MEMORANDUM AND PAPERS

AGAINST THE LOWERING OF THE PLIOCENE-PLEISTOCENE BOUNDARY

PREPARED BY THE SUBCOMMISSION ON NEOGENE STRATIGRAPHY (SNS) AS ATTACHMENT TO THE POSTAL BALLOT WITHIN SNS AND SQS

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AGAINST THE LOWERING OF THE PLIOCENE-PLEISTOCENE BOUNDARY: A DEFENSE OF THE PRESENT DEFINITION AND THE IMPROPRIETY OF THE PROPOSED CHANGE

by D. Rio (SNS Chairman), D. Castradori (SNS Secretary), J. Van Couvering (editor of the Vrica volume)

ATTACHMENTS

Papers by:

Van Couvering, 1997
Remane, 1997
Cita, 1997
Berggren, et al., in press
Vai, 1997
Shackleton, 1997
Rea et al., 1998
Behrensmeyer et al., 1997
Pasini and Colalongo, 1997

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I) BACKGROUND

Following a decade of study and discussions by the International Union for Quaternary Research (INQUA) Subcommission 1a on Stratigraphy (Pliocene/Pleistocene Boundary) and International Geological Correlation Program Project 41 (Neogene/Quaternary Boundary), a draft proposal on the choice of a boundary stratotype for the Pliocene/Pleistocene boundary was submitted and approved by the INQUA Commission on Stratigraphy (acting as the Subcommission on Quaternary Stratigraphy of ICS) at the 1982 Moscow INQUA Congress. A formal proposal was subsequently submitted to and approved by the ICS in 1983 and published two years later (Aguirre and Pasini, 1985) together with the announcement (Bassett, 1985) that the content of the proposal had been formally ratified by the IUGS Executive as GSSP of the Pleistocene. The GSSP was placed at the base of a claystone unit conformably overlying the sapropelic bed "e" in the Vrica section in Calabria (Southern Italy).

In spite of this, a small part of the stratigraphic community, including several continental stratigraphers, has refused to accept such a definition (see the brochure distributed to the participant to the XIV INQUA Congress in Berlin, 1995, where the Quaternary was arbitrarily defined as the period of time that "... covers the past two and a half million years ...") and has continued to argue against it. We note that the proposal made now by SQS is the same paleoclimatic argument that has been on the table since the 1960's, and which has been repeatedly evaluated and repeatedly rejected by the responsible stratigraphic groups after careful evaluations of the pros and cons.

An important improvement in the Global Chronostratigraphic Scale that occurred after the adoption of the Vrica GSSP, should be mentioned at this point. Following positive formal votes by SNS and ICS, the GSSP of the Gelasian Stage (Upper Pliocene) was ratified by IUGS at the XXX International Geological Congress (Beijing, 1996) (Rio et al., 1994; Rio et al., 1998). The base of the Gelasian Stage is located in the Monte S. Nicola section near Gela, Sicily, at a lithologic level close to the Gauss-Matuyama magnetic reversal. This level has been proposed for the redefinition of

the Pleistocene GSSP, according to SQS. After several behind-the-scenes attempts (we spare you the details) by SQS to overthrow the democratically approved Pleistocene GSSP came to nothing, an ad-hoc Committee was established by the IUGS Executive to advise on the matter. The Committee, chaired by A.R. Palmer and including an equal number of advocates on both sides of the question, met in Strasbourg in March 1997 and suggested to submit the possible lowering of the Pleistocene boundary to a postal ballot within SNS and SQS and, in case a majority favored the proposed change, within ICS. The committee also agreed that the Gelasian should remain a valid Stage, thus reducing the present debate to the possible lowering of the Pleistocene GSSP from the Vrica boundary to the base of the Gelasian.

As the officers of SNS, we asked the President of ICS to inform us in advance of the memorandum of SQS arguing in favour of the lowering of the boundary. The present document represents the response of SNS, in consultation with members of the Subcommission, to the arguments therein.

Before getting to the heart of the matter under discussion, we must frankly express our disappointment and frustration with the behaviour of this small part of the scientific community that has continued to resist the consensus on the Pleistocene boundary that has grown, through patient and careful work by many colleagues, on the basis of the directive approved at the London IGC in 1948. This blind opposition has exponentially increased the degree of confusion and misunderstanding on the matter, as well as fostering an erroneous view of what the Global Chronostratigraphic Scale should represent: i.e., a common language among scientists of different disciplines, from different parts of the world. It would have been much better (and much more useful) for these workers to have referred to a Pleistocene defined by the adopted GSSP at Vrica in all publications and talks of the last decade, while seeking to initiate a procedurally correct process of revision.

Finally, we must express our dismay that so much time continues to be wasted on this pointless problem. As stated recently by Berggren et al. (in press) "we have much more important issues to which we should direct our attention as we approach the millenium than the sterile arguments about moving a well defined Pliocene/Pleistocene boundary stratigraphically downwards into what is, for the vast majority of earth scientists, the Pliocene epoch (at 2.6, 2.8, or 3 Ma)". The SNS is facing many difficult and real challenges in the task of establishing a sound astronomically calibrated chronology of the Miocene Series and for defining the remaining Neogene GSSPs. As for the International Commission on Stratigraphy itself, it is faced with the job of finding appropriate definitions for more than a half of the GSSPs of the Global Chronostratigraphic Scale (GCS), as well

as clarifying nomenclature and stratigraphic principles, some of which will be touched upon in this report.

II) ORGANIZATION OF THE MEMORANDUM

To make your work and voting as easy as possible, especially for those of you not familiar with the Pliocene-Pleistocene boundary, we have attached to the present memorandum a set of papers that review: a) the considerable amount of stratigraphic information available on the Vrica section (Pasini and Colalongo's paper); b) the most powerful tools for world-wide recognition of the boundary (Vai's paper, see in particular p. 16, fig. 3); c) two updated studies (Rea et al.'s and Behrensmeyer et al.'s papers) and a review (Shackleton's paper) of the successive steps in the cooling of the Northern Hemisphere, demostrating in the clearest way how the cooling process began much earlier, and continued much later, than the Gauss/Matuyama boundary; d) the historical background and the basic concepts in the definition of chronostratigraphic standards which strongly point to the mantainance of the present Pleistocene GSSP (Cita's, Van Couvering's and Vai's papers).

In our contribution we will (1) try to summarize the state of the art in the Late Pliocene to early Pleistocene chronostratigraphy; and (2) counter the issues raised by SQS summarizing the most relevant facts that you should bear in mind when casting your vote. Finally, we will comment on the status and rank of the Pleistocene, the Neogene and the Quaternary and their mutual relationships, a problem that should be faced by ICS in the near future.

III) WHY CHANGE A DEFINED GSSP?

Remane and Vai in the attached papers discuss the reasons that justify a change of a defined GSSP. Both insist on the seriousness of such an act. It is important to note that the suitability of the Vrica section as GSSP is not under dispute: the section is a state of the art GSSP. According to Remane (attached paper), a key-reason for changing an existing GSSP would be to "considerably improve the correlation potential of the boundary". We, obviously, concur that correlation is the crucial problem. However, we would have phrased the sentence in a slightly different way. As ackowledged by Remane, stability in nomenclature is of top importance in stratigraphy and changing in a significant manner the position in time of a well **consolidated** chronostratigraphic unit **solely** on the basis of an improvement in correlation could open the door to a very conflicting and unstable situation. We would have said that a defined boundary of a traditional chronostratigraphic unit of GCS can be changed only when it is not recognizable worldwide and, thus, not used by stratigraphers, since in this case it would be useless. However, even if we accept the purpose of the

President of ICS, we will show that there is no improvement in the correlation potential of the Pliocene/Pleistocene boundary by lowering it from the Vrica GSSP to the Monte S. Nicola (Gelasian) GSSP. We consider, furthermore, that to make such a change for such a reason would strongly destabilize a well established literature, and would put under question the presently accepted philosophy of chronostratigraphy.

The main points in the argument made by SQS for lowering the Pleistocene GSSP are not centered, however, on the improvement of correlation potential (that, indeed, is not faced analytically in their memorandum), but, instead, on justifying opinions that 1) the Vrica boundary is a poor definition for the base of the Pleistocene because it is not coincident with the onset of glacial conditions, and 2) that the advancement in knowledge in the last ten years or so justifies the lowering of the boundary to where a more conspicuous step in Cenozoic climatic deterioration can be seen.

Neither of these opinions is tenable. On the contrary, we will show that the dramatic advances in the past 10-15 years in global chronocorrelations, paleoclimatology and paleoceanography of the Cenozoic, actually reinforce the validity of the definition of the Pleistocene by the Vrica GSSP, and demonstrate the value of a strict Hedbergian approach to chronostratigraphy in establishing the Vrica boundary.

We will also show that there is a strong partisan attitude in the papers and the statements of SQS.

IV) THE GLOBAL CORRELATION OF THE VRICA GSSP

Reading the papers reported by SQS, one gains the impression that the Vrica boundary was chosen almost by chance. Clearly this is false, as can be seen in the huge amount of work documented in the final report of IGCP 41 (Van Couvering, ed., 1997). Actually, the global correlation potential together with stratigraphic principles and historical priority were the key-points in reaching this definition. The success of the Vrica GSSP is amply demonstrated by the simple observation that it has been consistently and correctly used for thirteen years by all marine stratigraphers, paleoceanographers, most geologists and a majority of vertebrate paleontologists (see, for instance, the various volumes of the Ocean Drilling Program, as well as papers in the most important journals). In addition, ironically, the correlation potential of the Vrica GSSP continued to improve even after its adoption, with a better resolved calcareous plankton biostratigraphy and biochronology (Berggren et al., 1995), the development of a standard Marine Oxygen Isotope Stratigraphy (Ruddiman et al., 1989; Raymo et al., 1989; Shackleton et al., 1991; Tiedemann et al., 1995, etc), and, overall, the development of astrocyclostratigraphy (see review in Lourens et al.,

1996). Added to the criteria already described in the IGCP 41 report (Van Couvering, ed., 1997), the global correlation of the base of the Pleistocene as defined at Vrica is even easier than in the past. The key-issue of the global correlability of the Vrica GSSP is addressed in many of the attached papers. We summarize below the main chronocorrelation tools, listed in order of decreasing precision and accuracy.

1. **Astrocyclostratigraphy**: the Vrica GSSP has been shown to correspond to precession cycle 176, as counted from the present (Hilgen, 1991; Lourens et al., 1996).
2. **Magnetostratigraphy**: the Vrica GSSP has been shown to lie just below the top of the Olduvai Subchron (C2n Subchron of Cande and Kent, 1995) (Zijderveld et al., 1991).
3. **Marine Oxygen Isotope Stratigraphy**: the Vrica GSSP has been shown to correlate with the upper part of Marine Oxygen Isotope Stage (MIS) 65 (Lourens et al., 1996).

The abovementioned correlation tools allow for the most precise and accurate worldwide correlation of the Vrica GSSP and permit it to be dated accurately to 1.81 Ma (see Hilgen, 1991; Lourens et al., 1996). Magnetostratigraphy and, to a lesser degree, astrocyclostratigraphy allow the Vrica GSSP to be recognized in continental stratigraphy. Note that the astronomical and isotope data were unavailable, or not fully resolved, when the GSSP was approved.

4. **Marine biostratigraphy** (cf. attached papers by Vai, and by Pasini & Colalongo, and the references therein): the Vrica GSSP is best approximated in marine sediments of various facies and from different latitudes by the FO (First Occurrence) of the calcareous nannofossil *Gephyrocapsa oceanica* s.l. (normal sized *Gephyrocapsa* spp. of other authors), occurring some 80 ky younger than the boundary age. It is bracketed by the following calcareous nannofossil biohorizons: LO (Last Occurrence) of *Discoaster brouweri* in MIS 72, some 150 ky older than the boundary, and LO of *Calcidiscus macintyrei* some 150 ky younger than the boundary. Among planktonic foraminifera, the first (common) occurrence of left coiling *Neogloboquadrina pachyderma* occurs in MIS 64 (as in the North Atlantic Ocean), practically in coincidence with the boundary; the FO of *Globigerina cariacoensis* occurs in MIS 62, some 60 kyrs younger than the boundary.

5. **Continental biostratigraphy**: the Vrica GSSP is close to the *wolf* event (Azzaroli, et al., 1986), characterized in the Olivola fauna of the Val d'Arno by a major turnover in large mammals, especially carnivores, that can be followed into Africa and North America. Simultaneously, in

Eurasian small-mammal faunas there are continent-scale events associated with the index FO of *Allophaiomys* (Chaline, 1997). This level is also coincident with the evolution of erectus-grade humans and their dispersal outside of Africa (Aguirre, 1997). The same level is recognized by a sharp, permanent decrease in tropical and moist-temperate elements in the pollen spectra of Eurasia (Grichuk, 1997) during the cool, dry climate of the Eburonian phase. In Italy, it is represented in the disappearance of pollen grains of the so called "Tertiary elements" of the Taxodiaceae Group (the "Tiberian boundary" of pollen stratigraphers; see Lona & Bertoldi, 1973); the latter event has been shown to be virtually coincident with the appearance of the so-called "northern guests" (boreal molluscs) in the marine shelf depositional environment of the Mediterranean region. In fact, the appearance of the "northern guests" in the Mediterranean and the disappearance of the Taxodiaceae in the Italian region were historically the criteria for the Pleistocene boundary, and these criteria were included in selecting the globally correlatable lithic level defining the Pleistocene in the marine, deep water continuous Vrica section (see the attached paper by Pasini and Colalongo).

V) COMPARING THE CORRELATION POTENTIAL OF VRICA AND MONTE S. NICOLA (GELASIAN) BOUNDARIES AS GSSPs

There is no question that the mid-Pliocene level proposed as the revised base of the Pleistocene by SQS has a high global correlation potential. Indeed, the high correlation potential of the time interval centered at the Gauss-Matuyama boundary was the main reason for introducing the Gelasian Stage as the third, upper subdivision of the Pliocene Series (Rio et al., 1991; Rio et al., 1994; Rio, et al., 1998). Before we go on to comparing the properties of this level with Vrica, however, we must take note of a fundamental error in the SQS proposal to equate the base of the Gelasian with the base of the Pleistocene: the Gelasian strata and time have always been included in the Pliocene, by definition. We make this statement strongly and with conviction. The Gelasian is virtually coincident with the core concept of the Astian, a term now compromised by careless applications, but widely used in the literature (see Rio et al., 1991, 1994) for strata that were thought to be equivalent to the deposits of the northern Apennines and Sicily that Lyell (and all subsequent authors) included in the highest part of the Pliocene. The Gelasian is Pliocene not on the basis of some vague climatic or biostratigraphic criterion, but because its rocks and fossils are part of the Pliocene by original definition (Astian Auctorum). Consider the section of Castell'Arquato (Piacenza Province, Northern Italy), probably the most classical historical section for the definition of the Pliocene and Pleistocene. Just above a prominent calcarenitic bed (upon which the village of Castell'Arquato is built), that

represents the top of the historical Piacenzian stratotype, there is a packet of strata that in turn underlies beds with the first local occurrence of boreal molluscs ("northern guests"). This packet of strata has been regarded since the term Pliocene was defined as the reference for the Pliocene Series. To include these strata (Astian Auctorum) in the Pleistocene would mean upsetting an almost two century old usage.

Since it is the lithostratigraphic record that defines chronostratigraphic units, since Pliocene and Pleistocene are distinct and easily differentiated in the regional Mediterranean stratigraphic record (the type record for the time interval), and since we have already shown the global correlatability of the Vrica boundary as used by the large majority of stratigraphers, our defense of the base of the Pleistocene at Vrica should stop here if the basic principles of Stratigraphy are followed (see Section VI). However, the main paleoclimatic argument of the SQS is supplemented by a claim, directed to those who adhere to "correlation first, definition after" principles with indifference to Hedbergian guidelines (see paper by Berggren, et al.), that global correlation of the boundary would be improved by relocation to the Monte S. Nicola (Gelasian) GSSP with respect to the Vrica GSSP. Is this true? Let's compare the correlation potentials of the two GSSPs by considering the main chronocorrelation tools.

Astrocyclostratigraphy and Magnetostratigraphy

Both Vrica and Monte S. Nicola (Gelasian) GSSPs are well constrained by magnetostratigraphy and cyclostratigraphy. It seems to us that it is a poor argument to state that the onset of the Matuyama Chron is better recognized than the top of the Olduvai Subchron. In our experience the two reversal events are equally recognizable in most continental and marine records. Both suffer with the vagaries of the magnetostratigraphic technique: problems of poor magnetic properties of many rocks and sediments, difficulty in the correlation to the standard Geomagnetic Polarity Time Scale (GPTS) in absence of biostratigraphic or radiometric constraints ("flip-flop" record), inapplicability in routine subsurface geology (cuttings) and in isolated outcrops, and problems associated with the acquisition of the NRM ("rebound" problems; see Langereis et al., 1994), etc. The SQS document refers to the problems associated with the recognition of the top of the Olduvai Subchron in the Vrica section, but the same problems have been encountered with the recognition of the Matuyama Chron in Monte S. Nicola section, the GSSP of the Gelasian (Channell et al., 1992).

Marine Biostratigraphy

Biostratigraphy remains the most important correlation tool in stratigraphy. It is based on easily recognized non-repetitive events that are needed for framing the better resolved and more global

chronocorrelations provided by cyclostratigraphy and magnetostratigraphy. Unfortunately, as is well known to marine biostratigraphers, no major faunal or floral discontinuities are present in the marine realm in the past 15 million years. Apparently, the response of the biota to the Neogene climatic deterioration has been gradual and floristic and faunal turnovers did not result in catastrophic major biostratigraphic breaks. Not surprisingly, there is no "magic", K/T-like, change in the marine flora and fauna around either the Gelasian or the Vrica GSSPs. However, close to both GSSPs there are biostratigraphic events that, when integrated with the other available correlation tools, allow the approximate global recognition of both boundaries in most practical instances. We note here that the SQS document gives poor, often wrong and partisan information on marine biostratigraphy in the time interval of interest, as will be discussed below. It is not by chance that no marine biostratigraphers are present among the authors of the SQS memoranda. We emphasize that marine biostratigraphy plays a crucial role in correlation and, hence, in the GSSP definition process (Hedberg, ed., 1976; Salvador, ed., 1994; Remane et al., 1996). To make things clearer we have preparared Fig. 1, where the significant and reliable biohorizons for the time interval are reported. For brevity, we discuss only the two most widely used microfossil groups: planktonic foraminifera and calcareous nannofossils.

Calcareous nannofossils

We can safely state that the Vrica boundary is better approximated than the Gelasian boundary on the basis of calcareous nannofossils. In the last years, the FO of *Gephyrocapsa oceanica* s.l. (normal sized *Gephyrocapsa* spp. of other authors), some 80 ky younger than the boundary, has been confirmed as a highly reliable event in low to high latitude areas, in oceanic sediments and in shelf and terrigenous sediments on land (the literature is immense, but you can consult Raffi et al., 1993 and Rio et al., 1996). In addition, the event has been shown to be remarkably synchronous over wide latitudes and various depositional environments (Raffi et al., 1993, Wei, 1993).

By contrast, the Gelasian boundary is best approximated by the LO of *Discoaster pentaradiatus* (at 2.51 Ma in the Mediterranean; Sprovieri, 1993) and by the LO of *Discoaster tamalis* (at 2.82 Ma in the Mediterranean; Sprovieri, 1993). These two biohorizons are based on forms that are much more ecologically controlled than *Gephyrocapsa* spp. Discoasterids are missing in high latitude areas and are rare to absent in depositional environments underlying water masses with high nutrient contents (upwelling, shelf, slope). In addition, the LOs of *D. pentaradiatus* and *D. tamalis* show a fairly high degree of diachrony according to the available data (e.g., Chepstow-Lusty et al., 1989). There is little doubt (believe us: it is everyday work for two of us) that the recognition of the Vrica

GSSP is easier than that of the Monte S. Nicola (Gelasian) GSSP on the base of calcareous nannofossils, the most widely used and reliable chronocorrelation tool in Cenozoic marine sediments.

Planktonic foraminifera

Both the Vrica and Monte S. Nicola (Gelasian) GSSPs are not particularly well constrained by means of planktonic foraminifera biostratigraphy. We are not informed of really global evolutionary events occurring in the time interval of interest and, indeed, they are not mentioned in the SQS memorandum. In the past, a widely used biohorizon has been the first evolutionary occurrence of *Truncorotalia* (*Globorotalia*) *truncatulinoides*, traditionally associated with the Olduvai Subchron (see Sprovieri, 1992, 1993 and references therein). However, this datum has proved diachronous in different water masses (Berggren et al., 1995) and cannot be used without an accurate regional biochronological evaluation. Concerning the Mediterranean and North Atlantic Ocean, the Vrica GSSP is well approximated by the FO of left coiling *Neogloboquadrina pachyderma* occurring in both areas within MIS 64 (Sprovieri, 1992, 1993; Pasini and Colalongo, 1996; Raymo et al., 1989), practically in coincidence with the boundary. The Gelasian GSSP is approximated by the LO of *Globorotalia bononiensis*, occurring some 140 ky younger than the base of the Gelasian (Sprovieri, 1992, 1993). However, *Globorotalia bononiensis* (*Globorotalia puncticulata* of some authors) is discontinuously distributed and the recognition of the event in the practical work is much more difficult than the FO of left coiling *N. pachyderma* (Sprovieri, personal communication, September 1998). In summary, also with planktonic foraminifera the Vrica GSSP is better recognized than the Monte S. Nicola (Gelasian) GSSP. As a matter of fact, the senior author (as the main culprit for the introduction of the Gelasian Stage) received protests by foram people because the base of the Gelasian is not easily picked with forams. It is not by chance that planktonic foraminifer micropaleontologists in the past have extended the Piacenzian up to the base of the Pleistocene (i.e. the Vrica boundary) (see Rio et al., 1991). The only reliable planktonic foram event in the Mediterranean and in the northern North Atlantic Ocean occurring between the Monte S. Nicola (Gelasian) and Vrica GSSPs is the FO of *Globorotalia inflata* (Fig. 1). This biohorizon has been used for a long time as a zonal boundary definition (Fig. 1) and has been widely used in Italy for recognizing the "Upper Pliocene" (see Rio et al., 1991). The event occurs, however, at 2.13 Ma (Sprovieri, 1992, 1993), closer to the Vrica than to the Monte S. Nicola GSSP.

COMMENTS ON THE PAPER BY SUC ET AL. (1997)

Suc et al. (1997) in the paper attached to the SQS memorandum, in the section Marine biostratigraphy, give a very unreliable caricature of the marine biostratigraphy in the interval of

interest here. Virtually all of the statements made by these authors (all pollen stratigraphers) are not warranted; furthermore, they do not quote the source of their information. We ask SQS and SNS members to go to the original works of specialists in marine stratigraphy for a faithful picture of the state of the art in marine biostratigraphy of this time interval (Fig. 1). However, we cannot refrain, here, from commenting on three of their statements.

1) Suc et al. (1997) state (p. 39) that the first common occurrence of left coiling *Neogloboquadrina pachyderma* "*...is now considered an unreliable biostratigraphic indicator*". They do not quote the source of this surprising statement. The FO of left coiling *N. pachyderma* in the Mediterranean has been used since the sixties for approximating the base of the Pleistocene in Italy (Dondi and Papetti, 1968) and, recently, it has been proved to be a synchronous event between the Mediterranean and the North Atlantic Ocean (Raymo et al., 1989; Pasini and Colalongo, 1996).

2) At p. 39, Suc et al (1997) state that "*..only the LADs of* N. atlantica *and of* Globorotalia acostaensis *can be retained as useful biostratigraphic events*". Our colleagues tell us that both species have a terminal range difficult to assess, and their extinction is not used in practical biostratigraphic work. However, both Glacon et al. (1990) and Sprovieri (personal communication September, 1998) report that *N. atlantica* is present up to the base of the Pleistocene as defined in Vrica.

3) At p. 39 they also state: "It was obvious from this evidence that the first significant climatic deterioration in the Mediterranean series occurred near the Gauss-Matuyama reversal and coincided with the entry into the Mediterranean Sea of the planktonic foraminifer *Neogloboquadrina atlantica*, which might be considered as the "true first cold guest" (Spaak, 1983)". We note that:

a) the term "northern guest" was introduced (see Raffi, 1986, for a review) for shelf shallow-water molluscs and can hardly be applied to planktonic and deep- water benthonic organisms;

b) the Pliocene FO of *N. atlantica* in the Mediterranean is a migration event at ca. 2.70-2.75 Ma that well predates the Gauss-Matuyama boundary and the associated climatic deterioration (see Figs 1 and 2a,b);

c) the true first occurrence of *N. atlantica* in the Mediterranean occurred in the late Serravallian (middle Miocene) and the species is well represented in the Messinian Tripoli Formation (Coccioni and Galeotti, 1995; Sprovieri et al., 1996).

If we were to follow Suc's approach to chronostratigraphy the definition of the Pleistocene should be located at about 10 Ma! And, be sure, plenty of "northern guests" *sensu* Suc et al. (1997) are present at even lower stratigraphic intervals!

CONTINENTAL BIOSTRATIGRAPHY (MAMMALS)

We are not specialists in mammal biostratigraphy and biochronology. However, to our knowledge and by reading the paper by Kolfschoten (in SQS Memorandum) there is no major clear-cut change at the base of the Gelasian that can make its correlation easier than the Vrica GSSP. There are faunal changes more or less close to both GSSPs under discussion and it is very difficult to keep the score. In support of this view, we attach a paper by Behrensmeyer et al. (1997) on the evolution of vertebrate fauna in the classical and well studied basins of East Africa. For those of you who do not have time to go through this paper we quote some sentences below.

"..no distinct turnover pulse is seen between 2.8 and 2.5 Ma; instead, the most significant period of faunal turnover began after 2.5 and continued through 1.8 Ma" (abstract)

"..between 2.1 and 1.7 Ma, during a period of continuing high fossil productivity, the pattern of FADs and LADs provide evidence for accelerated faunal turnover" (p. 1591)

" Most of this change appears to have occurred from 2.5 to 2.0 Ma. At the end of Pliocene (our emphasis), between 2.0 and 1.8 ma, the rate of turnover per 200.000-year interval increased, and disappearances outnumbered the appearances." (p. 1592)

"Thus, although a pulse of species turnover may have occurred elsewhere on the continent between 2.8 and 2.5 Ma, the absence of evidence for such a pulse from the best calibrated, fossil-rich deposits for this time period weakens the case for rapid climatic forcing of continent-scale ecological change and faunal turnover. Instead, our data indicate that late Pliocene evolution in East Africa was affected by the cumulative ecological consequences of cooler, drier, and more variable climatic conditions rather than by a sudden change toward open habitats." (p. 1593)

Where are the evidences for a vastly better correlation potential claimed by SQS? We note, in passing, that when the Vrica GSSP was proposed, some mammalian specialists were unhappy with this choice because they preferred either an older (base of the Villafranchian, somewhere between 3.4 and 2.6 Ma) or younger (top of the Villafranchian, at about 1.0 Ma) definition (see the attached papers of Vai and Cita). However, most vertebrate paleontologists have since conformed to the principle that the marine stratigraphic record is the main standard for defining chronostratigraphic units.

CONTINENTAL BIOSTRATIGRAPHY (POLLEN)

Zagwijn and Suc et al. in their papers (see SQS memorandum) raise the problems of the pollen stratigraphy as an argument in favour of the lowering of the boundary. We note that both Zagwijn and Suc were among those in the eighties that fought, on the basis of continental paleoclimatology, against the Vrica definition (see Section VI). These authors are partisan and incomplete in their

summary. They quote mainly their own work and ignore other evidence from the literature that is not in agreement with their conclusions. For the record, a few examples will suffice. They do not even mention that the major pollen change in the Italian pollen record is the aforementioned "Tiberian boundary" (almost coincident with the Vrica boundary), interpreted as a strong reduction of humidity and temperature in the Italian region. They base much of their discussion on the discontinuous and poorly dated continental record of Northern Europe or on the pollen data of Vrica section that are mainly represented by nonindicative pine pollen. On the basis of these records they make generalization on the evolution of the Mediterranean climate that are contradicted by others (i.e. Bertoldi et al., 1989). We report in Figure 2 a piece of the vegetational history in northern Italy (the Adriatic paleogulf), across the Gauss-Matuyama boundary from the richly polleniferous Val Marecchia section, located near Rimini (Bertoldi in Rio et al., 1997). The story documented in that section is fairly coherent with the informations from the deep sea isotope record and is at odds with the generalizations made by Suc and Zagwijn. There are evidence of the strong cooling associated with marine isotope stage (MIS) 100-98-96, but there are evidences of earlier coolings as well. In addition, and more important, after the MIS 100-98-96 cooling, a suptropical-type vegetation was restored. In this section, we find no evidence of a modern Mediterannean climate or of the establishement of arid conditions. On the contrary, the glacial intervals are characterized by the development of a forested mountain phase, while interglacials are characterized by the expansion of the subtropical to warm-temperate Taxodiaceae forests. Evidently, there are interregional differences in the floral patterns that reflect the existence of geographic climatic gradients within the Mediterranean (for more details see Bertoldi et al., 1989 and Rio et al., 1997, pp. 19-20). We have reported these data as an example of the complexity of the response in the stratigraphic record of the evolution of the global climatic system (see Section VI).

VI) THE PALEOCLIMATIC PREJUDICE

Judging from repeated statements in the SQS proposal, the principal reason for lowering the base of the Pleistocene is the lack of a strong global climatic deterioration associated with the Vrica GSSP. Recently, W. Berggren,. F. Hilgen, C. Langereis, D. Kent, N. Obradovich, I. Raffi, E. Raymo and N. Shackleton in an important paper in the GSA Bulletin (1995) stated that (emphasis ours): "Current attempts to relocate the Pliocene-Pleistocene boundary to coincide with the late Pliocene climatic change at ca. 2.6 Ma are judged here to be inappropriate and to **ignore stratigraphic first principles**."

We concur with these authorities in Cenozoic stratigraphy that the core of the quarrel is not just data interpretation but the principles of chronostratigraphy. In the sixties and seventies, the role of climate in defining the Pleistocene was the subject of prolonged and acrimonious debate (see Berggren and Van Couvering, 1979), which seemed to come to a sudden end after the publication of the International Stratigraphic Guide edited by Hedberg (1976). As Salvador (1994) pointed out in the introduction to the second edition, the number of papers devoted to all problems in stratigraphy fell dramatically to near zero in 1977, indicating that the Hedbergian guidelines, at least in theory, offered clear and effective solutions to nearly all the conflicts in definition and use of chronostratigraphic units. Let's quote some of these principles, taken from Salvador (1994) (emphasis ours).

a) Chronostratigraphic units are bodies of rocks, layered or unlayered, that were formed during a specified interval of geologic time [section A, p. 77];

b) The basic principles to be used in dividing the Quaternary into chronostratigraphic units should be the same as for older Phanerozoic rocks, although different emphasis may be placed on the various means (climatic, magnetic, isotopic, etc.) used for time-correlation [section G, p. 88];

c) Climatic changes leave a conspicous inprint on the geological record in the form of glacial deposits, evaporites, red beds, coal deposits, paleontological changes, and such. Since many climatic changes appear to have been regional or worldwide, their effects on the rock provide valuable information for chronocorrelation. The extent of their effects is complicated, however, by normal variations in climate due to latitude, elevation, oceanic circulation, plate movements, and other factors [section I, 6, p. 96].

d) The selection of the boundary-stratotype section of chronostratigraphic units of the Global Chronostratigraphic Scale, where possible, should take account of historical priority and usage and should approximate the traditional boundaries [section H, 3, p. 91]

These statements mean to us that "climatic deterioration", "ice age", and the like, are not chronostratigraphic criteria and cannot enter into the definition of the Pleistocene.

We would remark here that the often quoted London 1948 resolution admittedly refers to the intention of defining a Pleistocene boundary that coincided with the beginning of the "Ice Ages". At that time, of course, this was believed to be a single, sudden transition to glacial conditions. More precisely, the presence of the "cold guests" was cited as a justification for selecting the base of the marine Calabrian Stage as the location for the boundary. Justifications, however, are not definitions (the Hedberg guidelines make this clear), but in any case the Calabrian was already used as the basal Pleistocene unit in Italy for many years prior to 1948. When it proved, as time went on, that there

was no definitive paleoclimatic event to mark the "Ice Ages", the workers who eventually made the choice of the Vrica section retained from the 1948 resolution the only part that was in keeping with modern accepted philosophical principles of chronostratigraphy (see the papers by Pasini and Colalongo, and Van Couvering).

VII) THE CLIMATIC DETERIORATION: HOW AND WHEN DID IT OCCUR?

We claim that paleoclimate, in itself, plays no role in the definition of chronostratigraphic units, unless, of course, it creates changes in the stratigraphic record that provide chronocorrelation tools. But let us review what we know on the evolution of the global climatic system and if there are clear-cut breaks that would provide almost "natural" subdivisions of the Earth stratigraphic record. The evolution of the Earth's climatic system and its variability is probably the most intensively studied topic in Earth science in the last years. The data set is immense and growing everyday. We cannot enter here in such a review, but since SQS emphasized the importance of the climatic evolution of the Northern Hemisphere glaciation, let's stay with this part of the story. Two decades of paleoclimatic and paleoceanographic research have clearly shown us how the cooling process of the Northern Hemisphere is a very long and incremental process story punctuated by periods of acceleration and deceleration, with long intervals of stable warm climate (see the attached papers by Rea et al., 1998, and Shackleton, 1997). Please, read carefully the following summary (and the attached papers that form its background) and then answer the final question.

The main steps of the Northern Hemisphere climatic deterioration can be summarized as follows.

- polar cooling began in the middle Miocene (about 15 Ma; Cande and Kent's, 1995, timescale), as demonstrated by the oxygen isotope record and by seasonal ice rafting in the far North Atlantic;

-at around 9 Ma, the main phase of Himalayan uplift began, with consequences for the beginning of monsoonal climatic regimes, changes in vegetation, chemical weathering and CO2 drawdown;

- in the latest Miocene ice rafting began at high latitudes in both the Atlantic and Pacific Oceans;

- at about 4.6 Ma (Early Pliocene), closing of the Panamanian Seaway diverted equatorial Atlantic surface water north, resulting in increased formation rates of North Atlantic Deep Water, more moisture for snow and ice accumulation, and more intense zonal westerlies;

- at about 3.6 Ma (Early/Middle Pliocene boundary), Tibetan uplift caused the drying of central Asia and occasioned further mid-latitude to high-latitude cooling, entailing significant snow and ice buildup, as reflected by the ramp up of the oxygen isotope values; glaciers advanced to sea level in Iceland and Norway;

- at about 2.6 Ma (Middle/Late Pliocene boundary), a series of cycles (Glacial Stages 104, 102, and 100) represent clearly defined increases in the intensity of the glaciations;

- after the MIS 104 to 100 coolings, a period of less-well defined fluctuations characterizes the Late Pliocene, coming to an end at around 1.77 Ma (approximately at the Pliocene/Pleistocene boundary as defined at Vrica), at which point very regular 41,000 kyrs glacial cycles became well established, with a significant increase in the average deposition rate of the loess in China is observed (Ding et al., 1997);

- at about 0.9 Ma (MIS 22-24) a major transition occurred from the 41ky-long glacial cycles to the present climatic regime characterized by well known 100ky-long extreme glacial cycles.

So, the final question is:

If you want to adopt the paleoclimatic criterion in defining chronostratigraphic units, which of these transitions is the most significant? Where would you like to draw the base of the Pleistocene: At 15, 9.0, 4.6, 3.6, 2.6, 1.77, or 0.9 Ma?

We have not mentioned so far that plenty of evidence indicates that the probably most important threshold in the Earth climatic system was crossed in the interval of time from the late Eocene to basal Oligocene when the Antarctic ice sheet (the largest on the Earth) became established heralding the passage from a "Greenhouse world" to an "Icehouse world".

The truth is that if we were going to use the climatic criterion in defining chronostratigraphic units, we should change our stratigraphic principles. If we do so, however, we will return to the endless battles over the personal preferences and provincial criteria from different viewpoints that characterized stratigraphy before 1976, and we run a further risk of disrupting a literature two centuries old without, in the end, any improvement in our standard.

VIII) PLEISTOCENE, NEOGENE, QUATERNARY

We hope to have clearly demonstrated that it is no longer possible to link the base of the Pleistocene, as a Standard Chronostratigraphic Unit, to the concept of cooling of the Northern Hemisphere or to the beginning of the Ice Age. To do so would be at odds with the accepted principles of stratigraphy, would destabilize a well consolidated literature and would lead us back to pre-Hedbergian chaos. But one may ask: why has the Pleistocene boundary been so controversial, always making someone unhappy, whatever definition is envisaged or adopted? We asked ourselves this question in preparing this document. Most of the problem is certainly tied to the climatic prejudice, deeply rooted in the mind of some conservative palinologists and old-fashioned

"Quaternary" geologists. But we acknowledge that there might be problems associated with the IUGS resolution on the Vrica GSSP, that are faced below.

So far, in our document, we have deliberately referred only to Pliocene and Pleistocene chronostratigraphic units, avoiding the terms Quaternary and Neogene. Actually, according to the 1985 IUGS resolution, the Vrica boundary serves also as the definition of the Neogene/Quaternary boundary and thus, by default, of the first Pleistocene stage (Calabrian according to most authors, but see the attached paper by Van Couvering). It is not possible here to review the long and tortuous history of the definition of all these units and terms (excellent review are available; see Hays and Berggren, 1971; Berggren, 1971; Berggren and van Couvering, 1979). However, the fact that the Pliocene/Pleistocene boundary is equated with the Neogene/Quaternary boundary makes it a System or Subsystem boundary and this does not sound appropriate to many authorities in Quaternary and Cenozoic stratigraphy (see the attached paper of Berggren, et al., in press). Actually, one should ask if the rank of the Pliocene-Pleistocene boundary (either defined in Vrica or in the Monte S. Nicola sections) deserve the rank of system or subsystem. The other system boundaries are defined by major biotic breaks that are not observed in the last 15 my. One may ask: which is the rationale for interrupting the Neogene at 2.6 or 1.8 Ma? Most paleontologists would agree that we are in the same biotic world since the base of the Neogene, and, actually, the Neogene when it was introduced was inclusive of the Miocene, the Pliocene and the Pleistocene. We are aware that the problems we are arising here are of momentous importance and of very difficult solution, also for "geopolitical" and psychological reasons, but a debate within the whole stratigraphic community needs to be opened. Within the SNS the discussion is going on informally and the opinions are contrasting (see the attached papers by Vai and Berggren, et al.). As SNS we will formally open this discussion in the near future and we suggest that other bodies of ICS do the same.

IX) CONCLUSIONS

We strongly oppose to the proposal of SQS to lower the definition of the Pliocene/Pleistocene boundary from the presently approved GSSP in the Vrica section (at about 1.8 Ma) to the Monte S. Nicola (Gelasian) GSSP (at about 2.6 Ma) for the following reasons:

1) The SQS proposal ignores basic principles of stratigraphy, which demand that:

a) Chronostratigraphic boundaries in the Phanerozoic are defined in marine sections with GSSPs placed at lithic levels appropriate for regional/global correlation using fossils, paleomagnetism, stable isotopes, etc. The present Pliocene/Pleistocene boundary satisfies these criteria. This boundary is not different from any other chronostratigraphic boundary and arguments that it should be moved cannot depend on criteria that do not apply to the rest.

b) The climatic record plays no part in definition of chronostratigraphic record. While a reflection of climatic history (i.e. in form of stable isotopes, or astronomically forced depositional cycles) can be used for correlating a chronostratigraphic boundary, it is not *per se* involved in any way in its definition.

2) Lowering the base of the Pleistocene to the GSSP of the Gelasian Stage (Astian *Auctorum*) at ca. 2.6 Ma:

a) **would not improve** correlation potential of the Pliocene/Pleistocene boundary,

b) it would mean that rocks considered Pliocene by all marine stratigraphers, paleoceanograhers, most geologists and a majority of vertebrate paleontologists would be transferred to the Pleistocene. Only a few consevative palynologists and a few other old fashioned "Quaternary geologist" who live in their own world want to lower the boundary to a level that is, for all others, the Middle-Upper Pliocene boundary.

3) The Vrica GSSP is adequate in terms of the criteria followed in the definition and in terms of global correlation potential. In addition, the latter has improved significantly after its formal approval in 1985. This is supported by the fact that the Vrica GSSP has been consistently and correctly used for thirteen years by the entire marine stratigraphic community and by most continental stratigraphers. This consistent part of the scientific community would be certainly upset by a change that would be most probably felt as an unnecessary source of confusion. Elementary reasons of stability demands that the base of the Pleistocene as a Standard Series/Epoch boundary is to be maintained where it has been defined 13 years ago, at a point which is as significant as others in the cooling history of the Northern Hemisphere and "is in fact

as practical and appropriate as any other" (Van Couvering, 1997). Stability in (chrono)stratigraphic nomenclature is a feature of momentous importance and may be challenged, in our opinion, only when really unavoidable, and this is certainly not the case.

4) The stratigraphic community should address the problem of the status and rank of Quaternary and Neogene, and their relationships with the well established Pliocene and Pleistocene Series in order to clarify a controversial topic in the literature that might have played a role as source of this unfortunate proposal of changing the Vrica definition of the Pliocene/Pleistocene boundary.

X) EPILOGUE

Now, let us finish where we have begun, that is from complaining a little.

Why should we have devoted such a great effort trying to change existing, democratically agreed upon, easily correlatable, boundaries when so many other still lack a formal definition? A complete Global Chronostratigraphic Scale, with each boundary defined by a GSSP, lies quite a long way ahead of us: why should have we pushed this goal even farther away by dismantling the Guidelines and trying to change one of the (relatively) few boundaries we have already got?

Anyway, let us hope that this will be really the last step of the great controversy. In fact, we promise that, should the option of moving the boundary (regretfully) win, we will immediately conform to the new base of the Pleistocene, since it would be simply a nonsense to use the old one. Are the opponents of the Vrica boundary ready to (finally) accept it, should their preferred option fail?

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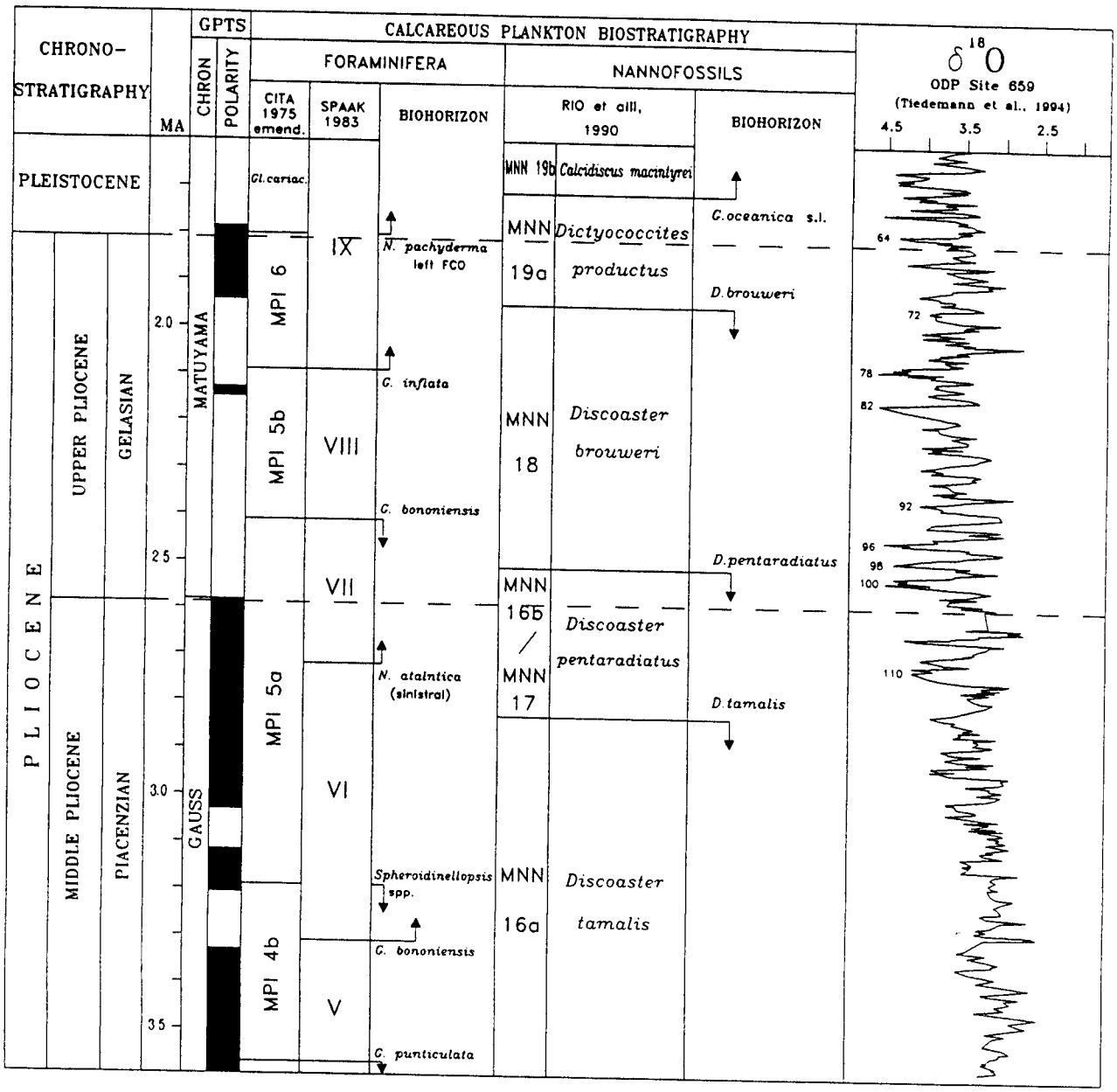

FIG. 1 – Middle Pliocene to early Pleistocene time framework. The chronology of magnetic polarity reversals and biohorizons is after Lourens et al. (1996).

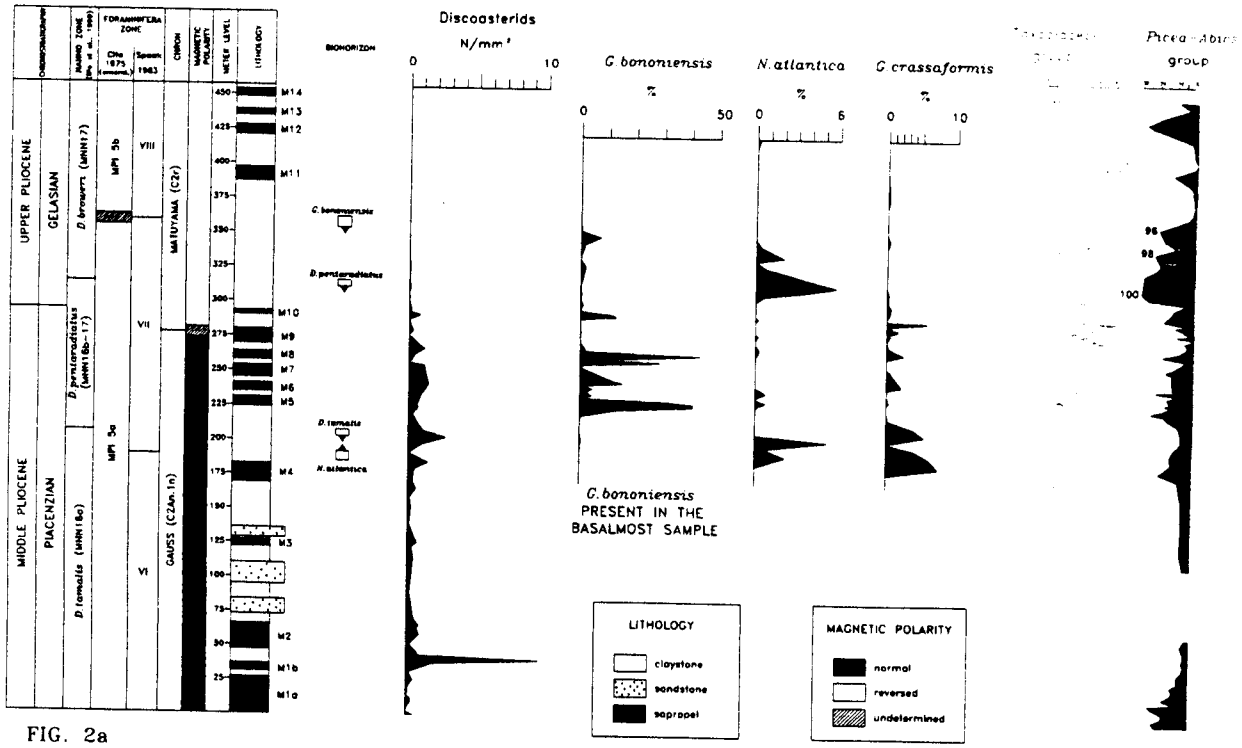

FIG. 2a

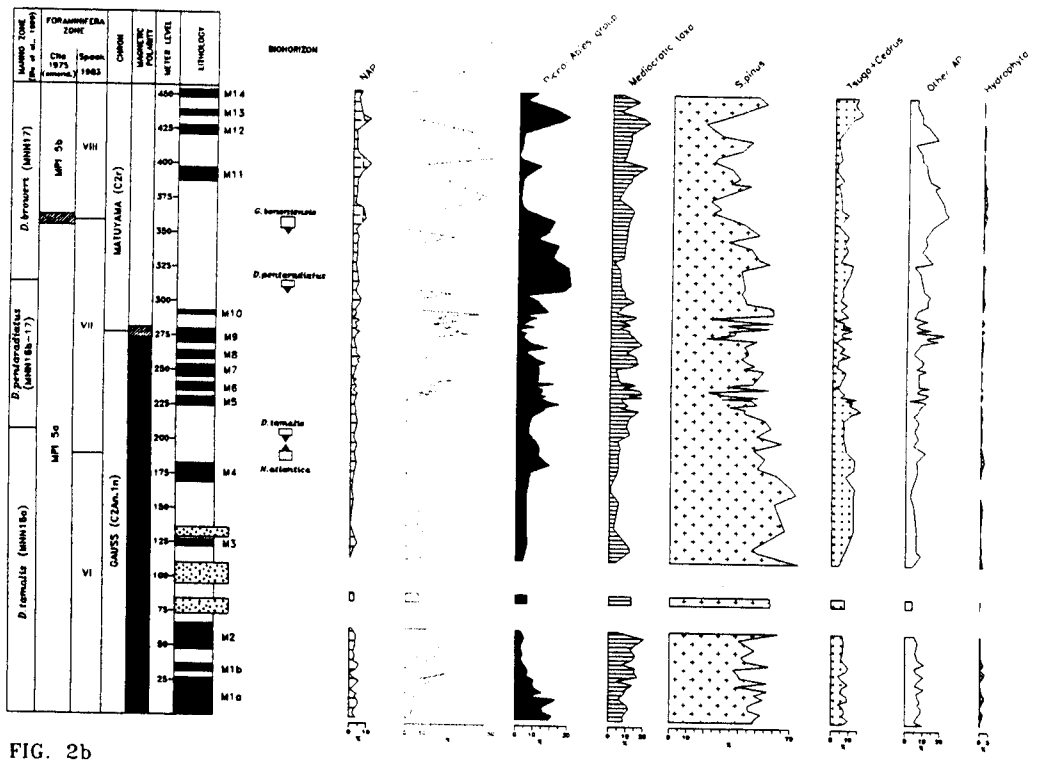

FIG. 2b

FIG. 2a – Chronostratigraphy, magnetostratigraphy and calcareous plankton (foraminifera and coccoliths) biostratigraphic data in the Marecchia Valley section. On the right the pollen data are reported for comparing the distribution of *N. atlantica* with continental climate.

FIG. 2b – Pollen spectra for the Marecchia Valley section. NAP=non arborel plants; AP=arboreal plants.