

Paleoclimatic significance of the Pliocene *Amphistegina* levels from the Tyrrhenian margin of Central Italy

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ABSTRACT - Two distinct *Amphistegina*-rich intervals are recognized within the Pliocene succession of Umbria and Latium, referred respectively to the Piacenzian and to the Gelasian; these deposits represent the last warm peaks before the strong Late Pliocene climatic deterioration. The investigated foraminiferal assemblages, characterized by specimens provisionally identified as *Amphistegina targionii* (Meneghini), testify to shallow, relatively warm and oligotrophic waters, according to the regressive trend caused by the regional uplift affecting the Tyrrhenian margin from Messinian to Early Pleistocene times. As indicated by extant populations in the Aegean Sea, *Amphistegina* is less temperature-dependent than other rotaliine larger foraminifers; this may help explaining the apparent paradox of its occurrence after the onset of Late Pliocene climatic deterioration.

RIASSUNTO - [Significato paleoclimatico dei livelli ad *Amphistegina* del Pliocene del margine tirrenico dell'Italia centrale] - Sono stati studiati alcuni livelli ad *Amphistegina* dell'area umbro-laziale allo scopo di definirne il contenuto faunistico e il significato paleoecologico e paleoclimatico. Questi livelli, costituiti da materiali più o meno coerenti, sono stati indagati nella media e bassa Valle del Tevere in località Baschi e Fosso San Martino, nell'area di Tarquinia e lungo l'attuale costa laziale a Palo presso Ladispoli e ad Anzio (Villa di Nerone). In questa prima fase della ricerca sono state considerate le associazioni a foraminiferi. L'analisi quantitativa ed il calcolo del rapporto $P/(P+B)$ sono stati effettuati sul campione più rappresentativo di ciascun sito; dal punto di vista tassonomico è stata posta particolare attenzione al genere *Amphistegina*. La maggior parte degli esemplari di *Amphistegina* del Pliocene umbro-laziale, generalmente attribuiti in letteratura ad *A. lessonii*, *A. gibbosa* o non assegnati ad un taxon di rango specifico, appare riferibile alla specie *A. targionii* (Meneghini); di questo taxon non sono stati rinvenuti individui interpretabili come microsferici nei campioni analizzati. Nei campioni analizzati quantitativamente, le frequenze di *Amphistegina* spp. variano da 3,32% a 13,91%, con le percentuali più alte nel sito di Fosso San Martino. Il resto dell'associazione è analogo nei vari siti esaminati ed è caratterizzato dall'abbondanza di forme prevalentemente epifite come *Elphidium* spp., *Lobatula lobatula* ed *Asterigerinata planorbis*. Per il sito di Palo le indagini si sono limitate allo studio di sezioni sottili, in quanto i sedimenti calcarenitici non sono risultati disgregabili. L'associazione bentonica e il basso valore del rapporto $P/(P+B)$ indicano ambienti di acque basse e relativamente calde in presenza di fondali probabilmente vegetati. La dominanza di *Globigerinoides ruber* e *G. trilobus* nella frazione planctonica conferma l'interpretazione di acque relativamente calde ed oligotrofiche.

Dal punto di vista stratigrafico sono stati individuati due livelli ad *Amphistegina*: il più antico, riferibile al Piacenziano, che precede il FO di *Bulimina marginata*, si rinviene nel sito di Tarquinia; il secondo, attribuibile al Gelasiano, è posteriore al FO di *B. marginata* nei siti di Villa di Nerone, Baschi e Fosso San Martino. Dal confronto con la curva isotopica del sito 653 del Mar Tirreno, i due livelli potrebbero essere collegati a due episodi caldi antecedenti al deterioramento climatico quaternario, localizzati rispettivamente tra 3,3 Ma e 3,0 Ma e tra 2,7-2,6 Ma e 2,1 Ma.

Nelle successioni marine umbro-laziali analizzate i due livelli ad *Amphistegina* si collocano al termine di cicli sedimentari, testimoniando un trend regressivo dovuto prevalentemente a fenomeni di sollevamento tettonico che hanno interessato l'area con tempi e modalità diversi nei vari settori.

INTRODUCTION

A prominent feature within the terrigenous Pliocene successions of the Italian peninsula is the occurrence of biotrital and silty or sandy levels containing abundant tests of *Amphistegina*. From Eocene times, amphisteginids thrived in tropical-subtropical warm and shallow waters along with other larger foraminifers. Shallow-water carbonate deposits yielding abundant *Amphistegina*, generally associated with *Elphidium*, are widespread throughout the Mediterranean area in Pliocene deposits. In Italy, these levels are recorded e.g. from the Middle Pliocene of the northern Apennines of Romagna ("Spungone Formation": Capozzi & Picotti,

2003), Tuscany, Umbria and Latium ("*Amphistegina* Limestone", "Tarquinia Limestone" and "Macco": De Amicis, 1885, 1886; Conti et al., 1983; Barberi et al., 1994; Iaccarino et al., 1994) and Sicily in the Caltanissetta and Belice basins (Catalano et al., 1998).

Mainly, the works dealing with the *Amphistegina*-bearing levels focus on depositional and geological aspects of these deposits. Generally, their stratigraphic position within the Pliocene succession is poorly constrained. In addition, there are no recent systematic or paleoecological studies on amphisteginids from the Pliocene of Italy.

Roveri & Taviani (2003) suggested a direct link between the formation of calcarenite levels and sapropel

deposition in the Mediterranean basin. Because sapropel deposits in Mediterranean sequences appear to be astronomically driven, the correlation of the shallow- and deep-water records may provide important paleoclimatic and paleogeographic clues for the recognition of paleoceanographic events. In the northern Apennines biocalcarene clusters occurred periodically since 3.1 Ma, contemporary to the onset of the Northern Hemisphere glaciation (Roveri & Taviani, 2003).

In this work, we investigate selected *Amphistegina* levels from different extensional basins of Umbria and Latium (Central Italy). These levels occur within Pliocene clayey sands and biocalcarenes, cropping out sparsely along the Tyrrhenian coast, from Tarquinia (northern Latium) to the structural high of Anzio, south of Rome. Generally, these *Amphistegina*-bearing deposits from Central Italy are considered as not older than Middle/Late Pliocene, i.e. within the *Globorotalia aemiliana* Zone of Iaccarino (1985) (Conti et al., 1983; Ambrosetti et al., 1987; Barberi et al., 1994; Carboni & Di Bella, 1997; Chiocchini & Potetti, 2003). Among a large number of *Amphistegina*-bearing successions, we selected the following representative localities: Tarquinia, Baschi, Palo, Fosso San Martino, and Anzio (Fig. 1).

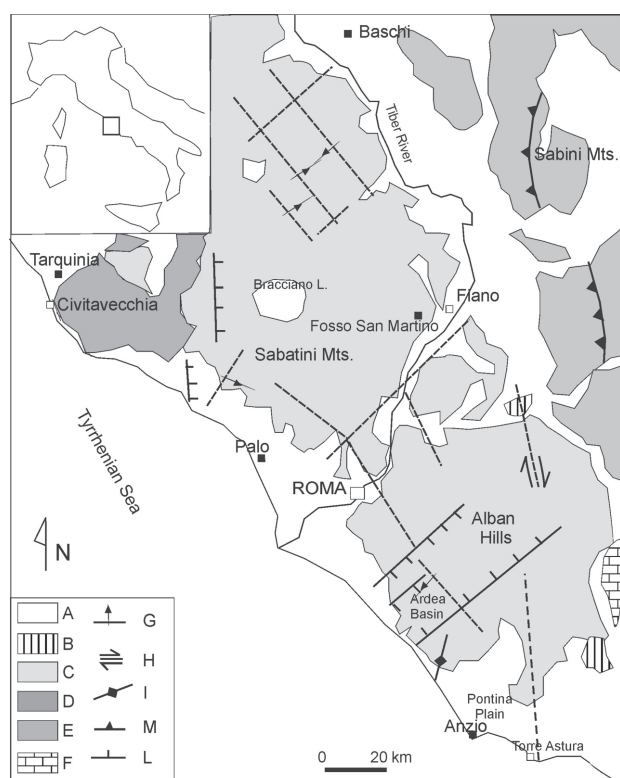


Fig. 1 - Structural sketch of the Central Italy Tyrrhenian margin (modified from Marra et al., 1995). A) sedimentary sequences of the "neo-autochthonous" cycles (Messinian- Pleistocene); B) travertine deposits (Quaternary); C) volcanic sequences (Plio-Pleistocene); D) Tolfa units (Upper Cretaceous-Eocene); E) Sabina units (Upper Triassic-Upper Miocene); F) Lepini Mts. units (Cretaceous); G) main buried faults, the arrow indicates the downthrow limb; H) strike-slip faults; I) anticline axis; L) normal faults; M) thrust faults; (■) studied sites.

The aims of this work are twofold: to investigate the taxonomic content of the foraminiferal assemblages from the *Amphistegina*-rich levels and their paleoenvironmental significance; and to define more accurately within the Pliocene record of Latium and Umbria the stratigraphic position of these levels, which are the outcome of tectonic, climatic and eustatic factors.

MATERIALS AND METHODS

In this work we adopt the three-fold subdivision of the Pliocene outlined by Rio et al. (1994, 1998) and for the Pleistocene the scheme proposed by Cita & Castradori (1995). Fig. 2 provides a simplified bio- and chronostratigraphic framework for the Mediterranean area, compiled after various sources (Cita, 1975; Spaak, 1983; Colalongo & Sartoni, 1979; Iaccarino, 1985; Sprovieri, 1992). From a biostratigraphical point of view, the most important planktic foraminiferal events recorded for the Mediterranean area are included (Berggren et al., 1995; Patacca & Scandone, 2001).

All studied samples were found to lack planktonic and benthonic foraminiferal biostratigraphic markers, a circumstance that considerably hampered a precise chronostratigraphic attribution. The age of the *Amphistegina*-bearing levels was thus deduced indirectly, by stratigraphic correlation and by taking into account layers below or above the *Amphistegina* levels yielding age-dating microfossils (Figs. 3-4).

The studied *Amphistegina*-bearing layers differ in thickness, from less than 1 m (Palo) to about 5 m (Villa di Nerone, Baschi; Fosso San Martino). We studied samples from three structural units: Tarquinia basin, Tiber Valley basin and Anzio.

The samples from the Tarquinia basin come from an unpublished borehole drilled in the cemetery of Tarquinia and from the vicinity of Palo. The Tarquinia cemetery core penetrated almost 15 m of sands, and subordinately silty and clayey sands, alternating with three calcarenite levels, each about 1 m thick. *Amphistegina* occurs in most of the samples from the Tarquinia core, but it was found to be frequent only in four samples, one of which was selected for quantitative analysis because of the fair preservation of the assemblage. The samples investigated from Palo (south of the town of Ladispoli), were collected at km 34.6 of the Via Aurelia.

From the Tiber Valley basin, samples from two outcrops were investigated: Baschi and Fosso di San Martino. The samples from Baschi were collected 2 km north of the village along the Via Amerina, at the beginning of a tunnel leading to a hydroelectric power station; Fig. 3 provides a summary of the lithology and biostratigraphy of the outcrop. The samples from Fosso San Martino (south of Mt. Soratte) were collected along the Fiano Romano-Sant'Oreste provincial road, 2 km west of Fiano Romano, from the "Tenaglie-Fosso San Martino Unit" (Mancini et al., 2004).

From Anzio, two samples were investigated, respectively from the Anzio-Villa di Nerone section (Figs. 3, 5-6), spectacularly exposed in the cliff on the

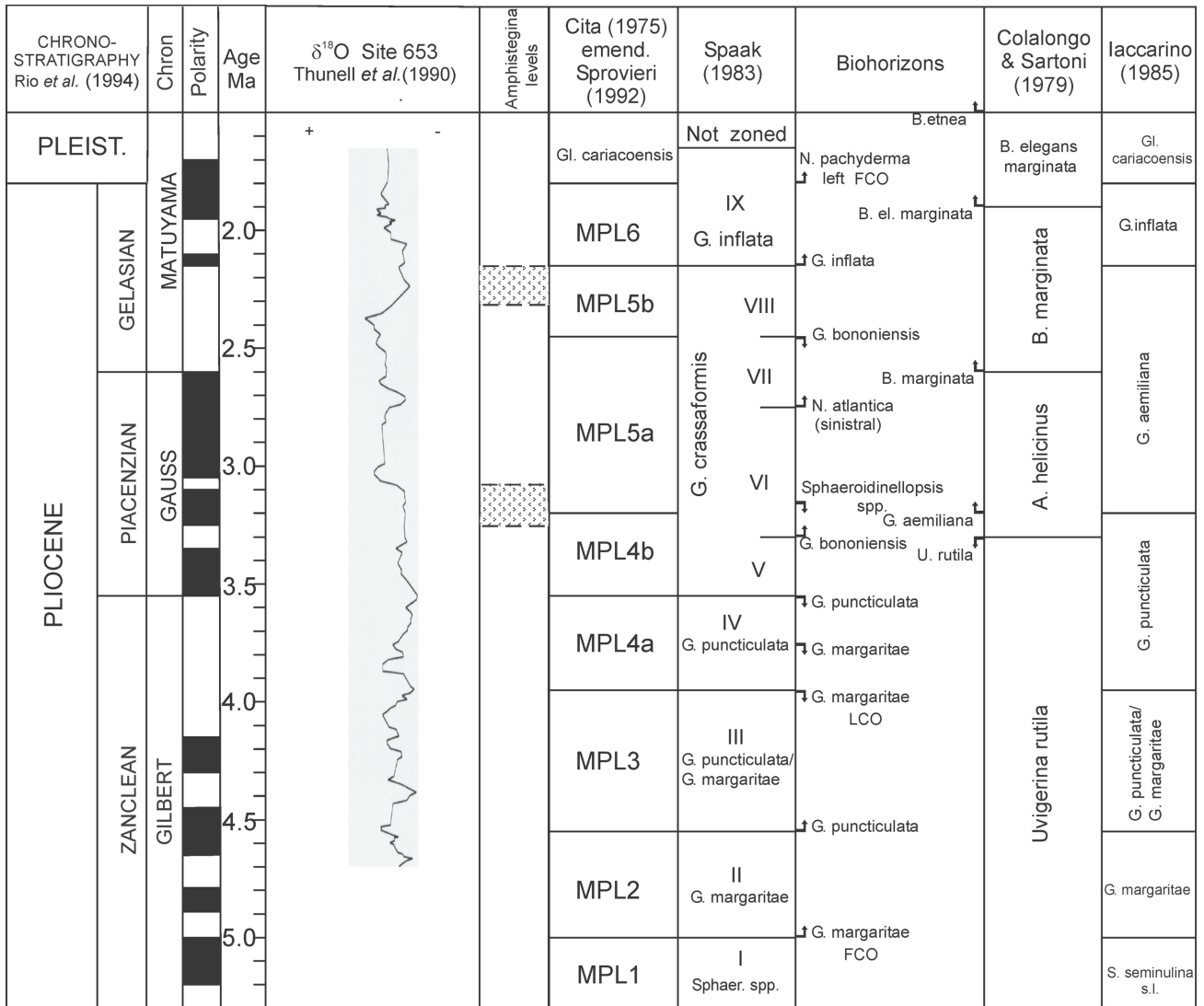


Fig. 2 - Bio- and chronostratigraphy of Pliocene and Early Pleistocene, showing the inferred age assignment of *Amphistegina*-rich deposits from Latium and Umbria and their relationship to the $\delta^{18}\text{O}$ isotopic curve.

beach at Anzio below the ruins of the grotto and villa of the Roman emperor Nero, and from an outcrop within the area of the railway station of Anzio.

All suitable samples represented by unconsolidated sediments (i.e., those from Baschi, Fosso San Martino, and Anzio-Villa di Nerone) were processed with a 0.125 mm mesh sieve and oven dried at 40°C. The sieved fraction was split into equal parts containing about 300 benthic specimens. Co-occurring calcareous plankton specimens were counted as well. For all samples, qualitative and quantitative analyses were conducted on the foraminiferal assemblages (Tab. 1) and the P/(P+B) ratio was calculated. In addition, in each sample all matrix-free specimens of *Amphistegina* were examined; for investigating inner test morphology, selected specimens were equatorially sectioned by grinding.

At three other localities (Tarquinia cemetery core, Palo, and the railway station of Anzio), the

Amphistegina-rich levels occur within consolidated biocalcarenes; in these instances rock thin sections were analyzed.

STRATIGRAPHY OF THE PLIOCENE SUCCESSION IN UMBRIA-LATIUM BASINS

The Neogene-Quaternary stratigraphy of Umbria-Latium basins has been widely studied in the 19th century. Progress in the stratigraphical knowledge led to the identification of two main sedimentary cycles in the marine Plio-Pleistocene successions. These cycles are diachronous in the Umbria-Latium basins, due to regional tectonic activity which affected these areas.

Tarquinia basin

In this basin, the first Pliocene sedimentary cycle developed from the Early Zanclean, *Sphaerodinellopsis*

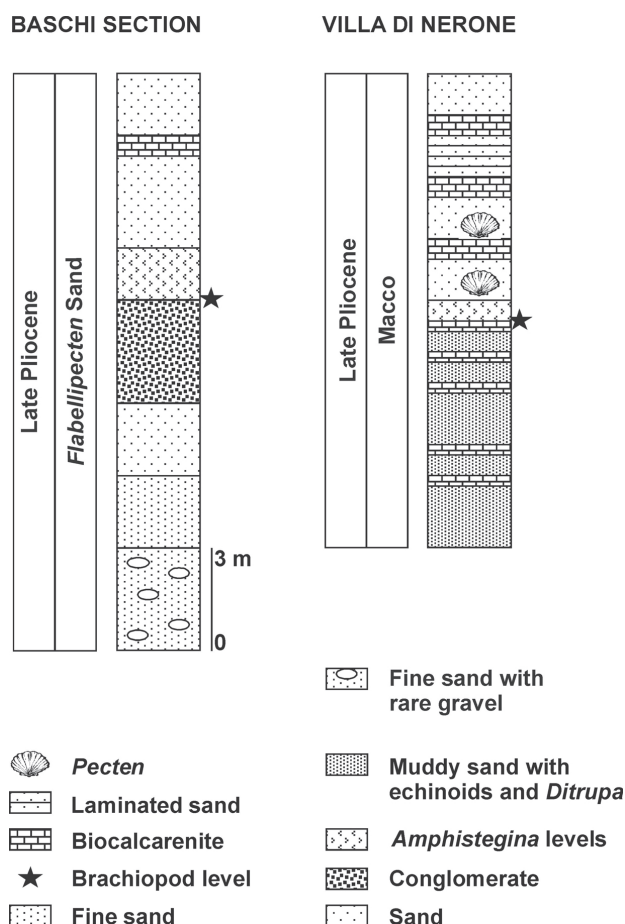


Fig. 3 - Simplified stratigraphy of the successions cropping out at Baschi and Villa di Nerone (modified after Conti et al., 1983 and Carboni & Di Bella, 1997).

seminulina s.l. Zone, to the Early Piacenzian, *Globorotalia puncticulata* Zone p.p. (Barberi et al., 1994). These Pliocene deposits overlie transgressively Ligurid units and are constituted of grey pelites with thin levels of sandy clay, interpreted to have formed in epibathyal and circalittoral environments (Carboni & Palagi, 1998; Chiocchini & Potetti, 2003). The second sedimentary cycle ranged from the Piacenzian, marked by the occurrence of *Globorotalia bononiensis* and *G. aemiliana*, to the Santernian, characterized by *Bulimina etnea* (Mazzini et al., 2000). It is represented by a 30 m thick sequence of calcarenites and biotrital sands known in the regional geological literature as “Tarquinia Calcarenite”, “Tarquinia Limestone” (Fazzini et al., 1972), or “Macco” (Mazzini et al., 2000). These two sedimentary cycles are separated by a hiatus inferred to correspond to 0.3-0.4 Ma, according to Barberi et al. (1994). The *Amphistegina*-rich levels are within the second cycle; their age is Piacenzian because of the occurrence of *G. aemiliana* and *G. bononiensis* (Barberi et al., 1994). In the *Amphistegina*-bearing biocalcareneites of Monte Riccio (ca. 6 km ESE of Tarquinia), Colalongo et al. (1973) recorded the occurrence of *G. aemiliana*, along with *G.*

crassaformis, which indicates that these deposits are younger and belong to the late Middle Pliocene (*sensu* Colalongo et al., 1982, 1984) or the Gelasian (Rio et al., 1994). However, Colalongo et al. (1973) do not provide details on the faunal composition of the benthic foraminiferal assemblages of *Amphistegina*-bearing levels and their paleoecology.

The studied samples from the borehole drilled in the cemetery of Tarquinia represent the oldest *Amphistegina* level within the Piacenzian cycle (Fig. 4).

Along the coast of northern Latium, *Amphistegina*-rich biocalcareneites crop out south of Tarquinia along a NNW-SSE trending belt (Compagnoni et al., 1986). The samples from Palo (Fig. 7) are from this belt, from deposits locally known as “Macco”. Because of the presence of *Globorotalia crassaformis*, these deposits are attributed to the Middle Pliocene *sensu* Colalongo et al. (1982, 1984) or to the Gelasian (Rio et al., 1994). They rest directly on Lower Pliocene clay (Malatesta & Zarlenga, 1986).

Tiber Valley basin

In this area the first sedimentary cycle began later than in the Tarquinia basin. The occurrence of *Globorotalia puncticulata* allows to attribute these sediments to the Zanclean (*Globorotalia puncticulata* Zone). The cycle ended in the Gelasian p.p., as indicated by the presence of *Bulimina marginata* (Girotti & Mancini, 2003). The second sedimentary cycle is chronologically restricted to the Santernian (*Globigerina cariacensis* Zone). The two cycles are separated by an unconformity, widely recognized along the Tyrrhenian margin (Ambrosetti et al., 1987; Carboni & Di Bella, 1997; Girotti & Mancini, 2003); in the regional literature this unconformity has been traditionally linked to the “Acquatraversa erosional phase” (Bonadonna, 1968), and corresponds to the *Globorotalia inflata* Zone.

Conti et al. (1983) and Ambrosetti et al. (1987) recorded the occurrence of *Amphistegina*-rich levels in outcrops of the first sedimentary cycle, within the lower part of the *Flabellipecten* Sand Formation. In these levels, Conti et al. (1983) recognized *G. crassaformis*, and *B. marginata* in the deposits below, and attributed them to the Middle Pliocene (*sensu* Colalongo & Sartoni, 1979). Our samples from near Baschi (Fig. 3) were collected in the same area and are interpreted to correspond to the same level investigated by Conti et al. (1983).

In the southern sector of the middle Tiber Valley, Girotti & Mancini (2003), recognized similar deposits coeval to the *Flabellipecten* Sand, which they named the “Tenaglie-Fosso San Martino unit”, assigned by them to the Gelasian for the presence of *B. marginata* (FCO 2.63 Ma, Patacca & Scandone, 2001). Our samples from Fosso San Martino are attributed on the base of lithological features and fossil content to the Gelasian “Tenaglie-Fosso San Martino Unit” (Fig. 4). In Tuscany, analogous deposits cropping out in the Radicofani basin (Fonte Vetriana) may correspond to the same biochronological event because of the occurrence of *B. marginata* (Iaccarino et al., 1994).

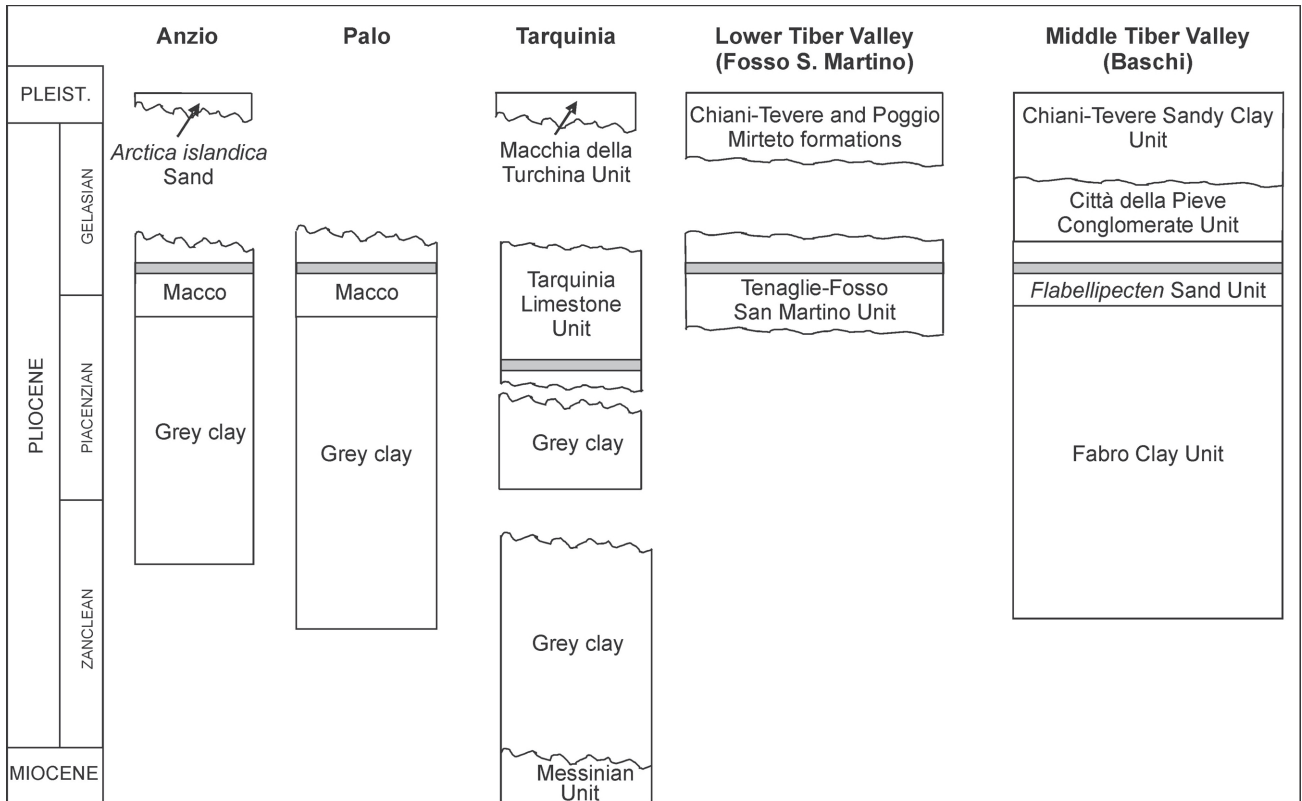


Fig. 4 - Stratigraphic correlation of the *Amphistegina*-bearing successions (gray shading; vertical extent is approximate) from Umbria and Latium.

Fosso San Martino		Baschi		Villa di Nerone		Tarquinia	
Benthos	%	Benthos	%	Benthos	%	Benthos	%
<i>Ammonia beccarii</i>	0,58	<i>Amphistegina</i> spp.	6,23	<i>Ammonia parkinsoniana</i>	1,33	<i>Ammonia beccarii</i>	2,87
<i>Ammonia inflata</i>	2,03	<i>Asterigerinata planorbis</i>	22,34	<i>Amphistegina</i> spp.	3,32	<i>Ammonia parkinsoniana</i>	0,64
<i>Ammonia parkinsoniana</i>	0,87	<i>Cancris auriculus</i>	0,26	<i>Asterigerinata planorbis</i>	43,19	<i>Amphistegina</i> spp.	5,43
<i>Amphistegina</i> spp.	13,91	<i>Elphidium</i> spp.	26,49	<i>Astrononion stelligerum</i>	0,33	<i>Asterigerinata planorbis</i>	38,66
<i>Asterigerinata planorbis</i>	4,35	<i>Florilus boueanus</i>	2,60	<i>Dorothia gibbosa</i>	0,33	<i>Bolivina punctata</i>	1,60
<i>Astrononion stelligerum</i>	0,29	<i>Lobatula lobatula</i>	20,52	<i>Elphidium</i> sp.	10,30	<i>Cancris auriculus</i>	0,32
<i>Bolivina punctata</i>	1,16	<i>Planorbulina mediterraneensis</i>	2,34	<i>Fissurina orbignyana</i>	1,33	<i>Elphidium</i> spp.	24,91
<i>Cornuspira involvens</i>	0,58	<i>Reussella spinulosa</i>	1,82	<i>Guttulina communis</i>	2,32	<i>Florilus boueanus</i>	8,31
<i>Elphidium</i> spp.	35,66	<i>Rosalina bradyi</i>	0,26	<i>Lobatula lobatula</i>	23,25	<i>Florilus citai</i>	0,64
<i>Florilus boueanus</i>	2,03	<i>Spiroplectinella wrightii</i>	0,52	<i>Planorbulina mediterraneensis</i>	2,99	<i>Lobatula lobatula</i>	12,46
<i>Guttulina communis</i>	0,29	<i>Textularia</i> spp.	9,61	<i>Reussella spinulosa</i>	1,66	<i>Reussella spinulosa</i>	1,60
<i>Haynesina depressula</i>	0,29			<i>Rosalina bradyi</i>	4,32		
<i>Heterolepa bellincionii</i>	1,16	Plankton		<i>Spiroplectinella wrightii</i>	2,32	Plankton	
<i>Lobatula lobatula</i>	20,58	<i>Globigerina bulloides</i>	0,26	<i>Textularia</i> spp.	2,66	<i>Globigerina bulloides</i>	0,64
<i>Planorbulina mediterraneensis</i>	0,29	<i>Globigerinoides elongatus</i>	0,26	<i>Trifarina angulosa</i>	0,33	<i>Globigerina falconensis</i>	0,64
<i>Reussella spinulosa</i>	3,48	<i>Globigerinoides obliquus</i>	0,52			<i>Globigerinoides trilobus</i>	0,32
<i>Rosalina bradyi</i>	1,74	<i>Globigerinoides ruber</i>	2,60	Plankton		<i>Neoglobobadrina acostaensis</i>	0,64
<i>Textularia</i> spp.	7,25	<i>Globigerinoides trilobus</i>	2,10	<i>Globigerina apertura</i>	0,50		
Plankton				<i>Globigerina bulloides</i>	3,32		
<i>Globigerinoides obliquus</i>	0,29			<i>Globigerina decoraperta</i>	0,76		
<i>Globigerinoides ruber</i>	1,74			<i>Globigerina falconensis</i>	0,50		
<i>Globigerinoides sacculifer</i>	0,29			<i>Globigerinoides conglobatus</i>	0,25		
<i>Globigerinoides trilobus</i>	1,16			<i>Globigerinoides elongatus</i>	0,50		
				<i>Globigerinoides obliquus</i>	1,78		
				<i>Globigerinoides ruber</i>	9,38		
				<i>Globigerinoides trilobus</i>	2,28		
				<i>Neoglobobadrina acostaensis</i>	0,50		
				<i>Neoglobobadrina pachyderma</i>	0,25		
				<i>Orbulina universa</i>	3,04		
				<i>Turborotalita quinqueloba</i>	0,25		

Tab. 1 - Quantitative composition of foraminiferal assemblages from the investigated samples.

Anzio high

Along the coast south of Rome, at Anzio, a discontinuous Plio-Pleistocene succession crops out, only in places unaltered by anthropic disturbance. Carboni & Di Bella (1997) proposed a biostratigraphic and paleoenvironmental interpretation of the Plio-Pleistocene succession along the coast, from Tor Caldara to Anzio, recognizing two sedimentary cycles, one of which incomplete. The first one developed from the Early Pliocene, *Globorotalia margaritae* Zone (Zanclean), to the Late Pliocene, *Globorotalia aemiliana* Zone *sensu* Iaccarino & Salvatorini (1982). This is a typical regressive cycle, ranging from circalittoral (Lower Pliocene clay) to infralittoral environments (sands and biocalcarenes, locally known as "Macco") representing the upper part of the marine Pliocene sequence. The second cycle is represented by Santerian clayey sands and sands, trasgressively overlying the Pliocene sediments. The hiatus corresponds to the *Globorotalia inflata* Zone.

In the investigated succession (Villa di Nerone section; Fig. 3), spectacularly exposed in the cliff on the beach at Anzio below the ruins of the grotto and villa of the Roman emperor Nero, the *Amphistegina*-rich level is located in the topmost part of the first sedimentary cycle within sands passing upsection to biocalcarenes (Figs. 4-5). Its age is Gelasian for the presence of *Bulimina marginata*, occurring in samples below the *Amphistegina* level. An outcrop of biocalcarenes within the area of the railway station of Anzio yielded similar *Amphistegina*-rich assemblages (Fig. 8).

AMPHISTEGINA LEVELS: LITHOLOGY AND FOSSIL CONTENT

The *Amphistegina*-rich levels from Latium and Umbria are within either sands and silty sands, or irregularly stratified, massive, well-cemented calcarenites. Fragments of pectinids, echinoids, ostreids, celoporid bryozoans, balanids, brachiopods, coralline algae and foraminifers represent the main component of these deposits. At Villa di Nerone, concentrations of *Ditrupa* and rhodoliths are present,

whereas at Baschi and Fosso San Martino the macrofauna mainly consists of terebratulids. The foraminiferal assemblages are characterized by high abundances of foraminifers with epiphytic or attached life style, such as *Elphidium* spp., *Lobatula lobatula*, *Asterigerinata planorbis* and *Amphistegina* spp. (Tab. 1). *Reussella spinulosa*, *Rosalina bradyi* and *Florilus boueanus* are less abundant but always present. *Planorbulina mediterraneensis*, *Astrononion stelligerum* and some textulariids are occasionally present. Planktonic foraminifers are rare (<6%), mainly represented by *Globigerinoides* (*G. ruber*, *G. trilobus*, and *G. obliquus*) and rare *Globigerina bulloides*. In each sample, *G. ruber* is the most abundant planktonic species; this is a shallow dweller in the warm oligotrophic mixed layer (Tolderlund & Bè, 1971; Van Leeuwen, 1989). The sample from Villa di Nerone shows the highest P/(P+B) ratio value (23%).

The thin sections of biocalcarenes from Palo and Anzio railway station and the cemented levels of Tarquinia core show a microfaunal content similar to that found in the weakly consolidated samples. They contain abundant rhodoliths, *Ditrupa* fragments and amphisteginids, whereas only rare planktic species are recognized (Fig. 7).

A systematic revision of Oligocene to Pliocene amphisteginids from the Mediterranean area is high on the agenda of larger foraminiferal research; the present work does not attempt to investigate in detail the systematics of this group. Species level identification of *Amphistegina* tests was difficult because most specimens are poorly preserved. Sinistrally coiled megalospheric forms prevail in each sample. For taxonomic identification and paleoecologic analysis, initially the following characters were considered: a) coiling direction (chirality) of the tests; b) number of chambers in the final whorl of the tests and diameter of the latter; c) mean diameter/thickness ratio (index shape *sensu* Larsen, 1978); d) suture patterns; e) size and shape of supplementary chamberlets (visible only in well-preserved tests).

However, intraspecific variation does not seem to hamper significantly species identification in recent amphisteginids even from axial centered sections. In contrast, the main hindrance for fossil amphisteginid



Fig. 5 - Anzio-Villa di Nerone section. The arrow indicates the position of the *Amphistegina*-bearing level studied in the present work.

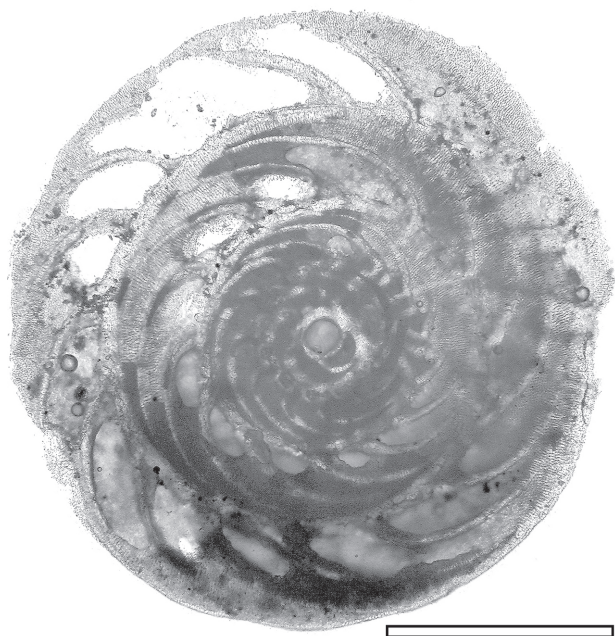


Fig. 6 - Sub-equatorial centered section of *Amphistegina targionii* from Anzio-Villa di Nerone. Scale bar = 0.5 mm.

species identification is the general lack of figured centered horizontal and vertical sections. Horizontal (equatorial) and vertical (axial) centered sections provide a number of invaluable systematic characters which are generally not taken into account (Larsen, 1978).

In the last decades, when identified at species level, the amphisteginids from Central Italy have been generally referred to *A. gibbosa* d'Orbigny, 1839 or *A. lessonii* d'Orbigny, 1826 (see e.g. references in Conti et al., 1983). In a revision of the genus *Amphistegina*, Larsen (1978) recognized in the Pliocene of Italy, in addition to *A. gibbosa* from Tuscany (S. Frediano and Siena), also *A. bowdenensis* Palmer, 1945 from Sicily (Palermo); both these species were originally described from the Caribbean province.

However, none of these species identifications seem to apply to the material studied here (Figs. 6-8). *A. gibbosa*, as figured by O'Herne (1974) and Larsen (1978), has a higher spiral and a different pattern of supplementary chamberlets. *A. lessonii*, as illustrated by O'Herne (1974) and Reiss & Hottinger (1984), differs from our specimens for several features, among which are a stronger inequality of the test, less curved septa and a higher spiral. Topotypes of *A. bowdenensis* figured by Larsen (1978: Pl. 2, figs. 7-8, 10-11) possess a central boss and slightly inflated sutures, both apparently more pronounced on the spiral side; these features are missing in the specimens from Central Italy. The specimens studied here also differ strongly from those doubtfully referred to *A. bohdanowiczii* Bieda, 1936 by Esu et al. (in press) from the Oligocene-Miocene transition of Apulia.

In contrast, most of the specimens of *Amphistegina* studied here closely resemble the somewhat schematic

illustrations of *A. targionii* (Meneghini in de la Harpe, 1881) from Parlascio near Pisa by De Amicis (1886), and especially its axial section. This species has been rarely recorded in the literature (e.g., Sangiorgi, 1899). The specimens which we tentatively refer to this taxon are characterized by an entirely or almost entirely involute spiral side and pronounced angled sutures; the aperture is interiomarginal, provided with a rarely observed overhanging lip; the apertural area is generally abraded and it is thus uncertain to what degree it is papillate.

Relative shell thickness, as measured by the ratio of the (largest) equatorial diameter to the axial diameter, reflects species-characteristic growth and structural patterns as well as ecological light and depth gradients. Direct correlation between shell flattening and the depth gradient, and, conversely, wall thickness (determined by the thickness and number of inner and outer lamellas), and light intensity along with water turbulence have been convincingly proved in live populations from the Gulf of Aqaba (Reiss & Hottinger, 1984). Unfortunately, the number of well-preserved specimens was too low for attempting a detailed investigation of these parameters, useful for paleoecological inferences. All studied specimens have slightly asymmetric tests and show a mean index shape of about 2.21-2.7. Only in the Fosso San Martino population this value is as high as 4.82. The frequency of *Amphistegina* ranges from 3.32% to 13.91% of the total foraminiferal assemblages (Tab. 1).

PALEOENVIRONMENTAL AND PALEOCLIMATIC ASPECTS

After their demise in the Mediterranean basin during the Messinian salinity crisis (Cahuzac & Poignant, 1997; Betzler & Schmitz, 1997), very few larger foraminifers were able to recover in Pliocene times. In the Western Mediterranean, the most important rotaliine larger

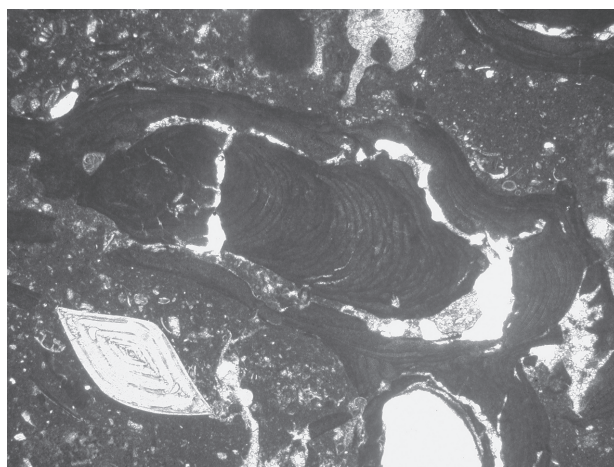


Fig. 7 - Skeletal wackestone-packstone yielding *Amphistegina targionii* and rhodoliths from Palo. Base of photograph is 7 mm long.

foraminiferal genus which survived the Late Miocene event is *Amphistegina*, which attained widespread distribution throughout the Mediterranean in Early and Middle Pliocene times. It is assumed (although not proved) that the genus became extinct in the Western Mediterranean in Late Pliocene-Early Pleistocene times. It may have survived in the Eastern Mediterranean, or, alternatively, it may have recolonized more recently the Mediterranean along with other larger foraminifers as a Lessepsian immigrant from the Indian Ocean (Reiss & Hottinger, 1984). Pleistocene and Holocene records of other rotaliine larger foraminifers from the Western Mediterranean are most likely spurious (e.g., the single, doubtfully live specimen of *Assilina ammonoides* (Gronovius) recorded as *Operculina ammonoides* by Silvestri (1950) from near Venice) or based on misidentification. In contrast, a few ephemeral live populations of porcellaneous larger foraminifers, such as *Sorites orbiculus* (Forskål, 1775), are recorded locally from the northern shores of the present-day Western Mediterranean (Blanc-Vernet, 1969; Pecheux, 1998).

Amphisteginids are symbiont-bearing circumtropical species thriving in warm and shallow waters within climatic belts defined by minimum winter isotherm of surface waters of 14°C (Murray, 1991; Rögl & Brandstätter, 1993). Recent species inhabit marine environments from the shallowest subtidal to ca. 150 m (Hallock, 1984; Reiss & Hottinger, 1984) and are restricted to the photic zone. Recent studies demonstrate, by means of both laboratory cultures and field studies, that their depth range is influenced by several concurring factors (light, water energy, nature of substrate, temperature, thermocline and nutrient supply) (Hollaus & Hottinger, 1997; Hohenegger et al., 1999). Although taxonomy-based comparisons are possible, this evidence based on recent species cannot be easily extended to Late Miocene-Pliocene assemblages (Hottinger, 1997).

In the present-day Eastern Mediterranean, *Amphistegina* spreads from the Levant Sea to the west and north up to Crete (Hollaus & Hottinger, 1997) and the Middle Aegean Sea. Here, it may survive at surprisingly low SST (Sea Surface Temperature). For example, along the southern shores of the island of Andros in the Cyclades, where the annual minimum SST is <13°C and the maximum SST is >24°C, healthy to slightly stressed populations of *Amphistegina* identified as *A. lessonii* thrive from very shallow water to at least up to 20 m depth, where they may total up to 30-65% of the live benthic foraminiferal assemblages (Triantaphyllou et al., 2003). The annual minimum SST of <13°C represents a very low value, thus indicating that some species of *Amphistegina* are much more tolerant to low temperatures than other larger foraminifers, and is consistent with their late demise in the fossil record of the Western Mediterranean.

The Late Pliocene was a critical timespan for amphisteginids also elsewhere. In Miocene to Late Pliocene times, in the Eastern Pacific province, *Amphistegina gibbosa* d'Orbigny attained wide distribution along the NW American coast and became extinct there ca. 2.5 Ma. Its latest occurrence from

this province has been reported from Carmen Island, Gulf of California, within littoral sediments redeposited downslope, radiometrically dated ca. 2.6 to 1.97 Ma (Dorsey et al., 2001). *A. gibbosa* is tropical, reef dwelling species is still extant in the Caribbean-Atlantic province, but it no longer lives in the Eastern Pacific (Crouch & Poag, 1979).

As concerns the samples analyzed in the present work, it is difficult to assess whether the inferences on water temperature and trophic conditions based on the occurrence of *Amphistegina* along with some euritherm planktonic foraminifers, is justified. Clearly, since a large number of physical, biological and anthropogenic factors (e.g., temperature, salinity, UVB radiation, algal overgrowth, eutrophication, heavy metal pollution) are known to influence the distribution of *Amphistegina* (Hallock, 2000), it would be naïve to assume that its Mediterranean Pliocene record is primarily temperature-controlled. However, in the light of the overwhelming evidence for the Late Pliocene-Pleistocene climate cooling, we deem that, ceteris paribus, it is necessary to assume that the latter must have played a key role for the demise of euritherm organisms such as amphisteginids in the Mediterranean.

The foraminiferal assemblages indicate an infralittoral environment and testify to the regressive trend of the Plio-Pleistocene succession in Umbria and Latium. The planktonic component is characterized by the dominance of *G. ruber* and *G. trilobus*, which are interpreted as proxies for warm and oligotrophic waters. In the benthic assemblage, the high percentages of *Asterigerinata planorbis*, *Elphidium crispum*, and *Lobatula lobatula*, as well as the grain size of sediments, indicate high-energy biodetrital bottoms (Sgarrella & Moncharmont Zei, 1993). Since no unquestionable microspheric forms of *Amphistegina* were found, the occurrence of megalospheric individuals may indicate asexual reproduction which occurs at depths far from the ecological optimum or in environmentally stressed conditions (Hollaus & Hottinger, 1997).

The Pliocene represents the last period in which the climate was significantly warmer than today (Crowley, 1991; Dowsett et al., 1996). In the Mediterranean basin until about 3.1 Ma warm climate prevailed, with inferred annual SST >19°C-20°C (Monegatti & Raffi, 2001); in these conditions, biodetrital carbonate sedimentation took place.

A first climatic change set at about 3.1 Ma and it marks the transition from the Early Pliocene climatic regime with low amplitude oscillations, to the Middle Pliocene regime with high amplitude variation (Monegatti & Raffi, 2001). In Middle Pliocene times (ca. 3 Ma), the paleoclimate was still generally warmer than present, particularly at middle to high latitudes. For much of the Western Mediterranean area, Haywood et al. (2000) inferred surface temperature changes with ΔT values of +2 to 4 °C compared to present. The first climatic effects of the expansion of ice volume in the Northern Hemisphere (2.5 Ma) is reflected in the Mediterranean Sea at 2.6-2.7 Ma (Thunell et al., 1990), followed by a strong cooling of the SST at 2.1 Ma (Thunell et al., 1990; Monegatti & Raffi, 2001).

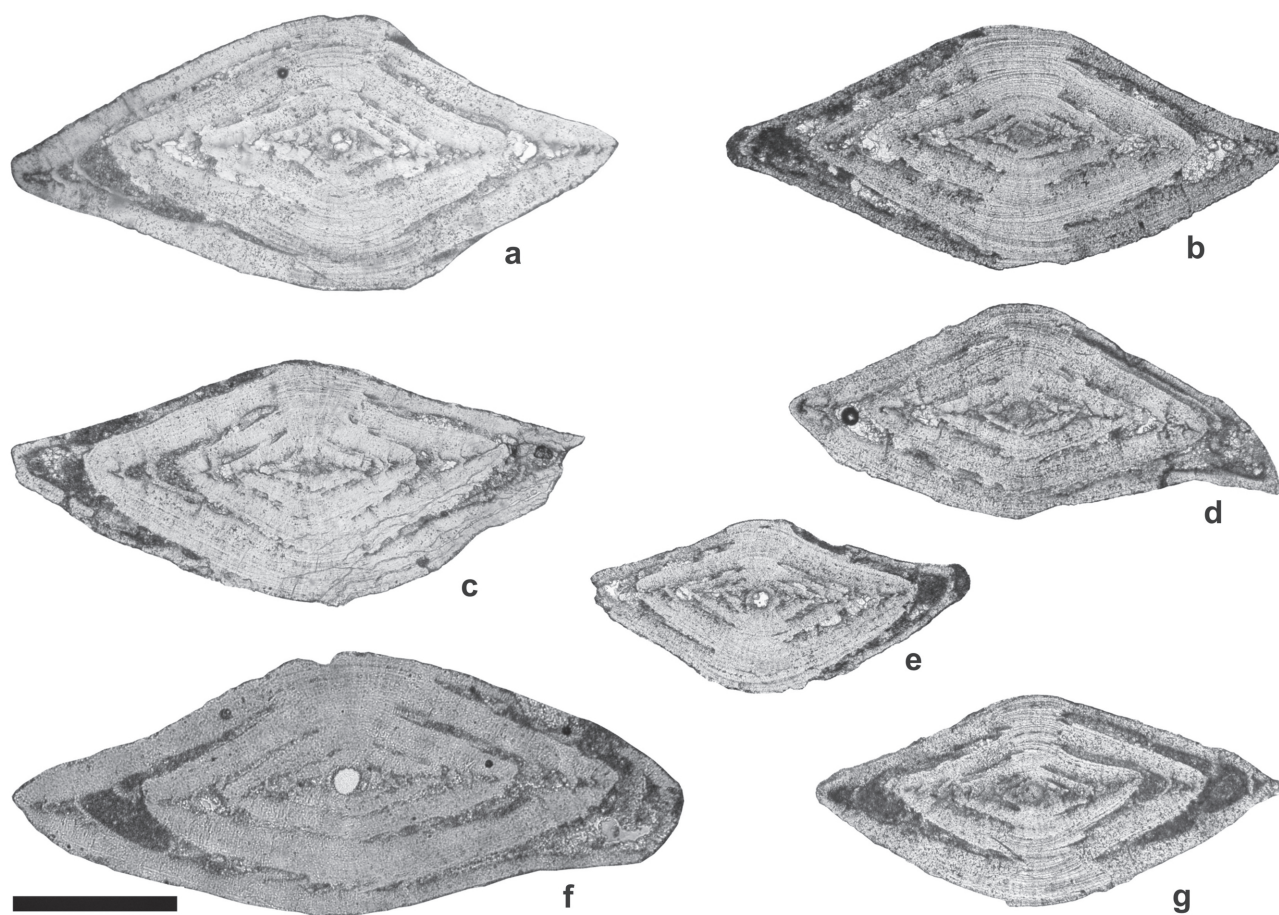


Fig. 8 - *Amphistegina targionii* from the outcrop of Anzio railway station: a-g) vertical (axial) sections. Scale bar = 0.5 mm.

From a chrono-biostratigraphic point of view, two clusters of *Amphistegina*-rich levels are recorded: the first one can be referred to the Piacenzian, preceding the *Bulimina marginata* FO (Tarquina), the second one to the Gelasian, post-*Bulimina marginata* FO (Fosso San Martino, Baschi, and Villa di Nerone). The oldest deposits may be possibly dated between 3.3 and 3.0 Ma because of the co-occurrence of *G. bononiensis* and *G. aemiliana*, testifying to warm conditions before the first Pliocene climatic deterioration (3.1 Ma). The second calcarenite event is located between two climatic changes dated respectively at 2.6-2.7 and 2.1 Ma. For the presence of *B. marginata*, this time interval may eventually prove between 2.3 and 2.1 Ma, when another relative increase in SST is recorded in the Tyrrhenian Sea (ODP Site 653, Thunell et al., 1990).

The development of infralittoral environments with warm microfaunal assemblages was probably caused by the combined effect of the last warm oscillations before the final climatic deterioration and extensional tectonics (Elter et al., 1975; Patacca et al., 1991), that affected the Tyrrhenian margin from the Messinian to the Early Pleistocene. The studied deposits are correlated to a regressive phase caused by the combined effects of regional subsidence/uplift and local tilting. These factors are currently interpreted as the main

controls on sedimentation in the basins of Umbria and Latium in Pliocene and Early Pleistocene times (Mancini et al., 2004).

CONCLUSIONS

The Pliocene succession of Umbria and Latium is characterized by two distinct *Amphistegina*-rich intervals belonging to two different ages, which testify to relatively warm climatic conditions: the first can be referred to the Piacenzian, preceding the *B. marginata* FO, the second to the Gelasian, after the FO of *B. marginata* (Figs. 2, 4). It is unclear whether these levels actually represent two different episodes or if they are related to a single sedimentary event, diachronous in different basins. In any case these deposits represent the last warm oscillation before the strong Late Pliocene climatic deterioration (2.1 Ma).

The foraminiferal assemblages testify to shallow, relatively warm and oligotrophic waters, in agreement with the regressive trend caused by the regional uplift affecting the Tyrrhenian margin from Messinian to Early Pleistocene times.

Pending a systematic revision of the Oligocene-Pliocene *amphisteginids* from Northern Europe, the Paratethys and the Mediterranean area, most of the

specimens from the investigated assemblages are provisionally identified as *A. targionii* (Meneghini). *Amphistegina* is less temperature-dependent than other rotaliine larger foraminifers, as indicated by recent populations living in the Aegean Sea, which thrive in shallow-waters with an annual minimum SST of <13°C; this may help explaining the apparent paradox of its occurrence after the onset of Late Pliocene climatic deterioration.

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