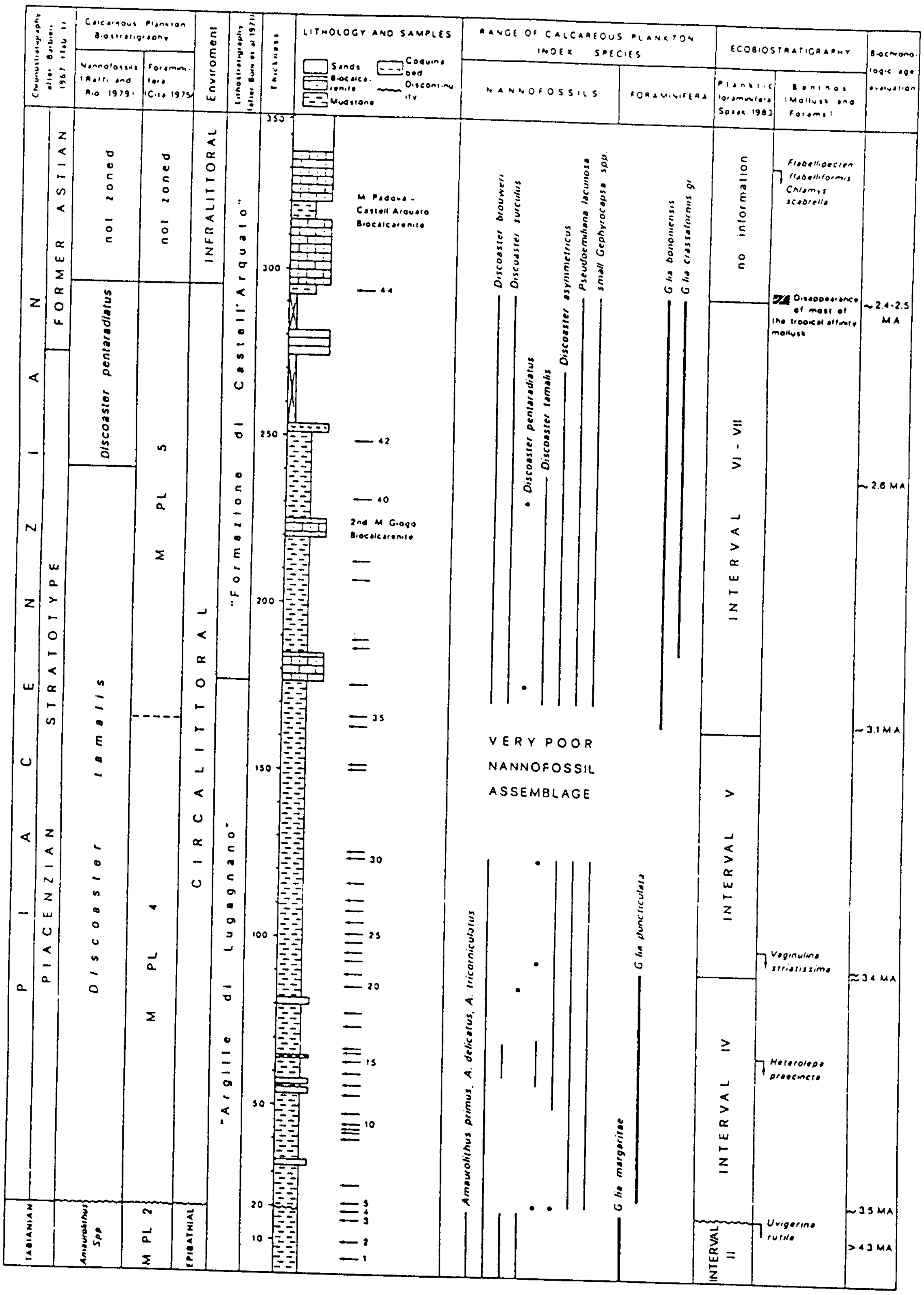

Fig. 2 - Summary of main stratigraphic data on the historical Piacenzian stratotype (After Raffi *et al.*, 1989).

Fig. 3 - The 10-20 cm thick bed representing the base of the Piacenzian historical stratotype. It is represented by a hardened sandy mudstone, strongly bioeroded by *Aspidopholas rugosa* and it marks a significant temporal hiatus. *Globorotalia margaritae* last occurrence is below this bed (After Raffi *et al.*, 1989).

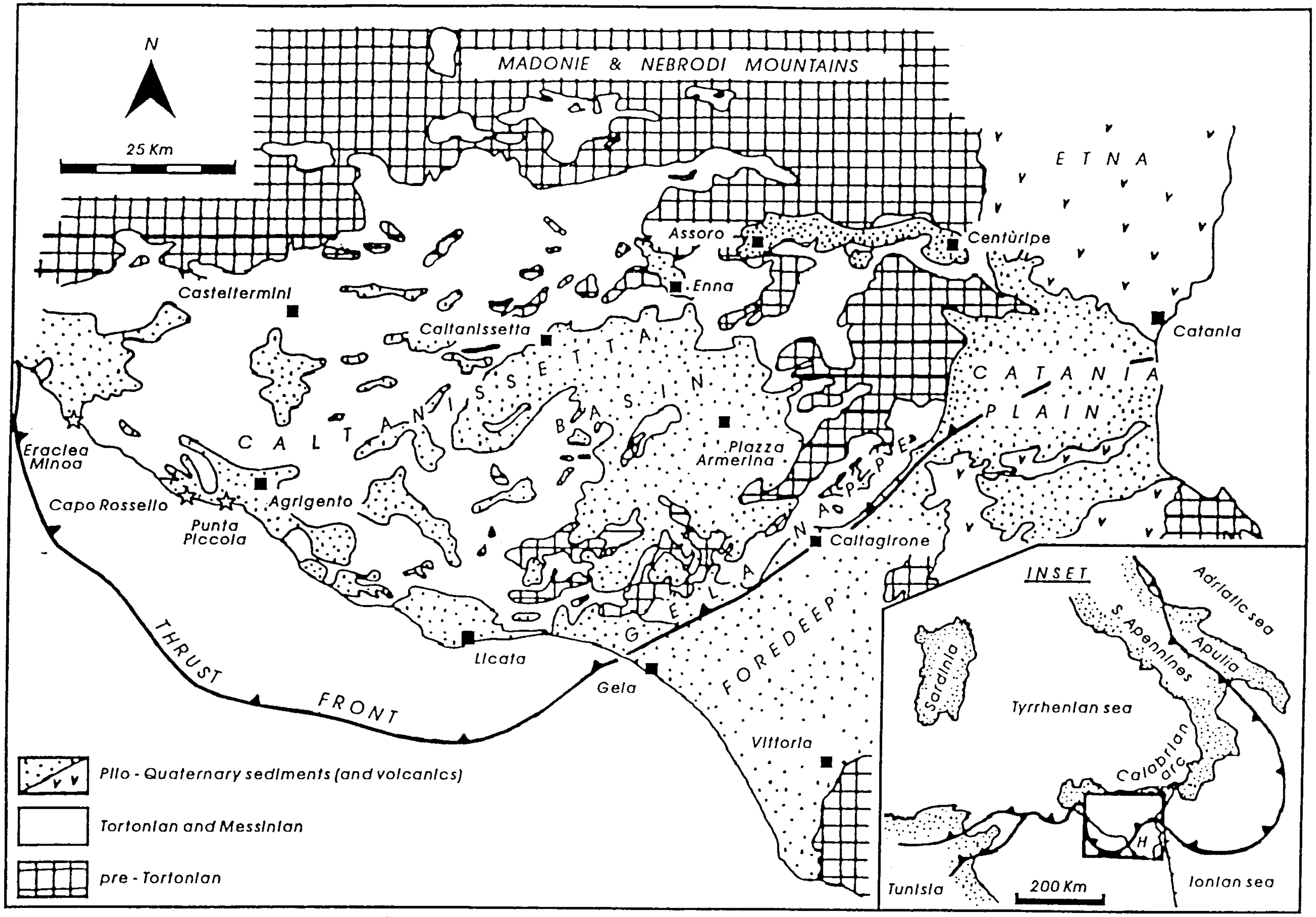

Fig. 4 - Geological sketch map of central-southern Sicily showing the distribution of Pliocene-Pleistocene sediments across the thrust-belt ("Caltanissetta basin") and the adjacent foredeep. Inset: location of Sicily in the Apenninic-Maghrebian thrust belt. H: Hyblean plateau (After Butler *et al.*, 1995; mod.).

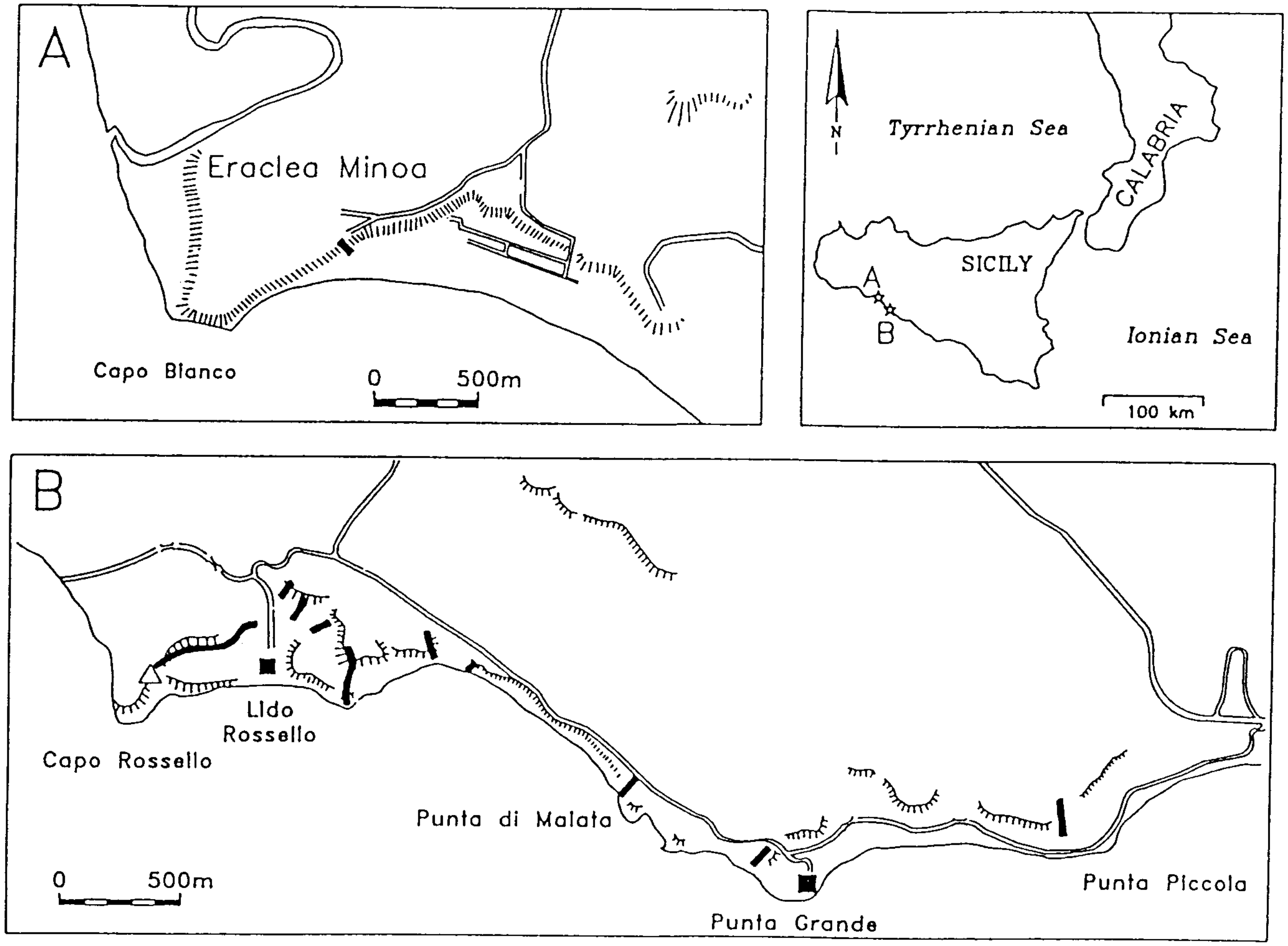

Fig. 5 - Location of the Eraclea Minoa, Punta di Maiata, Punta Grande and Punta Piccola subsections of the Rossello composite section of Hilgen (1987).

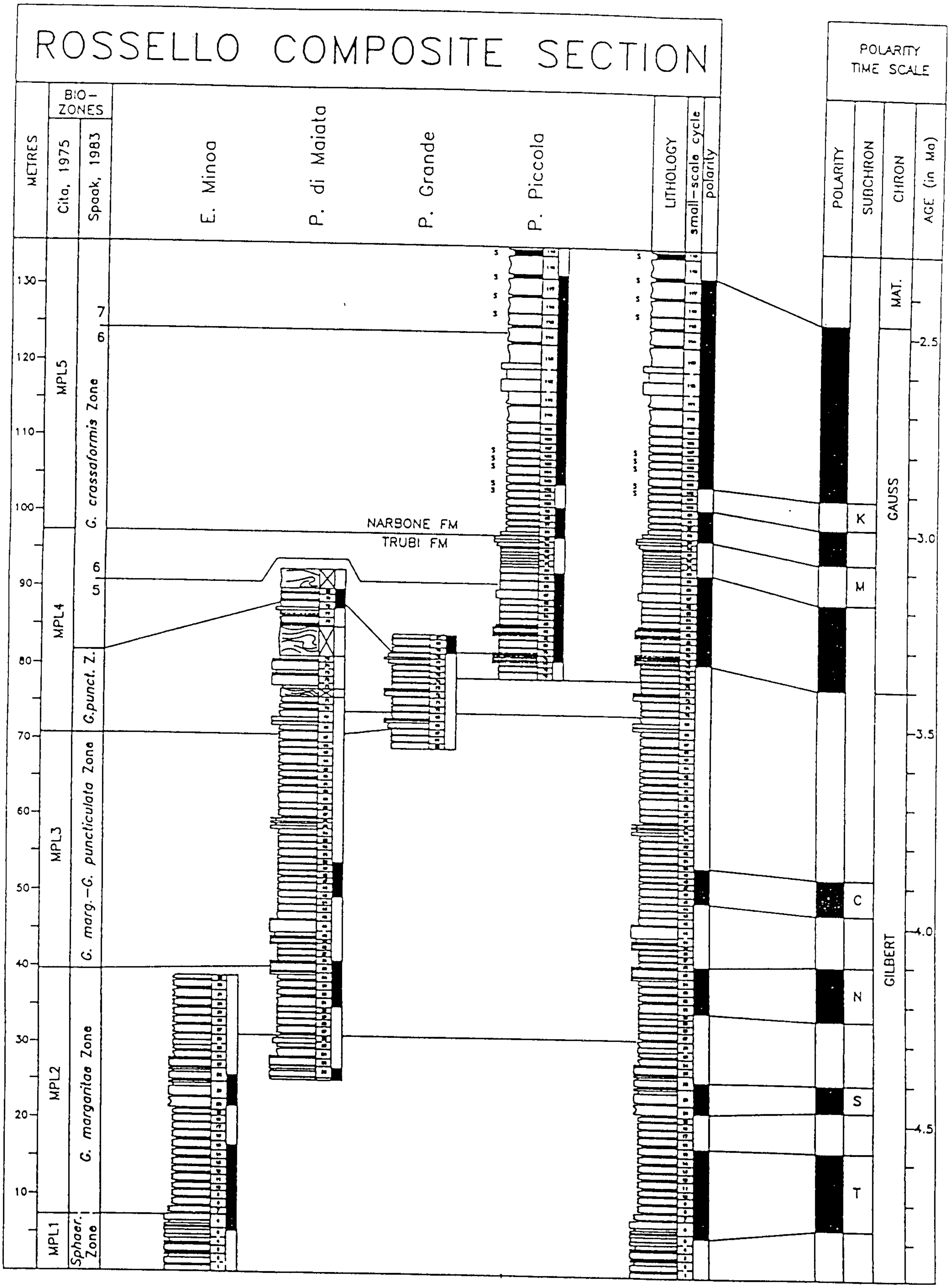

Fig. 6 - Integrated stratigraphy of the Rossello composite section showing calibration of the total polarity sequence to the geomagnetic polarity time scale of Berggren *et al.* (1985). Horizontal lines indicate which part of the subsections has been used for the construction of the composite section. Grey levels marked with *s* in the Punta Piccola section contain brown, laminated ("sapropels") sediments.

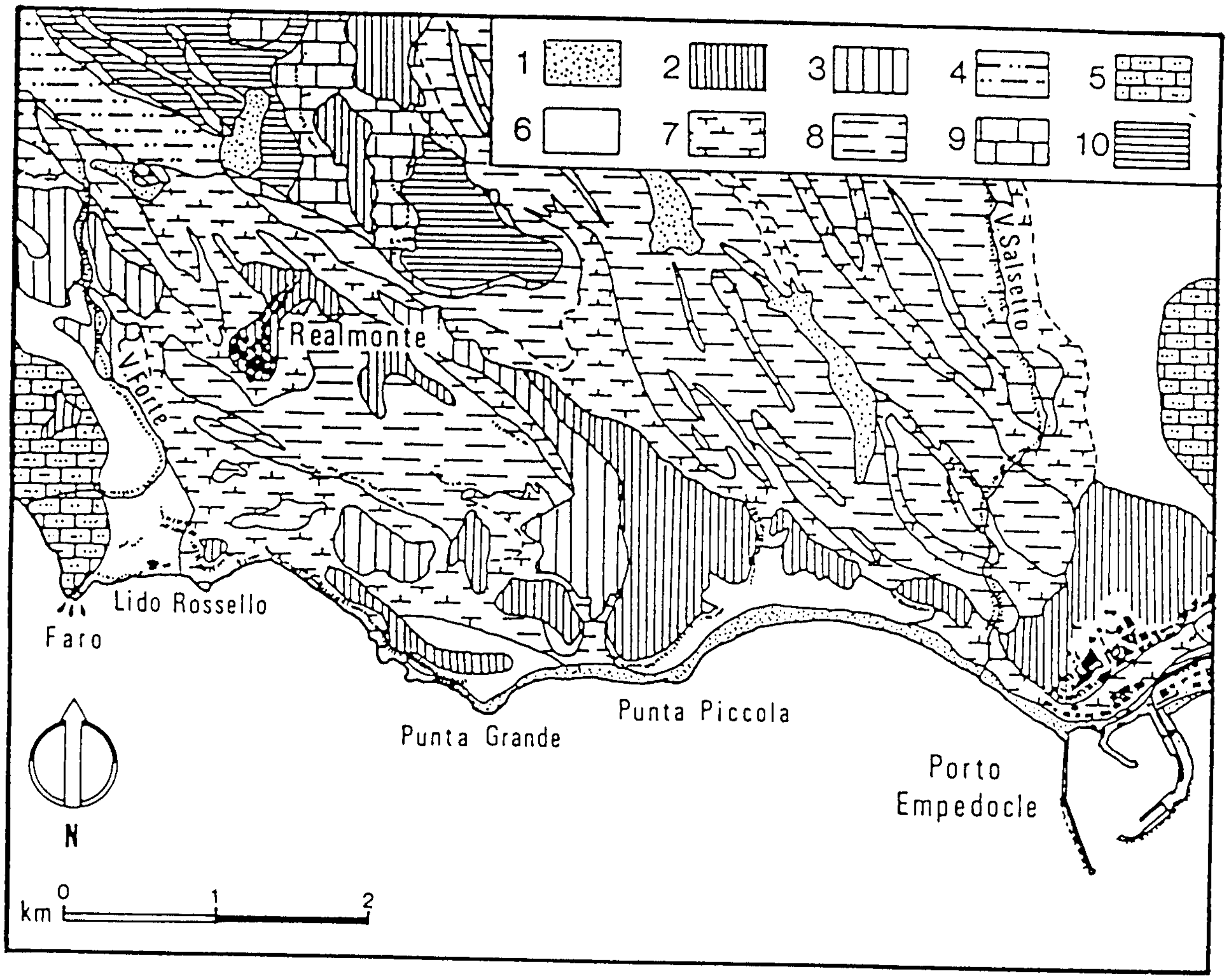

Fig. 7 - Geological sketch map of the area near Agrigento (Southern Sicily) where the composite Capo Rossello section and Punta Piccola component section are located. The units mapped are as follows: 1 = alluvional deposits and beach sands (Holocene); 2 = marine terraces; 3 = continental deposits; 4 = Montallegro Formation; 5 = Agrigento Formation; 6 = Monte Narbone Formation; 7 = "Trubi"; 8 = "Arenazzolo"; 9 = "Calcare di base" e Gessi; 10 = clayey complex with Miocene marly and/or clayey exotic and lithic blocks of various ages (After Decima *et al.*, 1972: Carta Geologica d'Italia, Foglio 636 Agrigento; modified).

Fig. 8 - Punta Piccola section, showing the topmost Trubi beds at the left and the overlying Monte Narbone marls (stike and dip 330° and 10°). The arrow indicates the part of the section where the GSSP of the Piacenzian is located (After Brolsma, 1978).

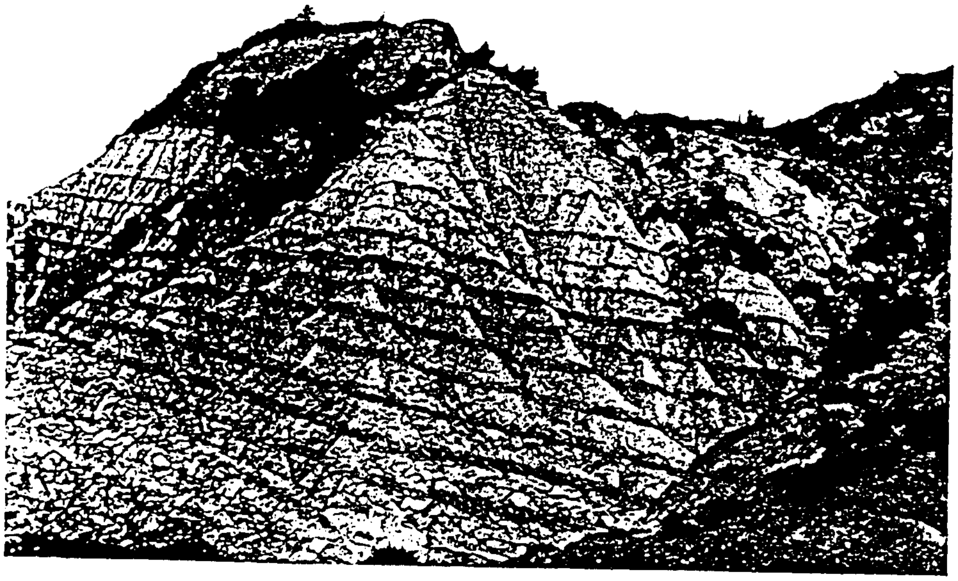

Fig. 9 - Close-up of the boundary interval of the Trubi and Monte Narbone marls at Punta Piccola. Dark coloured, ferromanganese-rich interbeds are indicated with A to L (After Brolsma, 1978).

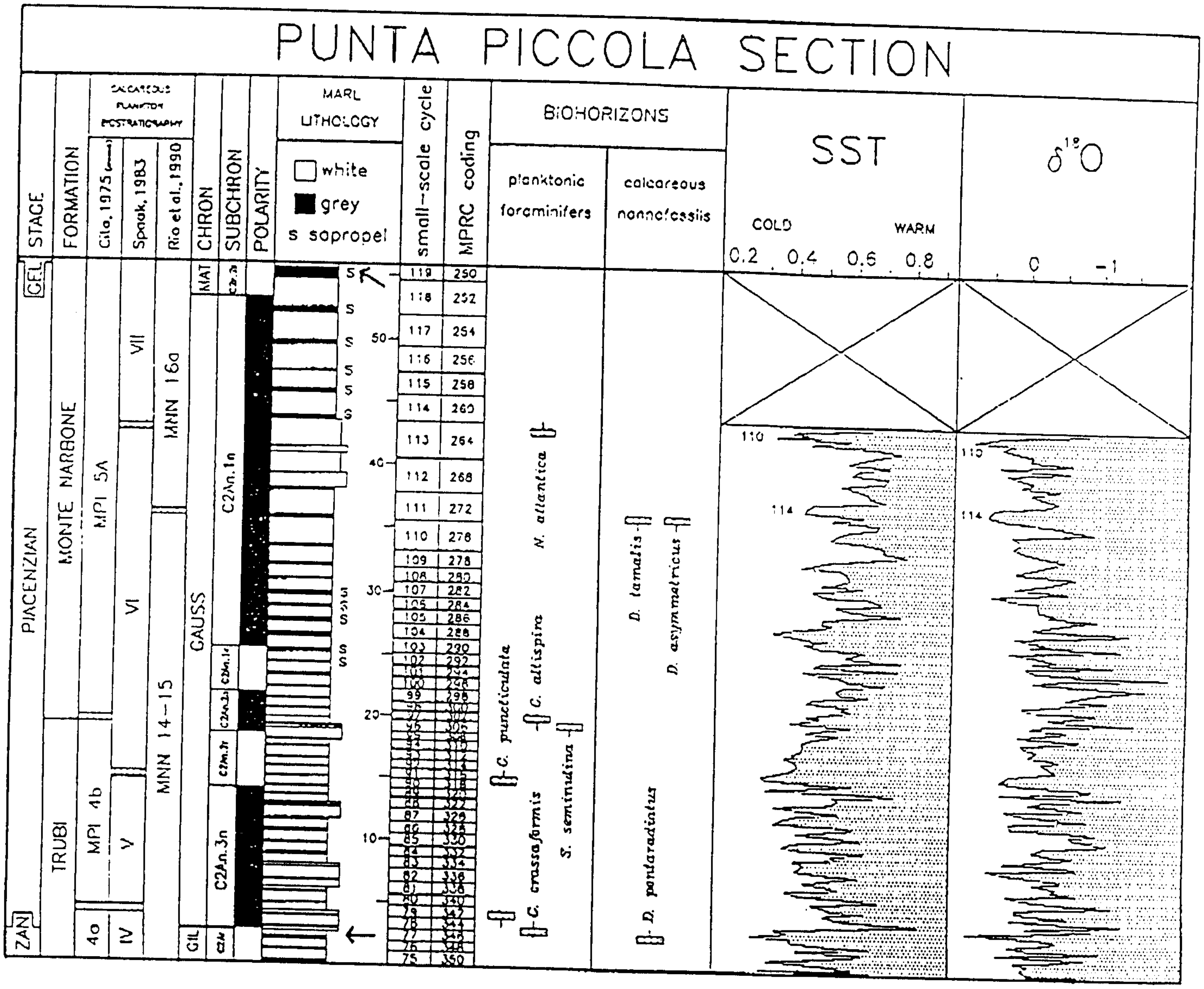

Fig. 10 - Lithostratigraphy, cyclostratigraphy, biomagnetostratigraphy, faunal fluctuations (planktonic foraminifera) and oxygen isotope stratigraphy in Punta Piccola section (from various sources quoted in the text).
SST = Sea Surface Temperature.

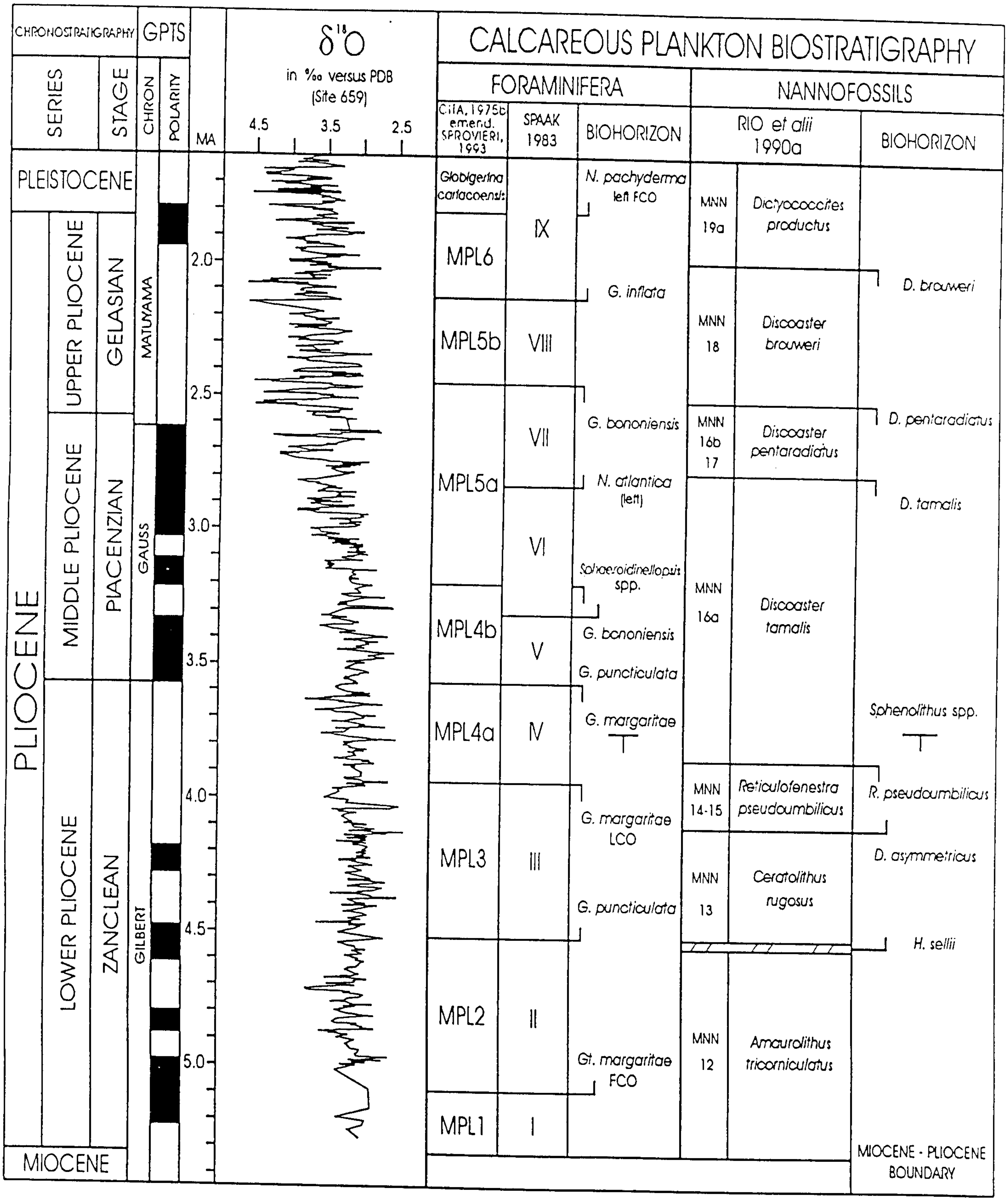

Fig. 11 - Integrated Pliocene time framework. Geomagnetic Polarity Time Scale and calibration of calcareous plankton biohorizons is after Berggren *et al.* (1995a). The Oxygen isotope stratigraphy at ODP Site 659 (subtropical eastern Atlantic Ocean) is after Tiedemann *et al.* (1995).

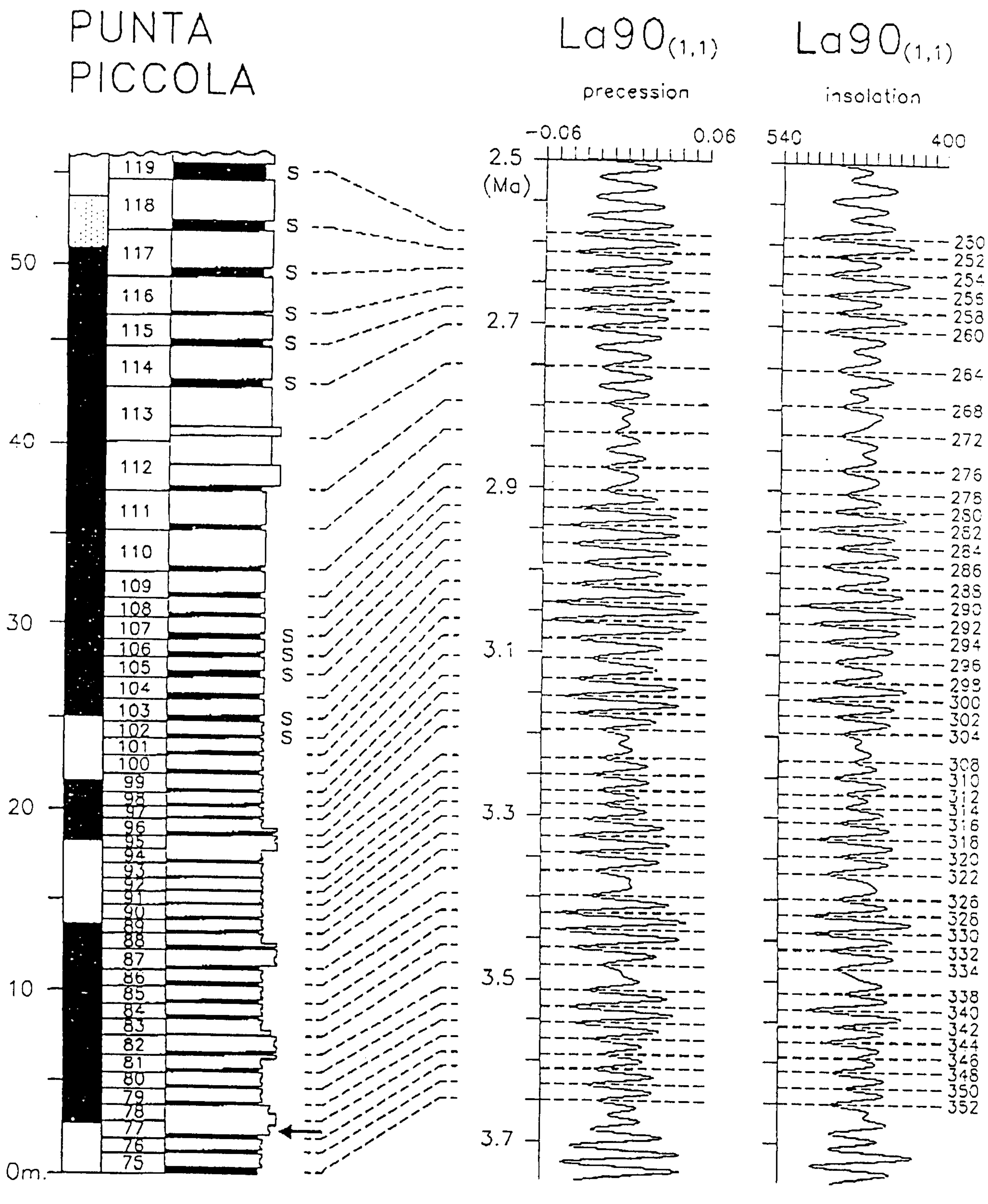

Fig. 12 - Cyclostratigraphy of the Punta Piccola section and correlation of the sedimentary cycles to astronomical target curves (precession and 65° Nlat summer insolation) derived from solution La90 (Laskar *et al.*, 1993; see Lourens *et al.*, 1996 for more details).