Global Standard Stratotype-section and Point (GSSP)
for the Zanclean Stage and Pliocene Series

A proposal by:

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Introduction

A formal definition for the base of the Pliocene is still the subject of controversy, 25 years after deep-sea drilling conclusively demonstrated that the classical Pliocene "transgression" in the Mediterranean Basin was in fact a regional isochronous event -- the end of the Messinian Salinity Crisis -- and well worth the status of a global boundary. M. B. Cita (1975a) pointed to this newly acquired understanding in proposing to define the base of the Zanclean Stage, and the base of the Pliocene Series, at Capo Rossello (Sicily), at the base of the first Trubi bed that marks the re-establishment of open marine conditions following the Mediterranean Salinity Crisis.

Since then, a heated discussion has erupted between those stratigraphers who contend that the Zanclean definition embodies the historical sense of the Pliocene, unchanged throughout the Mediterranean Basin since Lyell's time, and those who advocate an extra-Mediterranean definition of the boundary in order to better serve the operational requirements of modern normative stratigraphy (Remane et al., 1996).

In regard to this second option, a working group of the Subcommission on Neogene Stratigraphy (SNS), organized in 1986 under the chairmanship of R.H. Benson, developed a detailed proposal to locate the Pliocene GSSP in the Bou Regreg section on the Atlantic coast of Morocco, close to a former portal of the Miocene Mediterranean, and at a stratigraphic level coincident with the base of the Gilbert Chron, or base of magnetochron C3r (Benson and Rakic El-Bied, 1996; see also Benson and Hodell, 1994). This level is some 0.6 myr older than the base of the Zanclean, and the proposal would result in the decoupling of the Messinian/Zanclean boundary from the Miocene/Pliocene boundary. According to the orbitally-tuned cyclostratigraphy of the Late Miocene (Krijgsman et al., 1995; Hilgen et al., 1995), the Messinian Salinity Crisis would then entirely take place during the Pliocene. However, as Benson and Hodell (1994) point out, the "barren interval" of the Salinity Crisis was not allocated either to Miocene or Pliocene in Lyell's essentially biochronological subdivisions of the Cenozoic.

A compromise has been proposed by Suc et al. (1997), who suggest locating the GSSP of the Pliocene in the extra-Mediterranean section of Bou Regreg, but at a stratigraphic level correlated to the re-establishment of open marine conditions in the

Mediterranean according to magnetostratigraphy, cyclostratigraphy and isotopic stratigraphy.

A questionnaire was circulated in spring 1997 to members of SNS (both voting and corresponding) to determine preferences for the primary criteria and the best stratigraphic section in selecting GSSPs of the remaining Neogene Stage and Series boundaries, not yet adopted by IUGS.

The results were discussed at a workshop held in Erice (Sicily) in September 1997 and circulated in the 4th issue of the "Neogene Newsletter" (pp. 23-34), issued by SNS. Out of 21 replies, 11 favoured the Zanclean position of the boundary, while only 2 advocated the proposal of Benson's working group. Out of the 11 votes for the Zanclean position, 7 approved of the Eraclea Minoa section as the best choice for locating the basal Pliocene GSSP.

SNS members attending the Erice workshop, which followed a tour of the Messinian and Zanclean exposures along the Sicilian coast from Capo Rossello to Eraclea Minoa, were unanimously in favor of a postal ballot on a proposal to approve the Eraclea Minoa section (fig. 1 and 2) as the GSSP of the Zanclean Stage and of the Pliocene Series. This proposal, which you have before you, outlines advantages and disadvantages of this choice. We respectfully request your attention, and your vote.

Background and purpose

The Zanclean Stage (and Age) comprises the lowest part of the Pliocene Series (and Epoch), in the global standard scale (Cowie & Bassett, 1989). In the hierarchical logic of global chronostratigraphy (Hedberg, 1976; Salvador, 1994), the boundary-stratotype at the base of the Zanclean is the first (some would say only) choice for the location of the GSSP that defines the lower boundary of the Pliocene. The stratigraphic relationships at the base of the Zanclean are also closely consistent with the original definition of the Pliocene in Italy.

Few of the temporal subdivisions from the early days of geology are as unambiguously identified in terms of modern stratigraphy as the boundary between Miocene and Pliocene. In the various editions of the *Elements of geology* wherein Lyell added detail to the epochs that were erected in the first edition of the *Principles of* *geology* (Lyell, 1833), he never failed to reiterate that they were ".. originally invented with reference purely to [marine] conchological data .. " (Lyell, 1871, p. 144). Even in the latter editions of the *Elements* such as this, we find that the primary examples of Miocene and Pliocene marine strata shown in the "Tabular view of the fossiliferous strata" (op. cit., pp. 132-136) are almost the same as in the original definition: the Loire Valley, the North Sea Basin, Italy, and the Vienna Basin. Setting aside the French and Austrian examples, no parts of which are Pliocene or even upper Miocene, as well as sections outside of Europe and those mentioned only in the text, the definition of the boundary between the epochs in Lyell's own terms rests on superimposed fossiliferous beds in the remaining two locations that he listed: the Lowlands of Flanders and England, and the margins of the upper Po Valley in northern Italy. In the North Sea basin the youngest of the shallow-marine formations originally designated by Lyell as Miocene, the Diest sands, are separated by widespread regional erosion from the oldest of those that he designated as Pliocene: the "middle Antwerp Crag" (=Kattendijk Formation) and "upper Antwerp Crag" (=Lillo Fm., Kallo horizon, Mol Sands) in Flanders, as well the correlative White or Coralline Crag on the English side of the Channel. Research has shown that in the modern time scale these classic exposures are in fact assignable to late Miocene (Syltian) on the one hand, and to early Pliocene (Kattendijkian) and middle Pliocene (Scaldisian), on the other (Laga & de Meuter, 1972; Hooyberghs & de Meuter, 1972; Bosch, Cadée & Janssen, 1975; Wilkinson, 1980; Gramann, 1988; Laga, 1988). Despite this happy coincidence, the North Sea example of the boundary has little value for global correlation, because of endemic paleontology and the lack of geochronometric data; in addition, an unknown part of the transition interval is lost to erosion.

In Italy, however, the fossil-rich, open marine strata assigned by Lyell to these two epochs – the Miocene "beds of the Superga near Turin" and the Pliocene "sub-Appenine marls", respectively -- can be mapped in an essentially continuous sequence, divided by a section of barren evaporative beds and fluviatile clastics. The evaporative interval is now seen as the record of a relatively brief (0.62 myr, from the base of the Calcare di Base to the base of the Zanclean; Hilgen et al., 1995) and faunally catastrophic desiccation event known as the Messinian Salinity Crisis (Ruggieri, 1967; Hsü, Cita & Ryan, 1973), which synchronously affected the entire Mediterranean Basin. Thus, in all parts of the basin, the normal-marine beds that directly overlie the deposits of the Salinity Crisis can be correlated exactly to the lowermost strata in Lyell's Italian example of the Pliocene Series. This fundamental relationship was in fact recognized earlier, when the beginning of the Pliocene throughout the basin was linked to a single regional marine transgression (e.g., Gignoux, 1955) following deposition of end-Miocene gypsiferous beds.

Since 1868, distinctive deep-water deposits of the lowermost Pliocene in southern Italy, the Trubi foraminiferal marls, have been assigned to the Zanclean Stage, and the evaporative and nonmarine clastic deposits of the Salinity Crisis below them have been reconized as the upper part of the Upper Miocene Messinian Stage. It is probable that the transition between the evaporative and overlying deep marine facies reflects a rapid, some might say geologically instantaneous, refilling of the Mediterranean Basin (Brolsma, 1975; Cita & Colombo, 1979), so that there is little or no depositional hiatus in deep-water sections where Trubi marls were deposited.

To the extent that this horizon is marked by lithologic and above all paleontologic changes, however, it deviates from the recommendation that a chronostratigraphic boundary should be defined in a marine section with a continuous record above and below the boundary (e.g., Salvador, 1994, pp. 90-91). On the other hand, the basin-wide discontinuity itself has been the sole criterion for the base of the Zanclean Stage for more than a century (cf. Roda, 1971). To locate the base of the Zanclean at any other level – higher in the Trubi, for instance, or down within the Messinian section (see below) -- would violate the more compelling recommendation (e.g., Salvador, 1994, p. 24) that a boundary should not be defined in a way that conflicts with established and accepted usage.

Remane et al. (1996) clearly state that not all the requirements of a perfect GSSP "...can be fulfilled in every case, but the fact that all GSSPs are voted by ICS in accordance with the present Guidelines insures that flexibility will not degenerate to arbitrariness." Therefore, we do believe that a GSSP located at the sharp facies change between the basically nonmarine Arenazzolo and the hemipelagic Trubi formations (see below) does not fulfill one of the requirements of a boundary-stratotype, but we also believe this to be one of the best case in which flexibility can be worth applying.

Moreover, in regard to the fundamental objective of all promulgated international guidelines (Hedberg, 1976; Cowie, et al., 1986; Salvador, 1994; Remane, et al., 1996), recent research demonstrates that in this case the historically justified boundary horizon can be correlated by multiple lines of evidence with reliable precision, as well as if it were in a fully continuous sequence.

The Zanclean Stage: historical review

The Zanclean Stage was defined by Seguenza (1868) as the lower part of the Pliocene, to complement Mayer's Astian Stage in the upper Pliocene. The term was first mentioned, however, the year before by Mayer (1867) in his original definition of the Messinian Stage, which he had designated as a unit encompassing the entire interval between Tortonian and Astian. Mayer observed that his stage would include the marine beds near Messina "..que M. Seguenza voudrait proposer le nom d'etage Zankléen" (Mayer, 1867, p. 12; cited by Cita and Gartner, 1973). The name, which by this evidence is older than that of the Messinian itself, derives from Zanclea, the classical name of Messina. The archetypal Zanclean strata crop out in the Gravitelli valley 4 km NW of the center of that city. The lower part of the sequence, identified by Seguenza as "marnes blanches à foraminifères", is overlain by sands also rich in microfossils but with abundant macrofossils; these sands are now considered to belong to the Piacenzian, s. str., leaving the white marls to exemplify the true Zanclean. At Gravitelli these marls, some 10 to 15 m thick (Roda, 1971), rest on a "puissante formation de sables sans fossiles", which after Seguenza's revision became the uppermost levels of a re-defined Messinian. A collection of Late Miocene mammal fossils noted by Seguenza (1907) in the lower part of the Messinian at Gravitelli has since been lost.

The white marls of the Gravitelli section belong to the Trubi Formation, a rhythmically bedded foraminiferal pelagic ooze widely exposed in Sicily and Calabria, and encountered in cores from many different parts of the Mediterranean Basin. This facies has been considered the quintessential manifestation of the Zanclean for over a century (Roda, 1971). Because the Gravitelli exposures are now largely inaccessible, a Zanclean stratotype was formally designated and described by Cita and Gartner (1973; see also Cita, 1975) in sea cliffs at Capo Rossello, on the southern coast of Sicily west of Agrigento, where the Trubi exceeds 100 m in thickness and is presumably more complete than at Gravitelli. In this section, as at Gravitelli, the base of the Trubi marls is in conformable contact with dark, sandy clays of the Upper Messinian "Arenazzolo", an alluvial unit deposited under shallow nonmarine conditions, and which is seen elsewhere (as at Eraclea Minoa) to rest on thick "Gessoso-solfifera" gypsum-anhydrite deposits that represent the final stages of marine desiccation in the basin.

Cita (1975a) formalized the proposal of Cita and Gartner (1973), that the base of the unit-stratotype of the Zanclean at Capo Rossello should also be the defining physical point, or "golden spike", for the Miocene-Pliocene boundary sensu Lyell. While this proposal was never brought up for adoption by IUGS, the detailed description of the Trubi micropaleontology (Cita and Gartner, 1973; Cita, 1975) and paleomagnetic data (Kennett and Watkins, 1974; Watkins & MacDougall, 1976) allowed the original Lyellian concept of the Pliocene to be extended worldwide in both marine and nonmarine sections at ca. 5 Ma (Berggren and Van Couvering, 1974). The global validation of the Zanclean corroborated the finding of Van Couvering and Miller (1971) that the Pliocene had been grossly mis-dated in most parts of the world, through a 19th-century error in assuming that the Messinian salts of Italy were correlative to much older salt beds in the Carpathian foredeep associated with the first appearance of *Hipparion*.

The Zanclean stage is now officially accepted as the lowest subdivision of the Pliocene in the global chronostratigraphic scale (Cowie et al., 1986), superseding Tabianian, Kimmerian, Kapitean, Repettan and other more or less coeval terms that remain limited to local use.

The criteria for correlation of the base of the Zanclean as a global standard stage are, however, different outside the Mediterranean Basin than within it. The sharp physical transition from shallow water to deep water deposits at the end of the Messinian Salinity Crisis in the Mediterranean is not seen, as such, in other ocean basins. Therefore, the position of the base of the Zanclean with respect to as many stratigraphic parameters as possible should be precisely assessed to allow for the extra-Mediterranean recognition and traceability of the boundary. The present-day knowledge concerning the position in time of the base of the Zanclean is briefly reviewed here below to demonstrate that, in spite of the geological peculiarity of the boundary in its type-area, the position in time of the base of the Zanclean is very well constrained (with a precision of a few thousand years).

The base of the Zanclean Stage and Pliocene Series: its position in time

During the last decade, detailed field work on the rhythmically bedded sedimentary succession widely outcropping in Sicily and Calabria led to the reconstruction of an ideal stratigraphic composite section which ranges from the base of the Pliocene to the middle Pleistocene (e.g. Hilgen, 1987, 1990, 1991a, b; Langereis and Hilgen, 1991; Zijderveld et al., 1991; Lourens et al., 1996a, b; Lourens et al., 1997). The cyclic limestone-marl and marl-sapropel alternations in this succession were linked to every single fluctuation of the Earth's precessional parameter (in turn modulated by orbital eccentricity), resulting in a continuous astrochronology of the lithostratigraphic record (Hilgen, 1991a, b). Later on, the influence of obliquity was also recognized in the lithologic record and the astronomical calibration slightly adjusted and improved (Lourens et al., 1996a) (fig. 3).

It is within this astrocyclostratigraphic framework that the nannofossil and foraminifer biostratigraphy (among many others, Rio et al., 1990; Sprovieri, 1992, 1993) and the magnetostratigraphy (e.g. Zachariasse et al., 1989, 1990; Zijderveld et al., 1991; Langereis & Hilgen, 1991) of the Mediterranean Plio-Pleistocene are calibrated in time (fig. 4 and 5).

To summarize, the most important stratigraphic features associated to the base of the Pliocene and useful for its precise location in time and worldwide correlation are: a) the base of the first Trubi bed (i.e. the boundary itself) corresponds to insolation cycle 510 (precession-related cycle 1 in the Mediterranean) from the present with an age of 5.33 Ma (Lourens et al., 1996a); b) the base of the Thvera magnetic event occurs in insolation cycle 500 (precession-related cycle 5) (Hilgen and Langereis, 1991; Hilgen, 1991b), with an age of 5.236 Ma (Lourens et al., 1996a); c) the last occurrence of *T. rugosus* is recorded in the marl (or sapropel) of cycle 5 in the Mediterranean (Di Stefano et al., 1996; Castradori, 1998), with an approximate age of 5.23 Ma. This event has been also calibrated at 5.23 Ma in the low-latitude Atlantic ocean (Backman and Raffi, 1997); d) the first occurrence of *Ceratolithus acutus* is recorded immediately below the Miocene/Pliocene boundary (as correlated through astrocyclostratigraphy) in the Ceara Rise (equatorial Atlantic; Backman and Raffi, 1997), with an age of 5.37 Ma; in fact, a few specimens of *C. acutus* are recorded since the very basal Zanclean in the Mediterranean (Cita and Gartner, 1973; Castradori, 1998); e) the last occurrence of *Discoaster quinqueramus*, a worldwide marker event in the latest Miocene (Martini, 1971; Okada and Bukry, 1980), is not recorded in the Mediterranean due to the occurrence of the Salinity Crisis. However, this event has been precisely calibrated outside the Mediterranean as occurring in Chron C3r at 5.537 Ma. For most purposes, it can be considered as a good approximation of the Miocene/Pliocene boundary.

Motivation for selection of the boundary level

1. Historical. As noted above, the Zanclean/Messinian transition in southern Italy and Sicily is fully consistent with the relationship Lyell described between basal Pliocene strata and underlying evaporites in northern Italy. 130 years ago, when the stage concept was being introduced in Italy, the regional extent of this relationship was not always apparent, and the chronostratigraphic position of the Zanclean in Sicily, relative to the Tabianian stage erected on the lower Pliocene of northern Italy, was slow to come into focus (see Benson and Rakic-El Bied, 1996). The application of planktonic microfossil biostratigraphy in the latter half of the 20th century, however, made it clear that the shallow-marine "beds of the Superga" described by Lyell were synchronous with the microfossil-rich deep-sea deposits overlying Messinian evaporites in Sicily and in offshore cores. For this reason Blow (1969) reintroduced the neglected Zanclean Stage in his classic review of planktonic foraminiferal zones, in order to emphasize the shift from molluscs to microfossils in global correlation. With the recognition of the basin-wide isochronicity of the end-Miocene desiccation episode (Hsü, Ryan and Cita, 1973), the proposal by Cita and Gartner (1973) to formally recognize the more complete, informative and correlatable Zanclean as the lower division of the Pliocene met with overwhelming acceptance by the oceanographic community, conspicuously including those members, Italian and others, with first-hand experience in Mediterranean stratigraphy.

2. Practical. In the years since Cita (1975a) described and pictured the Zanclean type-section at Capo Rossello, progressive retreat of the sea-cliff has sharply reduced the already small anticlinal exposure of pre-Zanclean Arenazzolo in which the basal contact can be observed. Without abandoning the well-displayed and stratigraphically complete unit-stratotype of the Zanclean at this site, it is appropriate to designate a separate boundary-stratotype for the Zanclean in physically correlative beds at Eraclea Minoa, as proposed by Hilgen and Langereis (1993). This is a better protected and more informative section for the location of the Messinian/Zanclean boundary, and includes a considerable exposure of the typical Messinian gyspum-anhydrite formation that is concealed at Capo Rossello.

The Eraclea Minoa section, moreover, is the lowest component in the Rossello Composite Section of Langereis and Hilgen (1991), on which the lower and middle Pliocene part of the high-resolution Astronomical Polarity Time Scale (or APTS) is founded (Hilgen, 1991a, b; Langereis and Hilgen, 1991; Lourens et al., 1996).

The GSSP of the Middle Pliocene Piacenzian Stage has also been proposed (Cita, et al., 1996) and recently officially ratified (see Castradori, et al., in press) in the Rossello Composite Section at Punta Piccola (fig. 3). In addition, this section also contains a very precisely correlated base of the Upper Pliocene Gelasian Stage, whose GSSP has been officially ratified in the Monte San Nicola section (near Gela, Sicily; Rio et al., in press; Rio et al., 1994) (fig. 3). It is important to note that stratigraphic boundaries defined within the Rossello Composite Section are, of course, dated automatically and unambiguously in the APTS. Thus, the strong historical justification for using the base of the Trubi as a marker for the beginning of the Pliocene go hand in hand with ideal conditions for determining and correlating its age.

3. Stratigraphic principles

The modern international stratigraphic guidelines, compiled from various national stratigraphic codes (Hedberg, 1976; Salvador, 1994), emphasize a hierarchical construction of the chronostratigraphic scale, with the Stage as the basic unit. In fact, the subdivision of Series (and Systems) into worldwide or pan-regional "standard stages" was widely adopted well before this time (cf. Grabau, 1926; Gignoux, 1953). Modern time scales (Berggren and Van Couvering, 1974; Cowie, et al., 1986; Harland, et al, 1982, 1990; Berggren, et al., 1995a) show a consensus on using European stages as standard divisions of the Cenozoic, although there has been a shift from those stages characterized by molluscan or endemic marine faunas to stages erected in sections of open-marine, microfossil-rich strata. The suppression of Tabianian in favor of Zanclean, as noted above, is a characteristic example.

There are exceptions to strict hierarchy in practise. Both the Hedberg and Salvador versions of the international guidelines, as well as the IUGS recommendations (Cowie, et al., 1986; Remane, et al., 1996) accept that series and systems boundaries may be validly established in GSSPs without reference to stage hierarchy. The international guideliness stress, however, that this procedure should be limited only to circumstances *where no stage has been adopted as the basal subdivision of the higher unit in question* (cf. Salvador, 1994, pp. 80-81). In addition, a stage boundary-stratotype is almost always placed at a level below the base of the unit-stratotype, thus enlarging (if very little) the scope of the unit. Unfortunately, these loopholes have been enlarged in the IUGS recommendations (Cowie, et al., 1986; Remane, et al., 1996) to allow the establishment of higher chronostratigraphic unit boundaries *a priori,* on the basis of convenient or pre-selected criteria without serious consideration of the standard stages. In some instances, such as the Ypresian base of the Eocene (Aubry et al., 1998 in press) and the Calabrian base of the Pleistocene (Van Couvering, 1997), series-boundary GSSPs that represent very considerable departures from hiererarchical principles were proposed and adopted, not because there was no stage available, but for simply expedient reasons. Reconciliation of stage boundary-stratotypes to the preconceived GSSPs may be possible, as in the case of the Calabrian (Van Couvering, 1996; 1997) or not, as in the case of the Ypresian (Aubry et al., 1998 in press), but this should not be necessary. The exemplary or standard stages comprise the essential and necessary physical manifestation of higher chronostratigraphic units, and it is of vital importance to respect the reality of their boundaries within the more abstract meaning of the higher units.

In this light, and with regard to the repeated recommendation in the *Guide* to select those boundaries that maintain stability and historical continuity wherever possible, we consider that stratigraphic principles require that the first consideration for the GSSP defining the base of the Pliocene must be given to the boundary-stratotype that exemplifies not only the long-established limit between the Messinian and Zanclean stages, but one that respects the clear historical significance of this boundary for the meaning of the Pliocene itself.

PROPOSAL: THE ZANCLEAN GLOBAL STANDARD STRATOTYPE-SECTION AND POINT (BASE OF THE PLIOCENE)

Name of the boundary: Base of the Zanclean, and of the Pliocene.

Rank and status of the boundary: Standard Stage/Age, and Series/Epoch GSSP.

Position of the defined unit: Lowest stage of the Pliocene Series, between the Upper Miocene Messinian Stage and Middle Pliocene Piacenzian Stage.

Type locality of the GSSP: the Eraclea Minoa section, on the southern coast of Sicily (Italy) (figs. 1, 2, and 3). The Eracela Minoa section is the basal component of the Rossello Composite Section (Langereis & Hilgen, 1991), which continues to the east in sea cliffs at Punta di Maiata below Realmonte through Punta Grande to Punta Piccola below Agrigento, and which is the global reference section for the Lower and Middle Pliocene part of the Astronomical Polarity Time Scale (APTS).

Geologic setting and geographic location: the Rossello Composite Section (of which the Eraclea minoa constitutes the lowest segment) is situated in the Caltanissetta Basin; from a structural point of view, the section belongs to a major tectonic element known as Gela nappe or Gela thrust system (Ogniben, 1969; Butler et al., 1995) (fig. 2). The depositional environment is inferred to be an open marine slope-basin setting (Brolsma, 1978). The composition of the benthic assemblage suggests a water depth of about 600-800 m (Sgarrella et al., 1997, and references therein).

The Eraclea Minoa section is located in Sicily (Agrigento Province); its geographic coordinates are: Latitude 37°23'30''N; Longitude 13°16'50''E of Greenwich.

The Eraclea Minoa section crops out continuously in a steep wave-cut bluff, approx. 30 m high and 500 m long, that rises along the north side of the summer home community of Eraclea Minoa (fig. 1). The bluff is parallel with and about 500 m inland from the modern beach. The basal Zanclean contact, proposed as GSSP, is very apparent and well exposed where white Trubi marl rests on dark brown Arenazzolo sands and marls approximately 75 m from the west end of the exposed section.

This well protected location, an abandoned wave-cut cliff in west-dipping upper Miocene and lower Pliocene strata, allows the basal Zanclean contact to be seen along a bedding plane length of more than 30 meters, at the base of a section of

Trubi marls more than 35.5 m thick. Stratigraphically below the contact, about 10 m of nonmarine Arenazzolo sands and marls is seen above a 200 m-section of gypsiferous strata representing the upper hypersaline facies, or Gessoso-Solfifera, of the Messinian (Cita et al., 1978; Schreiber, 1997). The upper contact of the Trubi with middle Pliocene strata is obscured by Pleistocene terrace to the west.

Map: The stratotype-section is represented on the Carta Topografica d'Italia at the 1:25,000, Foglio 266 (Sciacca), Quadrante II, Tavoletta S.O. Capo Bianco (fig. 1).

Accessibility: Access to the main face of the exposure is unrestricted, in all seasons. The exposure can be reached from the road that fronts the row of homes at its foot, via informal paths that go between the houses. The exposure can also be accessed via public land at its far western end, at the point where the frontage road turns sharply towards the beach.

Conservation: The steep rocky face of the exposure is not subject to building or landscaping. The exposure is an abandoned beach cliff which is no longer subject to wave undercutting, and it is distant from any active stream channels. Although completely barren of vegetation, and sharply eroded, the lack of active talus cones or slump blocks indicates that it is well stabilized. Designation as an international point of geologic interest can be established in future.

GSSP definition: The base of the carbonate bed of the small-scale cycle 1 (Hilgen, 1987; Hilgen and Langereis, 1988; Langereis and Hilgen, 1991) in the Eraclea Minoa section is proposed as the GSSP of the Zanclean Stage (and of the Pliocene Series). It corresponds to insolation cycle 510 from the present with an astrochronologic age estimate of 5.33 Ma (Lourens et al., 1996a).

Identification in the field: The field relationship between dark brown, poorly bedded sandy Arenazzolo above massive gypsum, and overlying cream-white, conspicuously banded, chalky Trubi is unmistakable, and the contact is isochronous along its exposed length.

Completeness of the section: The detailed bed-by-bed correlation of the basal Zanclean all along the southern coast of Sicily and Ionian Calabria (fig. 4), coupled with detailed magnetostratigraphy and biostratigraphy (e.g. . Hilgen, 1987; Hilgen and Langereis, 1988; Langereis and Hilgen, 1991; Zijderveld et al., 1986, 1991;

Zachariasse et al., 1989, 1990; Sprovieri, 1992, 1993; Rio et al., 1984; Cita and Gartner, 1973; Cita, 1975b; Di Stefano et al., 1996) clearly demonstrate the stratigraphic continuity of the basal Zanclean in the Eraclea Minoa section. In particular, the recognition of the base of the Thvera magnetic event always associated with cycle 5 is of momentous importance in this respect. As to the problem of the sharp vertical facies change between the basal Trubi and the underlying Messinian, we have already discussed its implications and drawbacks in the general section of this proposal.

Global correlation: Contrary to what reported by some authors (Benson and Hodell, 1994; Benson and Rakic-El Bied, 1996), the (of course, approximate) correlation of the base of the Zanclean Stage and of the Pliocene Series outside the Mediterranean and on a global scale is certainly easier and more precise than that of many other chronostratigraphic boundaries.

The key-tools can be summarized as follows:

Astrocyclostratigraphy: the boundary corresponds to insolation peak 510 from the present, with an astrochronologic age estimate of 5.33 Ma (Lourens et al., 1996a). This allows the most precise correlation of the boundary when an orbitally tuned cyclostratigraphic framework is available, as it is the case of many ODP Sites drilled in recent years (e.g. Leg 138, Shackleton et al., 1995; Leg 154, Shackleton and Crowhurst, 1997, Backman and Raffi, 1997)

Magnetostratigraphy: the basal boundary of the Thvera magnetic event (C3n.4n of Cande and Kent, 1992, 1995) has an astrochronologic age estimate of 5.236 (Lourens et al., 1996a), that is only 96 kyrs (5 precession cycles) younger than the proposed GSSP. It provides a very good approximation of the boundary which can be further improved when a cyclostratigraphic approach to the section is feasible (counting 5 precession-related cycle below the base of the Thvera).

Nannofossil biostratigraphy: this is the best biostratigraphic tool for the correlation of the boundary outside the Mediterranean. In fact, three important evolutionary events, recognizable on a global scale and included in the standard zonations of Martini (1971) and Okada and Bukry (1980), take place very close to the proposed Zanclean (and Pliocene) GSSP. In order of increasing age distance from the boundary, these are: The first occurrence of *Ceratolithus acutus*, calibrated at 5.37 Ma (Backman and Raffi, 1997) in the equatorial Atlantic (Backman and Raffi, 1997), that is 40 kyrs earlier than the proposed GSSP. In fact, a few specimens of *C. acutus* have been reported in the very basal Zanclean of the Mediterranean area (Cita and Gartner, 1973; Castradori, 1998). The last occurrence of *T. rugosus*, calibrated at about 5.23 Ma both in the Mediterranean (Di Stefano et al., 1996; Castradori, 1998) and in the equatorial Atlantic ocean (Backman and Raffi, 1997). The last occurrence of *Discoaster quinqueramus* (not recorded in the Mediterranean due to the occurrence of the Salinity Crisis), calibrated outside the Mediterranean as occurring in Chron C3r at 5.537 Ma (Backman and Raffi, 1997).

Probably of more limited (Mediterranean) applicability is the base of a paracme interval of *R. pseudoumbilicus* in cycle 6 (Di Stefano et al., 1996).

Foraminifer biostratigraphy: the first appearances of *Globorotalia tumida* and *Globorotalia sphericomiozea* have been calibrated at 5.6 Ma by Berggren et al. (1995), with reference to tropical/subtropical and transitional areas, respectively. Within the Mediterranean, the *Sphaeroidinellopsis* Acme Zone (MPl1 of Cita, 1975b) characterizes the first 10 precession-related lithologic cycles of the Zanclean, being defined at the top by the (local) first common occurrence of *Globorotalia margaritae*. These events are not recognizable, or strongly diachronous, outside the Mediterranean. Two sinistral shifts of *N. acostaensis* have been recently reported from cycle 2 and 3 (Di Stefano et al., 1996).

Isotope stratigraphy: Referring to the deep-sea oxygen-isotope data interpreted by Shackleton, Hall and Pate (1995) as reflections of orbitally forced Late Neogene ice volume changes, Suc, Gautier & Clauzon (1997) identified 22 isotope cycles in the lower part of submagnetochron C3r seen in the Salé core (Morocco), and located the "interglacial" or highstand TG5 peak at the level correlated to the base of the Zanclean, in agreement with Shackleton, Hall and Pate (1995). Lourens et al. (1996) show a classification into TG stages for the lower (pre-Thvera) part of the Gilbert chron. They report two "glacial" stages (namely TG2 and TG4) in the basal Trubi and correlate them with ODP Sites 846 and 677. So, "interglacial" stage TG5 represents a possible worldwide transgression correlated with the basal Zanclean deluge and cositutes a very good approximation of the base of the Pliocene. It was in fact proposed as the primary marker for the selection of an extra-Mediterranean boundary, a solution advocated by Suc et al., 1997 (see above).

Re-establishment of saline reflux plumes from the Gibraltar portal, as seen in deep Atlantic cores at about 5 Ma, has been correlated by Zhang and Scott (1996) to the refilling of the Mediterranean at the beginning of the Zanclean. Possible effects of the boundary event are also seen in extra-Mediterranean coral reef sequences that record sharp sealevel changes associated with the Messinian Salinity Crisis. Cores from the Great Bahama Bank show an exposure surface capping Messinian reefs overlain by Lower Pliocene deeper shelf carbonates (MacKenzie, Spezzaferri and Isern, 1997), suggesting a sudden drawdown (Mediterranean refilling) and then recovery of water depth on the subsiding bank. Drilling on Niue atoll on the margin of the Tonga Trench, where progressive Neogene uplift allows resolution of closely-spaced events, shows repeated eustatic sealevel changes of 10 m amplitude culminating in at least 30 m of sealevel drop dated to 5.26 Ma, essentially synchronous with the Zanclean infilling (Aharon, et al., 1993). Similar stratigraphic features reflecting the abnormally sharp change in sealevel at the boundary (Hsü, Ryan and Cita, 1973) may be sought in continuous sections elsewhere, offering a correlation tool unique to the Zanclean GSSP.

Summary of background studies on the Eraclea Minoa section

The Eraclea Minoa section constitutes the lowest segment of the Rossello Composite Section. A brief summary of the studies on this composite section is reported here below.

Lithostratigraphy and cyclostratigraphy: Hilgen (1987); Hilgen and Langereis (1988); Langereis and Hilgen (1991).

Magnetostratigraphy: Hilgen and Langereis (1988); see also Langereis and Hilgen (1991) and Zijederveld et al. (1986) for comparison with Calabrian sections.

Isotopic stratigraphy: Lourens et al. (1996a)

Nannofossil biostratigraphy: Cita and Gartner (1973); Rio et al.(1984); Di Stefano et al. (1996); see also Castradori (1998) for a comparison with the basal Zanclean in the eastern Mediterranean sea (ODP Leg 160).

Planktonic foraminifer biostratigraphy: Cita (1975b); Sprovieri (1992, 1993) and references therein.

Benthic foraminifers and depositional environment: Broelsma (1978); Sprovieri and Barone (1982); Sgarrella et al. (1997).

Climatic fluctuations and paleoceanographic interpretation: Sprovieri (1992, 1993); Di Stefano et al. (1996); Thunell et al. (1991); De Visser et al. (1991).

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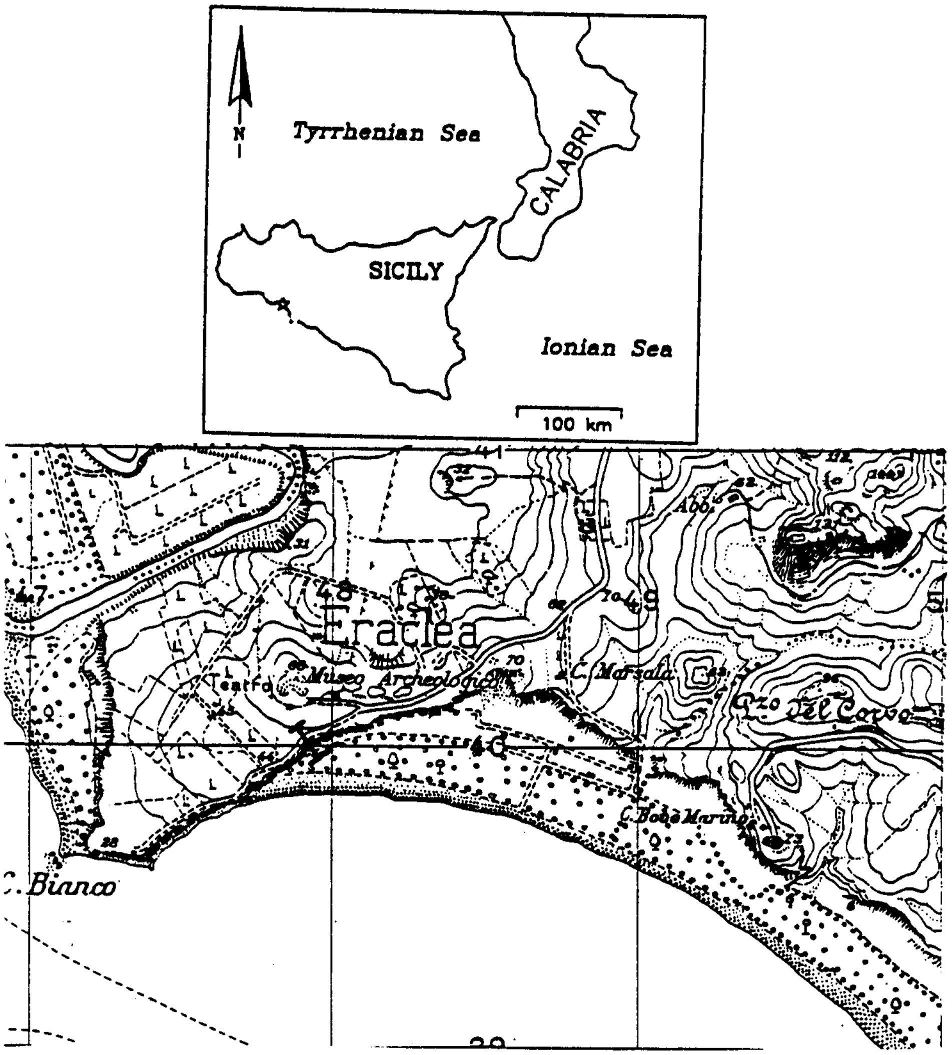

Figure 1. Location of the Eraclea Minoa section.

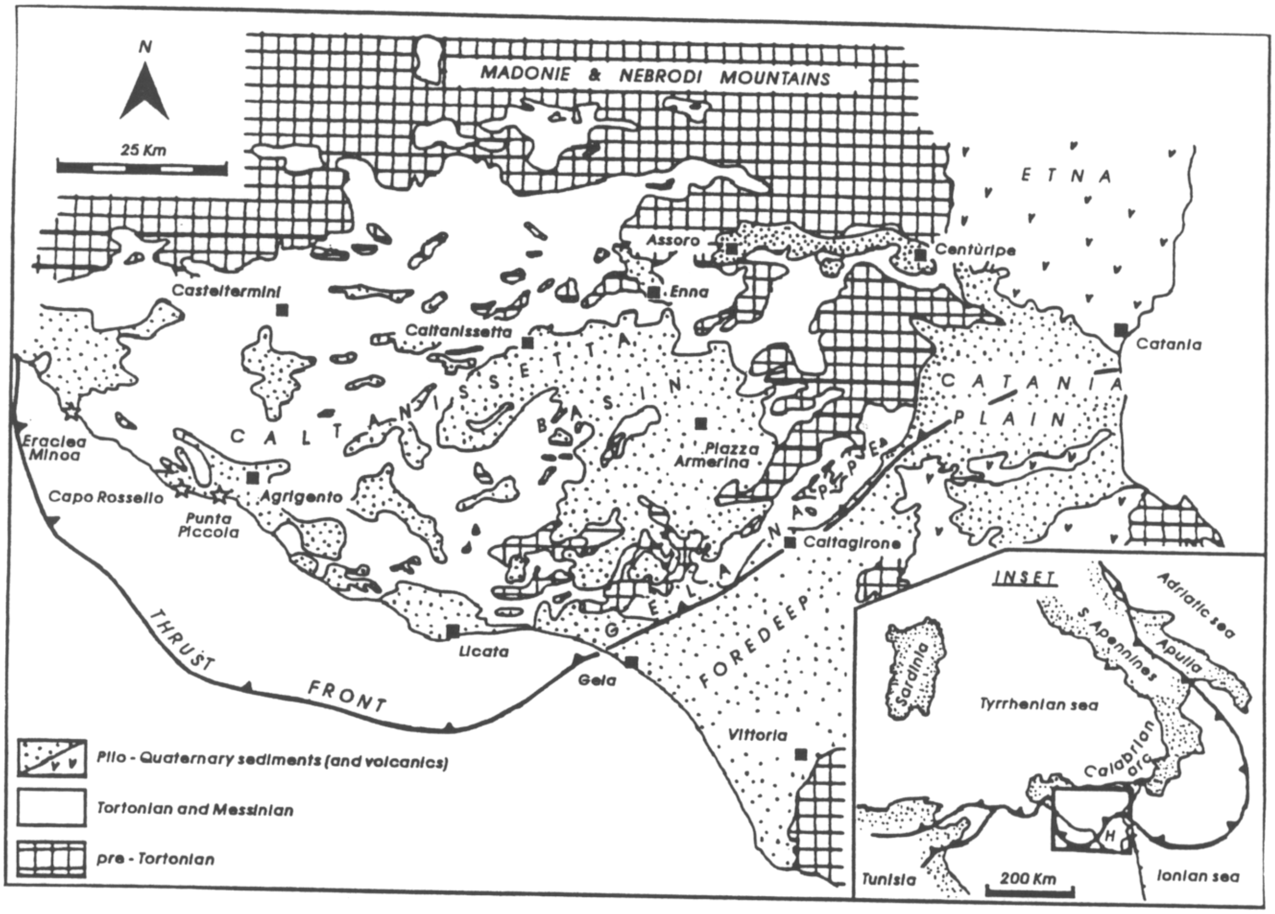

Figure 2. Geological sketch map of the central-southern Sicily showing the distribution of Pliocene and Pleistocene sediments across the thrust-belt ("Caltanissetta Basin") and the adjacebt foredeep. Inset: location of Sicily in the Apenninic-Maghrebian thrust belt. H: Hybkean plateau (after Butler et al., 1995; modified by Cita et al., 1996).

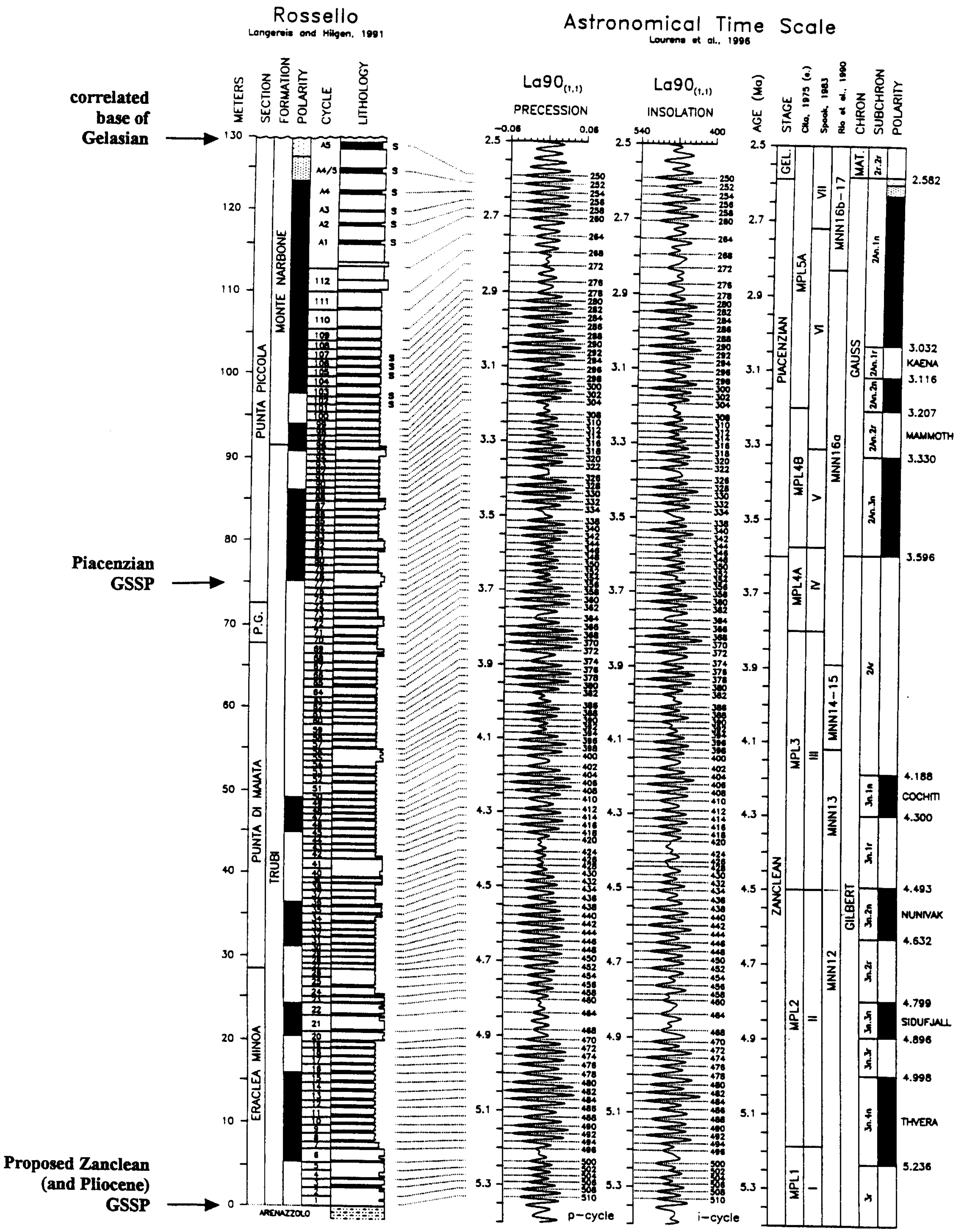

Figure 3. Chronology of the Rossello Composite Section based on the correlation of small-scale carbonate cycle patterns to the $La90_{(1,1)}$ (Laskar, 1990; Laskar et al., 1993) precession and 65°N summer insolation curves (Hilgen, 1991b; Lourens et al., 1996a). (After Castradori et al., in press).

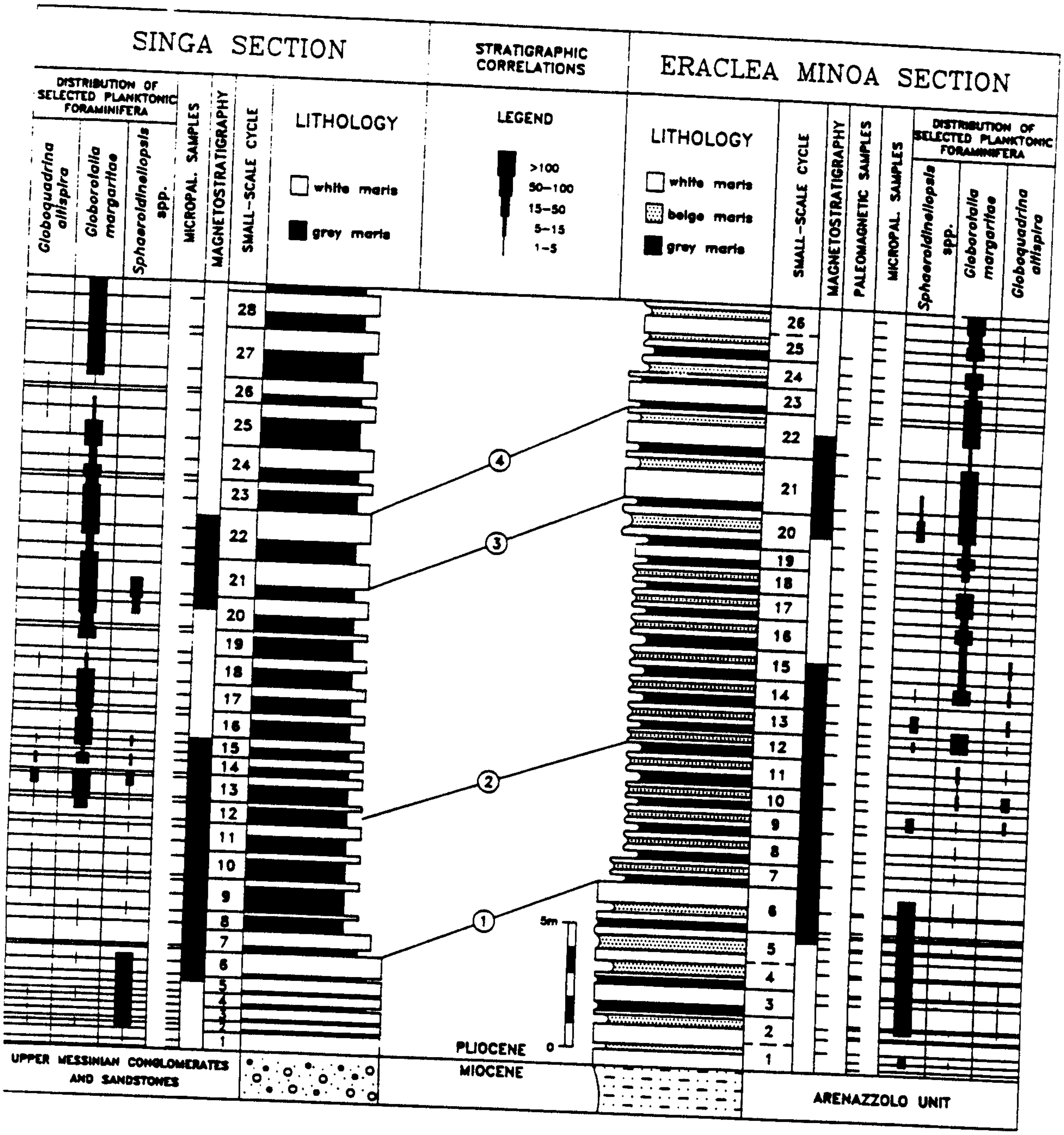

Figure 4. Magnetostratigraphy, biostratigraphy and lithostratigraphy of the Eraclea Minoa and Singa sections. The magnetostratigraphy and lithostratigraphy of the Singa section is based on Zijderveld et al. (1986), the magnetostratigraphy of Eraclea on data by Hilgen and Langereis (1988). The two normal polarity zones are the Thvera and Sidufjall subchrons. The subdivision in small scale sedimentary cycle is after Hilgen (1987). Numbered stratigraphic correlations refer to (1) top small-scale cycle 6, (2) first substantial increase of *G. margaritae* (the FCO of *G. margaritae* is now correlated to cycle 10; Sprovieri, 1992, 1993; Di Stefano et al., 1996), (3) cycle 21, (4) top cycle 22. The top of the *Sphaeroidinellopsis* acme corresponds with top cycle 6. (After Hilgen and Langereis, 1988).

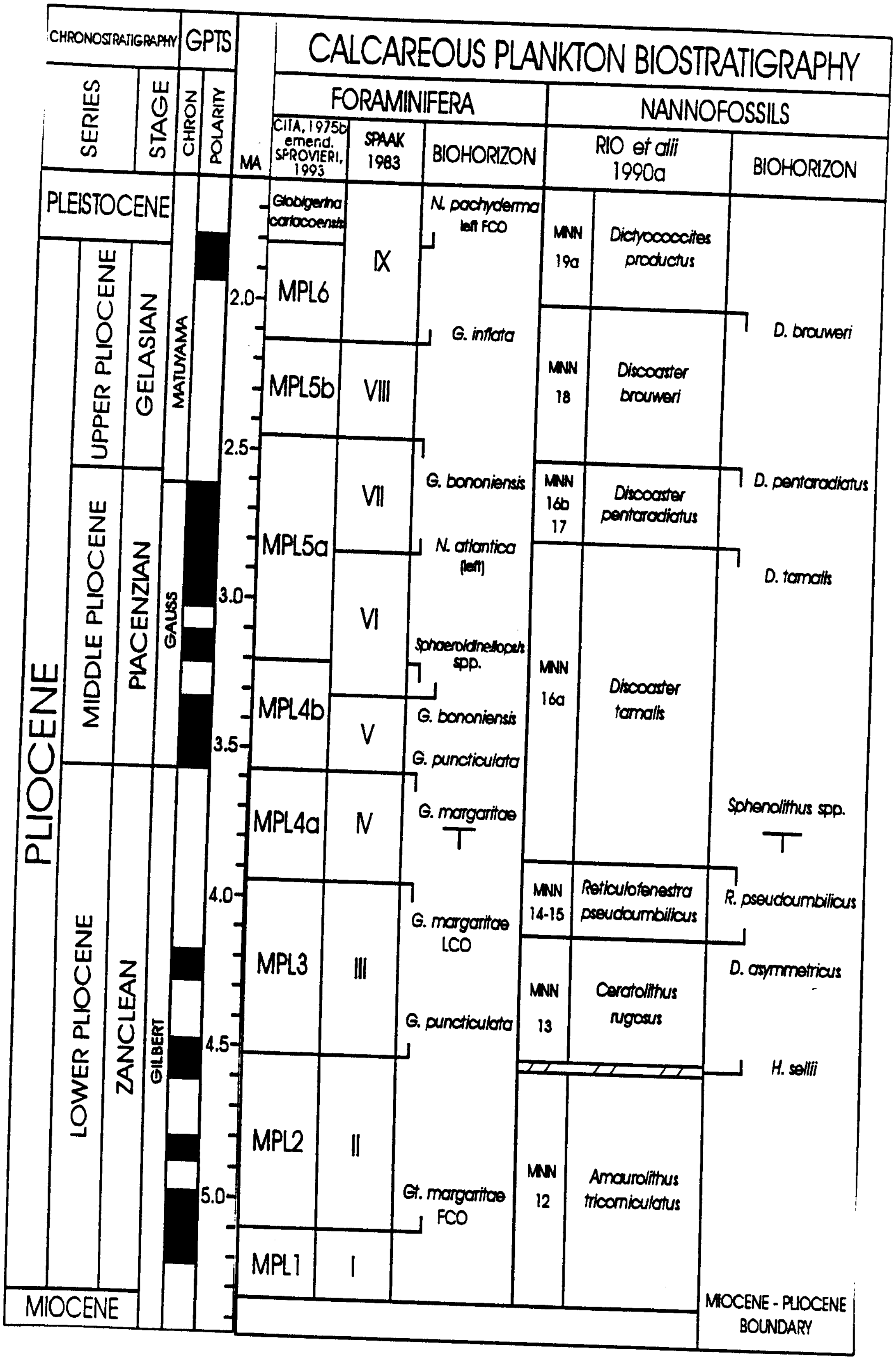

Figure 5. Integrated Pliocene time framework. The Geomagnetic Polarity Time Scale is that of Hilgen (1991b; incorporated into Cande and Kent, 1995); the calibration of calcareous plankton biohorizons is after Berggren et al. (1995b).