

<i>Bollettino della Società Paleontologica Italiana</i>	33 (1), 1994	ISSN 0375-7633	101-120	–	Modena, Maggio 1994
---	--------------	----------------	---------	---	---------------------

Proposal for the erection of the Santernian/Emilian boundary-stratotype (lower Pleistocene) and new data on the Pliocene/Pleistocene boundary-stratotype

Giancarlo PASINI
Istituto di Geologia Marina
del CNR, Bologna

Maria Luisa COLALONGO
Dipartimento di Scienze Geologiche
Università di Bologna

KEY WORDS – Boundary-stratotype, Pliocene, Pleistocene (Santernian/Emilian), Calabria (Vrica Section), Southern Italy.

ABSTRACT – The Santernian is the basal chronostratigraphic unit of the Pleistocene, according to the Quaternary chronostratigraphic scale proposed in 1991 by the «Working Group for the Quaternary Stratigraphy» of the Italian Geological Society.

In this paper the authors propose to locate in the Vrica section (Calabria) the Santernian/Emilian boundary-stratotype, in coincidence with the first appearance of *Hyalinea baltica*, proposed by Ruggieri & Sprovieri 1977a as marker of this boundary. *H. baltica* appears in the Vrica section 71.1 meters above the Pliocene/Pleistocene boundary-stratotype, in coincidence or in proximity of first or last appearances of species belonging to calcareous plankton, which allow global scale correlations of this boundary.

In the Vrica section it is possible to locate also the Santernian stratotype because: 1) in this section the Santernian sediments are continuous (unlike in the Santerno section, previously proposed as Santernian stratotype by Ruggieri & Sprovieri 1977a); 2) the Vrica section shows all the requisites requested by the International Stratigraphic Guide (Hedberg, 1976) for the definition of a stratotype.

In the present paper the new age of 1.795 ± 0.030 Ma is proposed for the Pliocene/Pleistocene (or Neogene/Quaternary) boundary, and new information on the climatic change occurred in coincidence with this boundary is given.

RIASSUNTO – [Proposta per l'istituzione dello stratotipo del limite Santerniano/Emiliano (Pleistocene inferiore) e nuovi dati sullo stratotipo del limite Pliocene/Pleistocene] – Il Santerniano è l'unità cronostatigrafica basale del Pleistocene, secondo la scala cronostatigrafica del Quaternario proposta nel 1991 dal «Gruppo di Lavoro per la Stratigrafia del Quaternario» della Società Geologica Italiana.

In questo lavoro si propone di ubicare nella Sezione Vrica (Calabria) lo stratotipo del limite Santerniano/Emiliano in coincidenza con la comparsa di *Hyalinea baltica*, proposta da Ruggieri & Sprovieri 1977a come marker di tale limite. *H. baltica* compare nella Sezione Vrica 71,1 metri sopra lo stratotipo del limite Pliocene/Pleistocene, in coincidenza o in prossimità di comparse e scomparsa di specie appartenenti al plancton calcareo che consentono correlazioni a scala globale del limite Santerniano/Emiliano.

Nella Sezione Vrica è anche possibile individuare lo stratotipo del Santerniano perché: 1) in tale sezione i terreni santerniani affiorano in continuità (a differenza che nella Sezione del Santerno, proposta in precedenza da Ruggieri & Sprovieri 1977a come stratotipo del Santerniano); 2) la Sezione Vrica presenta tutti i requisiti richiesti dalla International Stratigraphic Guide (Hedberg, 1976) per la definizione di uno stratotipo.

Nel presente lavoro viene proposta la nuova età di $1,795 \pm 0,030$ Ma per il limite Pliocene/Pleistocene (o Neogene/Quaternario) e vengono fornite informazioni sul cambiamento climatico verificatosi in corrispondenza di tale limite.

FOREWORD

Although the Quaternary is the most studied period in all the Earth, it is also the one characterized by the maximum stratigraphic confusion: the numerous Quaternary chronostratigraphic scales published up to now are in complete disagreement. Therefore, in the «IUGS 1989 Global Stratigraphic Chart» (Cowie & Bassett, 1989) the IUGS International Commission on Stratigraphy preferred to avoid any subdivision of the Quaternary system: in this Global Stratigraphic Chart the Quaternary is the *only* system – from the Proterozoic up today – not subdivided in stages.

This being the situation, the Commission on Stratigraphy of the Italian Geological Society – in a meeting held at Washington, D.C., on July 14, 1989 during the 28th International Geological Congress – decided to appoint an «Italian Working Group for the Quaternary Stratigraphy» (Chairman: M. B. Cita), with the purpose of clarifying the marine Quaternary stratigraphy in Italy. Italy being a classical area of the marine Quaternary, it is obvious that the clarification of the Italian Quaternary stratigraphy is fundamental for the clarification of the Quaternary stratigraphy worldwide.

In 1991 the Italian Working Group for Quaternary Stratigraphy issued a document entitled *The status of the Quaternary. A position paper by the Italian Commission on Stratigraphy*. In this document a Quaternary chronostratigraphic scale is proposed (Cita *et al.*, 1991), in which the Lower Pleistocene is

subdivided in three chronostatigraphic units, named Santernian, Emilian and Sicilian. This chronostratigraphic scale was presented by A. Azzaroli at the XIII INQUA Congress, held in Peking in August 1991.

In 1991 the present authors, members of the «Italian Working Group for Quaternary Stratigraphy», were charged by this Working Group to identify the Italian marine successions more suitable for the definition of the Santernian/Emilian boundary stratotype.

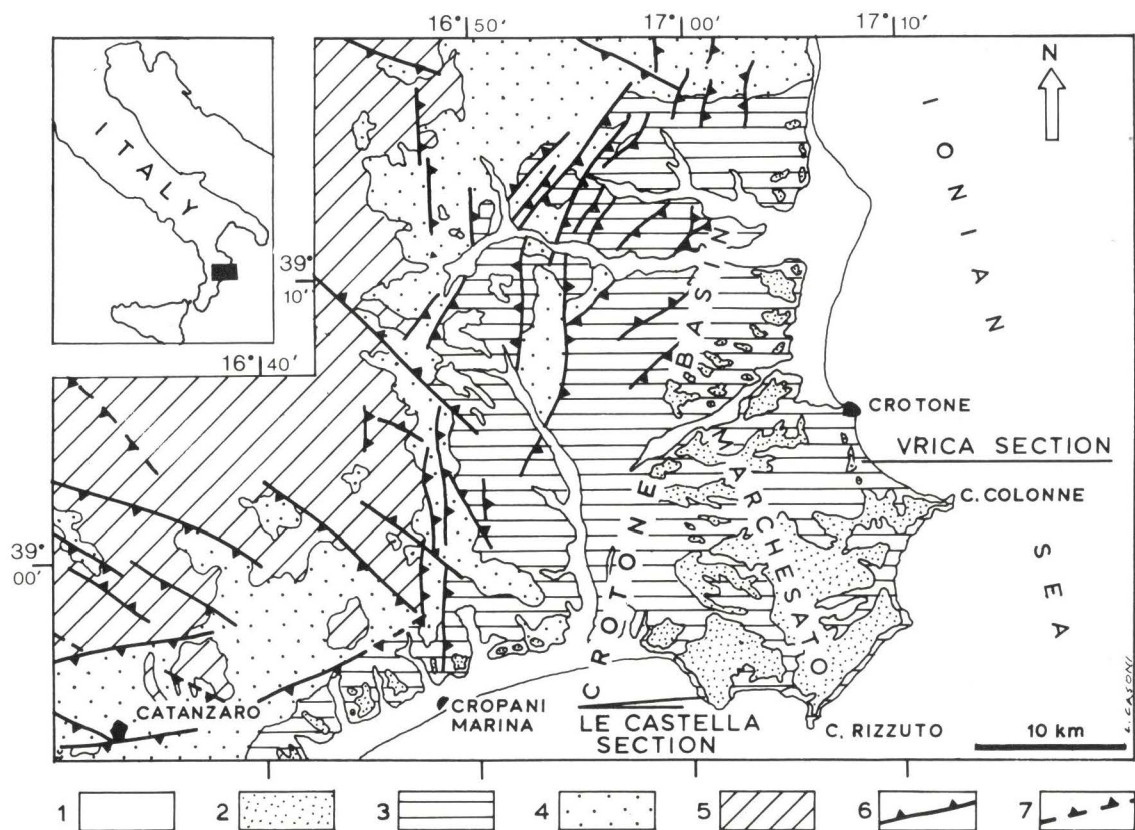
This paper documents the authors' proposal of locating the Santernian/Emilian boundary-stratotype (and the Santernian stratotype) in the Vrica Section (Calabria, Italy, Text-figs. 1-6), i.e. in the section where the Pliocene/Pleistocene boundary-stratotype, which coincides with the lower (older) boundary of the Santernian, is located (Aguirre & Pasini, 1985; Bassett, 1985; Pasini & Colalongo, in press).

THE SANTERNIAN

In 1977 Ruggieri & Sprovieri demonstrated that the classic subdivisions of the lower marine Pleistocene of Italy into Calabrian and Sicilian (Gignoux, 1913) or into Calabrian, Emilian and Sicilian (Ruggieri & Selli, 1950) were no longer tenable: in fact the definition of the Sicilian stratotype (at Ficarazzi, Sicily) made it possible to demonstrate that it overlaps in time with the Calabrian stratotype⁽¹⁾ (at Santa Maria di Catanzaro, Calabria) (Ruggieri & Sprovieri, 1977a).

The invalidation of the Calabrian (because of the priority of the Sicilian) and some inadequacies in the definition of the Emilian obliged Ruggieri & Sprovieri, 1977a to introduce some emendations in the lower Pleistocene stratigraphy. In particular, they maintained the subdivision of the Lower Pleistocene into three stages, but proposed for the

(1) The Calabrian and the Sicilian stratotypes have never been formally submitted to the ICS; so they are not yet accepted by the ICS nor approved by the IUGS.



Text-fig. 1 - Geologic map of the Marchesato peninsula, an emerged portion of the Crotone sedimentary basin (modified from Tortorici, 1982). The submerged part of the basin is located South-East of this peninsula. 1) Continental sediments (Pleistocene and Holocene). 2) Sediments of the upper Pleistocene marine terraces. 3) Middle-upper Pliocene and lower Pleistocene sediments. 4) Tortonian-lower Pliocene sediments. 5) Rocks of the substrate. 6) Main faults. 7) Possible faults.

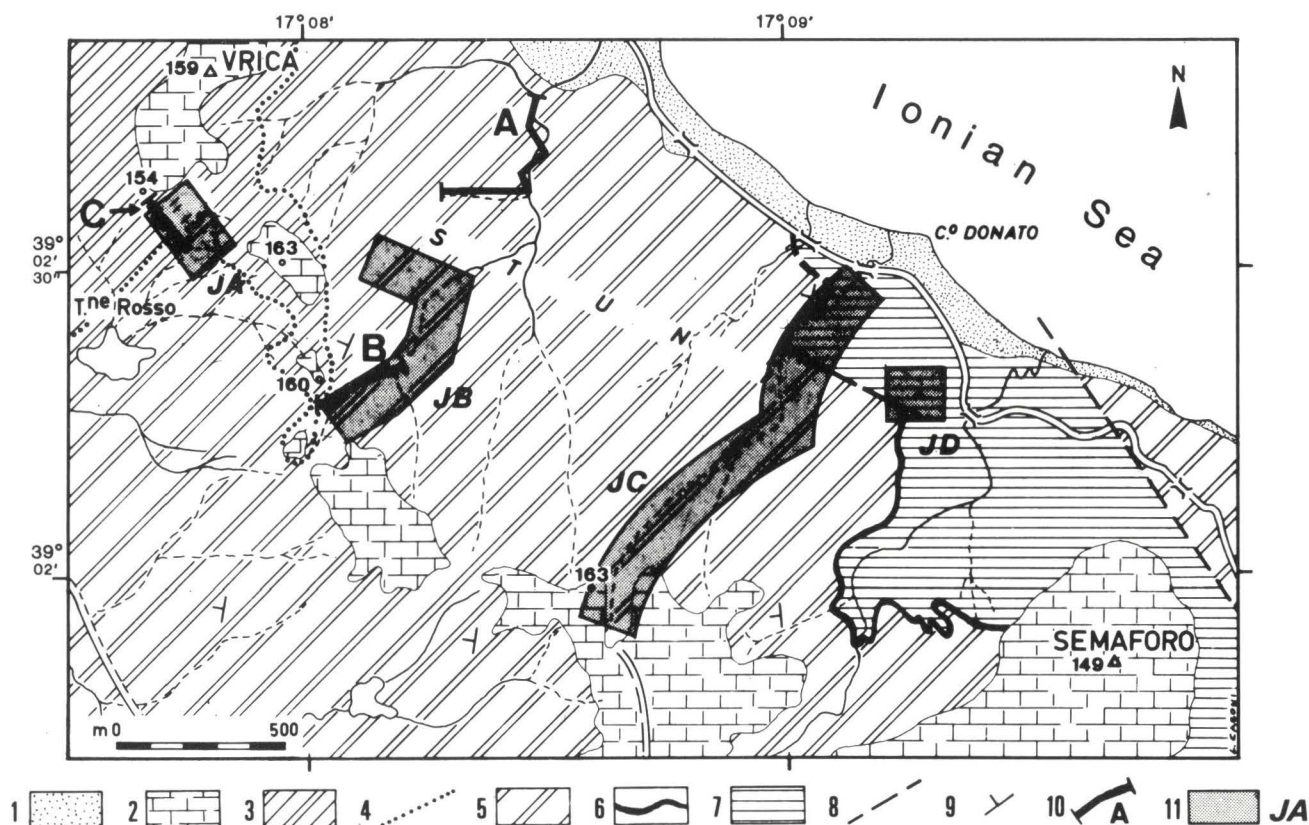
oldest one the new name «Santernian» (which derives from the Santerno valley, near Imola, Northern Apennines, where a section extending from lower Miocene to lower Quaternary is exposed).

According to Ruggieri & Sprovieri, 1977a the Santernian stratotype is located in the Santerno valley and covers a thickness of about 424 m of more or less sandy grey clays.

Ruggieri & Sprovieri, 1977b defined a new superstage, named Selinuntian and including the three stages Santernian, Emilian and Sicilian.

Ruggieri, Rio & Sprovieri in 1984 (p. 255) affirmed: «Santernian, Emilian and Sicilian are clearly recognizable in the Mediterranean marine geologic record, and recent analyses based on nannofossil in the Italian type region indicate that they are, at least roughly, recognizable in extra-Mediterranean regions (Rio, 1982). Nevertheless, it is quite evident that they represent short time-intervals, as suggested by nannofossil biochronology». Therefore Ruggieri

et al., 1984 proposed that the Selinuntian, defined as the interval between the Pliocene/Pleistocene boundary stratotype and the Lower Pleistocene/Middle Pleistocene boundary, be considered at the rank-level of stage-age and the Santernian, Emilian and Sicilian, which span short time intervals between the top of the Olduvai and the beginning of the «Glacial Pleistocene», be considered as substages. This opinion – accepted in 1991 by the Italian Working Group for Quaternary Stratigraphy – is questionable, because the minimum length of the chronostratigraphic units was never defined. Bowen, 1985 (p. 99) asserts that «whereas stages in pre-Quaternary time last from between 3 to 10 Ma, Quaternary stages are measured in thousands of years» (and that «a substage is a subdivision of a stage and is defined by boundary stratotypes»). The Santernian as defined in the present paper has a length of about 0.315 Ma (see below), while four Ordoevician stages have a length of about 0.5 Ma.



Text-fig. 2 - Geology of the Vrica area, modified from Selli *et al.*, 1977. 1) Beach sand and dunes. 2) Calcarenites and sands of the «Milaazzian» marine terrace. 3) Grey silty marly claystones with intercalated sapropelic layers (Lower Pleistocene). 4) First appearance of *Hyalinea baltica*, marker of the Santernian/Emilian boundary. 5) Grey silty marly claystones with intercalated sapropelic layers (Lower Pleistocene, Upper and Middle Pliocene). 6) Volcanic ash layer *l.a.* (2.22 Ma). 7) Grey claystones (Middle Pliocene). 8) Faults. 9) Strike and dip. 10) Component-sections measured and sampled by Pasini and coworkers (see Text-fig. 3). 11) Component-sections measured and sampled by Nakagawa and coworkers.

However, in order to avoid – for the time being – such kind of discussion, we will consider in the present paper the Santernian neither as a stage nor as a substage, but only as a chronostratigraphic unit whose rank is not yet defined.

LOWER BOUNDARY OF THE SANTERNIAN, THE PLEISTOCENE AND THE QUATERNARY

The Santernian has been proposed – as we said above – as the lowermost chronostratigraphic unit of the Pleistocene (Ruggieri & Sprovieri, 1977a, 1977b; Ruggieri *et al.*, 1984; Cita *et al.*, 1991). Therefore the lower limit of the Santernian coincides with the Pliocene/Pleistocene (P/P) boundary. The Pliocene/Pleistocene boundary stratotype – proposed by the IUGS-ICS Pliocene/Pleistocene Boundary Working Group, approved by the International Commission on Stratigraphy and ratified by the IUGS in 1985 (Bassett, 1985) – is located in the Vrica Section at the base of the lower epibathyal claystones that outcrop immediately above marker bed «e» of this section. This boundary-stratotype is a little above (Aguirre & Pasini, 1985; Pasini & Colalongo, in press) or a little below (Zijderveld *et al.*, 1991) the top of the Olduvai normal polarity subchron (Text-fig. 14) and is near the first appearances or last occurrences (= FA or LO) of planktic foraminifers (*Neoglobobuadrina atlantica* LO, *N. acostaensis* LO, beginning of dominance of left-coiling *Neoglobobuadrina pachyderma*, *N. dutertrei* s.s. FA, *Globigerina cariacensis* FA, *Globigerinoides tenellus* FA, *Globigerinoides obliquus extremus* LO) all of which are very useful for long range correlations (Text-fig. 14). These paleontologic events take place, in the Santerno Section (Raffi & Rio, 1980; Colalongo, unpublished data), near the first appearance of the mollusc *Arctica islandica* (the most renowned among the «northern guests»). The first appearance of *A. islandica* in the Mediterranean, in particular in the Italian sections, has been for decades one of the principal criteria for defining the base of the Pleistocene (Aguirre & Pasini, 1985; Pasini & Colalongo, in press) and the base of the Calabrian stage, as it was known in 1948 to the members of the IGC Subcommittee on the Pliocene/Pleistocene boundary.

The magnetostratigraphic position of the Pliocene/Pleistocene boundary-stratotype (P/P BS) has been redefined by Zijderveld *et al.* (1991). These Authors carried out a very close sampling for the paleomagnetism, by using a rock corer to collect unweathered samples (differently from Tauxe *et al.*, 1983, who collected fewer and more superficial samples). According to Zijderveld *et al.* (1991) the P/P

boundary-stratotype is located within the reversed polarity stratigraphic interval β , whose thickness is only 10 meters (Text-fig. 14); this interval is located between the normal polarity intervals α and γ , of which the first has a thickness of 45 meters and the second of 5 meters (these three intervals were labelled with greek letters by the present authors). Zijderveld *et al.*, 1991 demonstrated that intervals α , β and γ all belong to the Reversed Matuyama Chron, and proposed for them two options:

option I: interval α corresponds to the Olduvai normal polarity subchron, whose length – calculated by utilizing the astronomic ages of the sedimentary cycles (sapropels) (Hilgen, 1991) – would be in this case 115 ka; interval β is a short reversed subchron which lasted 30,000 years; interval γ is a short normal subchron (*Vrica subchron*) which lasted 15,000 years.

option II: intervals α , β and γ as a whole correspond to the Olduvai, which in this case would have a length of 160 ka according to the timescale of Hilgen, 1991 (180 ka according to the timescale of Shackleton *et al.*, 1990); this interpretation implies the presence of a short reversed polarity interval (β) near the top of the Olduvai.

In our opinion, which is in agreement with the one of Zijderveld *et al.*, 1991, option II is by far the most reliable, because:

a) A duration of 160 or 180 ka (instead of 115 ka) for the Olduvai subchron is in better agreement with estimates, on astronomic grounds, of 170 ka (1.82-1.65 Ma: Raymo *et al.*, 1989) and of 180 ka (1.95-1.77 Ma: Shackleton *et al.*, 1990);

b) The presence of a reversed polarity interval within the Olduvai was already noticed in the Boso Peninsula (Central Japan, Nakagawa *et al.*, 1982), in core V 20-109 (northern Pacific Ocean, Ninkovitch *et al.*, 1966), in several deep sea cores of Indian Ocean (Opdyke & Glass, 1969) and in loessic deposits of the Chinese Loess Plateau (Heller *et al.*, 1991).

Considering all this, we can affirm that the top of the polarity interval γ of the Vrica Section represents almost certainly the upper Olduvai polarity transition as it has been recorded in the literature, and that the P/P boundary-stratotype, coincident with the top of sapropel *e* of the Vrica Section, is located within the reversed polarity interval β of this section which – on the ground of data of Shackleton *et al.*, 1990 – has a duration of only 30,000 years (1.82 to 1.79 Ma). It follows that the magnetostratigraphic location of the P/P BS is now very precise and that, using the geomagnetic time scale proposed by Shackleton *et al.* 1990, the

Pliocene/Pleistocene boundary stratotype has an interpolated age of 1.795 ± 0.030 Ma (1.786 ± 0.039 Ma according to the timescale of Cande & Kent, 1992)⁽²⁾.

Hedberg, 1976 (p. 86) underlined that «the boundary-stratotypes between stages could be selected so that certain ones serve also as the boundary-stratotype between larger units (series, systems etc.)». Therefore the Pliocene/Pleistocene boundary-stratotype is also the Neogene/Quaternary boundary stratotype, as evidenced by the «1989 Global Stratigraphic Chart» of the IUGS.

In a meeting held in Kyoto during the 29th International Geological Congress some members of the INQUA proposed to displace the Pliocene/Pleistocene boundary-stratotype at about 2.5 Ma, in the proximity of the Gauss/Matuyama boundary, and to locate this boundary-stratotype in a continental section. The aforesaid INQUA members said that they had nothing against the P/P boundary-stratotype, but that it would be preferable to lower this boundary at about 2.5 Ma, because around 2.4 Ma B.P. took place:

1) a widespread climatic cooling, indicated by the stable isotope record and by the presence of ice rafted debris in the North Atlantic;

2) the beginning of sedimentation of loess in China;

3) the extension of the prairies in the place of the forests in Africa, accompanied by important faunistic changes;

4) an accentuation of astronomic cycles, with different course;

5) the first appearance of genus *Homo*.

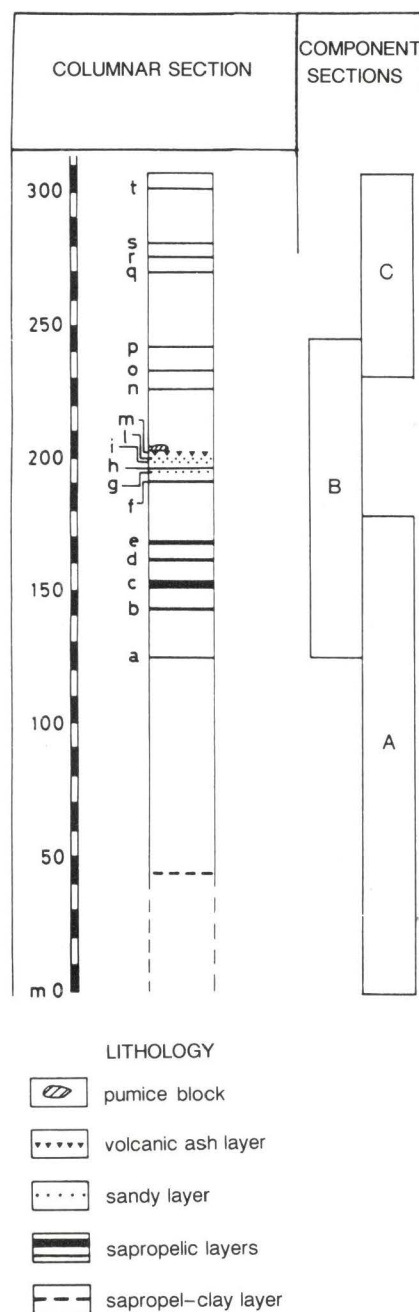
During the Workshop «Lower and Middle Pleistocene: type-areas in Sicily and Calabria» held in Southern Italy in november 1992 the members of the Italian Working Group for the Quaternary Stratigraphy discussed the proposal of the INQUA members made in Kyoto and underlined what follows:

a) only point 2 was unknown when the P/P boundary-stratotype at Vrica was proposed and approved;

b) point 5 seems a regression to the 1948 London Congress;

c) the proposal of locating a boundary-stratotype

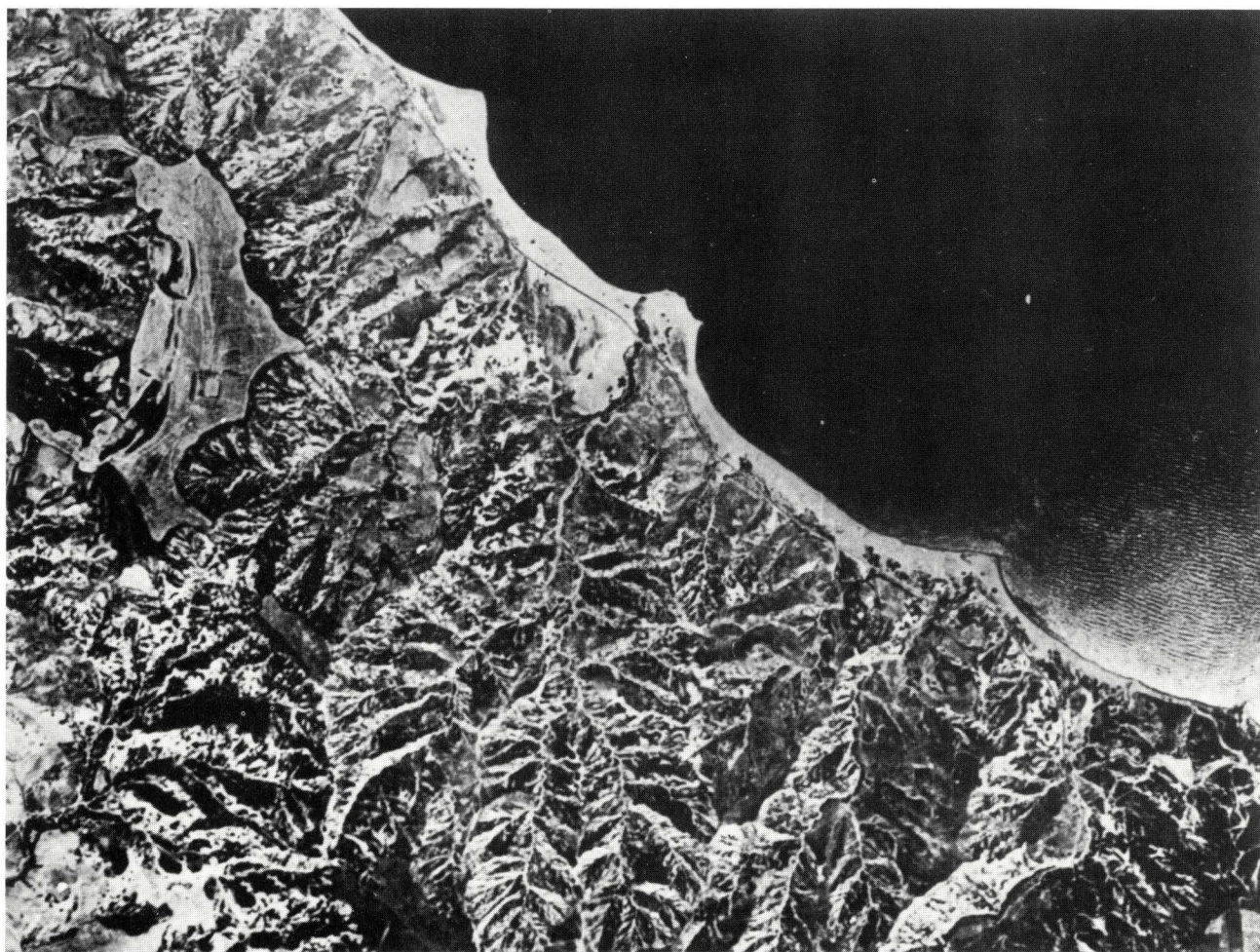
(2) Aguirre & Pasini 1985, utilizing the age of the top of the Olduvai subchron calculated by Mankinen & Dalrymple, 1979 and the sedimentation rate in the interval of the Vrica section between the top of the Olduvai and the top of marker bed *e* calculated by Tauxe *et al.*, 1983, obtained for the P/P BS the age of about 1.64 Ma; Hilgen, 1991, utilizing astronomical calibration of sapropels and his implication for the Geomagnetic Polarity Time Scale, obtained the age of 1.81 Ma; Zijdeveld *et al.*, 1991 suggested for the P/P BS the age of 1.69 Ma or 1.81 Ma.



Text-fig. 3 - The Vrica section and its component sections.

in a continental sequence is unacceptable, because it is against the basic stratigraphic rules (see Hedberg, 1976).

The members of the above mentioned Working Group decided to propose a new stage coincident with the upper part of the Pliocene and starting from about 2.5 Ma: the erection of this new stage should be a satisfactory reply to the proposal made by some members of INQUA at Kyoto.



Text-fig. 4 - Aerial photograph of the Vrica outcrop area (Istituto Geografico Militare, photo No. 227/10145, 1955; reproduced with permission of the S.M.A. No. 231 of April 7, 1970). For the location of the component-sections A, B and C compare this photograph with Text-fig. 5.

The present authors underline that a boundary at 2.5 Ma B.P. would be much more difficult to define and to correlate by biostratigraphic means than the boundary-stratotype located at Vrica. They are convinced that the P/P boundary-stratotype defined at Vrica has to be maintained, being the best P/P boundary-stratotype proposable so far.

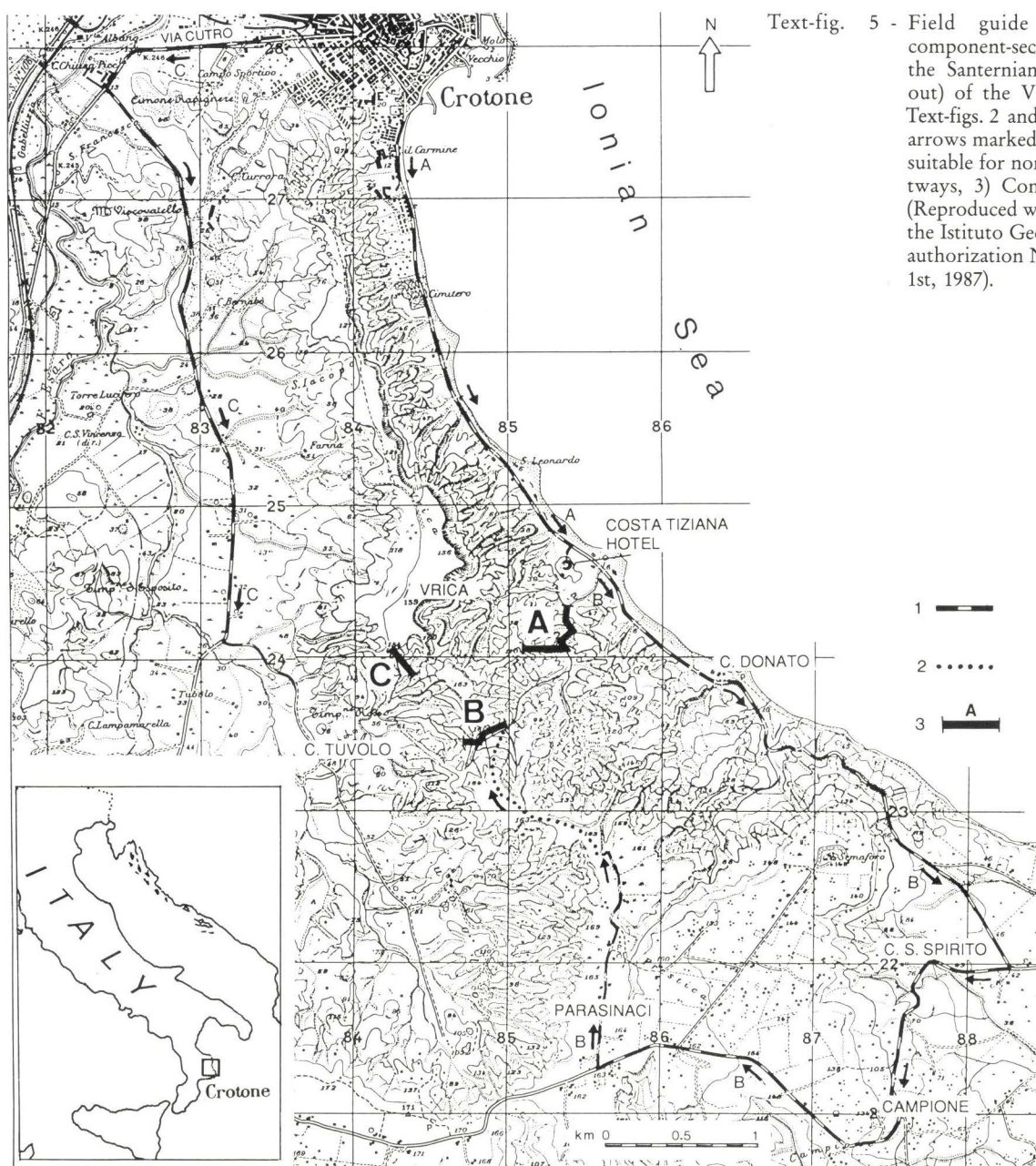
UPPER BOUNDARY OF THE SANTERNIAN

The upper boundary of the Santernian – considered as the base of the overlying chronostratigraphic unit, the Emilian – coincides with the first appearance of the northern guest *Hyalinea baltica* according to Ruggieri & Sprovieri, 1977a, 1977b and to Colalongo, Pasini & Sartoni, 1981.

The first appearance of *H. baltica* is an easily detectable event in many emergent Italian sections (e.g.: Santerno, Tenna, Vrica and Capo Rossello Sec-

tions) and in some cores collected in the Mediterranean Sea. Thus the boundary so defined is recognizable in all the Mediterranean area.

Moreover, the *H. baltica* FA is contemporaneous (in the Vrica and in the Capo Rossello sections), or penecontemporaneous (in the Santerno, the Tiepido, the Crostolo and the Stirone sections) to the first appearance of the «large» *Gephyrocapsa* spp. (= *Gephyrocapsa* spp. > 5.5 μ m) (Rio *et al.*, 1985). The «large» *Gephyrocapsa* spp. FA, a worldwide nanofossil event, is dated at 1.479 Ma in mid-latitude North Atlantic (DSDP Site 607) and at 1.457 Ma in eastern equatorial Pacific (ODP Site 677) (Raffi *et al.*, 1993). So this event is slightly older (22 ka) in mid-latitudes than in the equatorial Pacific, «presumably implying that this form first evolved nearer to the mid-latitudes» (Raffi *et al.*, 1993). Thus it is very likely that the «large» *Gephyrocapsa* FA occurred in the Mediterranean – a mid-latitude sea – about 1.480



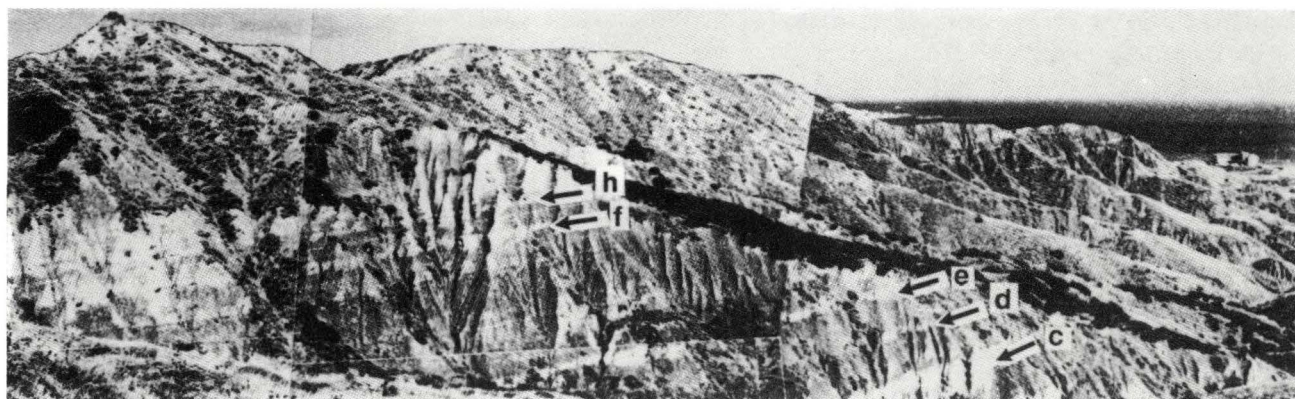
Text-fig. 5 - Field guide itinerary for component-section B (where all the Santernian sediments crop out) of the Vrica Section (see Text-figs. 2 and 3), indicated by arrows marked with B. 1) Roads suitable for normal cars. 2) Footways, 3) Component-sections. (Reproduced with permission of the Istituto Geografico Militare, authorization No. 2568 of April 1st, 1987).

Ma ago. All this allows long range correlations of the Santernian/Emilian boundary as above understood, whose age is of about 1.480 Ma.

THE VRICA SECTION

The Vrica Section is located 4 km South of the town of Crotona (Calabria, Southern Italy: Text-figs. 1-6). It has a stratigraphic thickness of 306 meters and consists of Plio-Pleistocene grey silty-marly claystones with intercalated 14 layers of sapropelic laminites (*a, b, c, d, e, f, h, n, o, p, q, r, s, t*), 3 sandy

layers (*g, i, l*) and 1 cineritic level (*m*), belonging to a monocline dipping 5° - 15° West (Text-figs. 2, 3). The fossil content of this section allows to affirm that the aforecited sediments were deposited in continuity of sedimentation, i.e. without appreciable hiatuses. The presence throughout the section of psycrosphaeric ostracods (*Agrenocythere pliocenica*, *Bathocythere vanstraateni*, *Zabythocypris antemacella*, *Bythoceratina scaberrima mediterranea*: Colalongo & Pasini, 1980), of deep-sea benthic foraminifera (*Articulina tubulosa*, *Discospirina italica*, *Eggerella bradyi*, *Gyroidina soldanii*, *Hoeglundina elegans*,



Text-fig. 6 - Component-section B of the Vrica section (in the foreground). Sapropel marker beds *c*, *d*, *e*, *f* and *h* are indicated. On the right side the uppermost part of component-section A and Costa Tiziana Hotel are visible.

Planulina wuellerstorfi, *Karreriella bradyi*, *Pleurostomella alternans*, *Pullenia bulloides* and *Rhabdammina linearis*: D'Onofrio, 1981), of deep-sea molluscs (*Propeamussium duodecimlamellatum* and *Malletia excisa*: Tampieri in Selli *et al.*, 1975) and of deep-sea fishes (*Cyclothone pygmaea*, *Lobianchia dofleini* and *Lampanyctus crocodylus*: Landini & Menesini, 1978a) indicate that the sediment deposition in the Vrica area took place in bathyal environment, at a depth of 500 to 800 meters.

In the last 18 years the Vrica Section has been studied from the sedimentologic, paleoecologic, biostratigraphic, biochronologic, magnetostratigraphic and radiometric point of view by numerous Italian (Pasini *et al.*, 1975; Selli *et al.*, 1977; Aguirre & Pasini, 1985; Rio *et al.*, 1985; Pasini & Colalongo, in press), French (Suc, 1982; Combourieu-Nebout *et al.*, 1990 *inter alios*), Dutch (Spaak, 1983; Zijderveld *et al.*, 1991), Swedish (Backman *et al.*, 1983), Japanese (Nakagawa, 1981; Nakagawa *et al.*, in press *inter alios*) and North American (Obradovich *et al.*, 1982; Tauxe *et al.*, 1983) scientists.

In 1985 the Vrica Section was proposed by the IUGS International Commission on Stratigraphy and approved by the International Union for Geological Sciences as stratotype of the P/P boundary (Bassett, 1985). The P/P boundary-stratotype is located at the bottom of the grey silty marly claystones that overlie in continuity the marker bed *e* of the section, and is coeval to the beginning of a cold climate period evidenced by pollen (see below).

SEDIMENTOLOGY AND PALEOECOLOGY OF THE SANTERNIAN OF THE VRICA SECTION

Some Authors – among which are Ruggieri, Rio & Sprovieri, 1984 and Rio, Sprovieri & Channell,

1990 – proposed informally the Santerno River Section (Romagna, northern Italy) as type section of the Santernian substage, and therefore of the Santernian/Emilian boundary.

The present authors re-examined the Santerno, the Lamone (Romagna), the Vrica and the Crati (Calabria) sections – some of which were recently re-sampled – with the purpose of finding a possible Santernian/Emilian boundary-stratotype. *In the Santerno River section the sediments of the Santernian are today not so well exposed as they were 15-20 years ago; they are in part shallow (circalittoral) sea sediments. Moreover, it is extremely difficult to find the level in which H. baltica first appears.*

Among the other sections re-examined, the Vrica Section has resulted to be by far the most suitable for the definition of the Santernian/Emilian boundary-stratotype. This section shows also the not negligible advantage that in it is located – as said before – the Pliocene/Pleistocene boundary-stratotype, i.e. the lower boundary stratotype of the Santernian.

The *Hyalinea baltica* FA – chosen as criterion of identification of the upper boundary of the Santernian – occurs in the Vrica Section 71.1 meters above the top of marker bed «*e*» (Pliocene/Pleistocene boundary-stratotype): therefore the Santernian sediments have in this section a stratigraphic thickness of 71.1 meters.

The Santernian sediments of the Vrica Section consist essentially of grey and blue-grey silty marly claystones, with interbedded:

- 4 sapropelic layers pink grey in colour (*f*, *h*, *n*, *o* in Text-fig. 6), which look like finely laminated shales, having thicknesses of 115, 90, 100 and 55 cm, respectively;

- 3 sand levels (*g*, *i*, *l*) pale grey in colour, reddish where weathered, whose thickness is 8, 6 and 5 cm, respectively;

- 1 cineritic silty level pale grey in colour (*m*), reddish where weathered, 5 cm thick.

The above mentioned layers and levels constitute very conspicuous marker beds.

From the biostratigraphic, chronostratigraphic and paleoecologic research carried out on the calcareous nannoplankton (Rio, Raffi & Backman, 1985), the planktic (Aguirre & Pasini, 1985; Pasini & Colalongo, in press) and benthic foraminifers (D'Onofrio, 1981), the ostracods (Colalongo & Pasini, 1980), the mollusks (Tampieri in Aguirre & Pasini, 1985 and in Pasini & Colalongo, in press), the fish remains (Landini & Menesini, 1978a, b) and the pollen (Bertolani Marchetti *et al.*, 1978; Combourieu-Nebout, 1990) of the Santernian sediments of the Vrica Section, it may be confirmed that these sediments were deposited with continuity of sedimentation at a depth of 500 to 800 meters (see pag. 108), i.e. in a bathyal environment.

In order to get further information on the sapropelic layers (interpreted as sediments deposited during short periods of oxygen deficiency in the sea bottom waters), on the sand levels and on the cineritic level (whose radiometric age is not yet established), the reader is referred to Pasini & Colalongo (in press).

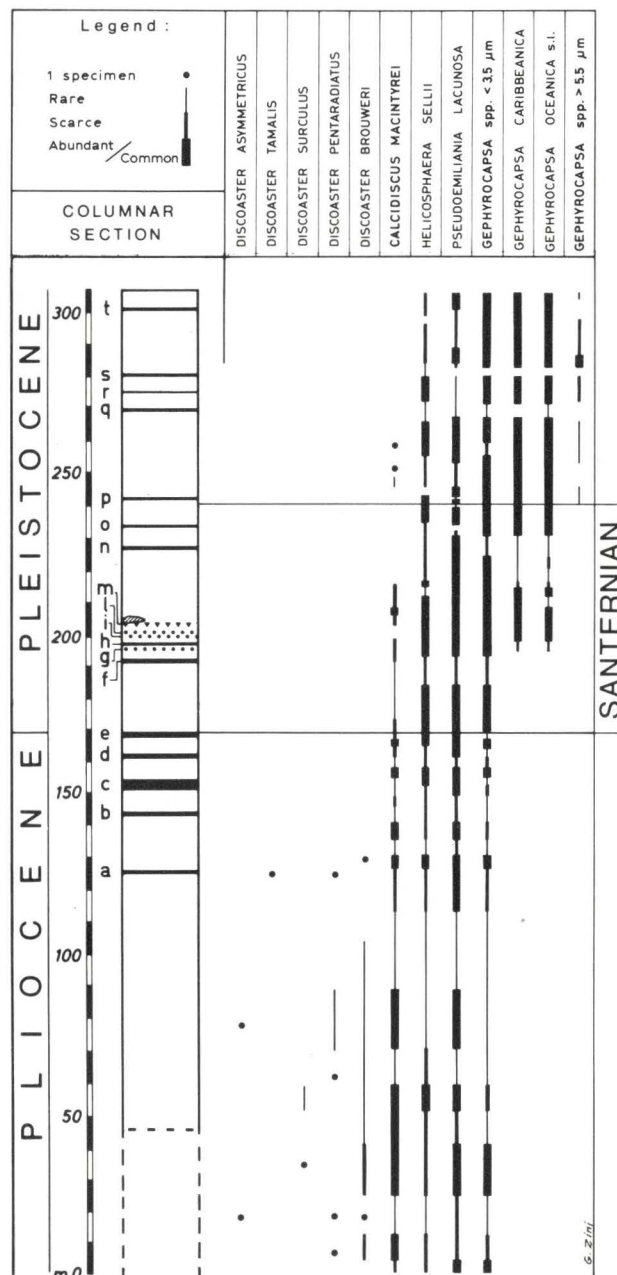
BIOSTRATIGRAPHY AND BIOCHRONOLOGY OF THE SANTERNIAN IN THE VRICA SECTION

The Santernian sediments of the Vrica section are very rich in fossils, in general perfectly preserved. The groups studied up to now include calcareous nannoplankton, planktic and benthic foraminifers, ostracods, mollusks, fishes and pollen. Besides these groups diatoms, silicoflagellates, radiolarians, octocorals, brachiopods, pteropods and echinoderms - not yet studied - are also represented in the Vrica Section.

In this chapter the first appearances (FA) and the last occurrences (LO) of the fossils considered by many Authors as key-events of Upper Pliocene or Lower Pleistocene for the Mediterranean and extra-Mediterranean regions are reported.

CALCAREOUS NANNOPLANKTON

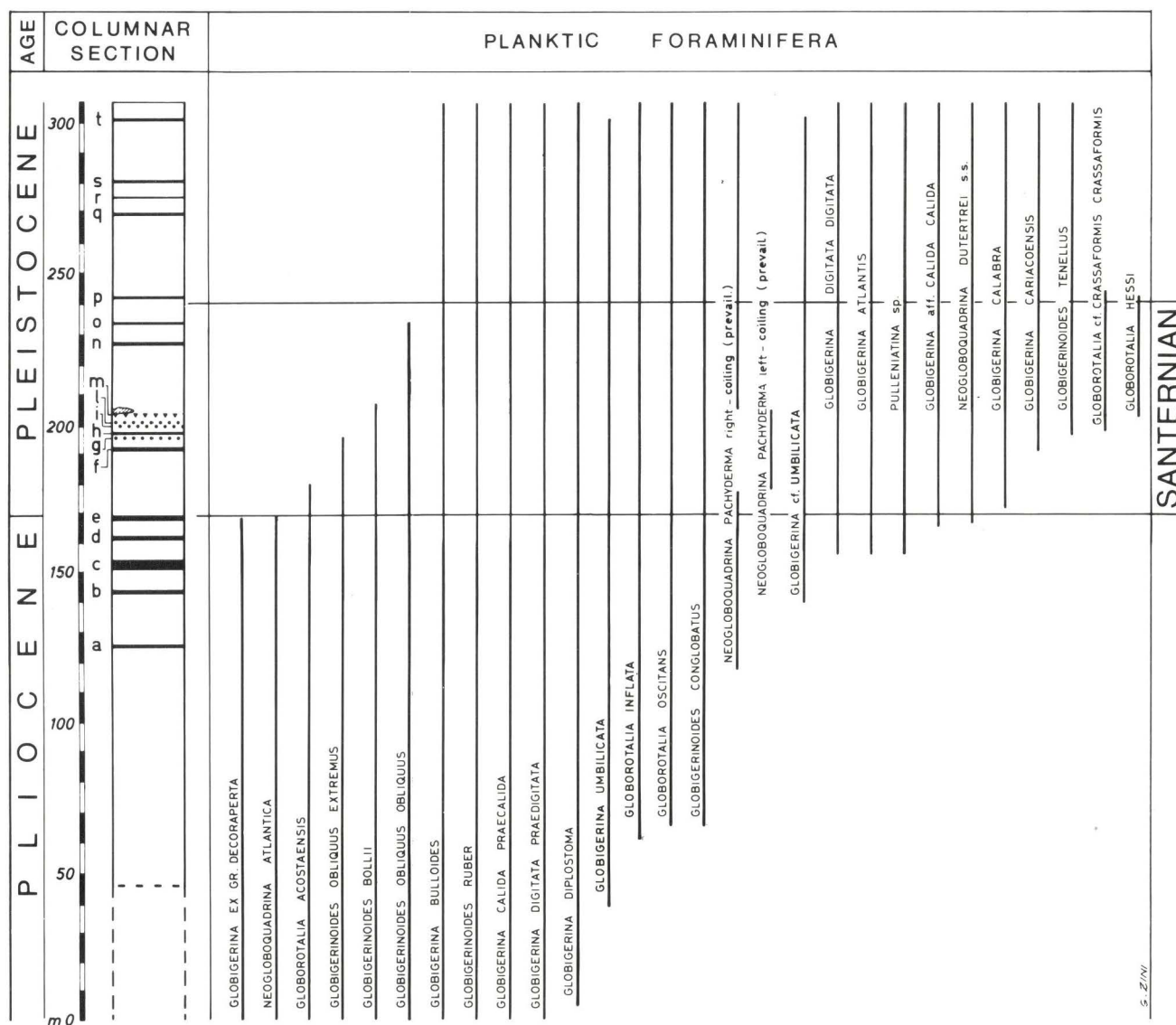
Among the nannofossil events identified by Rio, Raffi & Backman, 1985 in the interval of the Vrica section that the present authors ascribe to the Santernian, two are particularly important from a biochronologic point of view: the *Calcidiscus macintyre* LO and the «large» *Gephyrocapsa* spp. (= *Gephyrocapsa* spp. > 5.5 µm) FA. The relationships



Text-fig. 7 - Range of selected nannofossil species in the Vrica section according to I. Raffi and D. Rio (in Pasini & Colalongo, 1982).

of these events to one another and to the magnetostratigraphy are the same in the Vrica section and in cores from the Mediterranean, the Atlantic, the Caribbean and the Pacific.

The extinction of *Calcidiscus macintyre* is recorded about 13 m above marker bed *m* of the Vrica Section (Text-fig. 7). The age of this event is about 1.663 Ma in DSDP Hole 552A (North Atlantic), 1.640 Ma in DSDP Site 607 (mid-latitude North



Text-fig. 8 - Distribution of selected planktic foraminifera in the Vrica Section. (Modified from Colalongo *in* Selli *et al.*, 1977 and Colalongo *et al.*, 1981).

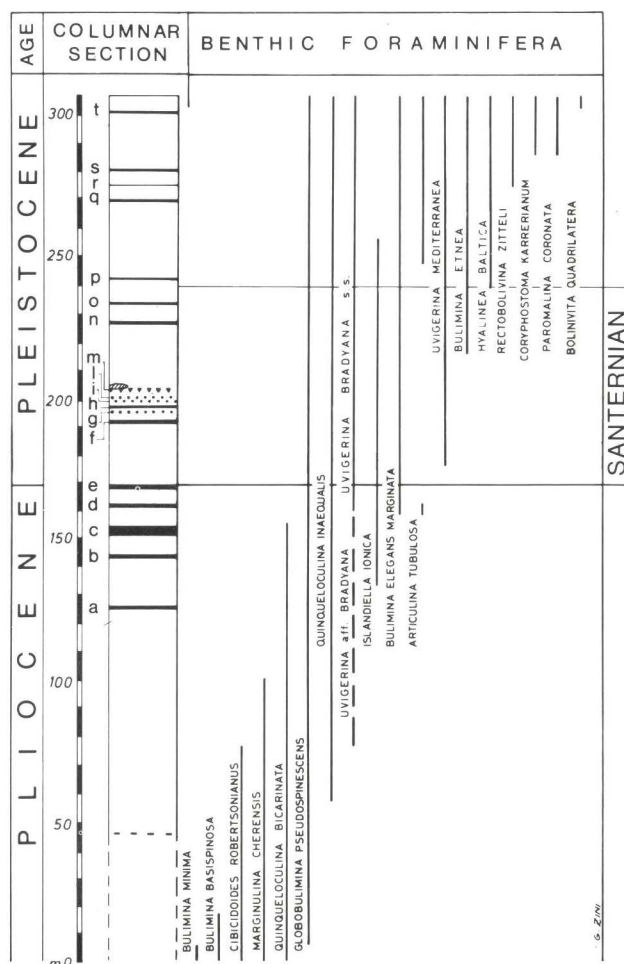
Atlantic) and 1.597 Ma in ODP Site 677 (eastern equatorial Pacific) (Raffi *et al.*, 1993). According to Raffi *et al.*, 1993, «*Calcidiscus macintyre*i obviously survived longer in the equatorial environment, having its earliest disappearance in the high-latitude Site 552A, followed by mid-latitude Site 607 and its youngest at the equatorial Site 677». Considering that the Mediterranean is a mid-latitude sea, we can assume that the *C. macintyre*i LO occurred in this sea (and in the Vrica area) about 1.640 Ma ago.

The FA of «large» *Gephyrocapsa* spp. is recorded 2 meters below marker bed *p* of the Vrica section (Text-fig. 7), exactly in the same sample in which is recorded the *H. baltica* FA, i.e. in coincidence with the Santernian/Emilian boundary here proposed. As

said above, it is very likely that the «large» *Gephyrocapsa* FA occurred in the Mediterranean Sea (and in the Vrica area) about 1.480 Ma ago.

PLANKTIC FORAMINIFERA

As evidenced by Colalongo *et al.*, 1984, during the Plio-Pleistocene the Mediterranean Sea acted as a distinct water mass with respect to the adjacent oceans, and so the Mediterranean planktic foraminifera assemblages of this time interval show a marked provincial character (Cita, 1973; Thunell, 1979). There is a fairly general consensus among Authors, however, about the stratigraphic distribution



Text-fig. 9 - Distribution of selected benthic foraminifera in the Vrica Section (Modified from D'Onofrio, 1981).

in the Plio-Pleistocene Mediterranean sequences of the main planktic foraminifera marker species.

In the Vrica Section, within or close to the Santernian interval, the following major datum events are recorded (Text-fig. 8): *Globigerina atlantis* FA, *G. digitata digitata* FA, *Neoglobobulimina dutertrei* s.s. FA (immediately below the P/P boundary), *Neoglobobulimina atlantica* LO, *N. acostaensis* LO, beginning of dominance of sinistrally-coiled *Neoglobobulimina pachyderma*, *Globigerina calabra* FA (immediately above the P/P boundary), *Globigerina cariacensis* FA, *Globigerinoides tenellus* FA, *G. obliquus extremus* LO, *Globobulimina hessi* FA (in the middle portion of the Santernian). Among these events, the dominance of sinistrally-coiled *N. pachyderma*, the *G. cariacensis* FA and the *G. obliquus extremus* LO are suitable for long range correlations.

The beginning of dominance of left-coiled *Neoglobobulimina pachyderma* occurs in the Vrica

section in coincidence with the top of the Olduvai subchron, and thus – according to Shackleton *et al.*, 1990 – has an age of 1.77 Ma. Also in sites 650 and 651 of ODP Leg 107 (Tyrrhenian Sea), in DSDP sites 552, 607, 609 and 610 (North Atlantic Ocean) the beginning of dominance of the left-coiled *N. pachyderma* almost coincides with the upper boundary of the Olduvai subchron, whereas in DSDP site 611 (North Atlantic Ocean) this planktic foraminifera event slightly predates the top of the Olduvai (Raymo *et al.*, 1989; Channell *et al.*, 1990).

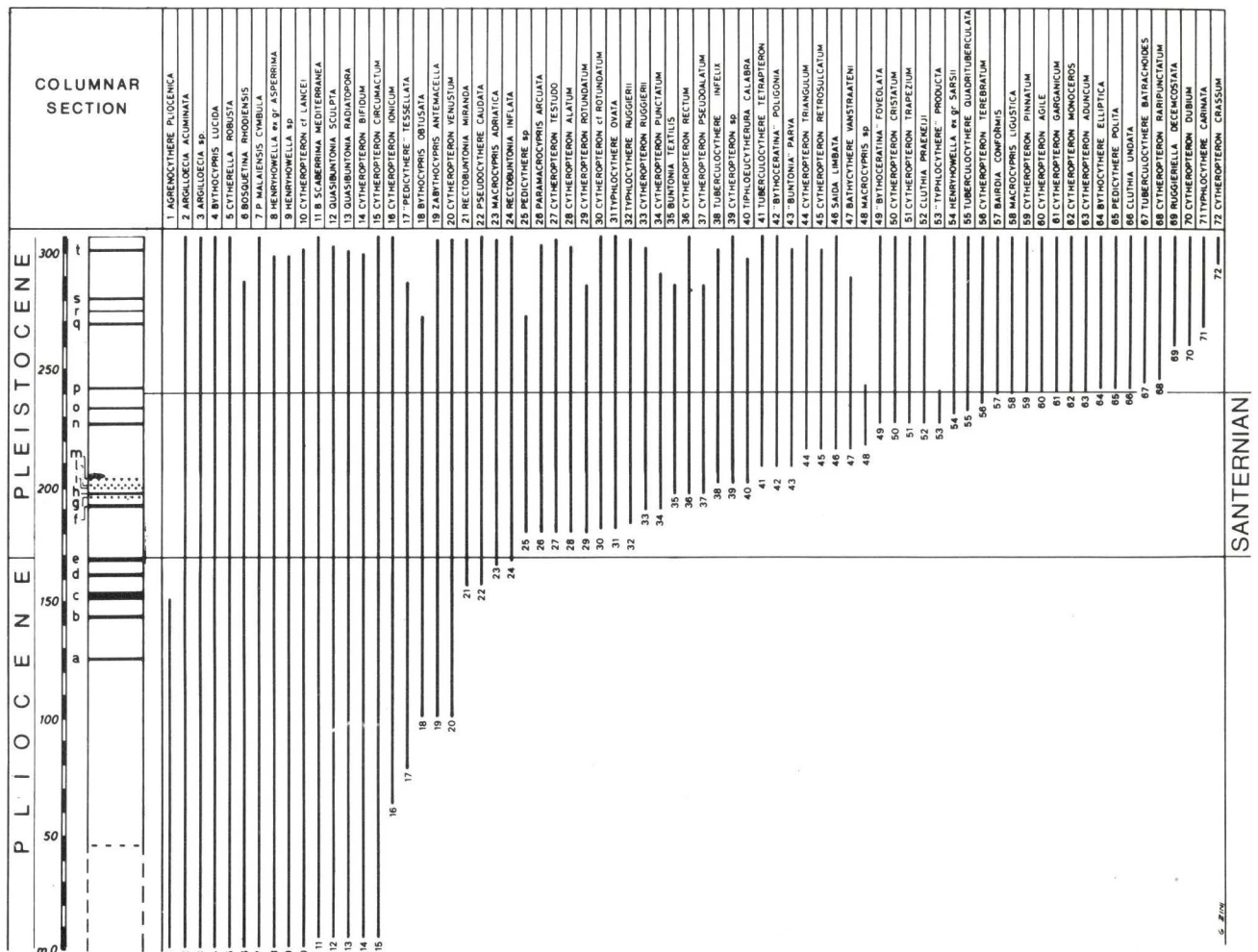
The *Globigerina cariacensis* FA occurs in the Vrica section just below the bottom of sapropel f, between the upper boundary of the Olduvai subchron (1.77 Ma) and the *C. macintyreii* LO (1.640 Ma): the interpolated age of the *G. cariacensis* FA in the Vrica section (assuming a constant sedimentation rate between the calibration points) is 1.728 Ma.

The *Globigerinoides obliquus extremus* LO is recorded in the Vrica section at the top of sand level g, between the upper boundary of the Olduvai subchron and the *C. macintyreii* LO; this event in the Vrica section has an interpolated age of 1.710 Ma. The *G. obliquus extremus* LO occurs in sediments considered to be basal Pleistocene in age in the regions of Romagna (e.g.: Santerno Section [Colalongo *et al.*, 1968] and Lamone Section [Colalongo, unpublished data]), Marche (e.g.: Tenna and Esino Sections [Cantalamesa *et al.*, 1986]) and in DSDP Site 132 (Tyrrhenian Sea).

The *N. atlantica* LO practically coincides with the Pliocene/Pleistocene boundary-stratotype, and thus has an age in the Vrica section of about 1.795 Ma. This event occurs close to the Pliocene/Pleistocene boundary in DSDP Site 132 (Tyrrhenian Sea) (Colalongo, unpublished data).

The *G. digitata digitata* FA occurs in the Vrica section one meter above marker bed c and 14 m below the Pliocene/Pleistocene boundary-stratotype, within the Olduvai subchron, and has an interpolated age in the Vrica section of 1.827 Ma. This event is recorded close to the P/P boundary in DSDP Site 132 (Colalongo, unpublished data).

The *Globigerinoides tenellus* FA occurs in the Vrica section in coincidence with marker bed h and one meter above the *G. obliquus extremus* LO (1.710 Ma); thus the age of this FA is about 1.707 Ma. This event is recorded in sediments assigned to the basal Pleistocene in the Caraffa di Catanzaro section (Calabria; Pasini *et al.*, 1977), the Capo Rossello Section (Sicily; Sprovieri, 1978), the Rio Vendina-Crostolo section (Emilia; Colalongo *et al.*, 1978) and in the DSDP Site 132 (Tyrrhenian Sea).



Text-fig. 10 - Distribution in the Vrica Section of the ostracodes considered autochthonous (Modified from Colalongo & Pasini, 1980).

BENTHIC FORAMINIFERA

According to Colalongo *et al.*, 1984, among the benthic foraminifera datum events recorded in the Vrica Section the three most important for the Italian region are the FAs of *Uvigerina bradyana*, of *Bulimina etnea* and of *Hyalinea baltica* (Text-fig. 9).

The *U. bradyana* FA is recorded immediately below marker bed *d*.

The *Bulimina etnea* FA is recorded between marker beds *m* and *n*. This event is also seen in sediments assigned to the basal Pleistocene in the Santerno River section (Romagna; Colalongo, 1968), in the Caraffa di Catanzaro section (Calabria; Pasini *et al.*, 1977) and in Sicilian sections at Agrigento (Sprovieri, 1968) and Capo Rossello (Sprovieri, 1978).

The *H. baltica* FA is synchronous with the «large» *Gephyrocapsa* FA (1.480 Ma) in the Vrica Section (Text-fig. 14) and in the Capo Rossello-Punta Piccola Section (Rio, Backman & Raffi, 1985). The

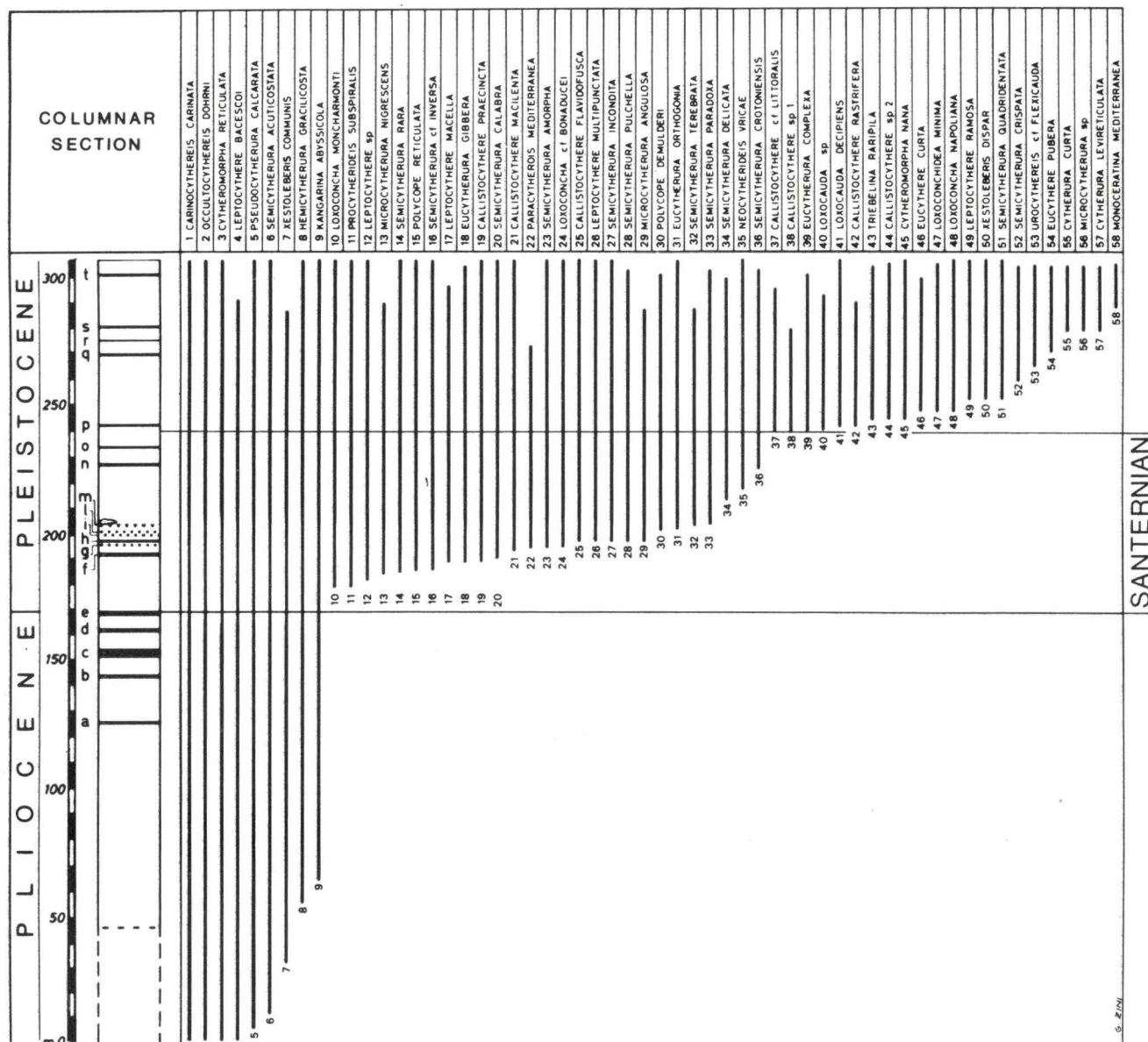
H. baltica FA slightly predates this nannoplankton event in the Tiepido Section (Emilia, Northern Italy) and slightly postdates it in the Santerno River Section (Rio, Backman & Raffi, 1985).

OSTRACODA

In correspondence of the P/P boundary a sharp change in the ostracofauna is recorded in the Vrica Section, evidenced by Text-figs. 10 and 11. In fact below marker bed *e* we notice a comparatively small number of species, which continue to the top of the section, while above this level many first appearances are recorded (Colalongo & Pasini, 1980).

Ostracoda «in situ»

Among the ostracods of the Vrica Section considered *in situ* (Text-fig. 10), *Rectobuntonia miranda*, *Pseudocythere caudata* and *Macrocypris adriatica* appear a little below the P/P boundary; *Rectobuntonia*

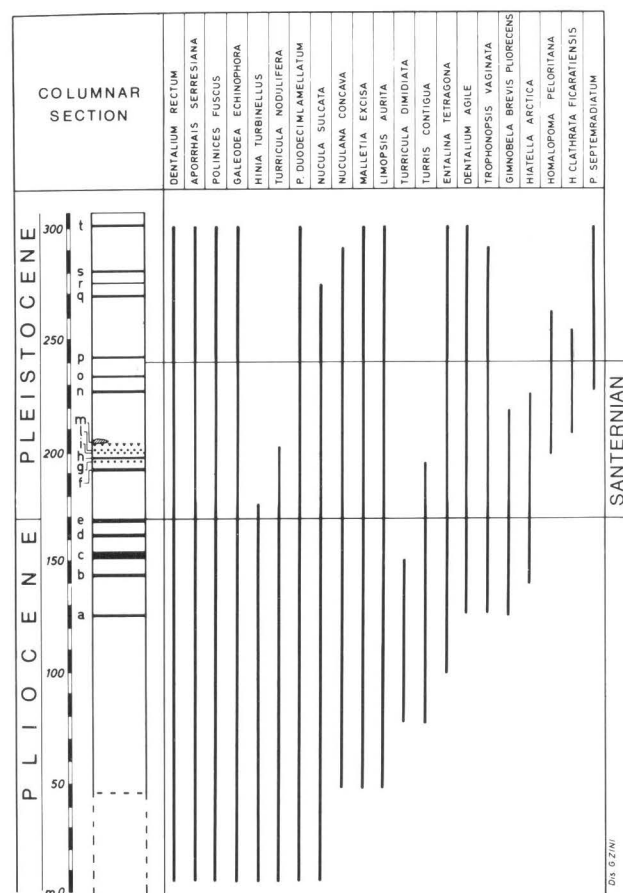


Text-fig. 11 - Distribution in the Vrica Section of the ostracodes considered displaced from shallow sea sediments penecontemporaneous with the sediments of the Vrica Section (Modified from Colalongo & Pasini, 1980).

inflata appears almost in coincidence with the P/P boundary; *Paramacrocypris arcuata*, *Cytheropteron alatum*, *C. rotundatum*, *Typhlocythere ovata* and *T. ruggierii* appear a little above the P/P boundary. These nine ostracods could be useful to draw, with a good approximation, the P/P boundary (= lower boundary of the Santernian) in other Mediterranean sections.

«*Bytoceratina*» *foveolata*, *Cytheropteron cristatum*, *C. trapezium*, *Cluthia praekeiji*, «*Typhlocythere*» *producta*, *Henryhowella* ex gr. *sarsii*, *Tuberculocthere quadrituberculata* and *Cytheropteron terebratum* ap-

pear in the Vrica Section a little below the Santernian/Emilian (S/E) boundary; *Bairdia conformis*, *Macrocypris ligustica*, *Cytheropteron pinnatum*, *C. agile*, *C. garganicum*, *C. monoceros*, *C. aduncum*, *Bytocythere elliptica*, *Pedicythere polita* and *Cluthia undata* appear almost in coincidence with the S/E boundary. *Tuberculocthere bathrachoides* and *Cytheropteron raripunctatum* appear a little above the S/E boundary. The 20 ostracods above mentioned could be useful in order to draw, with a good approximation, the upper boundary of the Santernian in other Mediterranean sections.



Text-fig. 12 - Distribution of selected mollusks in the Vrica Section. (Modified from Tampieri in Selli *et al.*, 1977).

In the Santerian sediments of the Vrica Section are also recorded the FAs of: *Cytheropteron ruggieri*, *C. punctatum*, *C. rectum*, *C. pseudoalatum*, *C. triangulum*, *C. retrosulcatum*, *Buntonia textilis*, «*B.*» *parva*, *Tuberculocthere infelix*, *T. tetrapterum*, *Typhloecytherura calabra*, «*Bytoceratina*» *poligonia*, *Saida limbata* and *Bathocythere vanstraateni*.

Ostracoda not «*in situ*»

Colalongo & Pasini, 1980 found in the sediments of the Vrica section ostracods considered not *in situ*, but displaced from penecontemporaneous shallower water environments (Text-fig. 11). Among them, *Loxoconcha moncharmonti*, *Procytherideis subspiralis*, *Microcytherura nigrescens*, *Semicytherura rara*, *Polycopse reticulata* and *S. cf. inversa* appear a little above the P/P boundary. *Leptocythere macella*, *Eucytherura gibbera*, *Callistocythere praecincta*, *Semicytherura calabra*, *C. macilenta*, *Paracytherois mediterranea*, *S. amorpha*, *Loxoconcha cf. bonaducei*, *C. flavidofusca*, *L. multipunctata*, *S. incondita*, *S. pulchella*, *Microcytherura angulosa*, *Polycopse*

demulderi, *Eucytherura ortogonia*, *S. terebrata*, *S. paradoxa*, *S. delicata*, *Neocytherideis vrica* and *S. crotonensis* appear in the Santerian of the Vrica Section. *Callistocythere cf. littoralis*, *C. sp. 1*, *Eucytherura complexa*, *Loxoconcha decipiens* and *C. rastrifera* appear almost in coincidence with the S/E boundary. *Triebelina raripila*, *Callistocythere sp. 2*, *Cytheromorpha nana*, *Eucythere curta*, *Loxoconchidea minima*, *Loxoconcha napolitana*, *Leptocythere ramosa*, *Xestoleberis dispar* and *Semicytherura quadridentata* appear a little above the S/E boundary.

Some of these 40 ostracods, as soon as the stratigraphic levels of their FAs will be definitely established, could be utilized to recognize the Santerian, the P/P boundary and the S/E boundary in Mediterranean shallow sea sections.

MOLLUSCA

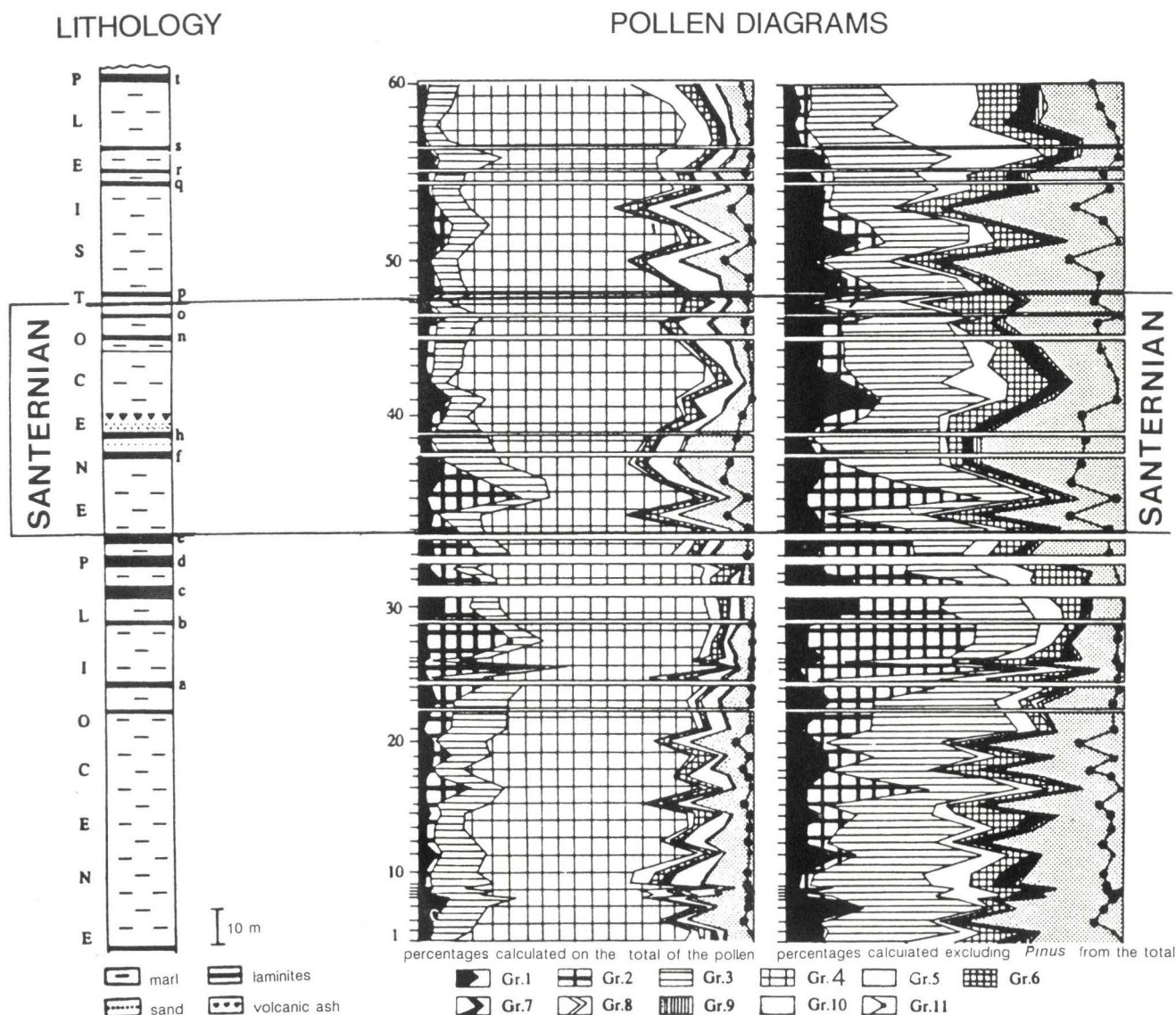
In the Santerian of the Vrica Section the LOs of *Hinia turbinellus*, *Turris contigua*, *Gimnobela brevis pliorecens* and the FA of *Pseudoamussium septemradiatum* are recorded (Text-fig. 12). According to the mollusk distribution scheme of Ruggieri, 1962 the *H. turbinellus* LO and the *T. contigua* LO occur in the Italian sections close to the P/P boundary; according to Ruggieri & Sprovieri, 1977a, the *G. brevis pliorecens* LO occurs in Italy in the lowermost Pleistocene. *P. septemradiatum* is considered a true «northern guest» by Pelosio & Raffi, 1973 and by Ruggieri & Sprovieri, 1977b; Raffi, 1986 affirms that this «northern guest» appeared in the Mediterranean Sea during the «first Quaternary migratory wave» of the «northern guests», that took place about at the beginning of the Santerian. Therefore, the mollusks datum events afocited can be useful to identify approximately the P/P boundary in Mediterranean area sequences.

FISH

Among the numerous fossil fishes identified in species by Landini & Menesini, 1978a and 1978b in the Santerian interval of the Vrica Section, *Cyclothone pygmaea*, *Lobianchia dofleini* and *Lampanyctus crocodilus* survive in the present in the Mediterranean Sea, exclusively or preferentially at depths exceeding 500 meters. This confirms that the Santerian sediments of the Vrica Section were deposited in a bathyal environment, as suggested by the benthic fossils.

POLLEN

Combourieu-Nebout, Semah & Djubiantono, 1990 – on the ground of pollen analyses concerning

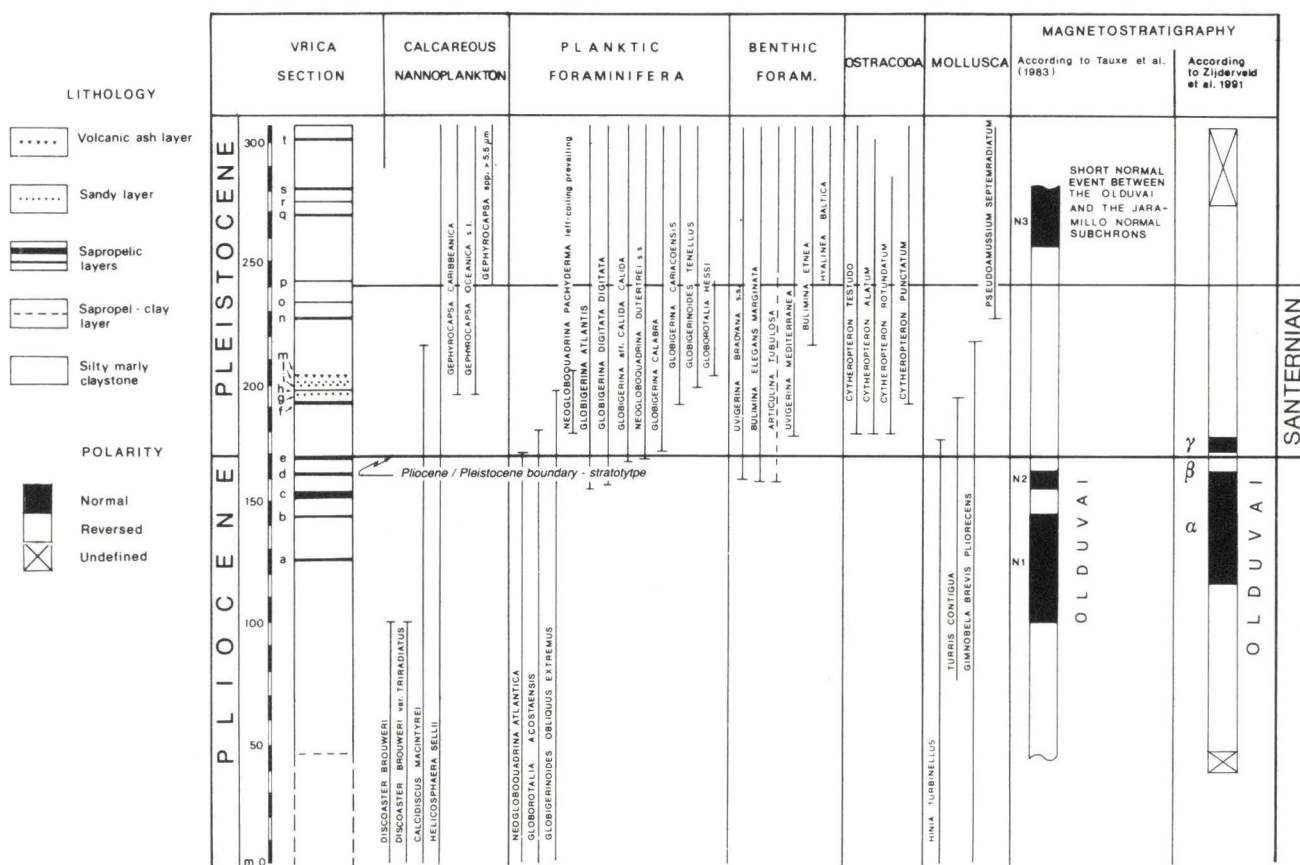


Text-fig. 13 - Synthetic pollen diagrams of the Vrica Section. Gr. 1) Taxodiaceae, *Engelhardtia*, Palmae etc. Gr. 2) *Cathaya*. Gr. 3) *Quercus*, *Carya*, *Ulmus-Zelkova*, *Carpinus*, etc. Gr. 4) *Pinus* and Abietaceae not determinable. Gr. 5) *Tsuga*. Gr. 6) *Cedrus*. Gr. 7) *Abies* and *Picea*. Gr. 8) taxa not classified. Gr. 9) Mediterranean xerophytes (*Olea*, *Phillyrea*, *Pistacia*, ...). Gr. 10) open vegetation herbaceous plants. Gr. 11) *Artemisia* and *Ephedra*. (Modified from Combourieu-Nebout *et al.*, 1990).

60 samples of the Vrica Section, among which 5 collected between marker beds *e* and *f* – evidenced that, in correspondence of the Pliocene/Pleistocene boundary, an important floristic modification is recorded (Text-fig. 13). From marker bed *a* to marker bed *e* pollen indicate a long forestal phase of subtropical to temperate-warm climate – with presence of Taxodiaceae, *Engelhardtia*, Palmae, *Cathaya*, *Quercus*, *Carya*, *Ulmus-Zelkova*, *Carpinus* etc. – ascribed to a long interglacial period («Tiglian stage» of Northern Europe). This forestal phase ends in the Vrica Section in correspondence with the Pliocene/Pleistocene boundary (coinciding with the

top of marker bed *e*). From this boundary up to the top of the section (and therefore throughout the Santernian) an increase of herbaceous taxa (especially of *Artemisia*) of cool and xeric climate – ascribed by Combourieu-Nebout *et al.*, 1990 to the «Eburonian» glacial period of Northern Europe – is recorded, while the forestal taxa decrease regularly and enrich progressively of high altitude trees⁽³⁾.

(3) It has been demonstrated that, in the Mediterranean region, the development of steppic elements can be correlated with a cooler and drier period: see Van der Hammen, Wijmstra & Zagwijn, 1971; Suc & Zagwijn, 1983; Zagwijn & Suc, 1984; Watts, 1985; Rossignol-Strick & Planchais, 1985.



Text-fig. 14 - Distribution in the Vrica Section of the planktic and benthic organisms most significant from the biostratigraphic and the biochronologic point of view. On the right, magnetostratigraphy of the section according to Tauxe *et al.*, 1983 and Zijderveld *et al.*, 1991.

Obviously the transition from floristic assemblages characteristic of a subtropical temperate-warm climate to floristic assemblages characteristic of cool and xeric climate, which occurs in the Vrica Section in coincidence with the Pliocene/Pleistocene boundary, can be very useful to draw this boundary in other sequences.

PROPOSAL OF THE SANTERNIAN/EMILIAN
BOUNDARY-STRATOTYPE

On the ground of the above, the present authors propose to the IUGS International Commission on Stratigraphy to locate the Santernian/Emilian boundary-stratotype («Global Standard Section and Point») in the Vrica section (Calabria, southern Italy), 71.1 meters above the P/P boundary-stratotype and 6 meters above marker bed o, in coincidence with the point (or «physical horizon») where – according to the present knowledge – the first appearance of the benthic foraminifer *Hyalinea ballica* in this section is recorded. This physical horizon is located in the Vrica Section

within a stratigraphic interval formed by grey silty marly bathyal claystones.

Following the remarks of Hedberg, 1976 (pp. 77 and 80) concerning the Silurian/Devonian boundary-stratotype fixed at Klonk (Bohemia), we want to underline that – if the above definition is accepted – the Santernian/Emilian boundary worldwide is *not* defined as the first appearance of *Hyalinea baltica*, but is simply fixed at a time-horizon coinciding with a point in the section at Vrica – marked as the boundary-stratotype – where, *to the extent of present knowledge*, the *H. baltica* first appears in this section. The *H. baltica* FA is a useful guide to this boundary in the Mediterranean area. *It is possible that in the Vrica section future discoveries may extend the range of H. baltica lower than the boundary-stratotype.* But this would not modify the location of the Santernian/Emilian boundary stratotype here proposed, in agreement with Hedberg, 1976.

The *H. baltica* FA in the Vrica Section is coeval with the «large» *Gephyrocapsa* (= *Gephyrocapsa* spp. with

coccoliths $> 5.5 \mu\text{m}$) FA, and this allows global scale correlations of the Santernian/Emilian boundary.

The Santernian/Emilian boundary-stratotype here proposed has an age of about 1.480 Ma.

COMMENTS ABOUT THE SUGGESTED SANTERNIAN/EMILIAN BOUNDARY STRATOTYPE

The suggested boundary stratotype fullfills almost ideally all the traditional requirements needed for a correct boundary definition. In fact the boundary would be located within a continuous, marine, pelagic sequence, completely exposed, with adequate thickness of sediments, with abundance of fossils, with favourable facies for widespread and reliable correlations; moreover this sequence is in a classical area for the Quaternary, is free from structural complications, metamorphism and unconformities, is potentially suitable for isotopic age determinations and chemostratigraphic investigations, is easily accessible.

The entire Santernian stage or substage plus the uppermost part of the Pliocene beneath the P/P boundary stratotype would be represented in the Vrica section below the suggested boundary stratotype, and about 1/3 of the Emilian stage above. Wide lateral exposure of the section would enable continued research on the best available correlation tools as well as large sampling and collection of comparison material.

Finally the suggested boundary stratotype would give stability to a Santernian stage or substage almost perfectly coincident with the historical concept of this chronostratigraphic unit as originally introduced by Ruggieri & Sprovieri, 1977a and traditionally used since.

On the ground of all the above considerations – although since the seventies only the boundary-stratotypes and not the unit-stratotypes are defined – it would virtually be possible to locate the Santernian unit-stratotype in the Vrica Section. The lower boundary of the Santernian stratotype should coincide with the Pliocene/Pleistocene boundary-stratotype, located in 1985 in this section at the base of the claystone overlying marker bed *e*. The upper boundary should coincide with the point between marker beds *o* and *p* where the first appearance of *H. baltica* in the Vrica Section is presently recognized.

The Santernian unit-stratotype, following the present proposal, would correspond to a stratigraphic interval of the Vrica Section 71.1 meters thick, which consists of grey silty marly claystones with intercalated 4 sapropelic layers, 3 sand horizons and 1 volcanic ash layer (Text-fig. 3),

very useful as «marker beds». In this interval important calcareous nannoplankton events (*Calcidiscus macintyre* LO, «large» *Gephyrocapsa* FA) and planktic foraminifera events (*Neoglobobadrina atlantica* LO, *N. acostaensis* LO, *Globigerinoides obliquus extremus* LO, beginning of dominance of *Neoglobobadrina pachyderma* left-coiled, *Globigerina calabra* FA, *Globigerina cariacensis* FA, *Globigerinoides tenellus* FA, *Globorotalia hessi* FA) are recorded, which allow global scale correlations.

APPENDIX: ACCESSIBILITY OF COMPONENT SECTION B OF THE VRICA SECTION

The Santernian stratotype and the Santernian/Emilian boundary-stratotype above proposed are completely exposed in the component-Section B of the Vrica Section (Text-fig. 3), that – being considered a site of great geological interest (because the Pliocene/Pleistocene boundary-stratotype is located in this section) – is legally protected against intentional damage as a nature preserve.

In order to reach component-section B and to traverse the exposures, a normal passenger car and good boots are the only equipment required.

Component-section B is located about 4 km South of the town of Crotone (Text-fig. 5). In order to reach this component-section one has to drive along the coastal asphalt road South of Crotone for about 8 km, past the Costa Tiziana Hotel and Cà Donato, till a crossroads. Here turn right and drive past Cà Santo Spirito and Campione, and about 2.5 km past Campione turn right again and go 1.5 km to the end of the country road which crosses the locality Parasinaci. Park and walk NW along the northern or north-eastern margin of marine terrace remnants. About 1 km NW of the end of the country road, a NE-trending valley cuts sharply into the terrace surface; in the cliff on the opposite side of this valley component-section B is exposed (see Text-figs. 3, 6 and 14). To reach the lower boundary of the Santernian interval, coinciding with the top of sapropelic marked bed *e*, go downhill (N-NE) along a gentle slope, as far as the torrent bed, normally dry.

Marker bed *e*, outcropping along the torrent bed, is easy to recognize being a laminite pink-grey in colour 190 cm thick, located about 7 meters above the laminite-marker bed *d* (155 cm thick) and about 14 meters above the laminite-marker bed *c* (which is unmistakable, because it is the only laminite in all the section with a thickness of 340 cm; Text-fig. 3). All the other marker beds of component-section B are easily recognizable in the northern cliff of the valley, taking into account their thickness (see p. 108)

and the thickness of the claystone intervals interposed between them (see Text-fig. 3). The most recent marker bed exposed in the component-section B is marker bed *p*, which crops out a few meters below the watershed.

ACKNOWLEDGEMENTS

We wish to thank J. Backman, I. Raffi, D. Rio, N. J. Shackleton and R. Sprovieri, who kindly placed their not yet published manuscripts at our disposal.

We are grateful to M. B. Cita, J. Remane, F. Ricci Lucchi, G. Ruggieri, R. Sprovieri, J. Van Couvering and particularly to G. B. Vai for the critical revision of this paper. The drawings were made by L. Casoni, P. Ferraresi and G. Zini.

REFERENCES

- AGUIRRE, E. & PASINI, G., 1985, The Pliocene/Pleistocene Boundary: Episodes (Internat. Geosc. Newsmagazine), 8: 116-120.
- AZZAROLI, A., COLALONGO, M.L., NAKAGAWA, H., PASINI, G., RIO, D., RUGGIERI, R., SARTONI, S. & SPROVIERI, R. (in press), The Pliocene/Pleistocene boundary in Italy. In Van Couvering, J.A. (ed.), The Quaternary Boundary Definition and Worldwide Correlation: 19 pp.
- BACKMAN, J. & SHACKLETON, N.J., 1983, Quantitative biochronology of Pliocene and Early Pleistocene calcareous nannoplankton from the Atlantic, Indian and Pacific Oceans: *Mar. Micropaleont.*, 8: 141-170.
- , —, & TAUXE, L., 1983, Quantitative nannofossil correlation to open ocean deep-sea section from Plio-Pleistocene boundary at Vrica, Italy: *Nature*, 304: 156-158.
- BASSETT, M.G., 1985, Towards a «Common Language» in Stratigraphy: Episodes (Internat. Geosc. Newsmagazine), 8: 87-92.
- BERGGREN, W.A., KENT, D., FLYNN, J.J. & VAN COUVERING, J.A., 1985, Cenozoic geochronology: *Geol. Soc. Amer. Bull.*, 96: 1407-1418.
- , —, & VAN COUVERING, J.A., 1985, Neogene geochronology and chronostratigraphy. In Snelling, N. J. (ed.), The Chronology of the Geological Record: Geological Society of London, Memoir 10: 211-250.
- BERTOLANI MARCHETTI, D., ACCORSI, C.A. & BANDINI MAZZANTI, M., 1978, Primi dati palinologici sulla serie marina plio-pleistocenica di Vrica presso Crotone (Calabria): *Giorn. Botanico Ital.*, 4: 296.
- BOWEN, D.Q., 1985, Quaternary Geology. A Stratigraphic Framework for Multidisciplinary Work. Pergamon Press: 237 pp.
- CANDE, S.C. & KENT, D.V., 1992, A new geomagnetic polarity time scale for the late Cretaceous and Cenozoic: *Journ. Geophys. Res.*, 97, B 10: 13.917-13.951.
- CHANNEL, J.E.T., DI STEFANO, E. & SPROVIERI, R., 1992, Calcareous plankton biostratigraphy, magnetostratigraphy and paleoclimatic history of the Plio-Pleistocene Monte S. Nicola section (Southern Sicily): *Boll. Soc. Paleont. Ital.*, 31: 351-382.
- , RIO, D., SPROVIERI, R. & GLAÇON, G., 1990, Biomagnetostratigraphic correlations from Leg 107 in the Tyrrhenian Sea. In Kastens, K.A., Masle, J. *et al.*, *Proc. ODP, Sci. Results*, 107: 670-682.
- CITA, M.B., 1973, The Pliocene record in the deep-sea Mediterranean sediments. I. Biostratigraphy and Chronostratigraphy. In Ryan W.B., Hsu K.J. *et al.*, Initial Reports of the Deep Sea Drilling Project, 13, Washington DC (U.S. Government Printing Office): 1343-1379.
- , AZZAROLI, A., BARTOLINI, C., BINI, A., COLALONGO, M.L., GAETANI, M., MAZZANTI, R., MEDIOLI, F., OROMBELLI, G., PASINI, G., PETRUCCI, L., RICCI LUCCHI, F., RIO, D., RUGGIERI, R., SPROVIERI, R. & VAI, G.B., 1991, The Status of the Quaternary. A position paper by the Italian Commission on Stratigraphy. Report presented at XIII Inqua Congress (Peking, 1991).
- COLALONGO, M.L., 1968, Cenozoico a Foraminiferi ed Ostracodi nel Pliocene e basso Pleistocene della Serie del Santerno e dell'Appennino romagnolo: *Giorn. Geol.*, 35: 29-61.
- , CREMONINI, G. & SARTONI, S., 1978, La sezione stratigrafica di Rio Vendina (Messiniano-Pleistocene, Reggio Emilia): *Soc. Ital. Sc. Nat. e Museo Civ. Stor. Nat. Milano, Atti*, 119: 61-76.
- , NANNI, T. & RICCI LUCCHI, F., 1979, Sedimentazione ciclica nel Pleistocene anconetano: *Geologica Romana*, 18: 71-92.
- & PASINI, G., 1980, La ostracofauna della Sezione Vrica in Calabria (con considerazioni sul limite Neogene/Quaternario): *Boll. Soc. Paleont. Ital.*, 19: 44-126.
- , PELOSIO, G., RAFFI, S., RIO, D., RUGGIERI, G., SARTONI, S., SELLI, R. & SPROVIERI, R., 1982, Opredelenie Neogen-Cetverticnoi Granitsy. In Kartashov I. P. & Nikiforova K.V. (eds), *Issledovaniya cetverticnogo perioda. Izbrannye stat'i XI Kongressa INKVA*: 23 pp.
- , —, RAFFI, I., RIO, D., SARTONI, S. & SPROVIERI, R., 1984, Biochronology of the Italian marine Pliocene and Lower Pleistocene. *Proc. of XXVII Internat. Geol. Congr.* 3: 109-127.
- , — & SARTONI, S., 1980, Neogene-Quaternario e definizione del relativo stratotipo: *Paleont. Stratigr. ed Evoluz.*, 1: 91-94.
- , — & —, 1981, Remarks on the Neogene/Quaternary boundary and the Vrica Section (Calabria, Italy): *Boll. Soc. Paleont. Ital.*, 20 (2): 99-120.
- COMBOURIEU-NEBOUT, N., SEMAH, F. & DJUBIANTONO, T., 1990, La limite Pliocène-Pleistocène: précisions magnétostratigraphiques et climatiques par l'étude série de la coupe-type de Vrica (Crotone, Italie): *C.R. Acad. Sci. Paris*, 311 (II): 851-857.
- COWIE, J.W. & BASSETT, M.G., 1989, IUGS 1989 Global Stratigraphic Chart. Supplement to Episodes 12, 2.
- DONDI, L. & PAPETTI, I., 1968, Biostratigraphical zones of Po valley Pliocene: *Giorn. Geol.*, 35: 63-98.
- D'ONOFRIO, S., 1981, I Foraminiferi bentonici della Sezione Vrica (Calabria, Italia): *Giorn. Geol.*, 43: 327-364.
- GLAÇON, G., RIO, D. & SPROVIERI, R., 1990, Calcareous plankton Pliocene-Pleistocene biostratigraphy in the Tyrrhenian sea (Western Mediterranean, Leg 107). In Kastens K.A., Masle J. *et al.*, *Proc. ODP, Sci. Results*, 107: 683-693.
- HEDBERG, H.D., (ed.), 1976, International Stratigraphic Guide. A Guide to Stratigraphic Classification, Terminology and Procedure. J. Wiley and Sons: 200 pp.
- HELLER, F., LIU, X.M., LIU, T.S. & XU, T.C., 1991, Magnetic susceptibility of loess in China: *Earth Planet. Sci. Lett.*, 103: 301-310.
- HILGEN, F.J., 1991, Astronomical calibration of Gauss to Matuyama sapropels in the Mediterranean and implications

- for the Geomagnetic Polarity Time Scale: *Earth Planet. Sci. Lett.*, 104: 226-244.
- KLITGORD, K.D., HUESTIS, S.P., MUDIE, J.D. & PARKER, R.L., 1975, An analysis of near-bottom magnetic anomalies: Sea-floor spreading and the magnetized layer: *Geophys. J.R. Astron. Soc.*, 43: 387-424.
- LA BRECQUE, J.L., KENT, D.V. & CANDE, S.C., 1977, Revised magnetic polarity time scale for Late Cretaceous and Cenozoic time: *Geology*, 5: 330-335.
- LANDINI, W. & MENESINI, E., 1978a, L'ittiofauna plio-pleistocenica della Sezione Vrica (Crotone - Calabria): *Boll. Soc. Paleont. Ital.*, 17: 143-175.
- & —, 1978b, Una nuova forma di Teleosteo (*Tavania crotonensis* n. gen., n. sp.) del Pliocene superiore italiano: *Boll. Soc. Paleont. Ital.*, 17: 257-261.
- LENTINI, F., 1971, La sezione plio-pleistocenica di Pistecchi sul bordo appenninico della fossa Bradanica: *Atti Soc. Gioenia Sc. Nat.*, 7: 109-192.
- MANKINEN, E.A. & DALRYMPLE, G.B., 1979, Revised geomagnetic polarity time scale for the interval 0-5 m.y. B.P.: *J. Geophys. Res.*, 84: 615-626.
- MCDougALL, I., 1979, The present status of the geomagnetic polarity time scale. In McElhinny, M.W. (ed.), *The Earth, its Origin, Structure and Evolution*. Academic Press, New York: 543-565.
- NAKAGAWA, H., 1981, Neogene/Quaternary boundary and correlation of Vrica Section. In Sastry, M.V.A., Kurien, T.K., Dutta, A.K. & Biswas, S. (eds), *Field conference Neogene/Quaternary boundary, India, 1979, Proceedings*, Geological Survey of India: 107-111.
- , MATOBA, Y., KITAZATO, H. & NIITSUMA, N., 1982a, Plio-Pleistocene stratigraphy in Oga Peninsula, northern Honshu, Japan. In Itihara, M. & Kuwano, Y. (eds), *The third report on the Pliocene-Pleistocene Boundary in Japan*: 59-69.
- , NIITSUMA, N., MITSUNASHI, T., ODA, M., TAKAYAMA, T. & SAKAI, T., 1982b, Plio-Pleistocene stratigraphy in Boso Peninsula, central Japan. In Itihara, M. & Kuwano, Y. (eds), *The third report on the Pliocene-Pleistocene Boundary in Japan*: 76-80.
- , —, ODA, M. & KITAZATO, H., 1982c, Plio-Pleistocene stratigraphy of Kakegawa area, central Japan. In Itihara, M. & Kuwano, Y. (eds), *The third report on the Pliocene-Pleistocene Boundary in Japan*: 81-86.
- , —, TAKAYAMA, T., MATOBA, Y., ODA, M., TOKUNAGA, S., KITAZATO, H., SAKAI, T. & KOIZUMI, I. (in press), Magnetostratigraphy of the Vrica Section, Italy, and its correlation with the Plio-Pleistocene of the Boso Peninsula, Japan. In: Van Couvering, J.A. (ed.), *The Quaternary Boundary definition and worldwide correlation. Final Report of the Internat. Geol. Correl. Progr. Proj. 41 «Neogene/Quaternary Boundary»*.
- NINKOVITCH, D., OPDYKE, N.D., HEEZEN, B.C. & FOSTER, J.H., 1966, Paleomagnetic stratigraphy, rates of deposition and tephrochronology in North Pacific deep sea sediments: *Earth Planet. Sci. Lett.*, 1: 476-492.
- OBRADOVICH, J.D., NAESER, C.W., IZETT, G.A., PASINI, G. & BIGAZZI, G., 1982, Age constraints on the proposed Plio-Pleistocene boundary stratotype at Vrica, Italy: *Nature*, 298: 55-59.
- OPDYKE, N.D., 1972, Paleomagnetism of deep-sea cores: *Rev. Geophys. Space Phys.*, 10: 213-249.
- & GLASS, B.P., 1969, The paleomagnetism of sediment cores from the Indian Ocean: *Deep-Sea Res.*, 16: 249-261.
- PASINI, G. & COLALONGO, M.L., 1977, The Vrica section (Calabria, Italy): III. Ostracoda distribution and their importance for the Neogene/Quaternary boundary. *Abstr. X INQUA Congr. (Birmingham 1977)*: 90.
- & —, 1980, Planktonic foraminifera as markers for the Neogene/Quaternary Boundary. *Abstr. XXVI Congr. Geol., Internat. (Paris, 1980)*: 644.
- & —, 1982, Recent research on the Vrica Section (Calabria, Italy), the proposed Neogene/Quaternary boundary-stratotype section. Report presented at the XI INQUA Congress (Moscow 1982): 75 pp.
- & — (in press), The Pliocene/Pleistocene Boundary-Stratotype at Vrica (Calabria, Italy). In Van Couvering, J.A. (ed.), *The Quaternary Boundary definition and worldwide correlation. Final Report of the Internat. Geol. Correl. Progr. Proj. 41 «Neogene/Quaternary Boundary»*.
- & SELLI, R., 1977, The marine terraces of the Crotone peninsula (Calabria, Italy): *Giorn. Geol.*, 41: 440-445.
- , — & COLALONGO, M.L., 1977a, The S. Maria di Catanzaro section (Calabria, Italy): *Giorn. Geol.*, 41: 423-430.
- , — & —, 1977c, The section of Caraffa di Catanzaro (Calabria, Italy): *Giorn. Geol.*, 41: 430-435.
- , —, — & D'ONOFRIO, S., 1977b, The section of Le Castella (Calabria, Italy): *Giorn. Geol.*, 41: 436-440.
- , —, TAMPIERI, R., COLALONGO, M.L., D'ONOFRIO, S., BORSETTI, A.M. & CATI, F., 1975, The Vrica Section. In Selli R. (ed.), *The Neogene-Quaternary Boundary, II Symposium (Bologna-Crotone), Excursion Guide-Book*: 62-72.
- PELOSIO, G. & RAFFI, S., 1973, Considerazioni sul limite Plio-Pleistocene della serie del T. Crostolo (preappennino reggiano): *L'Ateneo Parmense, Acta Nat.*, 2: 39-63.
- RAFFI, I., BACKMAN, J., RIO, D. & SHACKLETON, N.J. 1993, Plio-Pleistocene nannofossil biostratigraphy and calibration to oxygen isotope stratigraphies from DSDP Site 607 and ODP Site 677: *Paleoceanography*, 8 (3): 387-408.
- & RIO, D., 1979, Calcareous nannofossil biostratigraphy of DSDP site 132 - Leg 13 (Tyrrhenian Sea - Western Mediterranean): *Riv. Ital. Paleont. Strat.*, 85: 127-172.
- & —, 1980, Nuove osservazioni sulla distribuzione del nannoplancton calcareo nella serie de Le Castella (Calabria): *Paleont. strat. ed Evoluz.*, 1: 181-195.
- RAFFI, S., 1986, The significance of marine boreal molluscs in the Early Pleistocene faunas of the Mediterranean Area. *Abstr. Paleogeogr., paleoclimat. paleoecol.*, 52: 267-289.
- RAYMO, M.E., RUDDIMAN, W.F., BACKMAN, J., CLEMENT, B.M. & MARTINSON, D.G., 1989, Late Pliocene variation in northern hemisphere ice sheets and North Atlantic deep water circulation: *Paleoceanography*, 4: 413-446.
- RIO, D., 1982, The fossil distribution of coccolithophore genus *Gephyrocapsa* Kamptner and related Plio-Pleistocene chronostratigraphic problems. In Prell, W.L., Gardner, J.V. et al., *Initial Reports of the Deep Sea Drilling Project (Washington DC, U.S. Government Printing Office)*, 68: 325-343.
- , BACKMAN, J. & RAFFI, I., 1985, Calcareous nannofossil biochronology and the Pliocene/Pleistocene boundary. Preprint: 31 pp.
- , RAFFI, I. & BACKMAN, J. (in press), Calcareous nannofossil biochronology and the Pliocene/Pleistocene boundary. In

- Van Couvering J.A. (ed.), The Quaternary Boundary definition and worldwide correlation. Final Report of the Internat. Geol. Correl. Progr. Proj. 41 «Neogene/Quaternary Boundary».
- , — & VILLA, G., 1990a, Pliocene-Pleistocene calcareous nanofossil distribution patterns in the western Mediterranean. *In* Kastens, K.A., Mascle, J. *et al.*, Proc. ODP, Sci. Results, 197: 513-533.
- , SPROVIERI, R. & CHANNELL, J.E.T., 1990b, Pliocene-Early Pleistocene chronostratigraphy and the Tyrrhenian deep sea record from Site 653. *In* Kastens, K.A., Mascle J. *et al.* (eds), Proceedings of the Ocean Drilling Program, Scientific Results, 107: 705-714.
- , — & RAFFI, I., 1984, Calcareous plankton biostratigraphy and biochronology of the Pliocene-lower Pleistocene succession of the Capo Rossello area (Sicily): Marine Micropal., 9: 135-180.
- , — & THUNELL, R., 1991, Pliocene-Lower Pleistocene chronostratigraphy: a re-evaluation of Mediterranean type sections: Geol. Soc. Am. Bull., 103: 1049-1058.
- ROSSIGNOL-STRICK, M. & PLANCHAIS, N., 1985, Proj. Nat. et Dyn. Climat: 1 p.
- RUDDIMAN, W.F., RAYMO, M.E. & MAC INTYRE, A., 1986, Matuyama 41,000-years cycles: North Atlantic Ocean and Northern Hemisphere ice sheets: Earth Planet. Sci. Lett., 80: 117-129.
- , —, MARTINSON, D.G., CLEMENT, B.M. & BACKMAN, J., 1989, Pleistocene evolution: Northern Hemisphere ice sheets and North Atlantic ocean: Paleoceanography, 4: 353-412.
- RUGGIERI, G., 1962, La serie marina pliocenica e quaternaria della Romagna. Camera di Commercio, Ind. e Agric. di Forlì: 76 pp.
- , 1980, Sulla distribuzione stratigrafica di alcuni Ostracodi nel Pleistocene italiano: Boll. Soc. Paleont. Ital., 19: 127-135.
- , RIO, D. & SPROVIERI, R., 1984, Remarks on the chronostratigraphic classification of Lower Pleistocene: Boll. Soc. Geol. Ital., 103, 2: 251-259.
- , SPROVIERI, R., 1976a, Ricerche sul Siciliano di Palermo: le argille del Fiume Oreto: Boll. Soc. Geol. Ital., 84 (6): 1613-1622.
- & —, 1976b, La definizione dello stratotipo del Piano Siciliano e le sue conseguenze: Riv. Min. Sicil., 26 (151-153): 1-7.
- & —, 1977a, A revision of Italian Pleistocene stratigraphy: Geologica Romana, 16: 131-139.
- & —, 1977b, Selinuntiano, nuovo superpiano per il Pleistocene Inferiore: Boll. Soc. Geol. Ital., 96: 797-802.
- SELLI, R., ACCORSI, C.A., BANDINI MAZZANTI, M., BERTOLANI MARCHETTI, D., BIGAZZI, G., BONADONNA, F.G., BORSETTI, A.M., CATI, F., COLALONGO, M.L., D'ONOFRIO, S., LANDINI, W., MENESINI, E., MEZZETTI, R., PASINI, G., SAVELLI, C. & TAMPIERI, R., 1977, The Vrica Section (Calabria, Italy). A potential Neogene/Quaternary Boundary Stratotype: Giorn. Geol., 41: 181-204.
- SHACKLETON, N.J., BERGER, A. & PELTIER, W.R., 1990, An alternative astronomical calibration of the lower Pleistocene timescale based on ODP Site 677: Trans. R. Soc. Edinb., Earth Sci., 81: 251-261.
- SPAAR, P., 1983, Accuracy in correlation and ecological aspects of the planktonic foraminiferal zonation of the Mediterranean Pliocene: Utrecht Micropal. Bull., 28: 1-160.
- SPROVIERI, R., 1968, La serie plio-pleistocenica di Agrigento. Committee Medit. Neogene Stratig., Proc. IV Session. Bologna, 1967: Giorn. Geol., 35, 3: 295-301.
- , 1978, I foraminiferi bentonici della sezione Plio-Pleistocenica di Capo Rossello (Agrigento, Sicilia): Boll. Soc. Paleont. Ital., 17: 68-97.
- , 1992, Mediterranean Pliocene biochronology: a high resolution record based on quantitative planktonic foraminifera distribution: Riv. Ital. Paleont. Strat., 98: 61-100.
- SUC, J.-P. & ZAGWIJN, W.A., 1983, Plio-Pleistocene correlations between the northwestern Mediterranean region and northwestern Europe according to recent biostratigraphic and palaeoclimatic data: Boreas, 12, 3: 153-166.
- TAUXE, L., OPDYKE, N.D., PASINI, G. & ELMI, C., 1983, Age of the Plio-Pleistocene boundary in the Vrica section, southern Italy: Nature, 304: 125-129.
- THUNELL, R.C., 1979, Pliocene-Pleistocene paleotemperature and paleosalinity history of the Mediterranean Sea: Results from DSDP Sites 125, 132: Marine Micropal., 4: 173-187.
- TORTORICI, L., 1982, Analisi delle deformazioni fragili dei sedimenti postorogenici della Calabria: Boll. Soc. Geol. Ital., 100 (3): 291-308.
- VAN DER HAMMEN, T., WIJMSTRA, T.A. & ZAGWIJN, W.H., 1971, The Late Cenozoic glacial ages. Yale Univ. Press, New Haven and London: 392-424.
- WATTS, W.A., 1985, A long pollen record from Laghi di Monticchio, southern Italy: a preliminary account: J. Geol. Soc., 142, 3: 491-499.
- ZAGWIJN, W.H. & SUC, J.-P., 1984, Paleobiol. Cont., 14, 2: 475-483.
- ZIJDERVELD, J.D.A., HILGEN, F.J., LANGEREIS, C.G. & VERHALLEN, P.J.J.M., 1991, Integrated magnetostratigraphy and biostratigraphy of the upper Pliocene-lower Pleistocene from the Monte Singa and Crotone areas in Calabria, Italy: Earth Planet. Sci. Lett., 107: 697-714.

(manuscript received February 5, 1993
accepted March 10, 1994)

Giancarlo PASINI

Istituto di Geologia Marina del
Consiglio Nazionale delle Ricerche
Via Gobetti 101, 40129 Bologna, Italy

Maria Luisa COLALONGO

Dipartimento di Scienze Geologiche
dell'Università di Bologna
Via Zamboni 67, 40127 Bologna, Italy