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# Formal ratification of the GSSP for the base of the Calabrian Stage (second stage of the Pleistocene Series, Quaternary System)

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*The Calabrian Stage is now formally defined by the Global Boundary Stratotype Section and Point (GSSP) at Vrica, Calabria, Italy. This GSSP had previously defined the base of the Pleistocene Series. The Calabrian becomes the second stage of the Pleistocene Series and Quaternary System, following the Gelasian. The GSSP occurs at the base of the marine claystone conformably overlying sapropelic bed 'e' within Segment B in the Vrica section. This lithological level represents the primary marker for the recognition of the boundary, and is assigned an astronomical age of 1.80 Ma on the basis of sapropel calibration. It coincides with the transition from Marine Isotope Stage 65 to 64, and the underlying sapropel bed 'e' is assigned to the Mediterranean Precession-Related Sapropel layer 176. Secondary markers include calcareous plankton bioevents of widely distributed taxa. The boundary falls between the highest occurrence of* Discoaster brouweri *(below) and the lowest common occurrence of left-coiling* Neogloboquadrina pachyderma *(above), and below the lowest occurrences of medium-sized* Gephyrocapsa *(including* G. oceanica*) and* Globigerinoides tenellus. *The top of the Olduvai Subchron is identified c. 8 m above the GSSP. Ratification of the Calabrian Stage effectively completes the Lower Pleistocene Subseries.*

## Introduction

On 5 December 2011, the Executive Committee of the International Union of Geological Sciences (IUGS) ratified a request by the International Commission on Stratigraphy (ICS) that the Global Boundary Stratotype Section and Point (GSSP) at Vrica, Calabria, Italy (Fig. 1) be used to define the base of the Calabrian Stage of the Pleistocene Series and Quaternary System. The Vrica GSSP had previously defined the base of the Pleistocene and Quaternary before these datum points were lowered in 2009 to the Monte San Nicola GSSP in Sicily, Italy, which also defines the base of the Gelasian Stage (Gibbard and Head, 2010; Gibbard et al., 2010). The proposal had been submitted to the ICS by the Subcommission on Quaternary Stratigraphy (Table 1) on 29 November 2010, and was approved by the ICS on 2 May 2011 with an 85% majority (15 'yes', one 'no', one 'abstain', one 'non-response'). Ratification by the IUGS makes the Calabrian the second stage of the Pleistocene Series, immediately following the Gelasian as the lowest stage (Fig. 2). It is emphasised that the ratified proposal does not define a new GSSP, but merely names the stage that the GSSP now defines.

The Calabrian Stage has been in existence for just over a century (Gignoux, 1910, 1913) and is well rooted in the literature, although its use beyond the Mediterranean domain declined after 1984 when the ICS approved the base Pleistocene GSSP in the Vrica section (Aguirre and Pasini, 1985) with a currently assigned age of 1.80 Ma. Nonetheless, its use has increased internationally in recent years, and its definition has been clarified together with calls for it to be accepted as a formal stage within the international geological time scale (Cita et al., 2006, 2008). In particular, now that the Pleistocene has been expanded to incorporate the Gelasian Stage, the Calabrian offers a practical means of subdividing this lower part of the Pleistocene. Indeed, these two stages together will comprise the Lower Pleistocene Subseries (Early Pleistocene Subepoch).

## Background and Rationale

It is well known that most Quaternary deposits exposed on land are non-marine in nature, discontinuous in space and time, poorly fossiliferous, and often difficult to date. The Mediterranean is a small ocean basin with a complicated geodynamic history and active

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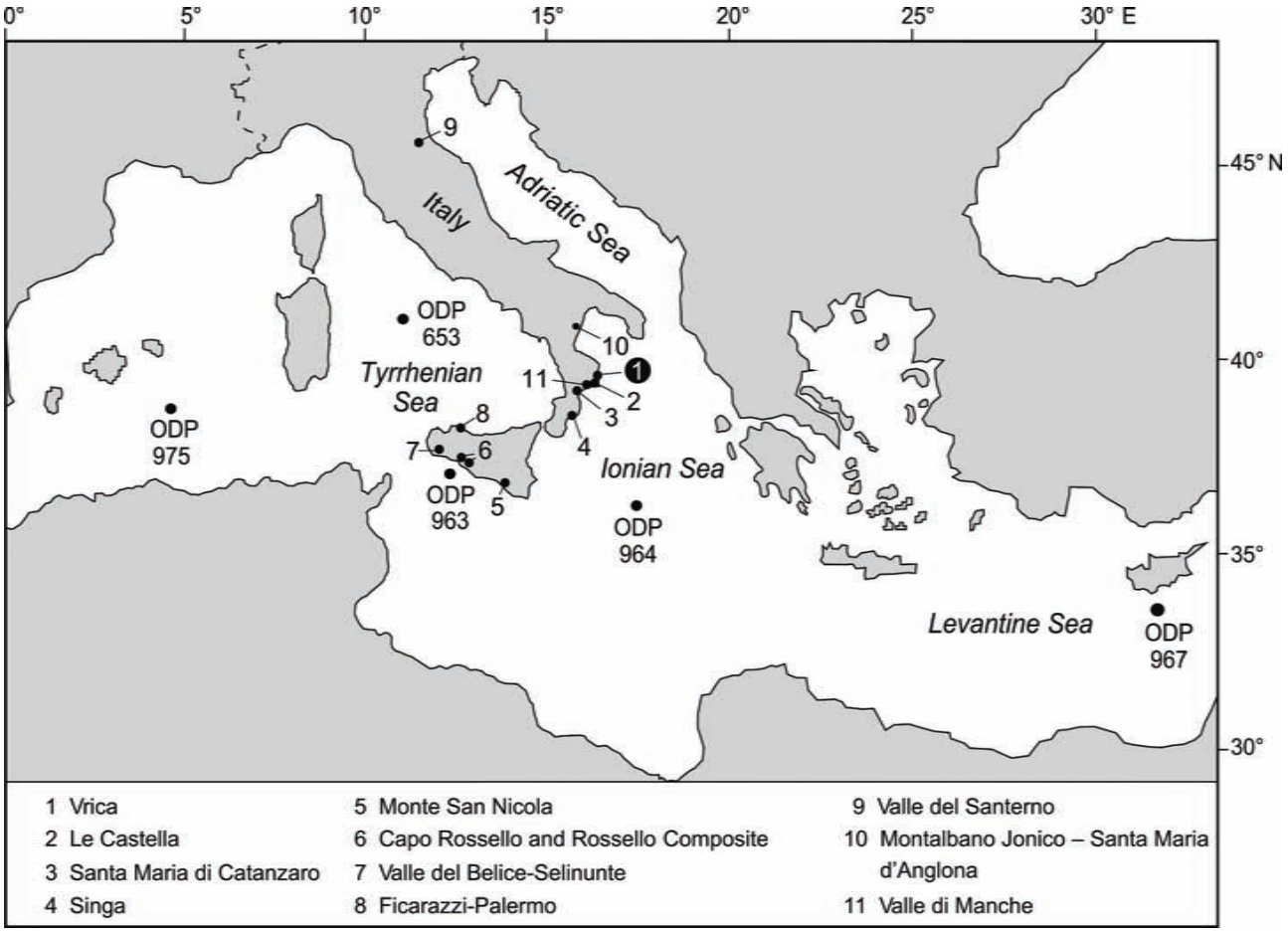


***Figure 1. Location of prominent onshore sections and ODP sites mentioned in the text.***

orogenic belts surrounding and crossing it. As a consequence, some coastal areas of Sicily and southern Italy expose relatively deep-water marine sediments that have been uplifted through the last three million years or so. This presents a unique opportunity to decipher the stratigraphy with an array of modern techniques, and compare this integrated stratigraphy with the deep-sea record investigated by scientific drilling in the Mediterranean (Fig. 1) and throughout the world's oceans.

When Selli et al. (1977) proposed the Vrica section as a potential Neogene/Quaternary boundary stratotype following the protocol of the International Stratigraphic Guide (Hedberg, 1976), they were also fullfilling the recommendation of the 1948 (London) International Geological Congress that the Neogene/Quaternary boundary be defined in a marine section in Italy in correspondence with the first immigration of 'northern guests' in the Mediterranean basin.

But this decision prompted a strong and persistent reaction among the large community of continental Quaternarists, and other stratigraphers, because evidence for the initiation of a marked cooling in the Northern Hemisphere was incontrovertably older than the 1.80 Ma age assigned to the Vrica GSSP (Figs. 3, 4; Head et al., 2008a; Gibbard and Head, 2010). Moreover, the first appearance of northern guests in the Mediterranean was considered irrelevant in a global context.

It follows from the above that the Quaternary Subcommission of the ICS, which consists largely of non-marine specialists, promptly favoured the adoption of the Gelasian GSSP to define the base Pleistocene and base Quaternary, although the Gelasian had been proposed as the youngest stage of the Pliocene as recently as 1998 (Rio et al., 1998), a few years after the first description of the Monte San Nicola section by Channell et al. (1992).

Following the IUGS ratification (on 29 April, 2009) of a coincident base for the Quaternary System, Pleistocene Series, and Gelasian Stage, it became appropriate to address the issue of the Calabrian Stage. Full details of the Calabrian Stage GSSP are given in Cita et al. (2008), and additional information is provided by the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) website at: *http://sgi2.isprambiente.it/geositiweb/gssp/lavrica.htm.* Essential information on the Calabrian Stage now follows.

## Essentials of the Calabrian Stage

The Calabrian is the second stage of the Pleistocene, following the Gelasian. Its upper limit, while currently undefined, will be established by the base of the stage representing the Middle Pleistocene Subseries, the recommended primary guide for which is the Matuyama/Brunhes polarity chron boundary (Head et al., 2008b) as this will facilitate marine/non-marine correlations. Several potential GGSPs for the Lower/Middle Pleistocene boundary (e.g., Head et al., 2008b; Maiorano et al., 2010) are under consideration. While treating the Lower, Middle, and Upper Pleistocene Subseries as formal subdivisions following current practice (e.g., Gibbard et al., 2010), we do note that these terms have yet to be officially sanctioned by the ICS/IUGS.

The base Calabrian GSSP is located in the Vrica section, province

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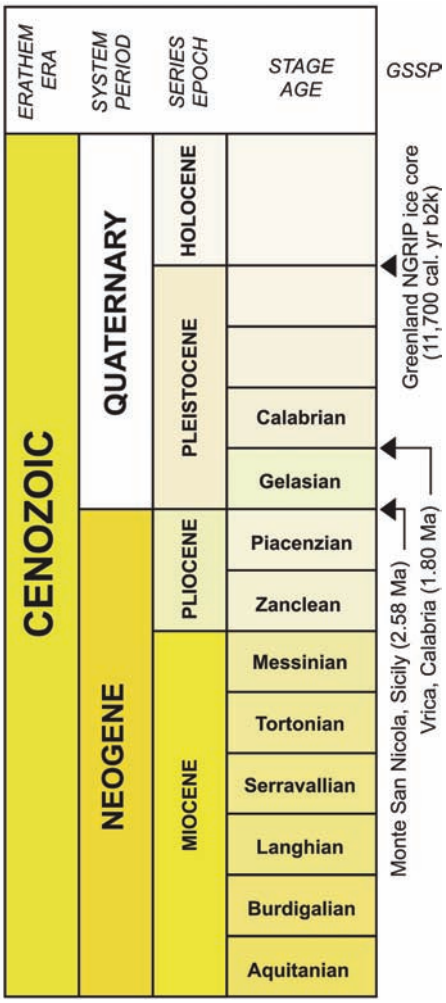


***Figure 2. Current IUGS-sanctioned time scale for the Cenozoic, showing GSSPs for the Quaternary and including the newly-ratified Calabrian Stage (Modified from Gibbard and Head, 2010, fig. 1).***

of Crotone, Calabria (latitude 39°02'18.61" N, longitude 17°08'05.79" E), some 4 km south of the town. The GSSP is defined at the base of the marl bed immediately overlying sapropel 'e', as identified in a succession of silty marls, dark grey or blue-grey in colour, that outcrop in badlands subject to regolith creep (Fig. 4). Interbedded with the marls are sapropelic layers, grey-pink in colour and finely laminated, indicative of poorly oxygenated conditions. The marls are richly fossiliferous, especially in calcareous nannoplankton and planktonic foraminifers but also in ostracods, benthic foraminifers (Figs. 5 and 6), and palynomorphs. Sedimentation rates are high in the Crotone series, ranging from *c*. 45 cm $ka^{-1}$ near the base, to *c*. 29 cm $ka^{-1}$ at around 1.8 Ma (Suc et al., 2010).

Magnetostratigraphic investigations by various groups of specialists have differed in identifying the top of the Olduvai Subchron (Fig. 5), these discrepancies being a result of complex early and late diagenetic overprinting. It is generally accepted, however, that the upper boundary occurs *c*. 8 m above the GSSP (Hilgen, 1990; Zijderveld et al., 1991; Roberts et al., 2010), but that the Vrica section should not be relied upon for further refinement of its age (Roberts et al., 2010).

Strontium isotope studies (Barbieri et al., 1998) support the age determinations based on biochronology and magnetostratigraphy.

The badlands geomorphology, in which the stratotype occurs, prevents the construction of permanent markers for the GSSP. However, this has not obstructed the numerous international groups that have measured and sampled the section following its original

***Figure 4. The Vrica section and surrounding area. (a) Panorama of the three Vrica segments, A, B, and C, and the nearby Santa Lucia section. Correlation is precise between Vrica A and Vrica B as they are on the same plane, but more speculative between both Vrica B and Vrica C, and Vrica C and Santa Lucia. Photograph courtesy of J.-P. Suc. (b) Lithological sequence of Segment B in the Vrica stratotype section showing the prominent sapropel layers: b, c, d, e, f, and h. The GSSP of the Calabrian Stage is fixed at the top of layer 'e'. (c) detail of Segment B showing a person (indicated by arrow) standing in front of layer 'e'. Photographs (b) and (c) taken in 2000, courtesy of Ilka von Dalwigk and Luca Capraro.***

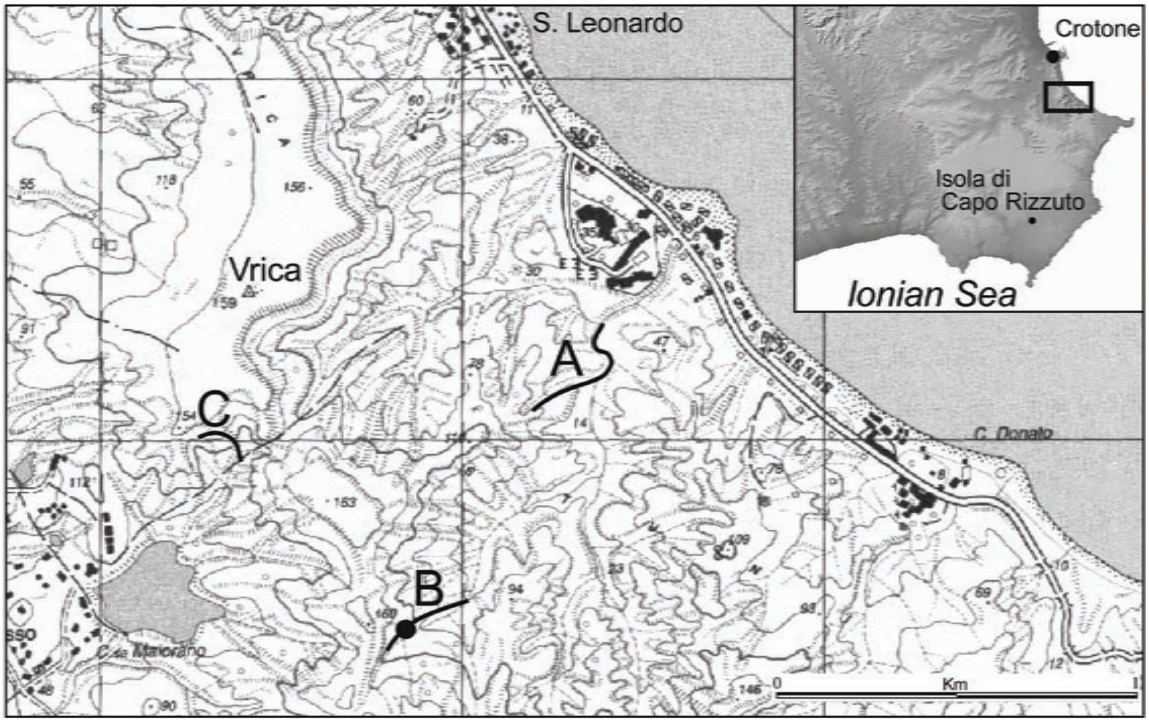


***Figure 3. Location of the Vrica boundary stratotype section. A, B, and C are the component segments of the section. The dot on segment B represents the position of the Calabrian GSSP. After Cita et al. (2008, fig. 2a).***


***Figure 4. Caption on opposite page.***

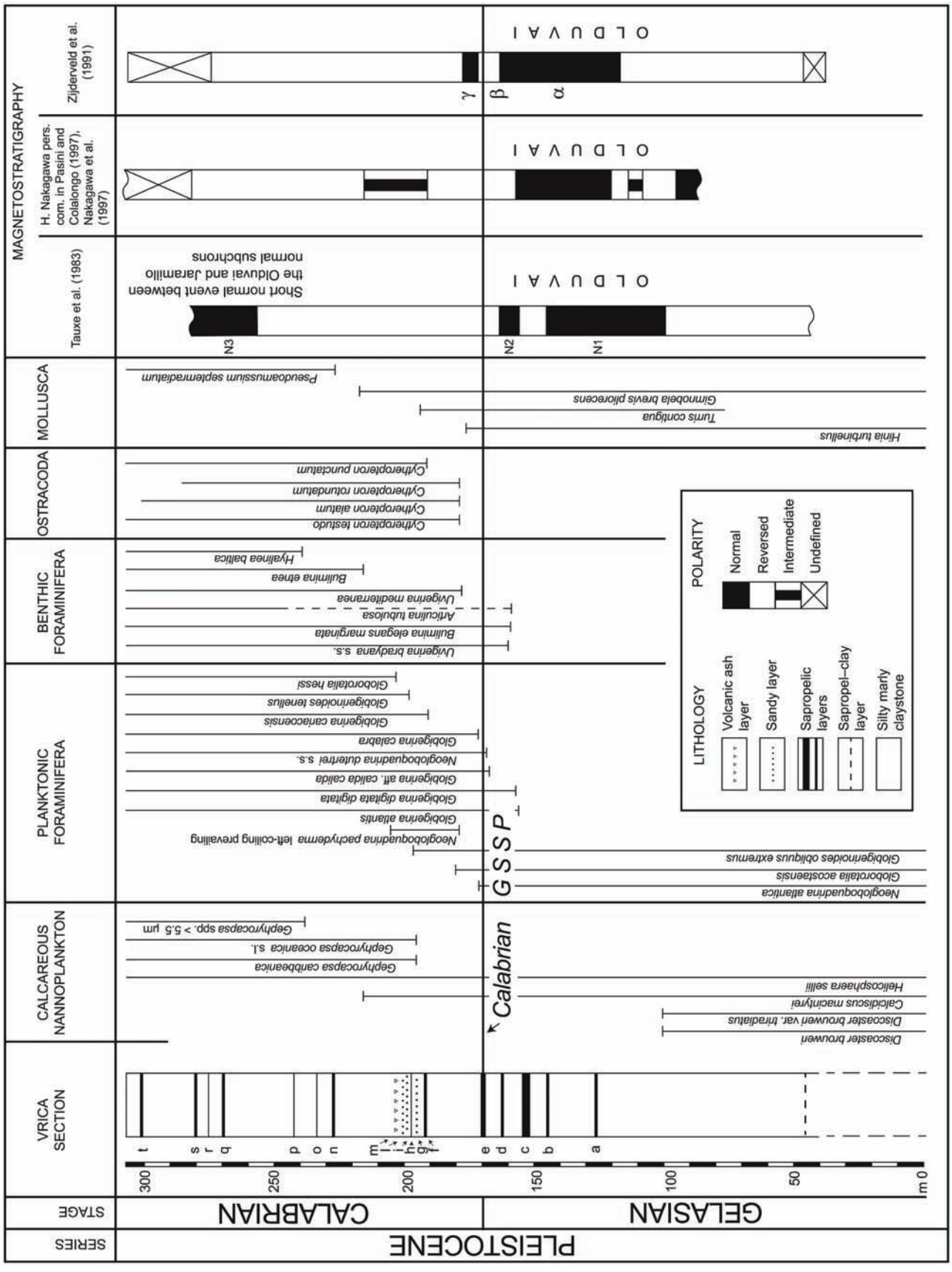


***Figure 5. Lithological log and distribution of the significant microfossil taxa and magnetostratigraphy of the Vrica section (300 m thick), extending from the Gelasian to the Calabrian stages. Modified from Pasini and Colalongo (1997, fig. 2.18).***

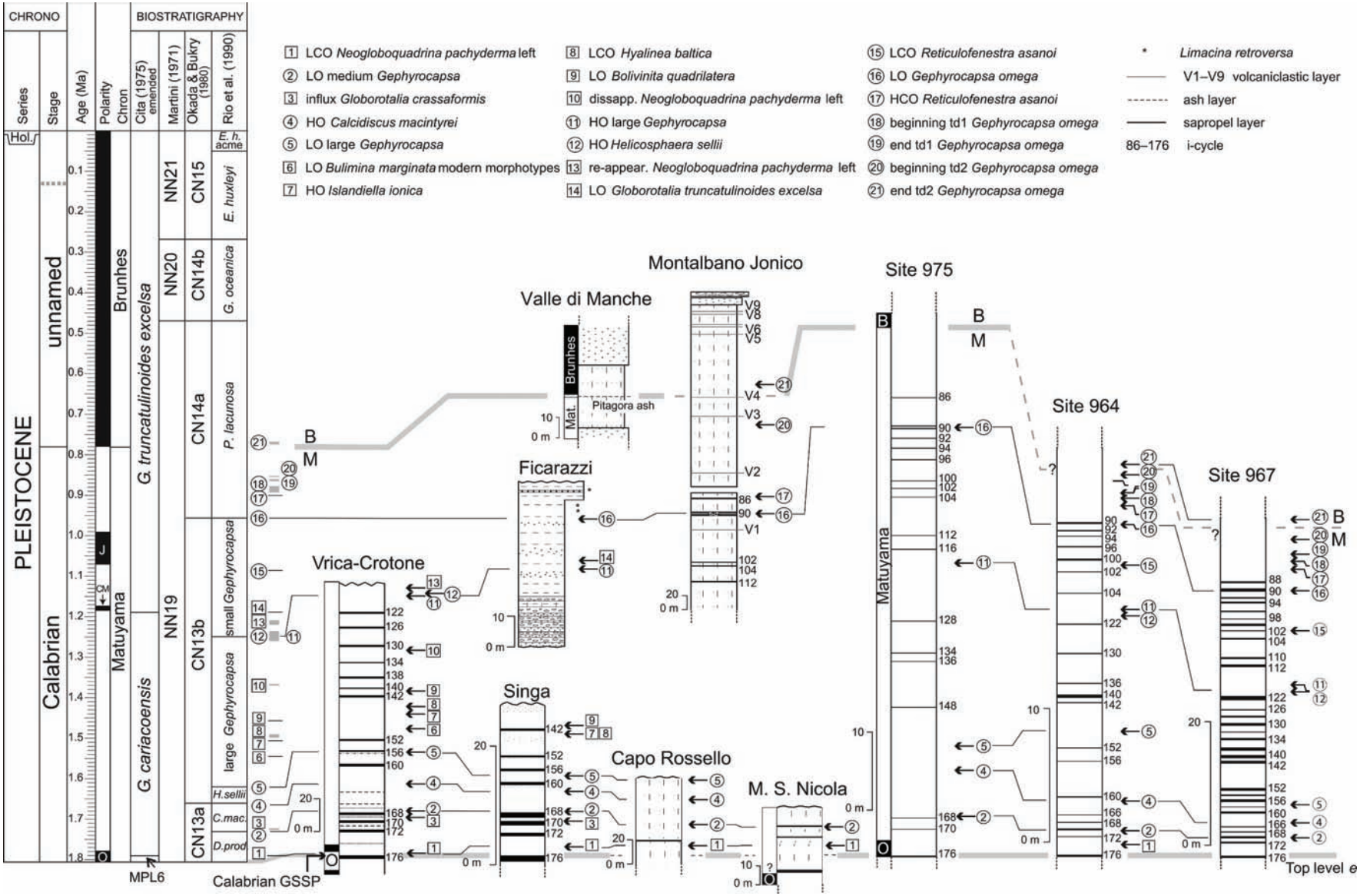


***Figure 6. Comparative and correlative stratigraphic framework of the lithology, biostratigraphy, and magnetostratigraphy of the Vrica boundary stratotype section and of other Mediterranean land sections and ODP sites in which the Calabrian Stage is well represented. Based upon: Vrica-Crotone, Singa (Lourens et al., 1996); Capo Rossello (Di Stefano et al., 1993); Ficarazzi (Di Stefano and Rio, 1981; Sprovieri, 1993); Valle di Manche (Massari et al., 2002; Capraro et al., 2005); Montalbano Jonico (Ciaranfi et al., 2001); Monte San Nicola (Channell et al., 1992; Sprovieri, 1993); ODP Site 975 (Murat, 1999); ODP Site 964 (Emeis et al., 2000); ODP Site 967 (Kroon et al., 1998). LO = lowest occurrence, LCO = lowest common occurrence, HO = highest occurrence, HCO = highest common occurrence, td1 = first temporary disappearance, td2 = second temporary disappearance. The circled numbers represent calcareous nannofossil events; boxed numbers represent foraminiferal events. After Cita et al. (2008, fig. 3).***

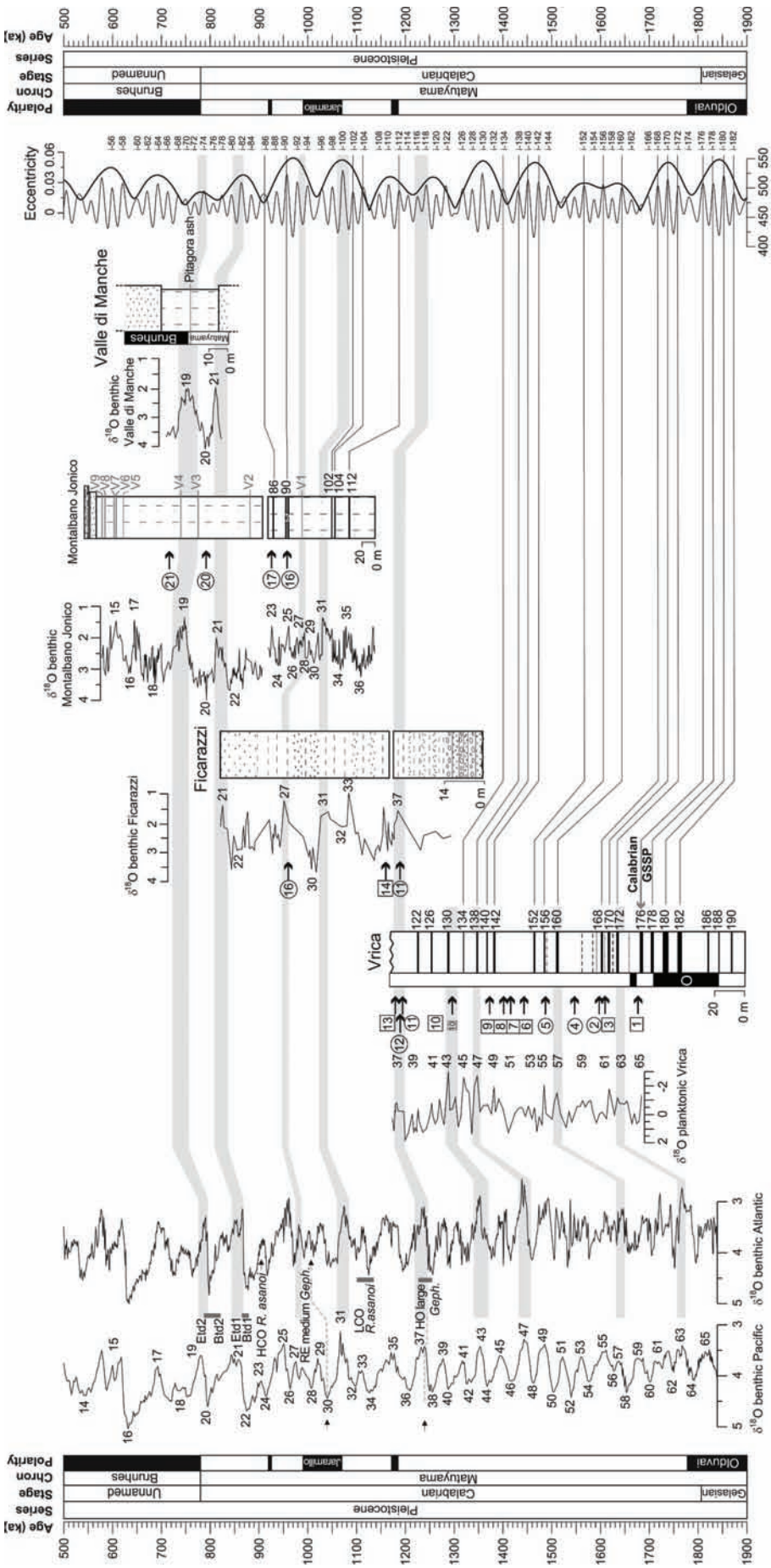


*Figure 7. Integrated stratigraphical framework for four selected land sections (Italy), which represent all the oxygen-isotope records for the Calabrian Stage, compared to standard Atlantic and Pacific benthic foraminiferal $\delta^{18}O$ stacks. The circled and boxed numbers, indicating calcareous nannofossil and foraminiferal events respectively, are as for Figure 6. After Cita et al. (2008, fig. 6).*

proposal (Selli et al., 1977) and formal approval (Aguirre and Pasini, 1985), as for example: Tauxe et al. (1983), Backman et al. (1983), Combourieu-Nebout (1987), Howell et al. (1990), Hilgen (1990), and Zijderveld et al. (1991).

Only biostratigraphic markers provide a unidirectional, non-repetitive succession of events. Those at Vrica include the following calcareous nannofossil events: highest occurrence (HO) of *Discoaster brouweri* at *c*. 70 m (= *c*. 210 kyr) below the GSSP, and lowest occurrence (LO) of medium-sized *Gephyrocapsa* (including *G. oceanica*) at *c*. 26 m (*c*. 78 kyr) above the GSSP; and the following planktonic foraminiferal events: lowest common occurrence of left-coiling *Neogloboquadrina pachyderma* at *c*. 3 m (= *c*. 9 kyr) above the GSSP, and LO of *Globigerinoides tenellus* at *c*. 28 m (= *c*. 84 kyr) above the GSSP. The durations in parentheses assume an average sedimentation rate of 1 m per 3000 years (Fig. 6). Of these events, the HO of *Discoaster brouweri* seems to have the greatest potential for global correlation, with an age of 2.06 Ma in the eastern equatorial Pacific, and 1.93 Ma in the western equatorial Atlantic (Lourens et al., 2005a). Cita et al. (2008) provided a detailed biostratigraphic evaluation of the Vrica section.

## Global correlation potential of the Calabrian Stage GSSP

The Vrica section has been investigated in recent years using isotope, sapropel, and pollen stratigraphies to construct a detailed astrocyclostratigraphy (Lourens et al., l996, l998; Suc et al., 2010), and this has created the potential for high-resolution global correlation alongside the previously-mentioned magnetostratigraphical and biochronological criteria. Indeed, the Crotone Series, which includes the Vrica section, is without doubt the best-studied Lower Pleistocene succession in the world, and has been the subject of a recent synthesis (Suc et al., 2010).

The base Calabrian GSSP occurs at the Marine Isotope Stage (MIS) 65/64 transition in the Quaternary marine isotope stratigraphy. Sapropel 'e', as originally identified in segment B of the Vrica section (Fig. 4), corresponds to layer 176 of the Mediterranean Precession-Related Sapropels (MPRS) in the calibrated scale of Lourens (2004). This is the highest temporal resolution available at this time, and is corroborated by the robust framework derived by other stratigraphical subdisciplines (Figs. 6, 7).

An age of 1.80 Ma is here assigned to the Vrica GSSP based on comparison with a detailed study of sapropel 'c', which is just below sapropel 'e' at Vrica. Sapropel 'c' has a duration of 9,180 years, beginning with a 2,300-year delay with respect to increased runoff directly correlated to precession, and ending *c*. 700 years after the decrease in runoff (Suc et al. 2010). The asymmetrical development of this sapropel results in a midpoint that is a little less than 2000 years younger than the precession minimum (Suc et al. 2010, fig. 8). Assuming sapropel 'e' at Vrica to be broadly similar, and given that its midpoint has been assigned an age of 1.806 Ma based on orbital tuning which includes an estimated 3000-year time lag between maximum insolation and sapropel midpoint (Lourens et al., 1996, 2005b), the age of the Vrica GSSP at the base of the overlying claystone can then be derived. Hence, by assuming a duration of *c*. 9000 years for sapropel 'e' and a time lag of *c*. 2000 (rather than 3000) years between its midpoint and peak insolation at 1.809 Ma, the Vrica GSSP has an age of *c*. 1.8025 Ma, assuming that the complete sapropel has been preserved. In rounding this figure to 1.80 Ma, allowance is made for small errors in orbital tuning and uncertainty in the precise duration of sapropel 'e' deposition. A similar approach was used to date the Monte San Nicola GSSP, which defines the base of the Quaternary (Gibbard and Head, 2009).

To summarise, the marl bed that defines the GSSP at its base may be correlated beyond Vrica by a combination of lithostratigraphy, cyclostratigraphy, and stable isotope analysis; broadly guided by magnetostratigraphy and biostratigraphy. Sapropel stratigraphy offers excellent potential for correlating this marl bed within the eastern Mediterranean basin, although it cannot be used for correlation beyond the Mediterranean.

No major cooling event is recorded at or near the GSSP level, where short-duration precessional cycles prevail in the Mediterranean domain, as well as in the world's oceans.

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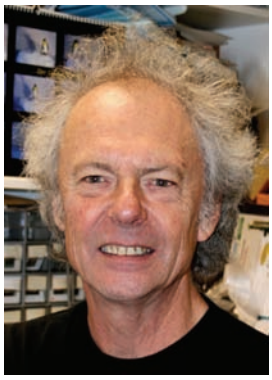

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