Geogr. Fis. Dinam. Quat.,
5 (1982), 59-68, 3 ff.

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THE NEOGENE/QUATERNARY BOUNDARY DEFINITION: A REVIEW AND PROPOSAL (*****)

ABSTRACT: COLALONGO M. L., PASINI G., PELOSIO G., RAFFI S., RIO D., RUGGIERI G., SARTONI S., SELLI R. & SPROVIERI R., *The Neogene/Quaternary boundary definition: a review and a proposal.* (IT ISSN 0084-8948, 1982).

The problem of the Neogene/Quaternary (N/Q) boundary is examined in the light of the stratigraphic approach favoured by the International Stratigraphic Guide (HEDBERG, 1976) and in the ligth of the most recent advances in uppermost Pliocene-lower Pleistocene biostratigraphy.

Based upon a critical review of the historical concepts of the Pliocene and Pleistocene epochs and upon the most recent data on the various N/Q boundary stratotypes proposed (Le Castella, Santa Maria di Catanzaro and Vrica) we consider that the Vrica Section is undoubtedly the most suitable for correctly defining the N/Q boundary.

Regarding the precise definition of this boundary, it is proposed to the International Committees in charge of the problem that the N/Q boundary be defined in the Vrica Section by the lithological level of the first appearance of *Cytheropteron testudo*, because it represents a chronohorizon widely recognizable in the global geologic record and because it is the most historically appropriate.

RIASSUNTO: COLALONGO M. L., PASINI G., PELOSIO G., RAFFI S., RIO D., RUGGIERI G., SARTONI S., SELLI R. & SPROVIERI R., *Il limite Neogene/Quaternario: rassegna dei relativi problemi e proposta per una soluzione* (IT ISSN 0084-8948, 1982).

Il presente lavoro è nato dal confronto fra esperienze diverse, compiute in regioni diverse, di tre differenti scuole, da uno scambio di idee e di dati e da proficue discussioni tra gli AA., che hanno alfine verificato una concordanza di opinioni circa la risoluzione dei vari problemi riguardanti il limite Neogene/Quaternario (N/Q).

Per giungere ad una corretta definizione del suddetto limite si ritiene anzitutto necessario tener ben presenti le raccomandazioni della International Stratigraphic Guide (HEDBERG Ed., 1976) riguardanti l'istituzione di stratotipi e limiti cronostratigrafici; le conclusioni a cui si è giunti sono quindi vincolate all'accettazione della filosofia stratigrafica suggerita da una attenta lettura della citata opera.

Dopo questa premessa viene effettuata una rassegna critica delle opere più significative riguardanti (più o meno direttamente) il problema del limite N/Q, onde cogliere lo sviluppo delle idee alle quali sono legati i concetti di Pleistocene e, conseguentemente, dello stesso limite N/Q. Sono inoltre prese in considerazione le deliberazioni del 18° Congresso Geologico Internazionale (Londra, 1948) riguardanti il limite N/Q e viene messa in evidenza la prassi stratigrafica seguita per tracciare tale limite da paleontologi e geologi prima e dopo il suddetto congresso. In base a tutto ciò vengono formulate due proposte: 1) lo stratotipo del limite N/Q deve essere posto in una sezione plio-pleistocenica italiana in corrispondenza dell'orizzonte litologico in cui si verifica la comparsa del primo « ospite nordico » (criterio d'altra parte già largamente accettato e seguito); 2) è da abbandonare il criterio espresso a Londra (1948) secondo il quale il limite N/Q deve essere tracciato in corrispondenza « ...della prima indicazione di deterioramento climatico nella successione neogenica italiana ». Quest'ultimo criterio infatti è oggi, oncor più che nel passato, fonte di equivoci e di confusione; d'altra parte esso è stato formulato alludendo alla prima comparsa nel Mediterraneo degli « ospiti nordici », comparsa considerata, a quel tempo, come una documentazione di un fortissimo deterioramento climatico, che non aveva avuto precedenti nel Pliocene mediterraneo.

In base ad un attento esame dei più recenti dati biostratigrafici del Pliocene superiore e del Pleistocene inferiore ed in base ad esperienze personali degli scriventi, viene poi documentato (con riferimento a studi compiuti su gruppi paleontologici diversi e in regioni diverse) che distinti « contingenti » di « ospiti nordici » sono entrati nel Mediterraneo in tempi diversi; tra questi « ospiti nordici » sono entrati in un primo momento *Arctica islandica* e *Cytheropteron testudo* e poi, ben distanziata nel tempo, *Hyalinea baltica.* Viene di conseguenza espressa la convinzione, a complemento della proposta 1) sopracitata, che lo stratotipo del limite N/Q deve essere posto in una sezione plio-pleistocenica italiana in corrispondenza dell'orizzonte litologico che segna la prima comparsa di un « ospite nordico » del « primo contingente ».

Dopo aver individuato il criterio-guida per definire il limite N/Q, vengono prese in esame le sezioni a tutt'oggi ufficialmente proposte per la scelta dello stratotipo (e cioè S. Maria di Catanzaro, Le Castella e Vrica), e viene dimostrato che l'unica idonea è la Sezione Vrica.

A conclusione del lavoro viene proposto alla INQUA Commission Stratigraphy e alla IUGS Commission on Stratigraphy di scegliere come stratotipo del limite N/Q l'orizzonte litologico corrispondente alla comparsa nella Sezione Vrica di *Cytheropteron testudo*, orizzonte che si trova 9 m sopra il tetto del livello-guida *e* e 13 m sotto il letto del livello-guida *f* (*e* ed *f* sono due strati sapropelitici ben riconoscibili sul terreno e, in particolare, lungo la Sezione Vrica). Tale proposta è suffragata da diversi elementi: 1) è

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(*****) *This research was supported by the « Consiglio Nazionale delle Ricerche » (Grant n. 80.01045.05 to* S. SARTONI*; grant n. 81.01976.05 to* S. RAFFI*; grant n. 81.00101.05 to* D. RIO*).*

storicamente appropriata; 2) corrisponde ad una prassi largamente seguita e *non* sconvolge la letteratura e le carte geologiche; 3) il limite proposto è largamente riconoscibile anche fuori dal Mediterraneo, poiché la comparsa di *C. testudo* nella Sezione Vrica è accompagnata da diversi eventi paleontologici interessanti forme planctoniche (foraminiferi e nannofossili calcarei) già ben conosciuti ed idonei per correlazioni ad amplissimo raggio; 4) l'orizzonte litologico contenente la comparsa di *C. testudo* è ben individuabile sul terreno.

TERMINI-CHIAVE: cronostratigrafia; biostratigrafia; Pliocene; Pleistocene.

INTRODUCTION

Italy is the classical region for the Pliocene-Pleistocene marine stratigraphy and, since the London Geologic Congress (1948), it has always been suggested as the region for a suitable definition of the Neogene/Quaternary (N/Q) boundary.

The impetus for the present paper was the need to compare ideas and data of three Italian schools involved in Pliocene-Pleistocene Stratigraphy in different Italian regions, in order to verify a possible agreement and to clarify or solve some problems relating to the N/Q boundary.

We review in this paper recent advances in the biostratigraphy of the time interval relevant for the definition of the N/Q boundary; we also make our proposal for the placement of the much debated "golden spike" for this boundary, in the light of the International Stratigraphic Guide (HEDBERG Ed., 1976).

THE PROBLEM OF THE N/Q BOUNDARY

In recent years, strikingly important advances were made in upper Neogene-Quaternary Geology (prompted particularly by extensive recovery of oceanic sediments, by the development of isotope geochemistry and of the paleomagnetic time scale) which have led to the opinion (BOWEN, 1978) that we are on the verge of a scientific revolution in Earth Science comparable to plate tectonics.

However, the essential problems of the chronostratigraphic classification of Quaternary, starting from the very definition of the N/Q boundary, still remain a matter of endless controversy. This has resulted mainly from different stratigraphic philosophies and unsuitable « stratotype » sections.

Regarding the former point, we adhere to the stratigraphic philosophy suggested by the International Stratigraphic Guide (HEDBERG Ed., 1976). Although the guidelines there given are not here regarded as definitive, nevertheless they represent, at the moment, the maximum of consensus on the subtle matter of stratigraphic classification. To follow the I.S.G. procedures means, therefore, to use a common language in the stratigraphic studies, thus avoiding dangerous misunderstanding, which can cause serious setbacks in the scientific work.

For the purpose of the present work, we quote and discuss here only the basic requirements suggested by the International Stratigraphic Guide with respect to the N/Q boundary:

a) the boundary must be defined in the marine lithostratigraphic record in a stratotype section;

b) the definition must be respectful, as much as possible, of the historical concepts of Pliocene and Pleistocene, which have guided stratigraphers for more than a century in their work;

c) the definition must be such as to allow the boundary to be identified elsewhere.

Within this approach, any boundary *definition* based *only* on paleomagnetic, paleoclimatic or biostratigraphic features is rejected. Such criteria do provide means for *correlation* and *recognition*, but do not represent the definition of a chronostratigraphic boundary (PELOSIO & *alii*, 1980).

In the following sections, therefore, we briefly review the history of the N/Q boundary, which leads us to discuss problems concerning the « northern guests » in the Mediterranean and the lower Pleistocene biostratigraphy. Within the biostratigraphic framework thus established, we discuss the stratotype sections so far proposed for the definition of the N/Q boundary and their suitability, in the light of historical appropriateness, geological setting and amenability to long distance correlations.

HISTORICAL SYNTHESIS OF THE N/Q BOUNDARY

There is an overwhelming amount of literature concerning the N/Q boundary and the development of the concept of the Quaternary. For a detailed analysis, the reader is referred to FLINT (1965), SELLI (1977), BERGGREN & VAN COUVERING (1974), PELOSIO & *alii* (1980), COLALONGO & *alii* (1980). We recall here only the basic historical benchmarks which may be useful for defining the N/Q boundary.

DESNOYERS (1829) first introduced the term Quaternary to indicate terrains above "Tertiary strata" in the Paris Basin.

LYELL introduced the terms Pliocene and Pleistocene, the latter referring to the strata where the fossil mollusc assemblage was represented by more than 70 % still-living species (1839, p. 621).

FORBES (1846, p. 402) considered LYELL's Pleistocene as equivalent to the "Ice Age", a term introduced by SCHIMPER with reference to the glacial theory, which was being developed at that time by AGASSIZ (1837). FORBES' opinion gave rise to the widely-accepted practice of recognizing and defining the beginning of Pleistocene on the basis of a climatic deterioration.

In the meantime, PHILIPPI (1844) documented the occurrence of molluscs, at the present restricted to boreal seas, in marine sediments of southern Italy. They were given the name "northern guests" (SUESS, 1883) or "boreal guests".

DODERLEIN (1872) assigned a stratigraphic value to these occurrences and consequently established the Sicilian stage to incorporate sediments containing "northern guests".

DE STEFANI (1876, 1891) further emphasized FORBES' concept, stressing at the same time the stratigraphic importance of the boreal elements in the Mediterranean

fauna. In fact, he interpreted the appearance of the "boreal guests" in the Mediterranean as a consequence of the first glacial expansion and, accordingly, made a clear distinction between Pliocene and Post-Pliocene (1891) (the latter must be considered as a synonim of Pleistocene, as intended for today). To recognize the Post-Pliocene (1), DE STEFANI introduced the criterion of the presence of northern guests (in particular the bivalve *A. islandica*), a practice thereafter largely followed by Italian stratigraphers.

Later on, GIGNOUX (1910; 1913) substantially retained the subdivision proposed by DE STEFANI in 1891, and established the Calabrian stage, corresponding to the lower Post-Pliocene of DE STEFANI. But, following the concept of sedimentary cycles for subdividing the chronostratigraphic scale, GIGNOUX ascribed "his" Calabrian (characterized by the occurrence of the first northern guests) to Pliocene, since he believed that its sediments belonged to the Pliocene cycle (see RUGGIERI & SPROVIERI, 1977 for a detailed discussion on this point).

On the other hand, authorities such as HAUG (1911) and ROVERETO (1925) maintained that formations containing northern guests should be ascribed to the Quaternary.

Apart from GIGNOUX'S opinion (2) until the International Geologic Congress of London (1948), general opinion and practice recognized the N/Q boundary as coincident with the first appearance of the northern guests in the Italian Neogene sections, an event considered indicative, at that time, of a climatic deterioration.

When proposing the criterion that "The N/Q boundary should be placed at the horizon of the first indication of climatic deterioration in the Italian Neogene succession" on the basis of the "changes in marine faunas", the 18th International Geologic Congress (London, 1948) confirmed and ratified the opinion and practice discussed above (3). We want to stress here that it was the already accepted general practice to recognize the base of the Pleistocene as coincident with the first appearance of the northern guests in the Mediterranean that inspired and promoted the definition "... first indication of climatic deterioration..." on the basis of the "changes in marine faunas".

Subsequently, the intentions which inspired the recommendations of the London Commission were generally accepted and followed and the N/Q boundary was correspondingly placed at the first occurrence of the first "cold guests" in the Italian marine sequences.

What does appear opportune to abandon is the abstract criterion of the "first indication of climatic deterioration", which has given rise to ambiguities and confusion. In fact, progress in research carried out in the last ten years has led to the discovery of real signs of climatic deteriorations during the course of, at least, the whole Neogene. In particular, during the middle-upper part of the Pliocene, well-documented coolings have been clearly recognized well before the arrival of the first northern guests in the Mediterranean (THUNNEL, 1979; RAFFI & MARASTI, in press, etc.). Therefore, if we accept climatic deterioration as a criterion *per se* for defining the N/Q boundary, the Piacenzian stage would be included within Pleistocene. Moreover, considering that the more and more sophisticated methodology and the ever growing amount of data might, in the future, indicate other climatic events, a "floating" or constantly changing Cenozoic Geological Time Scale would result: it is obvious that such a practice is untenable.

Nevertheless, if we want to respect the historical appropriateness in defining chronostratigraphic boundaries, as recommended by the International Stratigraphic Guide, we must refer to the sole symptom of climatic deterioration evident in the stratigraphic studies of that time, i.e. the arrival of northern guests in the Mediterranean. On the other hand, the same concept expressed in the London resolution was clearly confirmed in subsequent international congresses. According to our opinion, it is fundamental that this concept be respected in the definition of the N/Q boundary. However, it is obvious that the criterion of the appearance of the boreal guests does not constitute, in itself, the boundary definition, which must be firmly fixed in a well-defined stratotype.

In this context, the possible presence of signs of climatic deterioration, as well as speculation on the causes of the immigration of these faunal elements into the Mediterranean, are of minor importance. Of prime importance is the need to follow well-founded stratigraphic practice, and to "export" the boundary to the world geologic record, making use in this case of whatever methodology is available.

THE NORTHERN GUESTS AND THE LOWER PLEISTOCENE BIOSTRATIGRAPHY

Northern guests have been, and still are, not only of historical interest for the N/Q boundary definition, but are significant also for the lower Pleistocene Mediterranean biostratigraphy. Indeed, they represent a conspicuous stratigraphic event in the Mediterranean, upon which workers have relied for the local Italian bio- and chrono-stratigraphic subdivisions. Therefore, a brief review on their utilization is in order.

Until the 1930's, the boreal guests considered by the authors were essentially elements of the molluscan fauna and, among these, the well-known bivalve *Arctica islandica* (L.); later on, other forms belonging to foraminifera (TREVISAN & DI NAPOLI, 1938) and ostracods (RUGGIE-

(1) DE STEFANI (1891), defined a lower Post-Pliocene, characterized by the presence of the first northern guests (including *A. islandica*) in beds still yielding a faunal assemblage very similar to that found in the Pliocene, and a middle Post-Pliocene characterized by a further increase of northern guests with a concomitant decrease of Pliocene survivors. The latter is equivalent to DODERLEIN's Sicilian.

(2) In 1954 GIGNOUX, following general opinion, accepted the inclusion of "his" Calabrian in the Pleistocene. Accordingly, we may argue that also in GIGNOUX's opinion, the Pleistocene begins with the appearance of the northern guests.

(3) The 18th International Geological Congress of London (1948), taking into account the *abstract definition* of the Calabrian, also recommended that this stage be taken as base of the Pleistocene. As discussed further on, such a recommendation cannot be maintained after the introduction of the S. Maria di Catanzaro sequence as the stratotype for the Calabrian.

RI, 1952) were considered as northern immigrants. It is clear from priority reasons that the historically-most rigorous definition of the N/Q boundary should be based on the first appearance of *A. islandica* in Mediterranean sequences.

However, being a shallow water form, *A. islandica* is present in sections which are generally poor in planktonic fauna an flora and, consequently, unsuitable as good stratotype sections. Hence the need to find in a deep water section the appearance of boreal elements which entered the Mediterranean at the same time as *A. islandica.*

In this context, it is important to evaluate the time of appearance in the Mediterranean of the various "northern guests" and in particular of forms such as *Arctica islandica, Hyalinea baltica* and *Cytheropteron testudo,* which have been extensively studied and used. As these are all benthic forms, hinghly environmentally-controlled, the matter has been rather controversial for many years (PELOSIO & *alii*, 1980; COLALONGO & *alii*, 1980). According to numerous studies by RUGGIERI and coworkers (see in particular RUGGIERI & SPROVIERI, 1977), northern guests entered the Mediterranean gradually, by successive steps, as a response to changes in the paleooceanographic-hydrologic setting. On this basis, it was possible to obtain a detailed biostratigraphic zonation although of restricted regional value.

It is important to recall here that RUGGIERI and coworkers maintain that *A. islandica* first entered the Mediterranean together with *C. testudo* and other northern guests, while *H. baltica* migrated significantly later. Accordingly, they propose two biostratigraphic intervals

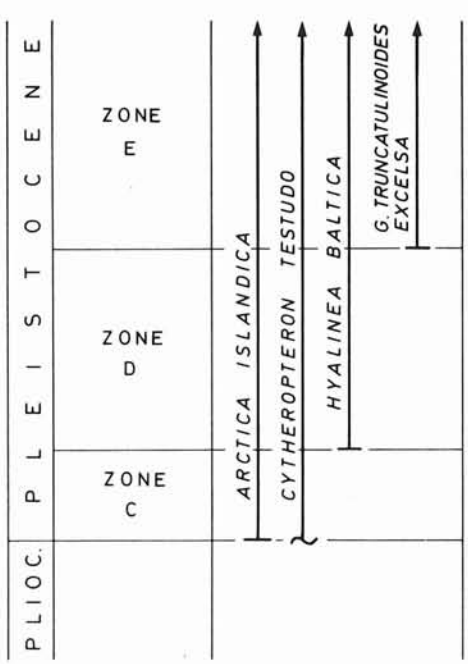

FIG. 1 - Biostratigraphic subdivision of the Italian lower Pleistocene according to RUGGIERI & SPROVIERI (1977, mod. from. COLALONGO & *alii,* 1980).

(fig. 1), the former marked by the appearance of the first cold immigrants (zone C), the latter by the appearance of *H. baltica* (zone D). Furthermore, the same authors asserted that the appearance of *G. truncatulinoides* (4) represents an even later event on which a third biostratigraphic interval is based (zone E) (5).

This biostratigraphic proposal was looked upon with skepticism by many authors and harshly criticized by HAQ & *alii* (1977) on the grounds that the boundary definitions were based on events concerning highly environmentally-controlled forms (*A. islandica, H. baltica*) and a taxon (*Globorotalia truncatulinoides excelsa*) uncommon in Italian Pleistocene sediments, and, therefore, of unreliable time-significance.

However, in the last few years a great number of stratigraphic studies carried out in the Italian upper Pliocene and lower Pleistocene have confirmed RUGGIERI's biostratigraphic scheme. In particular, the comparative and critical analysis of many sections confirmed that the appearance of *H. baltica* occurs after that of the first northern guests, such as *A. islandica* and *C. testudo* (COLALONGO & SARTONI, 1979; COLALONGO & *alii*, 1980; COLALONGO, 1968; COLALONGO & *alii*, 1978; RUGGIERI, 1977).

Quite recently, RUGGIERI & SPROVIERI's proposal has been supported also by nannoplankton studies. In the time interval considered here, forms belonging to the genus *Gephyrocapsa* underwent a marked evolution which may be followed both in deep-sea and near-shore sections (RIO, in press). In particular, the comparative study (RAFFI & RIO, 1980a) of several Mediterranean sections, displaying different depositional environments (Santerno, Vrica, Capo Rossello, D.S.D.P. Site 132, Stirone, Tiepido and Crostolo) have shown that:

— *A. islandica* first entered the Mediterranean together with other northern guests near the level of *G. oceanica s.l.* (KAMPTNER) FAD. *C. testudo* seems to appear in the same stratigraphic position.

— *H. baltica* arrived after a certain time-lag, when "large forms" are present in the *Gephyrocapsa* assemblage or have just appeared. The last forms (still unnamed) appear in the Mediterranean deep-sea record (Site 132, RAFFI & RIO, 1979; Site 125, RAFFI & SPROVIERI, in preparation) and in deep-sea extra Mediterranean record (Site 262, Timor Trough, Site 502, Caribbean Sea, Core V 26-40, Atlantic Ocean) in the lower-middle *H. sellii* zone of GARTNER (1977; RIO, in press).

— The appearance of *G.lia truncatulinoides excelsa* in the Mediterranean Sea is an even later event, as clearly demonstrated in Site 132 (COLALONGO in RAFFI & RIO, 1979), in the Sicilian type locality (SPROVIERI in DI STEFANO & RIO, 1981), in the D.S.D.P. Site 125 (RAFFI

(4) The form so classified by these authors must be actually ascribed to *Globorotalia truncatulinoides excelsa,* according to SPROVIERI & *alii* (1981).

(5) Assigning a time significance to this local biostratigraphic scheme, RUGGIERI & SPROVIERI (1977) proposed a chronostratigraphic three-fold subdivision of the lower Pleistocene. Lower Pleistocene chronostratigraphic problems are not relevant to the goals of this work.

& SPROVIERI, in preparation), where it occurs above the *H. sellii* LAD.

On the basis of this biostratigraphic scheme, largely confirmed by stratigraphic works which are presently being carried out in the Italian region, important conclusions may be drawn:

— the criterion of defining and recognizing the N/Q boundary by means of *H. baltica*, followed by numerous authors, is unsound. The appearance of this form is clearly a later event than that of the first northern immigrants. Although the time intervals involved are not large, it is unopportune to ignore the high biostratigraphic resolution now available:

— if one wishes to adhere rigorously to the concept that the definition of the N/Q boundary in a deep-sea sequence must approximate the arrival of *A. islandica* in shallow sea Mediterranean sections, only the first contingent of boreal guests can be utilized. Among these, the deep-water ostracode *C. testudo* is the most reliable (RUGGIERI, 1977; COLALONGO & *alii*, 1980).

THE SELECTION OF THE N/Q BOUNDARY STRATOTYPE'S SECTION

Three sections have received official consideration for defining the N/Q boundary sor far: S. Maria di Catanzaro, Le Castella and Vrica. In the light of the biostratigraphic framework discussed above, a brief critical examination of these sections follows, in order to discuss their respective suitability to define the N/Q boundary.

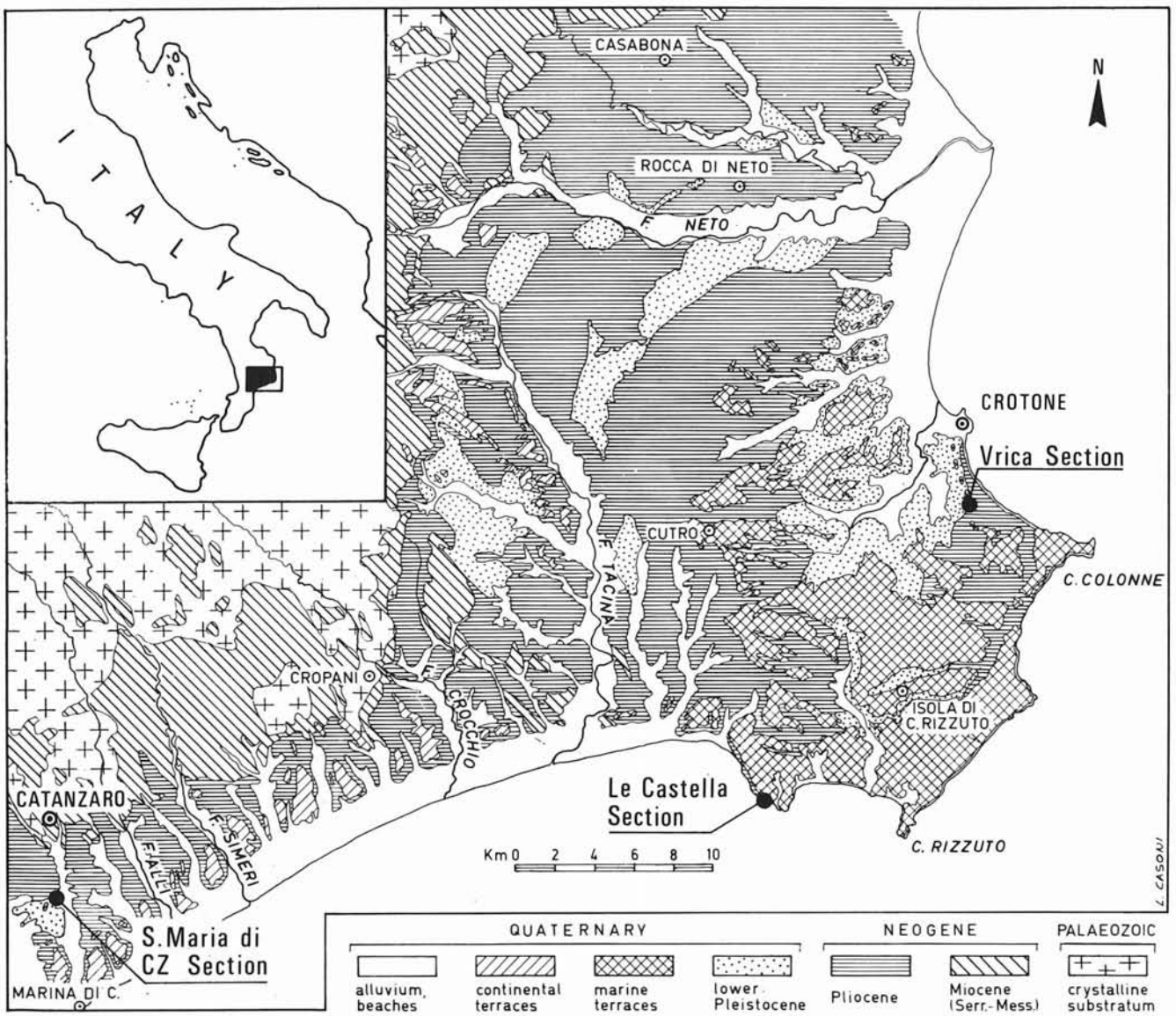

FIG. 2 - Location of the Pliocene-Pleistocene sections between Crotone and Catanzaro (Calabria, Italy) considered in the present paper (from SELLI & *alii*, 1977).

The S. Maria di Catanzaro Section

Gignoux, when proposing the Calabrian stage, indicated several localities in southern Italy where it is well developed. Among these, the most representative was considered (also by Gignoux himself) to be S. Maria di Catanzaro (in the Crotone-Spartivento sedimentary basin, fig. 2). In this locality he clearly indicated (Gignoux, 1913, p. 36, fig. 5) the base of the Calabrian stage at the bottom of a calcarenite lens (the well-known G-G1 bed), in which he erroneously thought he found the first appearance of *A. islandica* (Sprovieri & *alii*, 1973; Colalongo & *alii*, 1980).

The Temporary Committee for the Study of the Plio-Pleistocene Boundary of the 18th International Geologic Congress (London, 1948) recommended that the boundary:

a) "...should be placed at the horizon of the first indication of climatic deterioration in the Italian Neogene succession...", deterioration that has been generally intended (see above) as the first appearance of the northern guests);

b) "the Lower Pleistocene should include as its basal member in the type-area the Calabrian formation (marine)...".

Clearly, the latter criterion was recommended on the belief that the base of the Calabrian was coincident with the horizon of the first indication of climatic deterioration (mentioned in the former point) ([6]); since this was the only N/Q boundary definition fixed in a lithostratigraphic record, it was retained by many authors as the correct "physical" definition of the N/Q boundary (Berggren and Van Couvering, 1974).

In reality the G-G1 bed is located above the appearances of *A. islandica, H. baltica* and *G. trucatulinoides excelsa*, so that the *A. islandica* recorded in G-G1 bed is not the first appearance of this taxon in the Mediterranean (Sprovieri & *alii*, 1973; Pasini & *alii*, 1977; Colalongo & *alii*, 1980) and, therefore, the G-G1 bed as the definition of the N/Q boundary conflicts with the first criterion indicated in London.

Therefore, according to the most widely accepted criterion of the appearance of the first northern guests, *the base of the Calabrian, as presently defined in the S. Maria di Catanzaro Section* (Selli, 1971), *is untenable as the definition of the N/Q boundary.*

Consequently, defining the N/Q boundary at S. Maria di Catanzaro according to the second criterion of London means that:

a) if we choose the top of the Piacenzian as the end of Pliocene, this results in a gap in the Geological Time Scale;

b) if we adhere to the recommendation of Note 47 of the Stratigraphic Commission (McQueen & Oriel, 1977) in defining only the base of a time stratigraphic unit, i.e. that the top of Pliocene is automatically defined by the base of the Calabrian, many sequences yielding northern guests (*A. islandica, H. baltica*, etc.) would as a result be included in the Pliocene.

Furthermore, since the age of the G-G1 bed is younger than 1.2 - 1.3 m.y. B.P. (the age of immigration appearance of *Globorotalia truncatulinoides excelsa* in the Mediterranean (Di Stefano & Rio, 1981; Rio & *alii*, in preparation) ([7]), it follows also that part of the deep-sea stratigraphic record (at least intervals belonging to nannofossil biozones *C. macintirey* and *H. sellii* of Gartner, 1977) would fall in the Pliocene.

Finally, in Colle di S. Maria di Catanzaro (where the G-G1 bed outcrops) as well as in the surrounding area, the geologic-stratigraphic setting is very poor and the lowermost Pleistocene is completely lacking (Sprovieri & *alii*, 1973; Pasini & *alii*, 1977): therefore it is impossible to find any section which suitably represents, in this area, this time interval and the N/Q boundary itself.

In conclusion, taking into account all the previous facts, the N/Q boundary cannot be defined in the S. Maria di Catanzaro section.

The Le Castella Section

The Le Castella Section, located in the Crotone-Spartivento sedimentary basin (fig. 2) and described by Emiliani & *alii* (1961), was proposed for defining the N/Q boundary stratotype at the 7th INQUA Congress in Denver (1965) and accepted by many non-Italian authors (Berggren & Van Couvering, 1974; Haq & *alii*, 1977).

The application of a mutual boundary stratotype for defining the N/Q boundary was sorely needed in order to overcome the problem of the correlation between the last stage of the Pliocene (Piacenzian) and the base of the Pleistocene (Pelosio & *alii*, 1980).

The N/Q boundary was defined in this section at the base of a sandy level ("marker bed"), where the first local appearance of *H. baltica* is recorded. This choice was justified essentially by the following reasons:

a) the supposed lithostratigraphic correlatability between the "marker bed" and the "G-G1 bed" (Emiliani & *alii*, 1961), which at S. Maria di Catanzaro represents the definition of the base of the Calabrian;

b) the assumption, made by most Italian paleontologists until very recently, that the appearance of *H. baltica* in deep waters is synchronous with that of *A. islandica* in shallow waters.

Actually, neither of these assumptions is any longer tenable. The former has been rejected by all authors who have considered this problem in detail (Bayliss, 1969; Sprovieri & *alii*, 1973; Drooger, 1973; Brolsma & Meulenkamp, 1973) and, moreover, as pointed out before, the G-G1 bed is not suitable for defining the base

([6]) Actually, Gignoux (1913), conceived that the base of the Calabrian was coincident with the Mediterranean first appearance of the northern guests, even if all the sections he indicated do not contain this event.

([7]) Since the G-G1 bed is located above the *Globorotalia truncatulinoides excelsa* (immigration) appearance, the Calabrian, as defined at S. Maria di Catanzaro, represents a late lower Pleistocene time interval and should fall within the Sicilian stage, as recently defined (Ruggieri & Sprovieri, 1977).

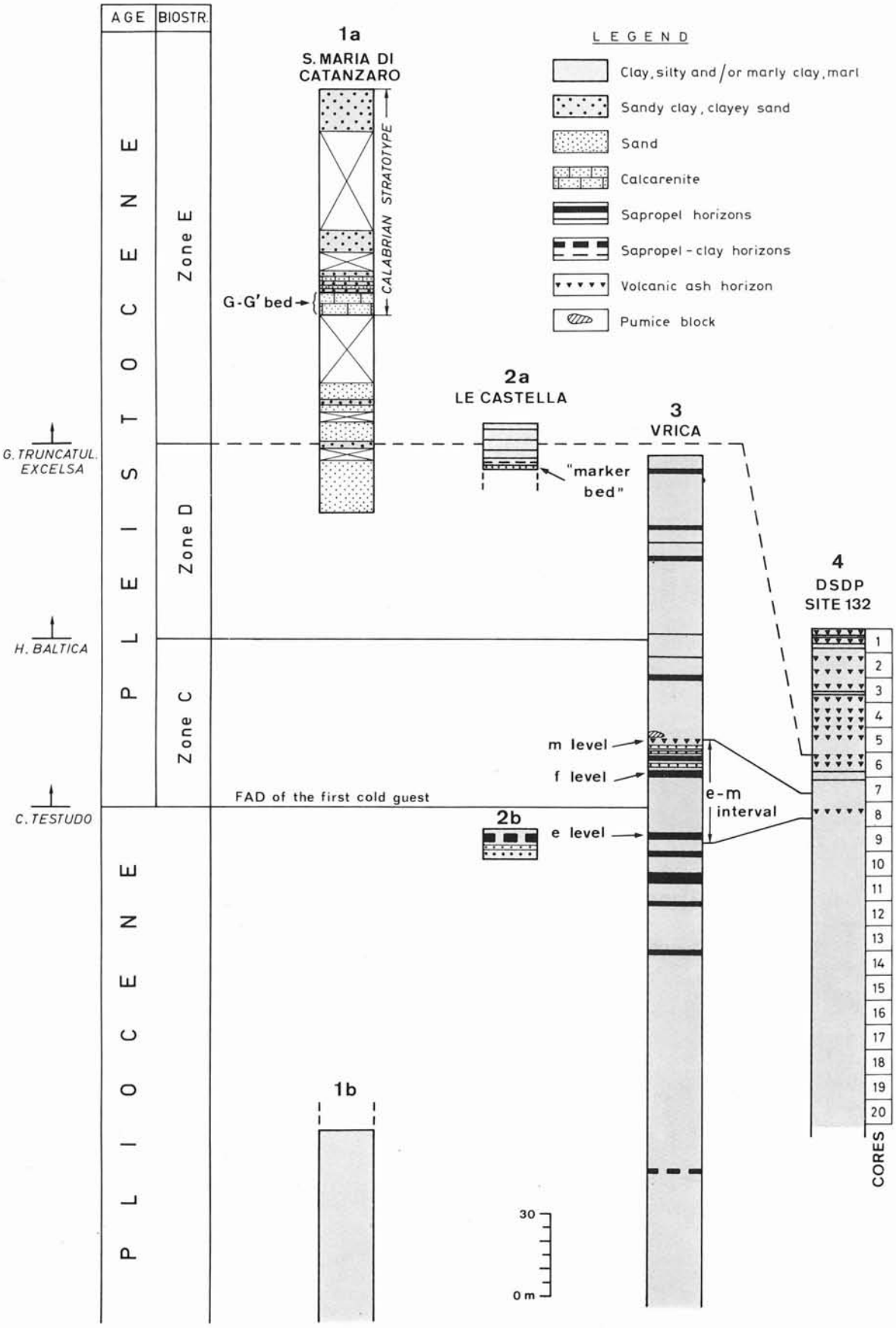

FIG. 3 - Correlation of the main Pliocene-Pleistocene sections of the Crotone-Spartivento sedimentary basin and the DSDP Site 132. The zonation adopted in this correlation is that of fig. 1. Column 1b represents sediments of the middle or upper Pliocene of the S. Maria di Catanzaro area, which come into contact with the Quaternary sediments of the S. Maria di Catanzaro Section (column 1a) through transgression or faults. Column 2a represents the Quaternary sediments of the Le Castella Section; column 2b represents the Pliocene sediments (underlying the "marker bed") of the same section; the drawing clearly shows the gap below the "marker bed". In the "e-m interval" of the Vrica Section several paleontologic events occur, which make possible a sure correlation with DSDP Site 132 (COLALONGO & *alii*, 1980), located about 60 km West of the Central Bathyal Plain of the Tyrrhenian Sea at a depth of 2835 m (from COLALONGO & *alii*, 1980).

of Pleistocene. The second assumption is incorrect for the reasons illustrated in the preceding chapter.

Furthermore, other features advise against the selection of the Le Castella Section as the standard for defining the N/Q boundary stratotype:

a) as a consequence of tectonic disturbances and landslides, the thickness of the sequence which can be confidently studied is rather short (a maximum thickness of 30 meters can be reconstructed: VENZO, 1975; SELLI & *alii*, 1977; PASINI & SELLI, 1977; COLALONGO & *alii*, 1980). Therefore, much thicker reconstructions of this section (HAQ & *alii*, 1977; BREMER & *alii*, 1980) are definitely questionable;

b) recent detailed biostratigraphic studies based on planktonic and benthonic foraminifera, ostracods (COLALONGO & *alii*, 1980) and calcareous nannofossils (RAFFI & RIO, 1980b) show the presence of a gap just below the "marker bed".

In conclusion, because of the above mentioned problems, the Le Castella Section must also be considered as unsuitable for defining the N/Q boundary.

THE VRICA SECTION

The Vrica Section is located in the Crotone-Spartivento sedimentary basin. It has been described by SELLI & *alii* (1977).

During the "Symposium on the Neogene/Quaternary boundary" (Bologna-Crotone, 1975) this section was unanimously proposed as the standard succession for defining the N/Q boundary. This proposal was maintained and accepted at the 10th INQUA Congress (Birmingham, 1977), at the 2nd Symposium on the Neogene-Quaternary boundary (U.S.S.R., 1977) and at the Joint Meeting of I.G.C.P. Project 41 and of the INQUA Subcommission 1a (Pliocene-Pleistocene boundary) held in India in 1979 and in Paris in 1980.

This section satisfies all the requirements for an adequate definition of the N/Q boundary: fairly good vertical development, complete exposure, abundance and variety of well-preserved fossils, favourable facies for recognizing time-significant bio-horizons for long-distance correlations, no structural complication, presence of an ash level suitable for testing the possibility of isotopic age analyses, accessibility; moreover it offers the possibility of selecting the N/Q boundary definition, so that the appropriate concepts of Pliocene and Pleistocene are carefully respected.

For all these reasons, we fully agree with the proposal of selecting the Vrica Section for the definition of the N/Q boundary stratotype.

For the selection in the field of the precise position of the boundary stratotype, some proposals have already been put forward, but the problem is still open. SELLI & *alii* (1977) suggest defining the N/Q boundary within a band encompassed between the *C. testudo* first occurrence and the first occurrence of *H. baltica*. COLALONGO & PASINI (1980) and COLALONGO & *alii* (1980) propose to define the boundary in the lithological level in which the *C. testudo* first occurrence is recorded, although they leave open the possibility of placing the boundary within the band between the levels *e* and *m*. COLALONGO & SARTORI (1977) and PELOSIO & *alii* (1980) propose defining the N/Q boundary at the lithologic level where the *C. testudo* first appearance is recorded.

At the Joint Meeting of the Working Group of I.G.C.P. Project 41 and INQUA Subcommission 1st held in Paris (July, 1980) during the 26th International Geological Congress, it was recommended that: "The N/Q boundary should be placed in the Vrica Section taking into account the FAD of the early cold guest *Cytheropteron testudo* (whatever its paleoclimatic significance could be) ...", or "... within the stratigraphic interval between level *e* and the volcanic ash level *m* ...".

Biostratigraphic studies carried out in recent years on the Vrica Section (COLALONGO & PASINI, 1980; COLALONGO & SARTONI, 1977; COLALONGO & *alii*, 1980) have shown that near the first occurrence level of *C. testudo*, a sufficient number of calcareous plankton biostratigraphic events are present. Two of them (FAD of *G. oceanica, sensu* RAFFI & RIO, 1979 and GARTNER, 1977; LAD of *Globigerinoides obliquus extremus*) are rather well established datum levels, which allow long distance extramediterranean correlations; others (FADs of *G. cariacoensis, G. tenellus* and *G. calabra*; frequency increase of *G. pachyderma* left) allow well established intramediterranean correlations and they may prove useful also for extramediterranean correlations.

It has already proved possible to correlate the Mediterranean deep-sea record (COLALONGO in RAFFI & RIO, 1979, Site 132; COLALONGO & *alii*, 1980, Site 132; RAFFI & SPROVIERI, Site 125, in progress) with the Vrica Section (fig. 3). In turn, the Mediterranean deep-sea record is easily correlatable with the extramediterranean marine geological record via nannofossils (ELLIS & LOHMAN, 1978; RAFFI & RIO, 1979). Therefore, the level of first appearance of *C. testudo* in the Vrica Section satisfies the basic requirement for a good definition of a chronostratigraphic boundary, i.e. the amenability to be recognized in the worldwide geologic record.

Concluding, the present authors are convinced that the level of first appearance of *C. testudo* in the Vrica Section represents the best definition of the N/Q boundary, in so far as it satisfies all the recommendations suggested by the International Stratigraphic Guide, and, in particular, it is historically appropriate and amenable to worldwide correlation.

CONCLUSIONS

On the basis of a critical review of the historical concepts of the N/Q boundary, and on the basis of the most recent advances in uppermost Pliocene/lower Pleistocene biostratigraphy, we consider that, of the sections so far proposed for defining the N/Q boundary, the Vrica Section is the only one suitable for this purpose, in agreement with the recent recommendations of International Committees in charge of the problem.

As far as the precise definition of this chronohorizon is concerned, we unanimously propose to the INQUA Commission on Stratigraphy and to the IUGS Commission on Stratigraphy that the N/Q boundary be de-

fined by the lithological level of the first appearance of *C. testudo* in the Vrica Section, because it represents a chronohorizon widely recognizable and because this definition is the most historically appropriate. The above-mentioned lithological level is located 9 meters above the top of the *e* level and 13 *m* below the bottom of the *f* level (fig. 3; both *e* and *f* levels are easily recognizable in the section).

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