REASSESSMENT OF THE POSITION OF THE PLIO-PLEISTOCENE BOUNDARY: IS THERE A CASE FOR LOWERING IT TO THE GAUSS–MATUYAMA PALAEOMAGNETIC REVERSAL?

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INTRODUCTION

Forty eight years have elapsed since formal discussions were initiated, in 1948, on the position of the Plio-Pleistocene boundary. At the 18th International Geological Congress held in London during that year the Commission on the Plio-Pleistocene boundary recommended that “the Lower Pleistocene should include as its basal member the marine Calabrian Formation together with its terrestrial (continental) equivalent the Villafranchian” (King and Oakley, 1950, p. 214). The suitability of the base of the Calabrian as the Plio-Pleistocene boundary was specifically linked to the first appearance, within the lowermost Calabrian as then defined, of the cryophilic mollusc species Arctica islandica and Hyalinea baltica: “according to the evidence given this usage would place the boundary at the horizon of the first indication of climatic deterioration in the Italian Neogene succession” (King and Oakley, op cit.).

From the time of the adoption of this resolution until the acceptance, at the 27th International Congress in Moscow, some 36 years later, of the Global Stratotype Section and Point (GSSP) at Vrica as defining the Plio-Pleistocene boundary, considerable advances in the understanding of the marine Plio-Pleistocene succession in southern Italy, and in defining and placing within a sound chronological framework important global biostratigraphic and climatic events in both marine and terrestrial sequences, have opened to question the appropriateness of the 1948 definition. The adoption of the Vrica GSSP in 1984, at a stratigraphic position essentially in keeping with the spirit of the 1948 resolution, represents, in the view of the writer and a number of other Quaternary stratigraphers, a compromise between historical usage and recent advances in Plio-Pleistocene stratigraphy, which fully satisfies neither tradition nor the evidence of modern stratigraphy. It seems somewhat ironical that, at a time of rapid advances in marine isotope stratigraphy and both terrestrial and marine chronostatigraphy, the stamp of approval was given to a stratotype whose position had been advocated in the light of the stratigraphic knowledge prevailing a full generation earlier.

There is no question that the formal requirements for the definition of the Vrica GSSP were met in 1984 and that the boundary, as placed presently at 1.8 Ma, must be accepted as dividing the Pliocene from the Pleistocene. What is, however, strongly questioned by many, including the present writer, is whether it is justified to maintain a boundary whose position is rooted in priority and historical usage rather than current evidence for the considerable earlier onset of a climatic regime which gives an essential unity to the Pleistocene and is clearly mirrored in the global stratigraphic record. Lowering of the boundary to this position would not only be in keeping with the 1948 conclusion that it be placed at the first indication of climatic deterioration in the Neogene succession, but would facilitate correlation through the marked lithostratigraphic and palaeontological changes with which it is associated in terrestrial sequences, through the unique marine isotopic signature with which it coincides, and through its correspondence with a major palaeomagnetic reversal (the Gauss–Matuyama at 2.6 Ma). These considerations must necessarily be viewed against the background of the desirability of stability in lithostratigraphic classification and the relative recency of the acceptance of the present GSSP; international stratigraphic correlation should certainly not be viewed as transient and subject to the whims or fashions of the day.

BRIEF REVIEW OF EVENTS LEADING TO THE APPROVAL OF THE PRESENT GSSP

The prolonged debate which preceded the acceptance of the Vrica stratotype provides considerable insights into the tortuous, and often conflicting, arguments which have surrounded the definition of the Pleistocene since the time of Charles Lyell. Thus despite the recommendations tabled at the 18th IGC in 1948, the International Union for Quaternary Research (INQUA) deemed it necessary to establish a Subcommission on the Plio–Pleistocene Boundary, which also served as a Working Group of the International Commission on Stratigraphy (ICS) of...
the International Union of Geological Sciences (IUGS). The work of this body led to the proposal, during the 8th INQUA Congress in 1969, of the Le Castella section in southern Italy as the type section for Calabrian, but the exposure was soon found to be incomplete and, at the suggestion of Selli (1971), the nearby section at Santa Maria di Catanzaro, first described by Gignoux (1913) as one of his type sections for the Calabrian, was substituted. On this basis the INQUA Commission on Stratigraphy recommended that "As an initial definition of the base of the Pleistocene in marine conditions, there is chosen the lowest level in the section at Le Castella, Catanzaro, Calabria, at which the fossils of *Hyalinea baltica* (Schroeter) occur". This proposal was subsequently accepted by the 24th IGC in Montreal in 1972, and a formal boundary stratotype for the Mediterranean region was thereby established.

It was, however, again soon realized that this section contained only the upper part of what had hitherto been accepted as the Calabrian. Subsequent micropalaeontological studies indicated that the strata in question correlate best with those of the subsequent Sicilian stage (Ruggieri and Sprovieri, 1977; Ruggieri et al., 1984; Rio et al., 1991), thus casting doubt upon the validity of the Calabrian as a stratigraphic unit. In response to these difficulties one of the earliest projects of the newly established International Geological Correlation Programme (IGCP) was initiated in 1974 under the title "The Boundary between the Neogene and the Quaternary" (IGCP 41). Under this umbrella a number of alternative proposals were discussed, ranging from the placement of the boundary below the so-called Glacial Pleistocene (<1 Ma), to its positioning at the base of the Calabrian and even as early as the base of the Villafranchian (ca. 3.5 Ma). Additional confusion was generated by the conference on the Plio–Pleistocene boundary held in India in 1979, where several broad-ranging proposals were accepted. These were:

1. that the Vrica section near Crotone constituted a more suitable boundary stratotype than the Le Castella and Santa Maria di Catanzaro sections;
2. that the first climatic deterioration in the Italian Plio–Pleistocene succession should not be adopted as the main criterion for defining the base of the Pleistocene;
3. that the equivalence of the marine Calabrian with the continental Villafranchian be rejected.

The last two decisions were directly contrary to the proposals tabled during the 18th IGC in 1948. In particular, the decision to abandon the climatic definition of the Pleistocene opened the way for the definition of a boundary stratotype which was not only at odds with the spirit of the 1948 resolution, but, in the view of many Quaternarists, removed the basis for the recognition of the Pleistocene as a unique and readily distinguishable chronostratigraphic unit. Some stratigraphers have argued, not without justification, that past climatic events have little relevance for chronostratigraphy; in the case of the Pleistocene, many Quaternarists urge, on the other hand, that the interval of cooling and aridification, now bracketed between 3.0 and 2.6 Ma (Fig. 1), was an event of global significance whose passage is widely preserved in the stratigraphic record. To them, the period which followed has an essential unity in its climatic regime of glacial–interglacial couplets, the signature of which is preserved in a wide variety of stratigraphic settings; this unity was not disrupted by the further interval of cooling which occurred between 1.2 and 0.9 Ma (see below). As Sibrava (1992) has observed, abandonment of the concept that the definition of the Pleistocene has a primarily climatic connotation "raises the question of what events and what criteria may be taken as justifying the existence of the Quaternary within the Cenozoic Epoch" (op.cit. p. 328).

Eventually, during the 26th IGC in Paris in 1980, it was decided that the Vrica section near Crotone, some 20 km northeast of the original Le Castella section, best met the requirements for a boundary stratotype. Since the status of the Calabrian had been called into question, there was no attempt to link the boundary to it. Despite the earlier decision to abandon the primarily climatic definition of the Pleistocene, it was proposed that the boundary be placed at the point of first appearance of the 'northern guest' *Cytheropteron testudo* (an ostracod) in the Vrica section, which coincided with the top of the prominent sapropelic marker bed 'e'. In the definition ultimately accepted by the ICS during the 1984 IGC in Moscow, linkage to the first appearance of *C. testudo* was abandoned. and the Plio–Pleistocene boundary was defined as coinciding with the base of the marine claystones conformable overlying the marker bed 'e' in the Vrica section.

It may be concluded that, although this definition conforms broadly with the spirit of the resolution of 1948 in its chronostratigraphic placement of the boundary, the original rationale upon which this resolution was based had been lost in the course of more than three decades of discussion and reconsideration. Despite the noteworthy advances which had been made in marine biostratigraphic correlation (through the medium of micropalaeontology) and in marine isotope stratigraphy, particularly during the latter part of this long period of gestation, important evidence from these sources appears to have remained largely neglected in the final definition of the boundary. No comprehensive publication of the Vrica GSSP has appeared to date, and the best existing overview is that of Aguirre and Pasini (1985).

**HOW ADEQUATE IS THE VRICA GSSP**

The principal objectives of stratigraphic classification are to promote uniformity in terminology and to facilitate correlation. To a very large extent, stratigraphic boundaries, whether formally defined or not, are conventional: they represent a common understanding based on long usage. In the case of the Pleistocene this conventional understanding is important because it has, for more than a century, been founded on a climatic premise which equates the base of the Pleistocene with the onset of
Reassessment of the Position of the Pli–Pleistocene Boundary

FIG. 1. Oxygen isotope record for the period 4.0 Ma to present (after Shackleton, 1995). Data have been derived from the SPECMAP stack for the interval 0–0.62 Ma, ODP Site 677 for the interval 0.62–2.0 Ma and ODP Site 846 for the interval 2.0–4.0 Ma.
glacial conditions (Forbes, 1846). It was for this reason that, in the resolution adopted at the 18th IGC in 1948, the proposed boundary was linked to "the first indication of climatic deterioration in the Italian Neogene succession". This conception of the Pleistocene as a period characterized by repeated glacial cycles is widely held within the International Union for Quaternary Research and the community of Quaternary science at large and can, in a very real sense, be regarded as having priority over all other definitions of the Pleistocene. For example, as Richard Foster Flint observed: "In most minds the Pleistocene connotes glaciation, and properly so, because repeated glaciation was the outstanding event of that epoch." (Flint, 1957, p. 1); Charlesworth in The Quaternary Era concurs: "The Pleistocene period and the Ice Age were coeval, as E. Forbes suggested in 1846." (Charlesworth, 1957, p. 596).

In setting guidelines for the definition of Stratigraphic boundaries Hedberg (1976) has observed that "if major natural changes ('natural breaks') in the historical development of the Earth can be identified at specific points in the sequences of continuous deposition, these may constitute desirable points for boundary stratotypes and stages". The current Chairman of ICS, J. Remane adds "the most important point is that the boundary has an optimum correlation potential. The boundary definition will be guided by one boundary event, the first appearance of a fossil marker or a magnetic reversal, to give just two examples. But it is important to have a certain number of auxiliary markers near the boundary, fossil species which occur also in facies or palaeobiogeographic provinces where the primary marker is missing and which will then allow an approximate boundary determination. In this procedure as many methods as possible should be involved and non-biostatigraphic methods should be given more weight in the future." (Remane, 1994).

How well does the Vrica GSSP meet these requirements? As has been indicated above, the final definition of the Vrica GSSP was based neither on bio-events, nor climatic criteria. While a number of bio-events have been recognized near the Vrica boundary, a careful examination of these shows these to be of lesser correlation value than has been claimed by some (see Vai, Shackleton and Sue et al. (this volume)). Among these events are the FADs of the nanoplankton Gephyrocapa oceaniae and of the left coiling planktonic foraminifer Neoglobobuadrina pachyderma, which are regarded by marine micropalaeontologists as the two key species useful for correlation in marine sections over this interval (Sprovieri, 1993). The FAD of G. oceaniae is, in fact, some 80 ka later than the boundary datum, which, translates into a stratigraphic separation of several tens of metres. As Suc et al. (this volume) have pointed out, this is unacceptable in the context of the precision, now attainable in correlation, at least in marine sequences, through the use of astronomical calibration methods (e.g. Hilgen, 1991). The FAD of left coiling N. pachyderma, although somewhat closer to the boundary, is of limited use in correlation because of the discontinuous presence of this species in many sections, particularly in the Mediterranean (Sprovieri, op.cit.). As Suc et al. (this volume) point out, almost all other micropalaeontological markers which have been put forward as facilitating correlation of the Vrica boundary suffer from similar, or worse, problems.

These shortcomings could be discounted if other events offering good correlation potential could be identified in proximity to the boundary. These are, unfortunately, not forthcoming. Pollen spectra spanning the period from ca. 2 Ma to 1.75 Ma show recurrent short glacial-interglacial oscillations but fail to reveal any significant climatic event (Combourieu-Nebout and Vergnaud Grazzini, 1991). There is likewise no significant climatic signal in the oxygen isotope record spanning this period (Shackleton, this volume). Indeed, the Vrica GSSP is centrally located within an interval during which spectral analysis of the oxygen isotope record reveals a dominance of the 41 year (obliquity) frequency band (Lourens and Hilgen, this volume), although as Shackleton (ibid.) points out, the cyclical signal prior to about 1.8 Ma is less clear than that of the succeeding period. There are thus no grounds for the assertion by Van Couvering (In press) that "although the Vrica was not mentioned by Gignoux it clearly demonstrates the concept of a change from warm to cold-climate deposition at the end of the Pliocene which was the basis of his Calabrian Stage" (Preface, p. 3). As Suc et al. (this volume) have indicated, this transition from warm to cold conditions occurs in the Crotone series some 350 m below marker bed 'e' at around 2.6 Ma.

Remane (1994) and others have emphasized the importance of magnetic reversals in the selection of GSSPs because of their usefulness for correlation, not only between marine sections, but with their terrestrial counterparts. At first sight the Vrica GSSP appears to have a good correlation potential because of its close proximity to the top of the Olduvai normal subchron. Here too, however, palaeomagnetic studies by Zijderveld et al. (1991) have revealed difficulties. The earlier studies of Tauxe et al. (1983) had placed the top of marker bed 'e' a short distance above the normal zone, but, following careful resampling of this part of the section and others in the vicinity, Zijderveld and his co-workers consider that the palaeomagnetic record near the top of the Olduvai permits of two interpretations; in terms of their second (preferred) alternative the top of bed 'e' should be placed some 8.5 m below the top of the Olduvai event. The Plio-Pleistocene boundary is, in terms of this interpretation, not strictly coincident with the actual termination of the Olduvai subchron. Two other problems arise in connection with the use of the Olduvai for purposes of correlation: its short duration (~0.16 Ma) makes it difficult to locate in some sections and there is also evidence that the main normal event did not end cleanly, but was followed by a brief reversed episode and a further normal interval (the Vrica subchron). These short-term oscillations are readily identifiable only under ideal circumstances and are thus not conducive to a high degree of precision in global correlation.

All of the foregoing evidence points to the fact that the Vrica GSSP defines a boundary which is, at best, weakly developed as a clear natural transition (a conclusion...
echoed by Vai, this volume). The question which must be asked is whether it is logical, or scientifically justifiable, to maintain a boundary which is accepted as marking no major change in the natural geological order and which can be shown to have lower than desirable correlation potential, in the face of long conventional usage and a strong body of stratigraphic evidence which supports the placement of a meaningful lower boundary for the Pleistocene some 0.8 Ma earlier.

QUO VADIMUS

Stratigraphy, in common with all branches of science, must be able to benefit from the advances made within its parent discipline. This is recognized in the Guidelines for the Establishment of Global Chronostratigraphic Standards, put forward by the International Commission on Stratigraphy: "A GSSP or GSSA can be changed if a strong demand arises out of research subsequent to its establishment". As has already been pointed out, the current Vrica GSSP was established largely in deference to a resolution adopted nearly four decades earlier. Its ratification in the early 1980s came near the beginning of a time of unprecedented advances in the study of oxygen isotope stratigraphy, in dating (especially through the use of astronomical calibration), and in the recognition of the global manifestations and singular importance (in the context of Neogene palaeoclimatic events) of the cooling and drying which occurred between 3 Ma and 2.6 Ma. It is incorrect to assert, as does Vai (this volume) that this evidence was largely taken into account in the process of selecting the Vrica GSSP: a substantial part of it became available only after the long discussions which preceded the acceptance of Vrica.

In summary, the wealth of new evidence now at our disposal indicates that the end of the interval of cooling between 3.0 and 2.6 Ma, which is well documented by global isotope stratigraphy, coincides with a change from a dominance of orbital precession (23 ka astronomical cycles) to a dominance of obliquity (41 ka cycles) (see Lourens and Hilgen, this volume). This interval witnessed the first major extension of the northern hemisphere ice sheets. The succeeding period has an essential unity, based on repeated glacial/interglacial cycles at periodicities controlled by orbital obliquity and later, orbital eccentricity; this contrasts strongly with the preceding part of the Neogene, during which the earth was almost entirely ice-free, except in polar latitudes. Although the change which ushered in the era of repeated mid-latitude glaciations occurred relatively gradually, its effects were profound. Major concurrent responses in mammalian and vegetation communities are now well documented (see, for example, Vrba et al., 1995; Suc et al., this volume) and are paralleled by lithostratigraphic changes in many terrestrial sequences. Examples are given by Tyracek and Ding et al. (this volume); the former documents the first accumulation of terraced alluvial sequences and loess in Central Europe, while the latter show that the main loess deposition in China began around 2.6 Ma. Of major significance, also, is the appearance about this time of the earliest species that is currently included in our own genus, Homo rudolfensis (Partridge et al., 1995).

Important, from the viewpoint of global correlation, are not only the clear signature of this change in both global marine oxygen isotope stratigraphy and in many terrestrial sequences, but the coincidence of its termination (and the shift from a dominance of orbital precession to orbital obliquity) with the Gauss/Matuyama palaeomagnetic reversal. This reversal is manifested in a clean change, without the oscillations which characterized the top of the Olduvai subchron, and was preceded and followed by lengthy intervals of stable magnetization (>400 ka). It is thus easy to identify unambiguously in magnetically susceptible sedimentary sequences. In addition, it coincides with a clearly defined event in oxygen isotope stratigraphy (glacial Stage 104 — Shackleton, this volume). Isotope Stage 104 coincides with the Gauss/Matuyama boundary, and also marks the first major incursion of ice-rafted debris into the North Atlantic at European mid-latitudes (Shackleton et al., 1984; Shackleton, this volume). This event ushered in the Pliocene, the start of which has, for some years, been recognized, informally, as the Plio-Pleistocene boundary by many European palynologists and terrestrial stratigraphers (e.g. Zagwijn, 1974).

Of the suitability of this position for the placement of a major stratigraphic boundary there is thus no question. An excellently exposed section, comprising deep-water marine sediments, and spanning the interval between about 3 Ma and 2 Ma, exists at Monte San Nicola in southern Sicily (Fig. 2); this section has been well studied (Suc et al., this volume; Hilgen, 1991; Channell et al., 1992; Sprovieri, 1993) and has recently been proposed as the GSSP for the uppermost ('Gelasian') stage of the Pliocene, the suggested beginning of which has been set

![FIG. 2. The Monte San Nicola section near Gela, southern Sicily. The whitish lower part of the section comprises 'Trubi' limestones and marls. Above the 'Trubi' well laminated silts and marls constitute the 'Monte Narbone Formation'. The arrow indicates the top of the fifth in a cluster of darkened, mangaferriferous beds; such beds have sometimes been referred to as 'sapropels'. The arrowed bed corresponds to Oxygen Isotope Stage 104 and its top coincides with the Gauss/Matuyama palaeomagnetic boundary (2.6 Ma). Below the arrow the darkened beds recur at precessional (23 ka) frequency; above it the wider intervals between beds indicate a shift to a dominance of obliquity (41 ka) cycles. The arrow indicates the position of the lowered Plio–Pleistocene boundary proposed in this paper (photo by T.C. Partridge).]
at Isotope Stage 103 (Rio et al., 1994). As in the case of Vrica, the coincidence of specific events in marine biostratigraphy with the Gauss/Matuyama boundary is not precise, but it does coincide generally with the peak in abundance, shortly after its first appearance in Mediterranean sequences, of the first true ‘cold guest’, the planktonic foraminifer Neogloboquadrina atlantica (Lorenz and Hilgen, this volume). Other LADs and FADs occur in suitably close proximity to provide a fair potential for marine biostratigraphic correlation (Rio et al., 1994; Suc et al., this volume). It is, however, the clear isotopic signature (glacial Stage 104) and the Gauss/ Matuyama palaeomagnetic reversal which furnish this boundary with excellent correlation potential in both marine and terrestrial sequences.

In a recent postal ballot, the Subcommission on Quaternary Stratigraphy of the International Commission on Stratigraphy resolved by 18 votes to 2: “That the Pliocene/Pleistocene boundary be lowered to the vicinity of the Gauss/Matuyama palaeomagnetic reversal contained within oxygen isotope Stage 104 (approximately 2.6 myr) and that the procedures necessary for this change to be put into effect be initiated by the International Commission on Stratigraphy. It is the view of the INQUA Commission on Stratigraphy, which also constitutes the Subcommission on Quaternary Stratigraphy of the ICS, that a strong demand exists for such a change, not only because it will facilitate global stratigraphic correlation in both marine and terrestrial sequences, but also because it will accord better with the current conception of the duration and nature of the Quaternary.”

This resolution was preceded by a symposium on the Plio–Pleistocene boundary convened during the 14th INQUA Congress in Berlin in 1994 which forms the subject of this volume, and by the deliberations of an informal working group established by the Subcommission on Quaternary Stratigraphy to debate the matter. In response to the resolution of the SQS the International Union of Geological Sciences has established an ad hoc working group to further consider the boundary problems and to make recommendations to the IUGS Executive. The outcome remains to be decided, but there is no doubt that the international geological community in general, and the community of Quaternary scientists in particular, will follow the ongoing debate with an unusual degree of interest. Shackleton, 1995

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