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The base of the Zanclean Stage and of the Pliocene Series

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The ratification by IUGS of the recently defined base of the Zanclean Stage and of the Pliocene Series brings years of controversy to an end. The boundary-stratotype of the stage is located in the Eraclea Minoa section on the southern coast of Sicily (Italy), at the base of the Trubi Formation. The age of the Zanclean and Pliocene GSSP at the base of the stage is 5.33 Ma in the orbitally calibrated time scale, and lies within the lowermost reversed episode of the Gilbert Chron (C3n.4r), below the Thvera normal subchron.

the proxy evidence of their specializations, and who argued strongly for a "paleoclimatic" boundary equivalent to the base of the Gelasian (e.g., Morisson and Kukla, 1998). The Vrica boundary was, however, reaffirmed in 1998 by a joint postal ballot of the Subcommission on Quaternary Stratigraphy (SQS) and the Subcommission on Neogene Stratigraphy (SNS).

In the present paper, we provide a concise description of the stratotype-section of the Messinian/Zanclean (and Miocene/Pliocene) boundary, of the "golden spike" or physical reference point at the boundary itself, and of the various tools available for its worldwide correlation. More information can be found in the authors' proposal (Van Couvering, et al., 1998), reported in Neogene Newsletter No. 5, that was forwarded to IUGS after successive favorable votes of SNS and the International Commission on Stratigraphy (ICS).

Introduction

The IUGS ratification of the Eraclea Minoa GSSP (Global boundary Stratotype-Section and Point) for the base of the Zanclean Stage and of the Pliocene Series completes the characterization of the Pliocene in the Standard Chronostratigraphic Scale. With this action, the Pliocene Series is probably the most perfectly defined of all higher chronostratigraphic units. All of Pliocene time, without a gap, is physically represented in the three stages of which it is composed, in a single demonstrably uninterrupted sequence of highly fossiliferous Upper Cenozoic deep-water strata on the southern coast of Sicily. From bottom to top, the Pliocene consists of the Lower Pliocene Zanclean Stage, with a boundary-stratotype at Eraclea Minoa and a unit-stratotype at Capo Rossello; the Middle Pliocene Piacenzian Stage, defined at Punta Piccola (Castradori et al., 1998); and the Upper Pliocene Gelasian Stage, defined at Monte San Nicola near Gela (Rio et al., 1994, 1998) (Figure 1). In addition, each bed in the sequence can be directly dated, since the cyclically deposited strata in this extraordinary section are also the lithologic template for the Pliocene part of the astrochronological time scale.

The top of the Pliocene is defined by the base of the Pleistocene Series, also in southern Italy. This level was established more than a decade ago when IUGS adopted the GSSP at Vrica, Calabria (Aguirre and Pasini, 1985; Bassett, 1985), in accordance with the original sense of Lyell's terms and the classic meaning of the Lower Pleistocene Calabrian Stage (Berggren and Van Couvering, 1979; Van Couvering, 1996). In the ensuing years, objections to the Vrica boundary were put forward by members of the stratigraphic community (mostly Quaternary continental stratigraphers and palynologists) who were impressed by the effects of pre-Pleistocene glacial episodes in

Background

For over a century after Lyell (1833) created the Pliocene Epoch, the application of this term outside the Mediterranean Basin, from western Europe to Asia and the Americas, was confused by a basic mis-correlation in which the boundary became associated with "Pontian" mammalian faunas and the first appearance of *Hipparion*. This error was conclusively exposed in an early application of K-Ar dating, in which Van Couvering and Miller (1971) showed that Pontian mammal faunas in the Mediterranean Basin, at 11 Ma, were twice as old as planktonic microfauna in the basal Pliocene of Italy. This advanced the credibility of the "young" Pliocene long advocated in vain by Italian and French stratigraphers, and invited renewed atten-

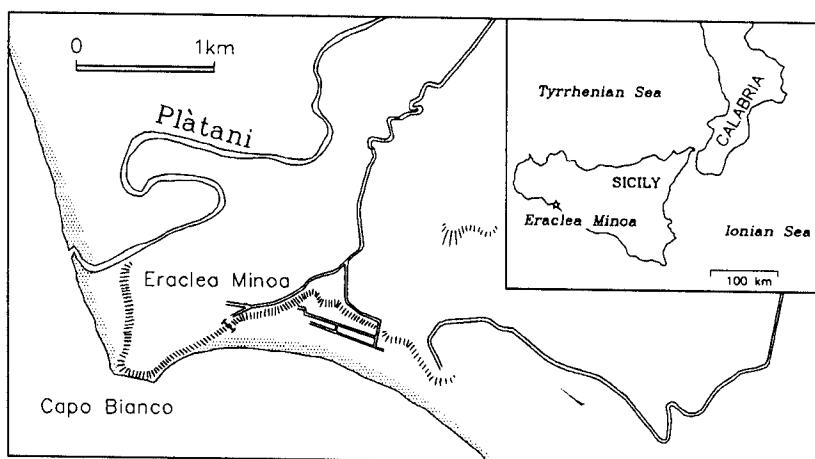


Figure 1 Location of the Eraclea Minoa section.

tion to the neglected historic origins of Cenozoic chronostratigraphy in southern Europe. Shortly thereafter, the discovery of huge thicknesses of evaporites beneath the floor of the Mediterranean basin (Hsü, Ryan and Cita, 1973) proved the complete desiccation of the Mediterranean Basin at the end of the Miocene, vindicating the prophetic vision of a "Messinian Salinity Crisis" put forward by the Sicilian micropaleontologist Giuliano Ruggieri (e.g., Ruggieri, 1967) based on the remarkable exposures of Upper Cenozoic deep-sea strata in the Sicilian nappes.

The rehabilitation of the Pliocene began when Cita (1975a) designated the exposures of Lower Pliocene Trubi marl at Capo Rossello, Sicily (Cita and Gartner, 1973) as the unit-stratotype of the Zanclean Stage. She proposed that the base of the stage, at the knife-sharp but concordant contact with fluvio-lacustrine Arenazzolo sands of the Messinian Stage, should be considered as the base of the Pliocene Series. This proposal formally recognized the long-held usage of this boundary in the Mediterranean Basin. It was also fully consistent with Lyell's (1835) observation of the marked difference between his Miocene and Pliocene macrofaunas in southern Europe, to which he alluded in distinguishing these epochs. In the light of the new deep-sea information, these epochal differences must be ascribed to the destruction of the Miocene communities during the Messinian Salinity Crisis. Thus, to identify the oldest Pliocene strata with the return of open marine conditions at the base of the Zanclean seems to be precisely consistent with Lyell's original meaning and intent.

Following Cita's proposal, a heated dispute erupted between those stratigraphers who agreed that the Zanclean definition embodied the historical sense of the Pliocene, unchanged throughout the Mediterranean Basin since Lyell's time, and those who advocated an extra-Mediterranean definition of the boundary in order to better serve the operational requirements of modern normative stratigraphy (Remane et al., 1996). The debate centered on the global correlatability of the Messinian-Zanclean boundary, because of the lack of fossil control below the dramatic stratigraphic discontinuity at the base of the Trubi.

In pursuit of an extra-Mediterranean definition, an independent GSSP for the base of the Pliocene Series was formally proposed at Bou Regreg, on the Atlantic coast of Morocco, by a working group of the Subcommission on Neogene Stratigraphy (SNS) organised in 1986 under the chairmanship of R.H. Benson. The proposed boundary was located in an open-marine sequence at a level coincident with the base of the Gilbert Chron (Benson and Rakic El-Bied, 1996; see also Benson and Hodell, 1994), several hundred thousand years older than the base of the Zanclean and unconnected with any stage boundary.

At the same time, studies of the Messinian and Zanclean strata along the Capo Rossello coastline showed that the cyclic alternations of marl and carbonate beds in the Zanclean could be precisely aligned with mathematical projections of orbitally-forced variations in global climate, offering a refined and reliable correlation of the base of the stage worldwide (Zijderveld et al., 1991; Hilgen, 1991a, b). These authors documented an exceptional section at Eraclea Minoa where the basal Trubi is well exposed overlying a thick section of Messinian strata, in contrast to the severely localized (and actively eroding) exposure of the upper meter or so of the Messinian at the base of the Trubi cliffs at Capo Rossello. In view of this, Hilgen and Langereis (1993) suggested that a boundary-stratotype for the Zanclean, and thus the GSSP for the base of the Pliocene, should be located at Eraclea Minoa.

In an effort to reconcile the historical and the practical, Suc et al. (1997) proposed to locate the Pliocene boundary in the Bou Regreg section, but at a level correlative with the base of the Zanclean within the Mediterranean Basin. These authors pointed to oxygen isotope variations (see discussion below) as indicators of paleoceanographic changes related to the end of the desiccation event.

In spring 1997, a majority of SNS considered the opposing concepts and voted to retain the base of the Pliocene coincident with the base of the Zanclean Stage, as defined at Eraclea Minoa. A formal proposal to this effect, prepared by the authors in 1998, was over-

whelmingly approved by SNS (24 in favor, 3 against, two abstentions) and forwarded to ICS in November 1998. Following a postal ballot, ICS accepted the Eraclea Minoa proposal in March 1999 and forwarded it for final ratification by the Executive Committee of IUGS.

Motivation

To the extent that the base of the Zanclean Stage, which in turn defines the base of the Pliocene Series, is marked by lithologic and above all by paleontologic changes, 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 (Remane et al., 1996; Salvador, 1994), as its critics have pointed out. 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. 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.

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." We believe that the Zanclean GSSP, as reported here, is a case history of the circumstances under which a careful and fully informed exception to stratigraphic continuity across a boundary is justified, in order to conserve a clearly recognized and widely used (and useful) definition. The information gathered by the opponents to this proposal also contributed significantly to knowledge of the stratigraphy and history of the interval that frames the GSSP.

The Zanclean Stage

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 (see also Vai, 1997, for a review). The term was first mentioned, however, the year before by Mayer (1867) in his original definition of the Messinian Stage, which he designated as a unit encompassing the entire interval between Tortonian and Astian. The name derives from Zanclea, the classical name of Messina, and 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, leaving the white marls to exemplify the true Zanclean. At Gravitelli the white 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 more restricted 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 the Upper Cenozoic nappes of Sicily and Calabria, and encountered in cores from many different parts of the Mediterranean Basin (Figure 2). 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, 1975a) 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 (i.e., at Eraclea Minoa) to rest on thick "Gessoso-solfifera" gypsum-anhydrite deposits that represent the final stages of marine desiccation in the basin.

The criteria for correlation of the base of the Zanclean as a global standard stage are 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 must be precisely assessed to allow for the extra-Mediterranean recognition and traceability of the boundary.

During the last decade, detailed field work on the rhythmites of the Trubi and the overlying Monte Narbone formation in southern Sicily has built up a sequence of lithologic cycles that correspond with orbitally forced climate change 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. 1996; Lourens et al., 1996; Lourens et al., 1997). The cyclic limestone-marl and marl-sapropel alternations of this succession record every single fluctuation of the Earth's precessional parameter, in turn modulated by orbital eccentricity, within this time interval. Citing this control, Hilgen (1991a, b) presented a continuous astrochronologic

calibration of the lithostratigraphic record for the Upper Cenozoic. Later on, the influence of obliquity was also recognized in the lithologic record and the astronomical calibration was slightly adjusted and improved (Lourens et al., 1996).

It is within this astrocylostratigraphic framework that the nanofossil and foraminifer biostratigraphy (e.g., 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. In this context, the base of the Pliocene, as defined, can be recognized and correlated worldwide.

Description of the boundary

The Eraclea Minoa section (lat. 37°23'30"N, long. 13°16'50"E) is the basal segment of the Rossello Composite Section (Langereis & Hilgen, 1991), which continues in overlapping sections to the east in sea cliffs at Capo Rossello, Punta di Maiata, Punta Grande and Punta Piccola. This composite section constitutes the Lower and Middle Pliocene part of the stratigraphic reference for the Astronomical Polarity Time Scale or APTS (Hilgen, 1991a, 1991b; Lourens et al., 1996). The stratotype-section is represented on the Carta Topografica d'Italia in the 1:25,000 series, Foglio 266 (Sciaccia), Quadrante II, Tavolella S.O. Capo Bianco.

The Eraclea Minoa section crops out continuously in a steep wave-cut bluff, approximately 30 m high and 500 m long, that rises behind the summer home community of Eraclea Minoa (Figures 1, 3). The bluff is parallel with, and about 500 m inland from, the modern beach. The basal Zanclean contact, adopted as GSSP, is very well exposed where white Trubi marl rests on dark brown Arenaz-

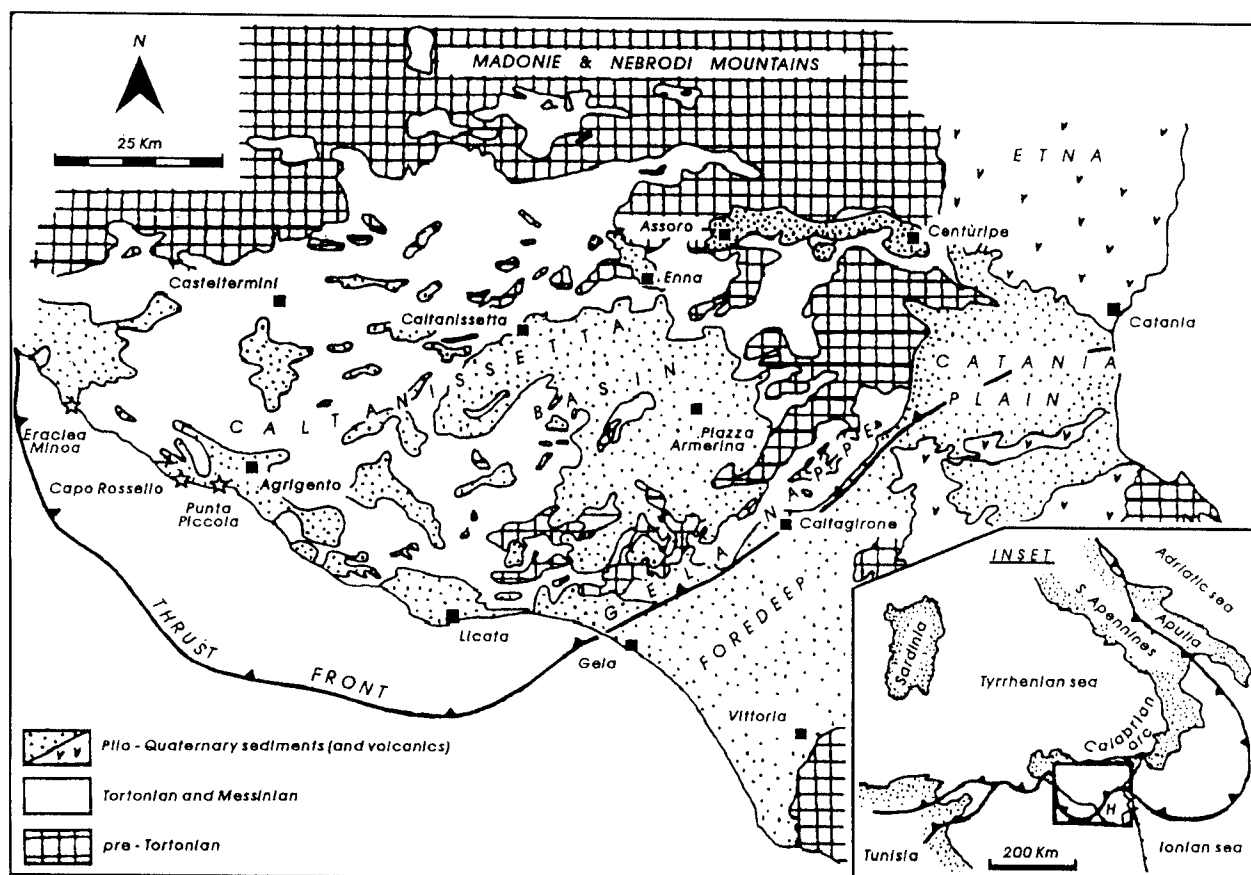


Figure 2 Geological sketch map of the central-southern Sicily showing the distribution of Pliocene and Pleistocene sediments across the thrust-belt ("Caltanissetta Basin") and the adjacent foredeep. Inset: location of Sicily in the Apenninic-Maghrebian thrust belt. H—Hyblean plateau. (after Butler et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



zolo sands and marls approximately 75 m from the west end of the exposed section.

Stratigraphically below the contact, about 10 m of nonmarine Arenazolo sands and marls are 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.

Access to the main face of the exposure is unrestricted, in all seasons. The exposure can be reached via informal paths between the houses along its foot, and also via public land at its far western end, at the point where the frontage road turns sharply towards the beach.

The Rossello Composite Section is situated in the Caltanissetta Basin, part of a major tectonic element known as Gela nappe or Gela thrust system (Ogniben, 1969; Butler et al., 1995). The paleodepositional setting is inferred to be an open marine slope-basin (Brolsma, 1978), and the benthic assemblage suggests a water depth of about 600–800 m (Sgarrella et al., 1997, and references therein).

The stratigraphic characteristics of the lower Zanclean Stage, detailed in exposures all along the southern coast of Sicily and Ionian Calabria (Figures 4, 5) and including bed-by-bed cyclostratigraphy as well as detailed magnetostratigraphy and biostratigraphy (e.g. Cita and Gartner, 1973; Cita, 1975b; Rio et al., 1984; Zijderveld et al., 1986, 1991; Hilgen, 1987; Hilgen and Langereis, 1988; Zachariasse et al., 1989, 1990; Langereis and Hilgen, 1991; Sprovieri, 1992, 1993; Di Stefano et al., 1996) are completely represented in the Trubi marls at Eraclea Minoa. In particular, the recognition here of the base of the Thvera magnetic event (C3n.4n) in association with precession cycle 5, just above the base of the Zanclean, is of paramount importance.

It has been assumed that the base-Zanclean discontinuity, which is recognized throughout the Mediterranean Basin in one context or another, was created in a sudden, catastrophic flooding of the basin in a dramatic end to the Messinian Desiccation Event (Hsü, Ryan and Cita, 1973). The worldwide potential for correlating the

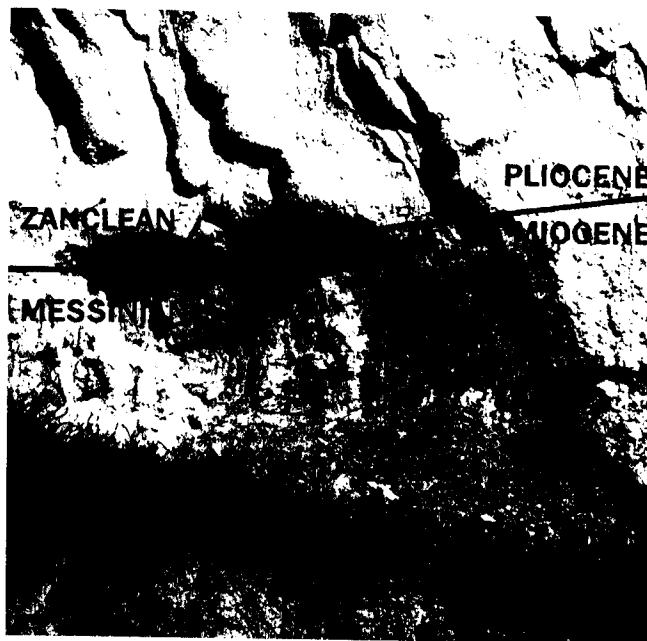


Figure 3 A view of the Eraclea Minoa section, GSSP of the Zanclean Stage and of the Pliocene Series.

effects of such a rapid redistribution of the global watermass is an important reason for retaining this level as the Pliocene Series boundary. We must be confident, therefore, that the basin refilled as rapidly as has been supposed, and for this it should be sufficient to demonstrate that the boundary is in fact synchronous at different paleoelevations in the basin.

In the type exposure, the Messinian evaporites and Zanclean marls in the Eraclea Minoa section, according to paleoenvironmental estimates (see above), were not deposited on the Mediterranean abyssal floor, but on a basin slope at a water depth of 800 m or less. In fact, Butler and others (1995) have suggested that the Caltanissetta Basin may have been tectonically isolated within the developing Gela Nappe, with a depositional history unrelated to that of the main basin. The recent coring in ODP Legs 160 and 161 appears, however, to suggest that the reestablishment of open marine conditions on the abyssal floor of the basin was at the same time as in the Zanclean of the Caltanissetta basin. In particular, Iaccarino et al. (1999) clearly show how the same stratigraphic signatures, in the same relative order as in the Eraclea Minoa stratotype, are recorded in the basal Zanclean along a W-E transect from the Alboran Sea to the Eratosthenes Seamount. The lack of measurable diachrony supports the assumption that the base of the Zanclean is an isochronous horizon generated during a geologically instantaneous refilling of the main basin.

Definition, age and correlation of the physical reference point

The beginning of the Pliocene, so defined, is readily correlated outside the Mediterranean (contra Benson and Hodell, 1994; Benson and Rakic-El Bied, 1996). The base of the carbonate bed marking the small-scale stratigraphic cycle 1 (Hilgen, 1987; Hilgen and Langereis, 1988; Langereis and Hilgen, 1991) at the base of the Zan-

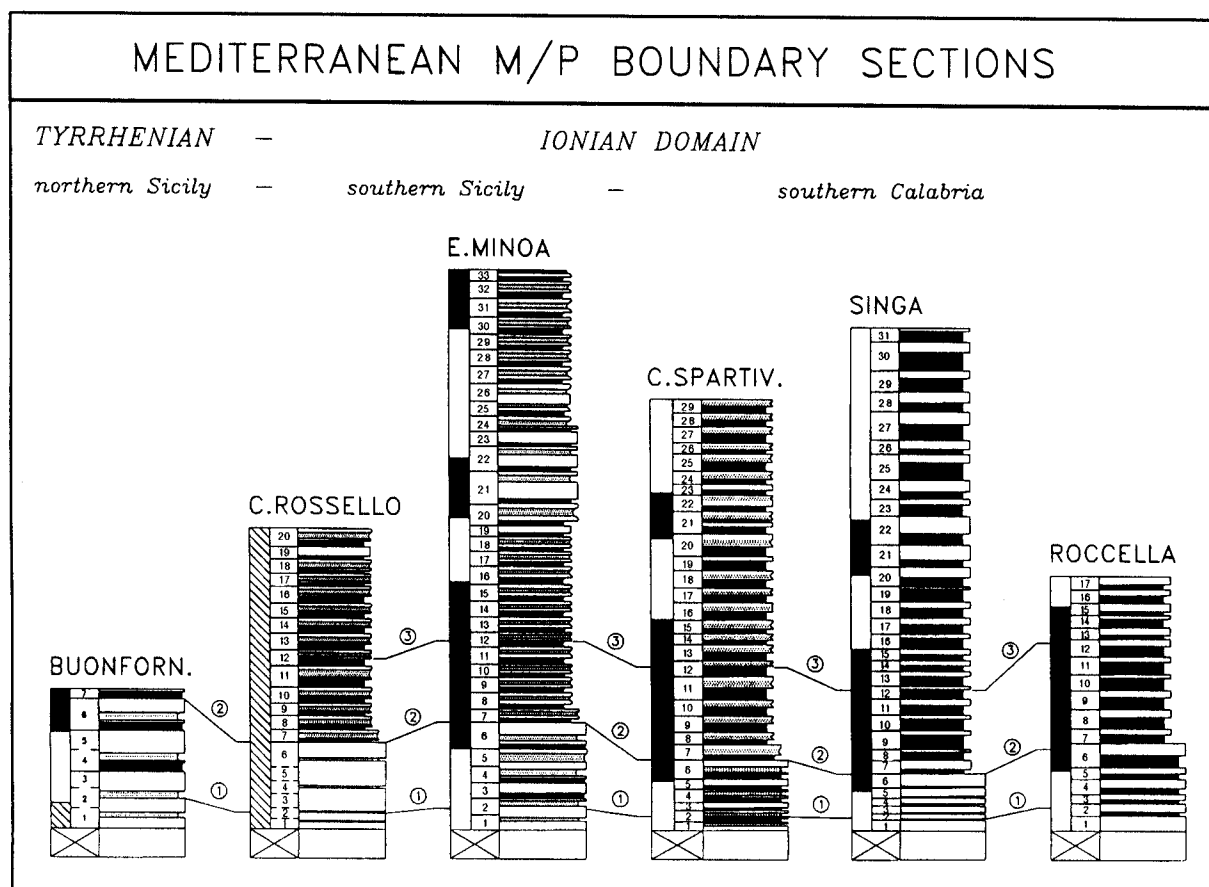


Figure 4 Review of the magnetostratigraphy, biostratigraphy and cyclostratigraphy of Miocene/Pliocene boundary sections of the Trubi Formation in southern Calabria and Sicily. Numbered biostratigraphic correlation refer to (1) base *Sphaeroidinellopsis acme*, (2) top *Sphaeroidinellopsis acme*, and (3) first substantial increase in *G. margaritae* (after Hilgen and Langeris, 1993).

clean Stage in the Eraclea Minoa section corresponds to insolation cycle 510 counted from the present, with an astrochronologic age of 5.33 Ma (Lourens et al., 1996). This exact level can be lithostratigraphically documented in the cyclic sequences of climate-sensitive depositional settings (i.e., high-productivity basins, abyssal floors), as well as by the orbitally-forced geochemical and isotopic variations exemplified in 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).

A second, highly reliable criterion is the base of the Thvera magnetic event (C3n.4n of Cande and Kent, 1992, 1995), dated to 5.236 Ma (Lourens et al., 1996), and only 96 kyr (5 precession cycles) younger than the proposed GSSP. This is a useful guide to the boundary in continental, igneous and non-cyclic marine deposits, as well as being a good anchor point for cyclostratigraphic or isotopic calibration of the boundary itself.

Calcareous nannofossils (coccoliths) afford the best marine biostratigraphic tool for the correlation of the boundary outside the Mediterranean. Three important biological 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. The first of these, ranked by proximity to the boundary, is the first occurrence of *Ceratolithus acutus*, calibrated at 5.37 Ma in the equatorial Atlantic (Backman and Raffi, 1997), just 40 kyr earlier than the proposed GSSP. It should be noted that specimens of *C. acutus* have been reported down to the very basal Zanclean of the Mediterranean area (Cita and Gartner, 1973; Castradori, 1998). The second is the disappearance of *Triquetrorhabdulus rugosus*, calibrated at about 5.23 Ma both in low-est Zanclean beds in the Mediterranean (Di Stefano et al., 1996; Castradori, 1998) and in the equatorial Atlantic Ocean (Backman

and Raffi, 1997). The third is the last occurrence of *Discoaster quinqueramus*. Although not recorded in the Mediterranean due to the Salinity Crisis, this event is dated outside the Mediterranean in Chron C3r at 5.537 Ma (Backman and Raffi, 1997).

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

In terms of planktonic foraminiferal biostratigraphy, the first appearances of *Globorotalia tumida* and *Globorotalia sphaeroidinellopsis* have been calibrated in the uppermost Miocene at 5.6 Ma by Berggren et al. (1995), with reference to tropical/subtropical and transitional areas, respectively. Certain well-known Early Pliocene events within the Mediterranean, such as the *Sphaeroidinellopsis* Acme Zone (MP11 of Cita, 1975b) that characterizes the first 10 precession-related lithologic cycles of the Zanclean, and the first common occurrence of *Globorotalia margaritae* at the top of this zone, have been shown to be of purely local significance (Benson and Rakic el-Bied, 1996). Two sinistral shifts of *N. acostaensis* have been recently reported from cycle 2 and 3 (Di Stefano et al., 1996) that may have more value in global correlation.

Shackleton, Hall, and Pate (1994) interpreted oxygen-isotope variations in planktonic foraminifera from ODP Site 846 as reflections of orbitally forced Late Neogene ice volume changes. In studies of the Salé core, near Bou Regreg, Hodell et al. (1994) identified 22 cycles between the isotope peaks TG2 to TG24 (where "TG" means "pre-Thvera", and the even-numbered peaks denote glacioeustatic lows), in a section spanning the lowest part of Chron C3r down to the uppermost part of Chron C4n. Suc et al. (1997) suggested that the TG5 "interglacial" or highstand peak near the top of the core could be correlated to the base of the Zanclean. At the same time, Lourens et al. (1996) identified the TG2 and TG4 lowstand

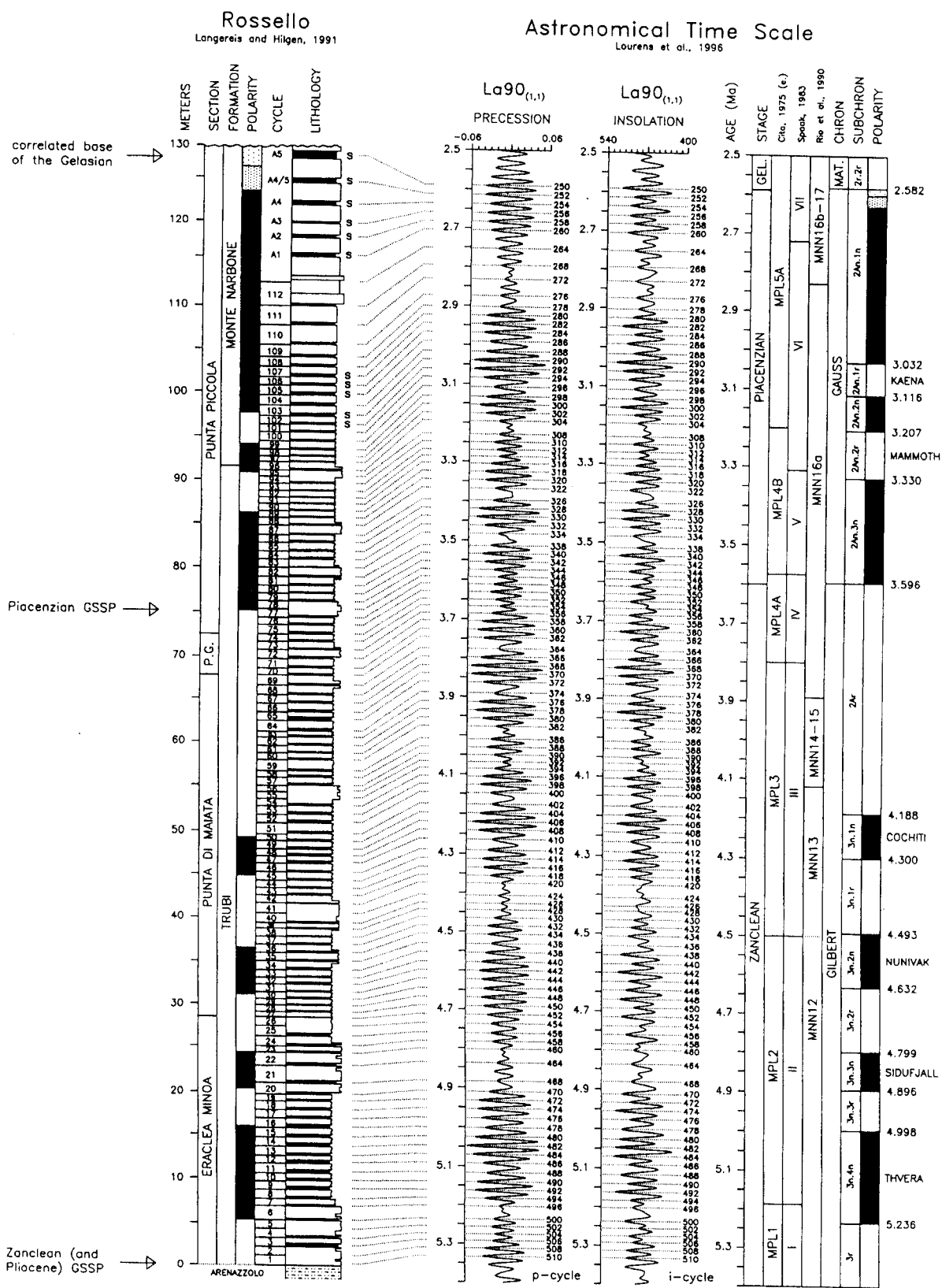


Figure 5 *Chronology of the Rossello Composite Section based on the correlation of small-scale carbonate cycle patterns to the La 90_(1.1) (Laskar, 1990; Laskar et al., 1993) precession and 65° N summer insolation curves (Hilgen, 1991b; Lourens et al., 1996a) (after Lourens et al., 1996a).*

peaks in the lowermost, pre-Thvera part of the basal Trubi, and correlated them with the isotope stratigraphy in ODP Sites 846 and 677 (Shackleton et al., 1995). This clearly suggests that the isotopic signature of highstand stage TG5 and the sedimentary signature of insolation peak 510 are genetically related, although this crucial link has not yet been documented. Nevertheless, it is reasonable to assume that the final breach of a steadily degrading Gibraltar barrier would have been facilitated by a transient rise in sea level. The TG5 highstand may thus be considered as a nearly, and probably exactly coincident marker for the base of the Pliocene worldwide, as suggested by Suc et al. (1997).

The 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 sea-level 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 (McKenzie, Spezzaferri and Isern, 1997), suggesting a sudden drawdown (Mediterranean refilling) and then recovery of water depth on the subsiding bank. Similarly, Aharon et al. (1993) reported that drilling on Niue atoll on the margin of the Tonga Trench, where progressive Neogene uplift allows resolution of closely-spaced events, shows repeated eustatic sea-level changes of 10 m amplitude culminating in at least 30 m of sea-level drop dated to 5.26 Ma, close to and possibly (given precision margins) synchronous with the Zanclean infilling. Similar stratigraphic features reflecting the abnormally sharp change in sea level at the boundary (Hsü, Ryan and Cita, 1973) may be sought in continuous sections elsewhere, offering a correlation tool unique to the Zanclean GSSP.

Conclusion

The Subcommittee on Neogene Stratigraphy has completed a major step in characterizing a Global Chronostratigraphic Scale for the Neogene, with the adoption of a formal definition of the Zanclean Stage as the lowest constituent of the Pliocene Series. It completes the designation of global standard Pliocene stages, following the definition of the Upper Pliocene Gelasian Stage (Rio et al., 1998) and the Middle Pliocene Piacenzian Stage (Castradori et al., 1998), in a single uninterrupted deep-marine sequence that is also the global template for the astrochronometric time scale. The base of the Zanclean, while represented in a regional lithological and paleontological discontinuity, is therefore precisely dated and correlatable in modern cyclostratigraphy and isotope stratigraphy, and is well constrained paleomagnetically and in terms of deep-sea micropaleontology. As a further important attribute, the base of the Zanclean is the historic definition for the Pliocene in the Mediterranean literature, and corresponds faithfully to Lyell's original meaning.

The Subcommittee on Neogene Stratigraphy is now facing the even harder task of defining boundary-stratotypes for the Miocene stages. It is encouraging, however, to note that the Messinian Stage boundary-stratotype, as the first of these, has been formally accepted and ratified in the meantime.

Acknowledgments

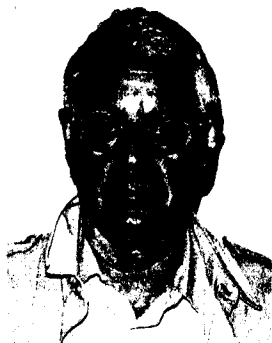
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