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Biostratigraphical and paleoecological evidences in non-costate *Bulimina* group of Pliocene-Pleistocene sediments (Latium - Southern Umbria, Central Italy)

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ABSTRACT – In the context of a main study on foraminiferal assemblages from the Plio-Pleistocene sediments of central Italy aimed at a paleoenvironmental reconstruction of the Neogene basins of Latium and Umbria, morphological variations and stratigraphical evidence of the non-costate *Bulimina* group are studied. The foraminiferal assemblages show a gradual increase in abundance of the non-costate buliminids from the Upper Piacenzian to the Lower Sannicciense either in circalittoral environment, or infralittoral at the transition between circalittoral and infralittoral environments. The highest concentration and intraspecific and specific morphological variation of the non-costate *Bulimina* group were recorded in more sheltered areas of the basin characterised by a fine sedimentation (area between M. Soratte-M. Cornicolani structural high and M. Sabini). Each species shows four main morphological trends: 1) greater development of the *Bulimina marginata* undercut as far as the N/Q boundary; 2) not aligned chamber arrangement starting from the Upper Pliocene, with the appearance of *Bulimina elegans marginata*; 3) reduction of the undercut and vertical aligned chambers starting from the base of the Pleistocene (*Bulimina etnea*); 4) development of elongate and slender forms. The presence of these morphotypes allows us to date the sediments of this area, which in general are devoid of planktonic markers.

RIASSUNTO – [Evidenze biostratigrafiche e paleoecologiche nel gruppo delle *Bulimine* non costate nei sedimenti plio-pleistocenici del Lazio e dell'Umbria meridionale (Italia centrale)] – Nell'ambito di uno studio più ampio riguardante le associazioni a foraminiferi delle successioni plio-pleistoceniche dell'Italia centrale e che mira alla ricostruzione paleoambientale dei bacini neogenici dell'area umbro-laziale, si sono studiate le variazioni morfologiche e le implicazioni stratigrafiche riguardanti il gruppo delle *Bulimine* non costate. Un'attenta analisi delle associazioni presenti, infatti, ha evidenziato un incremento graduale della loro frequenza dalla parte alta del Piacenziano fino alla base del Sannicciense sia in ambiente circalittorale che di transizione infralittorale-circalittorale ed infralittorale. Tuttavia la massima concentrazione delle *Bulimine* non costate, con una notevole diversità sia a livello specifico che intraspecifico, si è registrata in aree del bacino più protette a sedimentazione fine (area compresa tra l'alto strutturale M. Soratte-M. Cornicolani ed i Monti Sabini). Lo studio dei morfotipi, nell'ambito di ciascuna specie, ha inoltre mostrato quattro trend morfologici principali: 1) maggiore sviluppo dell'undercut nell'ambito di *Bulimina marginata*; 2) disposizione non allineata verticalmente delle camere a partire dal Gelasiano con la comparsa di *Bulimina elegans marginata*; 3) riduzione dell'undercut ed allineamento verticale delle camere a partire dalla base del Pleistocene; 4) sviluppo di morfotipi allungati e slanciati. Pertanto il rinvenimento di forme corrispondenti alle suddette tipologie morfologiche consente una precisa collocazione bio e cronostatigrafica di questi sedimenti i quali generalmente sono privi di markers planctonici.

INTRODUCTION

A study conducted on Central Italy foraminiferal assemblages of Pliocene/Pleistocene age showed significant intraspecific variability of some species belonging to the non-costate *Bulimina* group. As these species show a clear stratigraphic and environmental distribution, they may be used as ecobiostratigraphic indicators. The morphological characters of these species are described and suggest their preferred environments and age. In the past few years, several studies have been conducted (Collins, 1989; Violanti, 1996), above all by Dutch authors (Van der Zwaan, 1983; Verhallen, 1986, 1987, 1991; Jorissen, 1988; Van der Zwaan & Jorissen, 1991) on different species belonging to the non-costate *Bulimina* group, from both modern environments and fossil assemblages. Today, as these foraminifers still have a high

morphological variability, there is no agreement on whether they are to be regarded as morphotypes of a single species or as different species. Hence, while some authors consider many forms as separate species, also of stratigraphic relevance (Cantalamesa *et al.*, 1986, 1997; Carboni *et al.*, 1993; Carboni & Palagi, 1997), others view them as a varieties of a single or two species (Verhallen, 1991). In particular, the Dutch school recognises two groups belonging to the *B. marginata* and *B. aculeata* species and include all the other species in one of the two groups, depending on whether the species have the undercut (*B. marginata*) or fail to have the undercut (*B. aculeata*). This element is considered as «a typical angle at the lower margin of the chamber wall, which divides the outer chamber into a convex upper and flat lower part. The latter is more or less perpendicular to test axis» (Verhallen, 1991). Consequently, forms such as *B.*

elegans, *B. elegans marginata*, *B. etnea*, *B. corsiniana*, *B. fusiformis*, *B. sublimbata* are not recognised at a specific level but only as varieties. Though agreeing on the convenience of these subdivisions, the paper discusses the morphotypes mentioned above at specific or subspecific level. This choice is dictated by their distribution (in time and space) in the sediments of the Tiber-Latium area, where the lack of stratigraphic markers would make it difficult to accurately date these sediments.

GEOLOGICAL SETTING

The investigated sediments belong to dominantly clayey and clayey-sandy terrigenous sequences which were deposited in an area extending from the Latium coast (W) to the Sabini mountains (E), in a time range comprised between the Early Pliocene (*Globorotalia margaritae* Zone) and the Early Pleistocene (*Globigerina cariaensis* Zone). The basin is separated into two NW-SE-trending sectors by the Soratte-Cornicolani structural high (Faccenna & Funicello, 1993). The oldest sediments, ascribed to the top part of the *Sphaeroidinellopsis* Zone-basal part of the *Globorotalia margaritae* Zone, occur along the westernmost belt of the investigated area, which accommodates the most comprehensive portion of the sequence (Carboni & Di Bella, 1997). Younger sediments are exposed towards the Apennine ridge and they may be attributable to the Piacenzian (*Globorotalia aemiliana* Zone – Roman area, Valle Ricca), to the Gelasian (*Globorotalia inflata* Zone – Valle Ricca area) and to the Lower Pleistocene (*Globigerina cariaensis* Zone – Tiber-Latium area) (Ambrosetti *et al.*, 1987; Arias *et al.*, 1990; Carboni, 1975; Carboni *et al.*, 1992; Carboni *et al.*, 1993; Di Bella, 1995). The sedimentation is not always continuous. In particular, three sedimentary cycles may be observed: two of Pliocene age and one of Pleistocene age. In the Pliocene, the two cycles are separated by a hiatus spanning the *Globorotalia margaritae* - *Globorotalia puncticulata* concurrent Zone, which is found throughout the Tyrrhenian Tuscany-Latium ridge (Barberi *et al.*, 1994). Another hiatus, spanning the Upper Pliocene and the Lower Pleistocene, separates the Pliocene from the Pleistocene sediments. However, the length of this hiatus is variable; it reaches its maximum (Piacenzian and Gelasian) in the marginal parts of the Tiber basin and on the structural high, whereas it shrinks and spans only the Gelasian (or part of it) along the Anzio coast. At present, the sites with continuous sedimentation are rare and located in the deeper part of the Tiber graben (Carboni *et al.*, 1993; Di Bella, 1995).

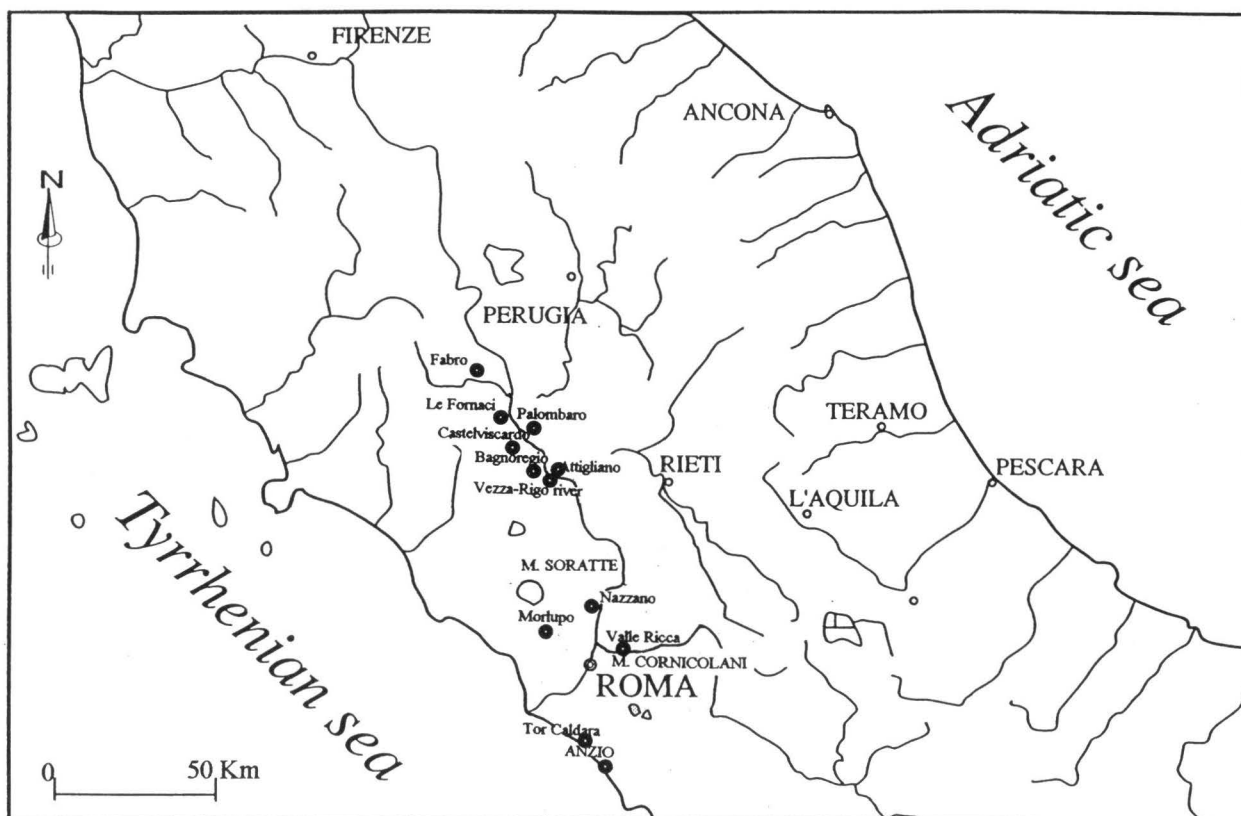
The marine sedimentation in the eastern sector of Rome (middle and low Tiber valley) ends in the basal Pleistocene (*Globigerina cariaensis* Zone). In these sediments, no nordic guests have ever been identified which in the contrary, in the area of Rome, in a simi-

lar setting yielded *Arctica islandica* (Bonadonna, 1968; Conato *et al.*, 1980; Marra *et al.*, 1995). Towards the west, marine sedimentation seems to continue as high as the Emilian as suggested by the presence of *Hyalinea balthica* (Carboni, 1980; Carboni & Di Bella, 1997; Malatesta & Zarlenga, 1985).

MATERIALS AND METHODS

The study was carried out on more than 200 samples, collected from both stratigraphic sections and single sites from an area covering the Latium and part of southern Umbria (Central Italy, Text-fig. 1). The analyses of the foraminiferal assemblages conducted in these samples confirmed the previous data reported in the literature. On the whole, four main environments were identified: circalittoral characterised by abundant plankton (30%), *Uvigerina* spp., *Melonis* spp. and Cassidulinidae; circalittoral to infralittoral with a Buliminidae-Cassidulinidae assemblage; infralittoral in the most abundant species are *Ammonia* spp., *Elphidium* spp., *Lobatula lobatula*; and a transition to continental facies characterised by low salinity tolerant species (*Ammonia tepida*, *Criboelphidium decipiens*, *Nonion depressulum*) (Ambrosetti *et al.*, 1987; Carboni *et al.*, 1993; Carboni, 1994; Di Bella, 1995; Carboni & Di Bella, 1996a, b, 1997; Carboni & Palagi, 1997). The buliminids were found in the first three environments (Tab. 1). Only the most significant sections (Bagnoregio, Fabro, Tor Caldara, Valle Ricca, Vezza and Rigo Rivers) are shown. The frequency and distribution of the identified species are indicated beside each section. The percentages of representatives of the genus *Bulimina* were computed on a population of 300 individuals from each sample (first treated with H₂O₂ and then rinsed with a 0.88 µm mesh sieve); their frequencies range from less than 1% up to 35%. The averages of the percentages, calculated in each site and for each different paleoenvironment, are shown in the diagram of Text-fig. 2.

For taxonomic purpose, the investigated forms were clustered on the ground of the presence or not of the undercut. Another group was established and comprises the forms whose undercut was only present in some portions of the test. For attributing the individuals to the different species, the following features were taken into consideration: slenderness (ratio between maximum length and maximum width), shape, inflation and chamber arrangement (vertically aligned or not aligned chambers). Subordinately, also the ornamentation (spinoseness), namely the distribution and shape of spines was considered, even if this feature might be related to external factors (Collins, 1989). Additionally, due to the high intraspecific variability of some species, reference was made to informal groups (*sensu* Borsetti *et al.*, 1986), including one typical form and one or multiple morphotypes with less evident typical features. As a result, the following groups were named: *B. aculeata* gr., *B. elegans*



Text-fig. 1 - Location map of the studied area with sampled sections.

gr., *B. elongata* gr.; the species *B. etnea*, *B. fusiformis*, *B. marginata* and *B. sublimbata*, for their great intraspecific variability, were considered also as discrete groups. *B. corsiniana* was not regarded as a separate group because of the low number of specimens.

For the biostratigraphy, Iaccarino *et al.* (1994) benthic foraminiferal scheme was adopted and correlated to the planktonic Mediterranean zonations of Iaccarino (1985) and Cita (1975) as emended by Sprovieri (1992). As regards the chronostratigraphy, the subdivision of the Plio-Pleistocene, recently proposed (Rio *et al.*, 1994; Cita & Castradori, 1995; Cita *et al.*, 1996), was followed.

DESCRIPTION OF THE SPECIES AND OF THEIR MORPHOTYPES

FORMS WITHOUT UNDERCUT

- *Bulimina aculeata* gr. (*Bulimina aculeata* d'Orbigny, *Bulimina basispinosa* Tedeschi & Zanmatti, *Bulimina gibba* Fornasini, *Bulimina minima* Tedeschi & Zanmatti)

This group comprises forms without undercut, (i.e. *Bulimina minima*, *B. basispinosa*, *B. gibba*), which have

morphological affinities with *B. aculeata*, the most easily identifiable species. The typical form (Text-fig. 5, a; Pl. 1, fig. 11) has: stumpy shape, length/width ratio <1.3 coilings with widespread granulation both on the wall and at the margins of the chambers and well developed spines in the lower portion of the test. These spines include a larger central one. The highest variability of these forms lies in the ornamentation and slenderness of the shells. Three morphotypes were distinguished: the first has a more slender shape, 3-4 more inflated chamber coilings and absence of real spines in the lower portion of the shell; sometimes, it has one more marked spine. Its chamber arrangement ranges from aligned to slightly staggered. This morphotype has a morphological affinity with *B. basispinosa* (Text-fig. 3, d and e). The second morphotype, instead, is smaller than the previous one, has 2 or 3 coilings, chamber walls with pustules and, occasionally, a larger central spine. This form is more similar to *B. minima* (Text-fig. 3, f and g). Finally, a third morphotype with 4-6 chamber coilings was observed. Its chambers are generally aligned with those of the last coiling (Text-fig. 3, i); they are particularly large and lobate and tend to overlap the chambers of previous coilings. This morphotype is similar to *B. gibba* (Text-fig. 3, i and l). Paleoecologically, the three forms have a similar distribution; as a matter of fact they are most-

Pliocene - Zanclean			
<i>(Uvigerina rutila Zone - Globorotalia margaritae Zone)</i>			
Sites	Environment	non-costate <i>Bulimina</i> gr.	costate <i>Bulimina</i> gr.
Tor Caldara	circalittoral-epibathyal	1.34%	0.96%
Pliocene - Zanclean			
<i>(Uvigerina rutila Zone - Globorotalia puncticulata Zone)</i>			
Sites	Environment		
Anzio coast	circalittoral	0.00	0.55%
Pliocene - Piacenzian			
<i>(Anomalinoidea helicinus Zone - Globorotalia aemiliana Zone)</i>			
Sites	Environment		
Fabro	circalittoral	3.99%	3.71%
Castelviscardo	infralittoral	0.59%	0.00%
Anzio coast	circalittoral	2.62%	3.32%
Pliocene - Gelasian			
<i>(Bulimina marginata Zone - Globorotalia inflata Zone)</i>			
Sites	Environment		
Le Fornaci	circalittoral	1.14%	0.46%
Valle Ricca	circalittoral	12.57%	1.22%
Nazzano	infralittoral	4.00%	0.00%
Pleistocene - Santernian			
<i>(Bulimina marginata Zone - Globigerina cariacensis Zone)</i>			
Sites	Environment		
Valle Ricca	circalittoral	14.84%	0.00%
Palombaro	circalittoral	6.26%	3.36%
Valle Ricca	infra-circalittoral	16.29%	0.30%
Vezza and Rigo river	infra-circalittoral	13.93%	0.00%
Nazzano	infra-circalittoral	1.43%	0.00%
Attigliano	infra-circalittoral	7.70%	0.00%
Morlupo	infra-circalittoral	18.70%	0.00%
Anzio coast	infra-circalittoral	5.27%	0.00%
Nazzano	infralittoral	2.98%	0.00%
Bagnoregio	infralittoral	6.22%	0.00%
Nazzano	infralittoral-brackish	1.20%	0.00%

Tab. 1 - List of sites and sections studied with their respective paleoenvironments and average percentages of non-costate and costate buliminids.

ly represented in sediments which were deposited in deeper environments (from circalittoral to upper epibathyal). These forms tend to diminish in the upper circalittoral and infralittoral environments and in coarser grain size sediments. In terms of time distribution, *B. minima* seems to dominate the non-costate *Bulimina* group of the Early Pliocene (Zanclean) and Middle Pliocene (Piacenzian), whereas *B. aculeata* (associated with forms similar to *B. basispinosa*), sharply increases starting from the Gelasian, but above all, in the Early Pleistocene where *B. minima* is missing (Text-figs. 4, 5, 6).

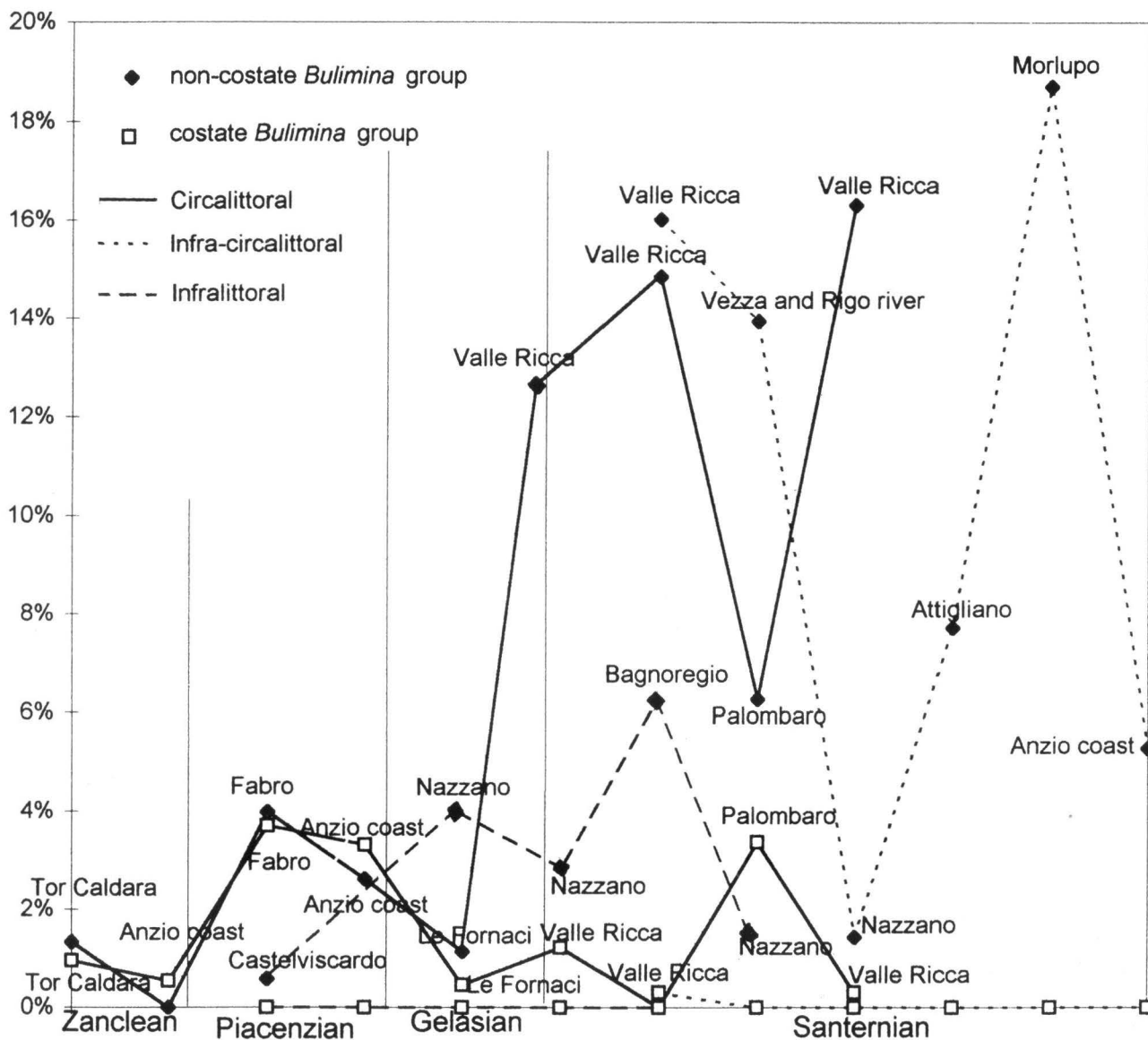
- *Bulimina elongata* gr. (*Bulimina elongata* d'Orbigny, *Bulimina lappa* Cushman & Parker)

These forms have a length/width ratio >1 and usually elongate morphotypes. The arrangement of the chambers, generally inflated, is not aligned and irregular. They belong to two morphotypes: the first, *B. elongata* (Text-fig. 7, a and b), without any spine, has an occasionally off-centred aperture with respect to the longitudinal axis of the test. The second, *B. lappa* (Text-fig. 7, g), with an arrangement similar to the first one, has small spines and pustules in the first

chambers. In the studied area these forms occur from the Pleistocene and are recorded in shallow environments (from the infralittoral to the infra-circalittoral transition), with coarser-grained bottom: sandy clays and sands (Text-figs. 8, 9).

- *Bulimina etnea* gr. (*Bulimina etnea* Seguenza)

The typical species is, in the sediments of the investigated area, the first and, sometimes, the only stratigraphic datum which signals the Pleistocene (Text-figs. 4, 6, 9). The distinctive features of this form, poorly reported in the literature (Carboni *et al.*, 1993; Carboni, 1994) are: typical triangular transversal section; alignment and inflation of chambers; no ornamentation, except for the first chamber which always displays a more or less developed strong spine. Generally, this species has no undercut. Occasionally, the chambers in the last coilings, are less rounded and have a poorly pronounced undercut (Text-fig. 10, a, b and c). *B. etnea* is always very rare and present in the Latium sediments of Pleistocene age (of both circalittoral and circalittoral/infralittoral transition environment). Forms similar to *B. etnea* are encountered in the Late Pliocene, associated with *B. elegans mar-*



Text-fig. 2 - Average percentages of non-costate and costate buliminids through Zanclean-Santernian interval recorded in the various sections in circalittoral, circalittoral to infralittoral and infralittoral environment.

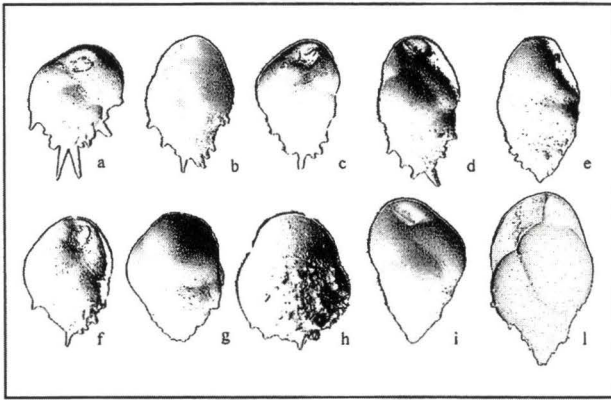
ginata. Like the typical form, also these morphotypes have a subtriangular section and a vertical alignment of the chambers; however, their distinctive features are: stronger spinoseness on the external margin of their chambers and albeit poorly evident undercut. These morphotypes are much smaller than the Pleistocene ones (*B. aff. etnea*, Text-fig. 10, d-h).

FORMS WITH UNDERCUT

- *Bulimina marginata* gr. (*Bulimina marginata* d'Orbigny)

This species is characterised by a constant undercut in all the coilings of the chambers. Its

length/width ratio is very variable. However, in the Pliocene, stumpy morphotypes prevail (Text-fig. 11, b and f). The arrangement of the chambers is generally regular and aligned and they show a great variability on inflation. The ornamentation, consisting of spines, mostly cover the outer margin of the chambers, even if the walls of the lower portion of the shell have granulations. The aperture has a wide periapertural depression (Verhallen, 1986, 1991). The species varies above all in terms of spinoseness (*B. marginata* forma *denudata* Cushman & Parker, Jorissen 1988), length/width ratio, more or less marked undercut and chamber arrangement. Intraspecific variability is noted above all starting from the upper part of the Gelasian, where two major morphotypes stand out: the first with a very



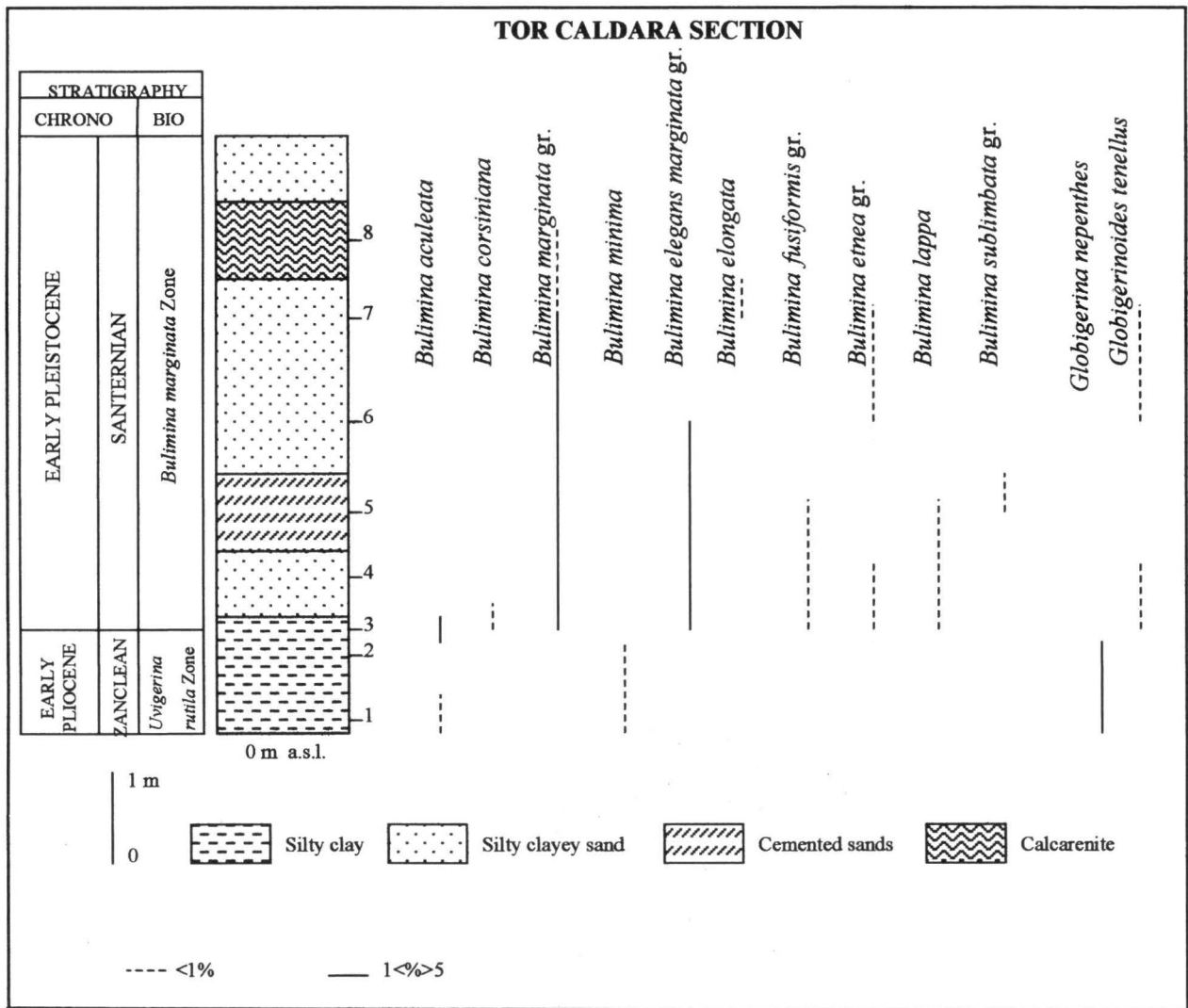
Text-fig. 3 - *Bulimina aculeata* gr.: a - c) *Bulimina aculeata* typical form; d, e) *Bulimina basispinosa*-type; f, g) *Bulimina minima*-type; h) detail of *Bulimina aculeata*-type showing the absence of undercut; i, l) *Bulimina gibba*-type.

pronounced undercut (Text-fig. 11, l and m), and the second one with a clear vertical alignment of the chambers (Text-fig. 11, n, o and p).

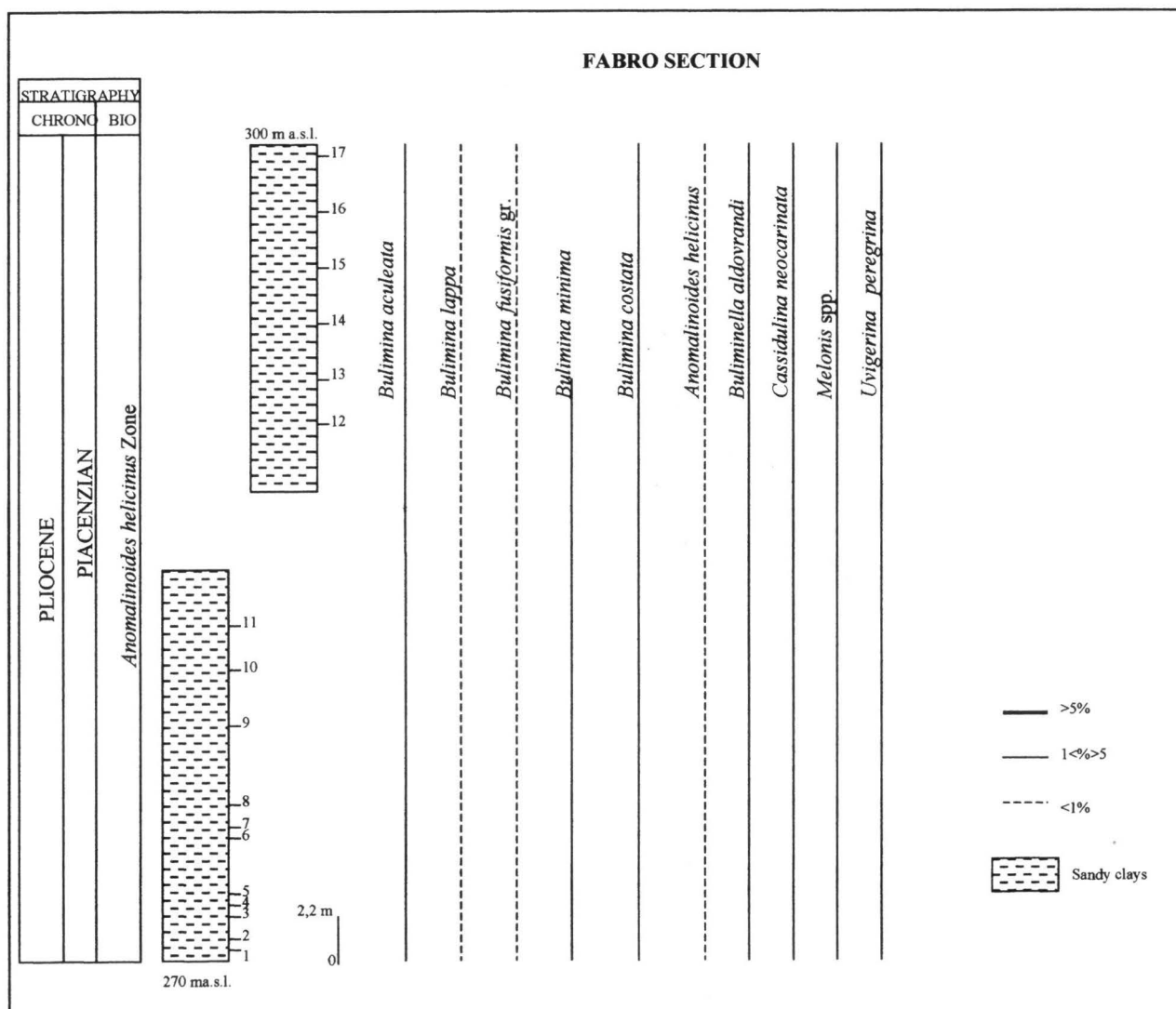
In terms of distribution and frequency, *B. marginata* is the most widespread species of the genus; it has its concentration peaks in fine sediments of circalittoral or infra-circalittoral transition environments; in the Gelasian and Santernian sediments of the middle and low Tiber valley, it becomes the dominant species, together with *Cassidulina neocarinata* (Text-figs. 6, 8 and 9).

FORMS WITH UNDERCUT LIMITED TO SOME PORTIONS OF THE TEST

This part of the study analyses the forms whose undercut is limited to some portions of the test. These forms may be regarded as intermediate



Text-fig. 4 - Lithology of the Tor Caldara section. The scheme shows the distribution and frequency of the non-costate *Bulimina* groups and the main taxa. Zones after Iaccarino *et al.* (1994).



Text-fig. 5 - Lithology of the Fabro section. The scheme shows the distribution and frequency of the non-costate *Bulimina* groups and the main taxa. Zones after Iaccarino *et al.* (1994).

between the *B. aculeata* and *B. marginata* groups. This group consists of the following species:

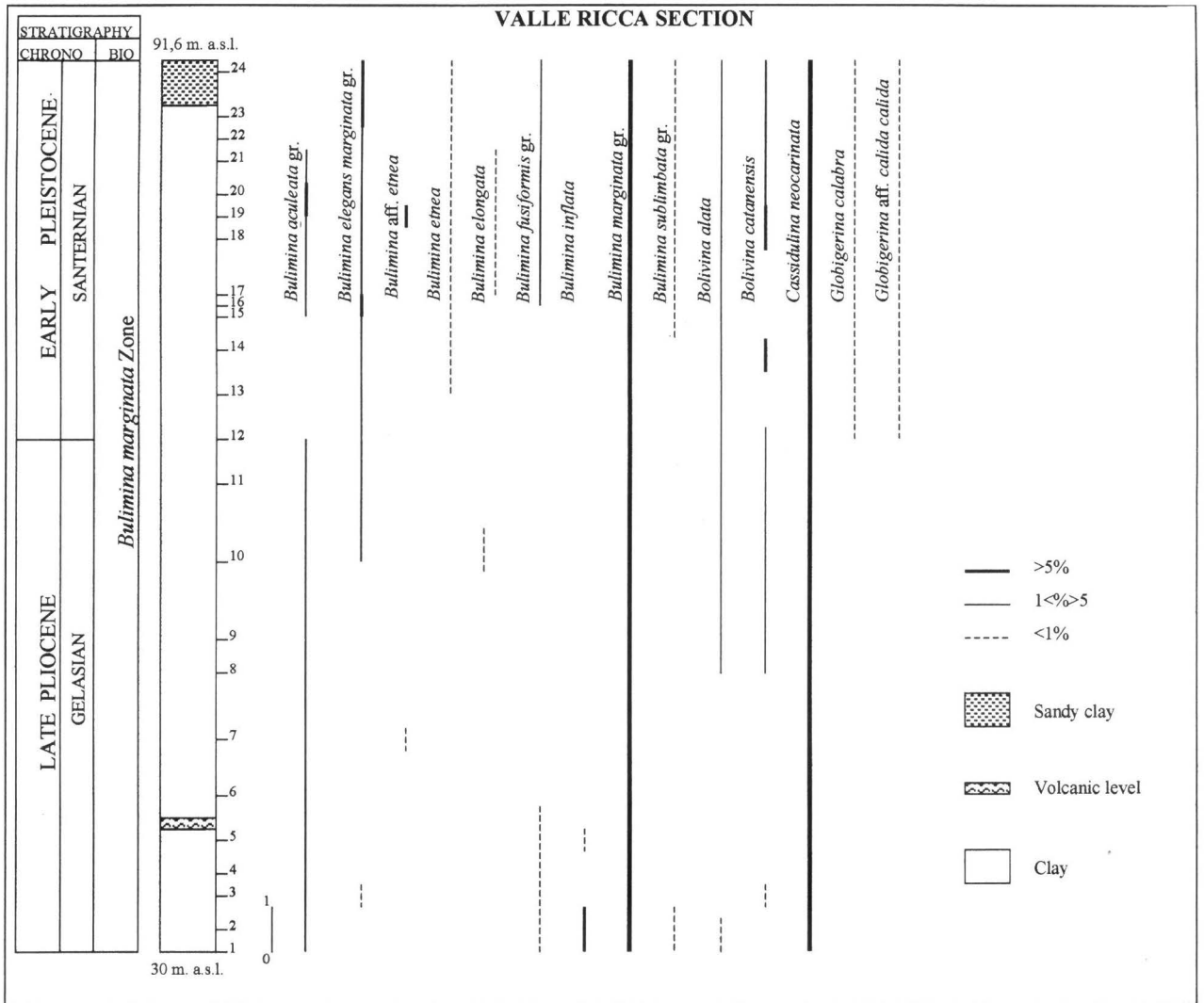
- *Bulimina fusiformis* gr. (*Bulimina fusiformis* Williamson *sensu* Fornasini)

The typical form has a length/width ratio >1 and a not aligned arrangement of chambers which form about 5 coilings. The chambers are usually elongate in their last coilings and, to a lesser extent, in the lower portion of the shell, where the undercut is present but poorly pronounced. These forms are rather variable and some of them can hardly be discriminated from some elongate morphotypes of *B. marginata* (Text-fig. 12, b - f; Text-fig. 11, g, h and j). The latter, however, displays undercut in all the coilings of the chambers. *B. fusiformis*, albeit rare, is encountered starting from the

B. marginata Zone (upper part of the *Globorotalia aemiliana* Zone), whereas small morphotypes with a limited undercut are found starting from the upper part of the *Anomalinoidea helicinus* Zone (lower part of the *Globorotalia aemiliana* Zone) (Text-fig. 12, a; Text-fig. 5). However, the species has its frequency peak in the Lower Pleistocene, in upper circalittoral and infracircalittoral transition environments (Text-figs. 6, 8 and 9), but its occurrence in infralittoral environment cannot be ruled out.

- *Bulimina corsiniana* Perconig

Elongate form with poorly marked undercut in its initial chambers. Small spines in its lower portion. Aligned and regular chamber arrangement except for the last two coilings where the chambers are staggered.



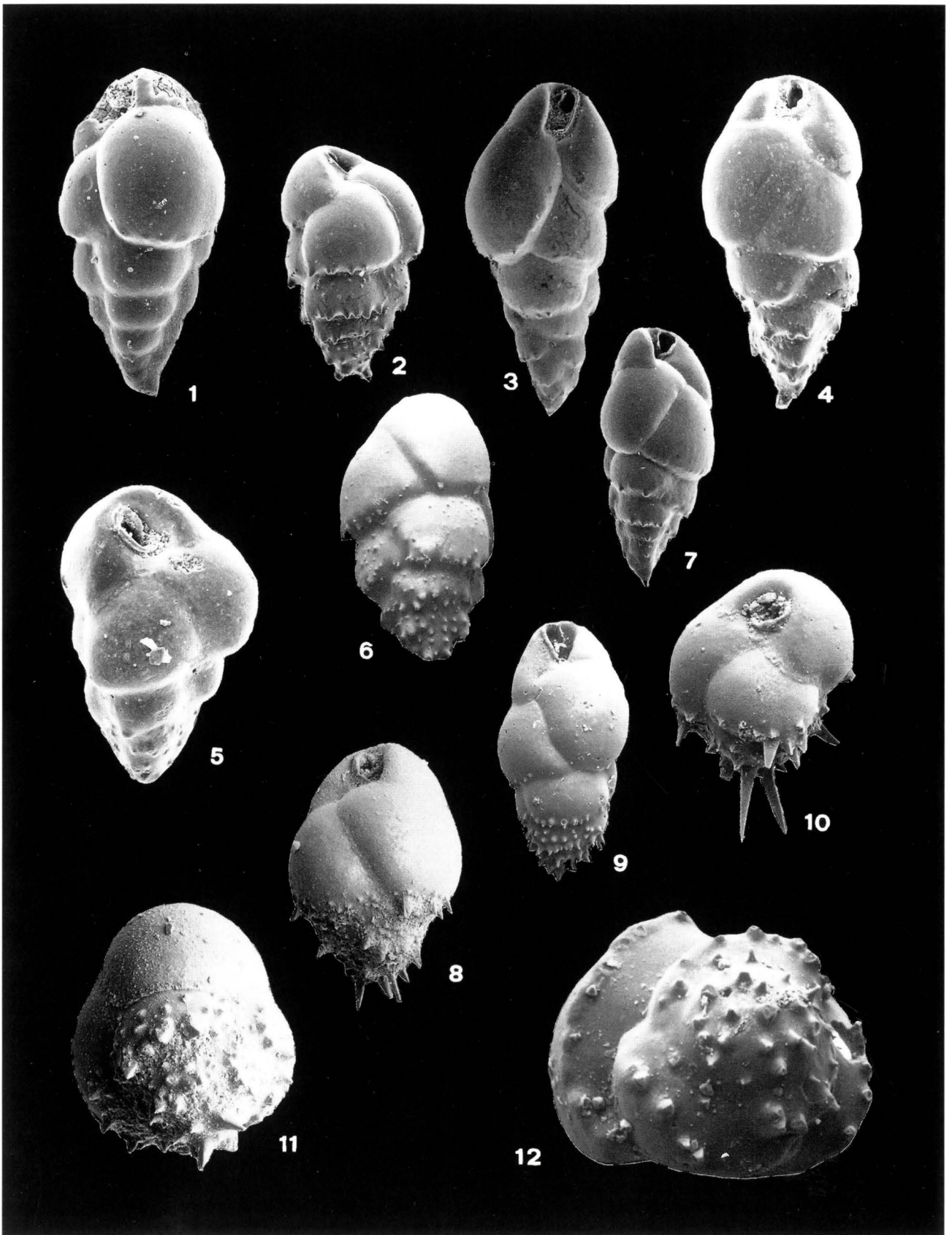
Text-fig. 6 - Lithology of the Valle Ricca section. The scheme shows the distribution and frequency of the non-costate *Bulimina* groups and the main taxa. Zones after Iaccarino *et al.* (1994).

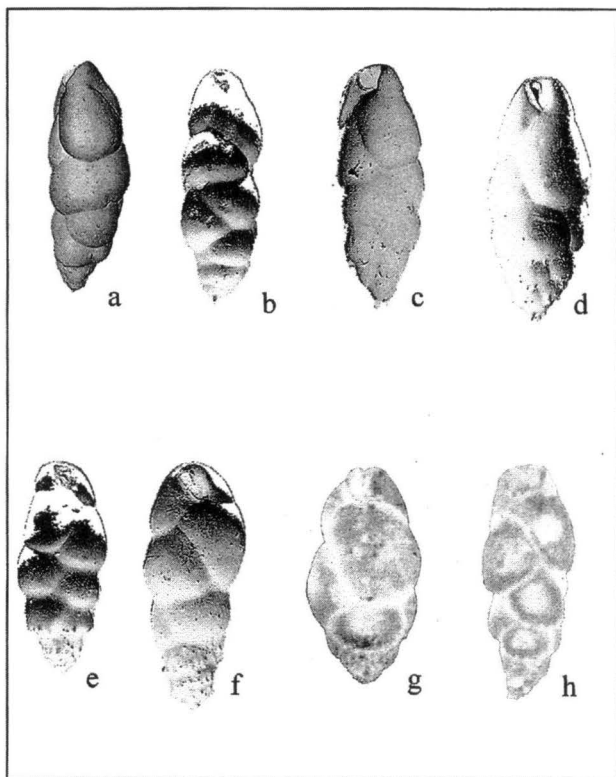
Inflated chambers and wide aperture along the longitudinal axis of the test, supported by a pronounced collar (Text-fig. 7, h). Among the species with undercut limited to some portions of the test, *B. corsiniana*

is generally poorly represented. Rare individuals of the species are identified in Lower Pleistocene sediments of infra/circa and circalittoral environments (Text-fig. 4).

EXPLANATION OF PLATE 1

- Figs. 1, 5 - *Bulimina etnea* Seguenza (x 60). Valle Ricca, sample 18.
 Figs. 2, 6 - *Bulimina marginata* d'Orbigny (x 80). Vezza and Rigo river section, sample 4.
 Fig. 3 - *Bulimina elegans* d'Orbigny (x 120). Valle Ricca, sample 11.
 Fig. 4 - *Bulimina elegans marginata* Fornasini (x 80). Bagnoregio section, sample 9.
 Fig. 7 - *Bulimina* aff. *etnea* (x 120). Valle Ricca section, sample 19.
 Fig. 8 - *Bulimina minima* Tedeschi & Zanmatti (x 120). Tor Caldara section, sample 1.
 Fig. 9 - *Bulimina* cf. *lappa* Cushman & Parker. (x 80). Fabro section, sample 8.
 Fig. 10 - *Bulimina aculeata* d'Orbigny (x 60). Valle Ricca section, sample 4.
 Fig. 11 - Detail showing the absence of undercut in *Bulimina aculeata* gr. specimen (x 60). Fabro section, sample 3.
 Fig. 12 - Detail showing the undercut in *Bulimina marginata* gr. specimen (x 30). Valle Ricca section, sample 13.





Text-fig. 7 - a, b, g: *Bulimina elongata* gr.; a, b) *Bulimina elongata*-type; g) *Bulimina lappa*-type. c - f) *Bulimina sublimbata* gr.; h) *Bulimina corsiniana*, typical form.

- *Bulimina sublimbata* gr. (*Bulimina sublimbata* Panizza)

Form with length/width ratio >1 with slender shape. The undercut is present above all in the lower portion of the test and is missing in the last coiling. Chambers are poorly inflated and aligned, except in the last coiling, where the chamber, immediately below the aperture, is more inflated and placed near the sutures of the previous chambers. The aperture is centred and the ornamentation, consisting of small spines, is concentrated along the basal margin of the chambers. Among the species with the undercut limited to some portions of the test, *B. sublimbata* is that with the highest infraspecific variability; however, it can be distinguished from the other species due to its larger size and usually elongate shape (Text-fig. 7, c, d, e and f). Its frequency peak is recorded in clayey-sandy and sandy Pleistocene sediments of infra-circalittoral and infralittoral environments (Text-figs. 4, 6 and 9).

- *Bulimina elegans marginata* gr. (*Bulimina elegans* d'Orbigny, *Bulimina elegans marginata* Fornasini)

The typical form has globular chambers, generally without undercut. Some individuals have signs of

the undercut in the lower portion of the test. The Dutch school considers it as a transition form between *B. marginata* and *B. aculeata*. Its distinctive features are: generally not aligned chamber arrangement; rather irregular chamber size, providing the species with a profile which is not always rectilinear and slightly flared in the lower portion of the test. Usually there is a sudden increase in the size of the penultimate chamber, tending to overlap the chambers of the previous coiling. The ornamentation is quite limited and consists of spines along the outer margins of the chambers; a more marked spine is observed in the lower portion of the test. In the length/width ratio, length is always dominant, providing the shell with an always slender appearance (Text-fig. 10, i, j, k, l, m and p). The frequency peak of *B. elegans marginata* is recorded in all the clayey and clayey-sandy Pleistocene sediments of the study area (Text-figs. 4, 6, 8 and 9). Even if its first occurrence is observed just before the N/Q boundary, some morphotypes with an elongate and irregular pattern are also encountered in more ancient sediments (*Bulimina marginata* Zone; Text-fig. 10, o and p). However, the chambers of these morphotypes have undercut and thus they are more similar to *B. marginata*. In associations with *B. elegans marginata*, and with the same distribution, small morphotypes are found. These specimens (*B. elegans*, Text-fig. 10, h) have a more regular shape and a more reduced ornamentation than *B. elegans marginata*.

PALEOECOLOGICAL AND STRATIGRAPHIC CONSIDERATIONS

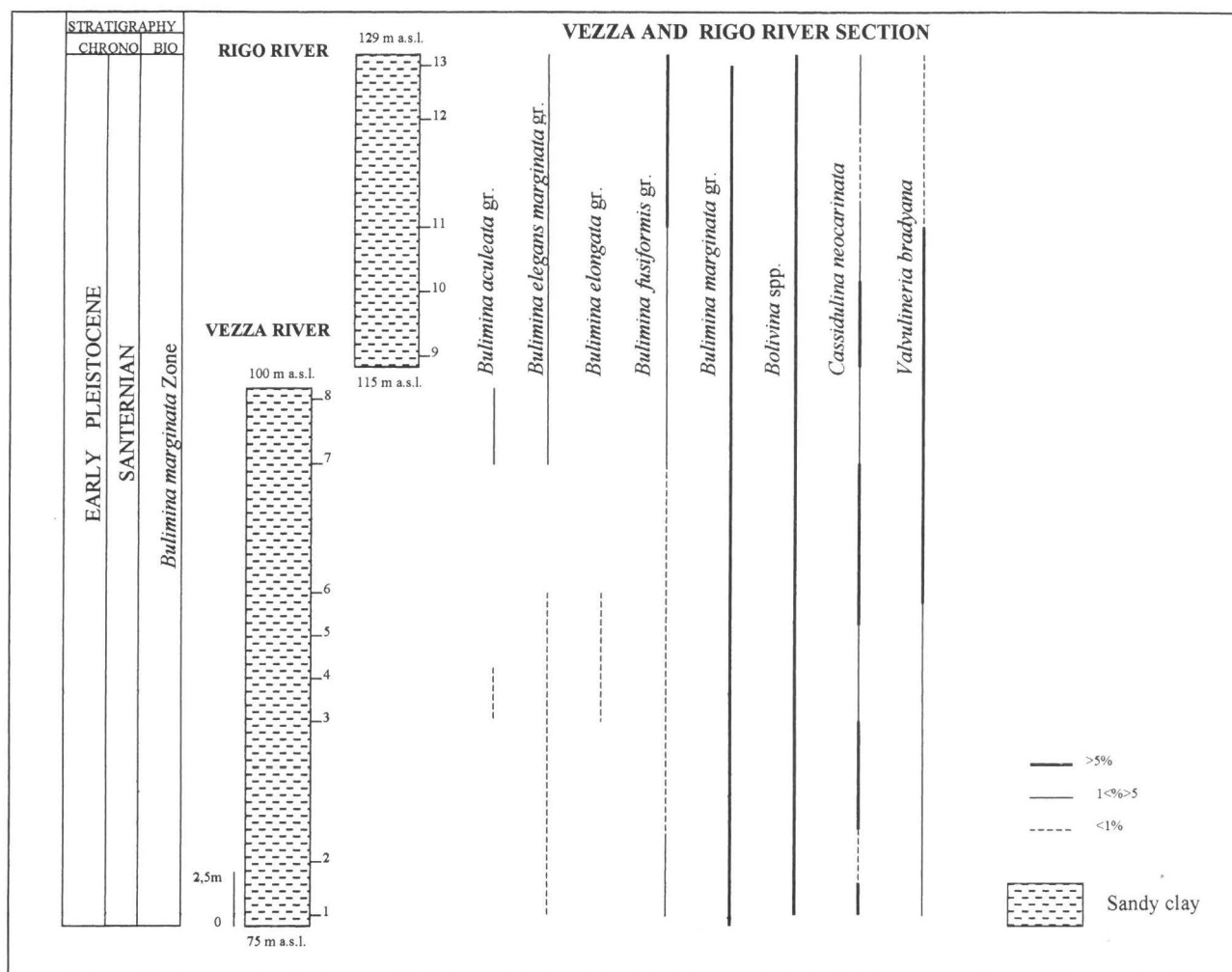
The detailed study on the morphological variability of some species belonging to the non-costate buliminids evidences that some morphotypes have a specific distribution in time and space and that they might serve as local ecobiostatigraphic indicators. The frequency peak of the non-costate *Bulimina* group is reached in circalittoral and circa-infralittoral paleoenvironments (Text-fig. 2).

Buliminidae and Bolivinidae assemblages also occur at shallower depths, in sheltered areas (Tiber sector) with fine sedimentation and poorly oxygenated seafloors (Di Bella, 1995).

The main records and the most important morphological trends of each species are summarized in four chronostratigraphic intervals as follows:

LOWER PLIOCENE (ZANCLEAN) - MIDDLE PLIOCENE (PIACENZIAN)

- Low frequency and scarce specific and infraspecific variability of the genus *Bulimina*. The studied area show a fairly uniform environment. No substantial differences are observed between the eastern sector and the western one. This low abundance might be dependent on environmental conditions, too deep



Text-fig. 8 - Lithology of the Vezza and Rigo river section. The scheme shows the distribution and frequency of the non-costate *Bulimina* groups and the main taxa. Zones after Iaccarino *et al.* (1994).

environments for their development (circalittoral to upper epibathyal) and evolutionary factors. The only forms, which occur in these sediments, may be ascribed to *Bulimina costata* and *B. cfr. alazanensis* (costate *Bulimina* group) or to *Bulimina aculeata* gr. (non-costate *Bulimina* group: *Bulimina aculeata* and *Bulimina minima*).

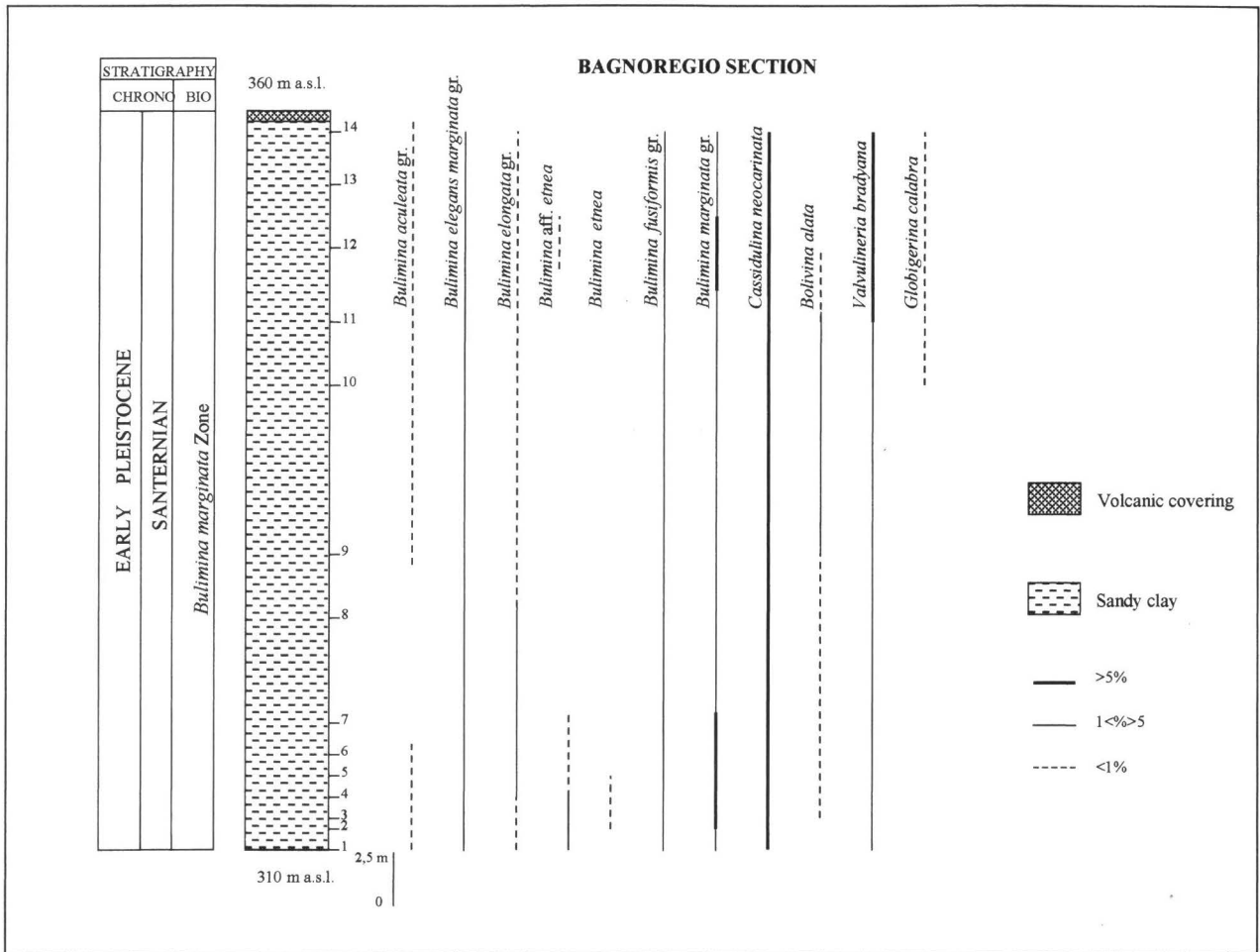
- Presence, in association with *Globorotalia aemiliana* (Piacenzian), of rare individuals of elongate *B. fusiformis*-like forms. These specimens have an elongate morphology and initial chambers with a slight undercut (Text-fig. 12, a; Text-fig. 13).

GELASIAN

- Increase of the non-costate *Bulimina* group; the most frequent species is *B. marginata*, which is the first form with undercut chambers and morphotypes similar to the typical one.

- Differentiation of an eastern and a western sectors of the deeper areas of the Tiber graben, based on the occurrence of buliminids: the eastern sector is richer in species of *Bulimina* than the western one.

- Gradual increase of specific and intraspecific diversity of buliminids, represented by different intraspecific morphotypes of *B. aculeata* and *B. marginata*, in the upper part of the Gelasian, near the FAD of *Globorotalia inflata*, a taxon very rarely recorded in the Pliocene sediments of the Umbria-Latium (Carboni *et al.*, 1993; Di Bella, 1995). As regards *B. aculeata*, the typical forms are associated with individuals having limited ornamentations, consisting of poorly developed spines or pustules in the first chamber of the test where a sturdy spine is present (*B. basispinosa* and *B. minima*, Text-fig. 12, d, e, i-l; Text-fig. 13). The latter morphotypes exhibit larger size, are more elongate, although their aspect is



Text-fig. 9 - Lithology of the Bagnoregio section. The scheme shows the distribution and frequency of the non-costate *Bulimina* groups and the main taxa. Zones after Iaccarino *et al.* (1994).

always small and stocky. As regards *B. marginata*, the typical form is associated with more slender morphotypes having more rounded chambers, whose not aligned arrangement is similar to *B. elegans marginata* (Text-fig. 10, k).

- Presence of typical forms of *B. fusiformis* starting from the occurrence of *B. marginata*; these forms reach their frequency peaks in the Early Pleistocene (Text-fig. 13).

- Occurrence of *B. elegans marginata* gr. with not aligned chamber arrangement.

N/Q BOUNDARY

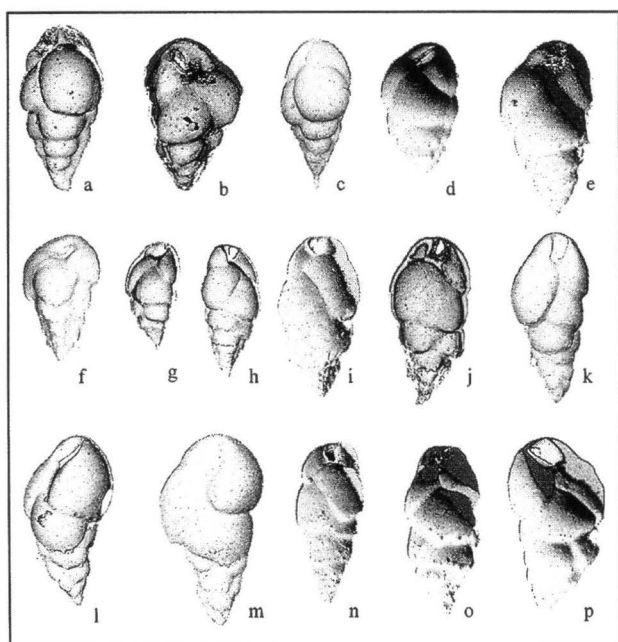
- Greater development of the *B. marginata* gr. and slender forms (Text-fig. 13) with a more marked undercut which substantiate the data from the sections of Calabria (Verhallen, 1987). Besides small-sized morphotypes, there are other individuals exhibiting rounded and vertically aligned chambers,

ornamentation limited to the external margin of the chambers with a poorly evident undercut (Text-fig. 10, d, e and f), very similar to *B. etnea* (*B. etnea* gr.: *B. aff. etnea*) (Text-fig. 13).

EARLY PLEISTOCENE (SANTERNIAN)

- High concentrations of the non-costate *Bulimina* species with development of elongate and slender morphotypes in each species (*B. corsiniana*, *B. elongata* gr., *B. fusiformis* gr., *B. sublimbata* gr., among *B. aculeata* gr.: *B. basispinosa*). The assemblages exclusively dominated by these forms, in association with abundant Bolivinidae and Cassidulinidae, can only be found in the eastern sector (medium and low Tiber valley). *B. sublimbata* (the most abundant and diversified form) and *B. elongata* gr. are frequent.

- Reduction of undercut among *B. marginata* morphotypes, although they are associated with individuals belonging to the typical form.



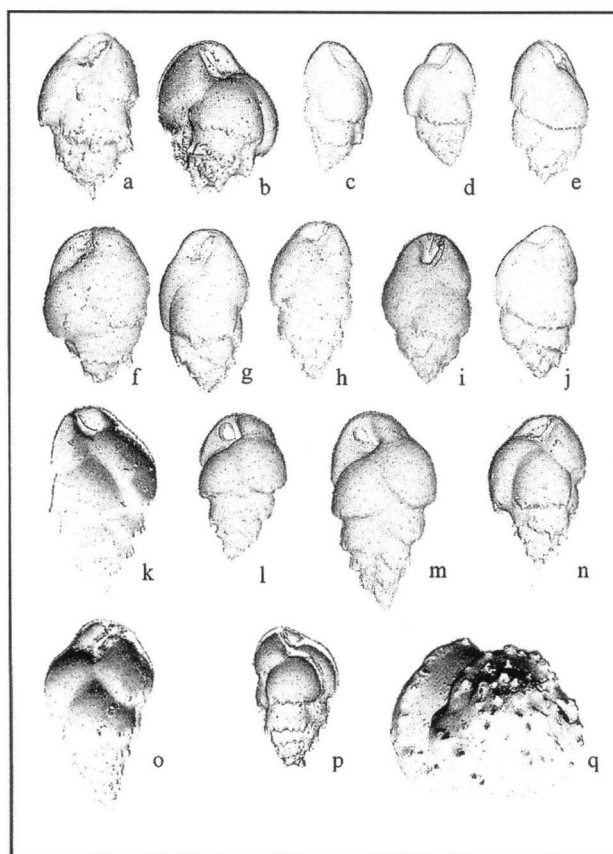
Text-fig. 10 - a - h: *Bulimina etnea* gr.; a - c) *Bulimina etnea* typical form; d - h) *Bulimina* aff. *etnea*-type. i - m, p) *Bulimina elegans marginata* gr.; n) *Bulimina elegans*-type.

- Occurrence of *B. etnea* (typical form) in few levels above the N/Q boundary, in accordance with the bio-chronostratigraphic schemes reported in the literature.

CONCLUSIONS

The study of foraminiferal assemblages from the Pliocene-Pleistocene sediments of the Tiber-Latium area indicates significant increase and diversification (both specifically and intraspecifically) of the genus *Bulimina*. This finding is in line with the records from other Mediterranean sites, namely from the basins of Southern Italy (Verhallen, 1991), which corroborate the assumption of scarcely oxygenated seafloors (Van der Zwaan, 1983; Verhallen, 1987; Van der Zwaan & Jorissen, 1991).

In the investigated area, two sectors may be distinguished: one to the E, against the Apennine range; and a more westerly one, connected with the open sea. Until Early Pliocene and Middle Pliocene the environment was uniform in both sectors characteristic of circalittoral and upper epibathyal depths. Starting from the Gelasian, the two sectors become different with the development of various environments. The eastern sector was poor oxygenated with limited water circulation; these conditions are dictated by the paleomorphology of the basin, which is NW-SE elongated between two ridges (Sabini to the E and Soratte-Cornicolani structural high to the W). Consequently, this is an isolated area with occa-



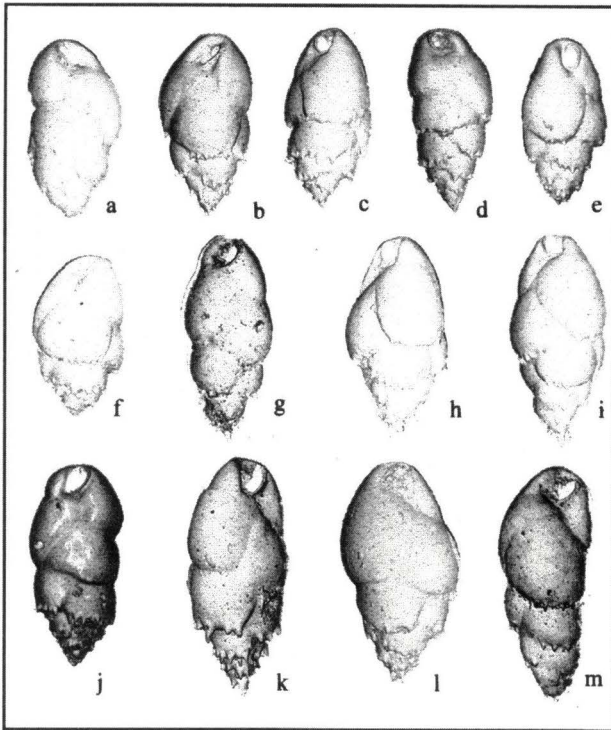
Text-fig. 11 - *Bulimina marginata* gr.: a - f) typical form; g - j) elongated morphotypes; l, m) morphotypes with well-developed undercut; n - p) specimens with vertical aligned chambers; q) detail of *Bulimina marginata* showing the undercut.

sional water exchange with the more westerly open sea. Additionally, the Paleo-Tiber discharged all its waters into this basin, enriching it with organic matter and making its floor oxygen-starved. On the contrary, in the western sector, more oxygenated bottom conditions and more active water circulation persisted although a widespread uplifting of the area occurs.

In this study, the assemblages in the two areas were compared and the different species and their morphotypes were carefully analysed. The findings from the study indicate some trends and forms which might be used as biostratigraphic indicators at local level, especially in places which lack the planktonic markers commonly used in this interval (Text-fig. 13). The main results singled out from this study can be summarised by the following details:

- Gradual increase of the non-costate *Bulimina* group which becomes dominant in the circalittoral, infra-circalittoral and infralittoral communities in the Late Pliocene and Early Pleistocene.

- Maximum development and diversification of the non-costate buliminids in the eastern sector



Text-fig. 12 - *Bulimina fusiformis* gr.: a) morphotype with limited undercut; b - f) intermediate morphotypes with *B. marginata*; g - m) typical form.

which, due to its paleomorphological features, had an environment more suitable to the development of these forms (high nutrient content, low degree of oxygenation, fine grain size). In fact, the non-costate buliminids have a highly developed periapertural depression near their central canal and are thus supposed to better withstand seafloor disoxia and anoxia (Verhallen, 1987). By contrast, the costate group (*B. costata* and *B. aff. alazanensis*) is always poorly represented or sometimes missing throughout the Middle Pliocene-Early Pleistocene interval.

- Presence of *B. marginata* gr. with the first occurrence of *B. marginata* in Gelasian stage. This event is important because, from this time on, the genus *Bulimina* is dominated by morphotypes of *B. marginata* with a more or less pronounced undercut. These forms are supposed to have greater adaptability to fine-grained, shallow (infralittoral-circalittoral transition), oxygen-starved seafloors with respect to the *Bulimina aculeata* gr. which is without undercut; the latter group, represented almost exclusively by *B. aculeata*, has its frequency peaks in deeper environments (clearly circalittoral) and in the westernmost sector of the study area.

- Trend from not aligned chamber arrangement to vertical chamber aligning and greater development of the *B. marginata* undercut starting from the N/Q boundary.

- Reduction of the undercut and chamber stacking from the base of the Pleistocene (*B. etnea* gr.).

The data of this study concerning distribution of the species and some of their morphotypes correlate well with those reported from the Vrica area (Verhallen, 1991). Usually, the non-costate *Bulimina* group has a well-defined undercut reaching its maximum development in some morphotypes of the Late Pliocene. Nonetheless, the investigated sediments never display such extreme forms as those identified at Vrica. Moreover, a greater variability of morphotypes is evidenced in the Umbria-Latium areas than those found in the Vrica section (Verhallen, 1991). The great intraspecific variability in the Late Pliocene and Quaternary sediments might be linked to both environmental factors and evolutionary trends within each species or combination of both.

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