

Planktic foraminiferal biostratigraphy across the Lower-Middle Eocene transition in the Betic Cordillera (Spain)

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With 6 figures

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Abstract: The planktic foraminiferal first and last appearances across the Lower - Middle Eocene transition in the Alamedilla and Agost sections (Betic Cordillera) allows us to establish a detailed new biozonation. This biozonation has been correlated with the Ypresian and Lutetian marine European standard stages and can be correlated with sections located in subtropical and temperate latitudes. The following biozones have been established: *Morozovella subbotinae* Biozone, with *Morozovella formosa* Subzone, *Morozovella aragonensis* Biozone, with *Morozovella aragonensis* Subzone and *Morozovella caucasica* Subzone, *Acarinina pentacamerata* Biozone, with *Acarinina pentacamerata* Subzone, *Subbotina boweri* Subzone and *Truncorotaloides praetopilensis* Subzone (Late Ypresian, Early Eocene), and *Hantkenina nuttalli* Biozone with *Hantkenina nuttalli* Subzone and *Globigerapsis subconglobata* Subzone (Early Lutetian, Middle Eocene).

Zusammenfassung: Erst- und Letztauftreten planktonischer Foraminiferenarten gestatten es, in den Profilen von Alamedilla und Agost (Betische Kordillere) den Übergang vom Unteren ins Mittlere Eocaen mit Hilfe einer neuen Biozonierung zu unterteilen. Die Biozonierung wird mit den marinen europäischen Standardstufen Yprésien und Lutétien korreliert und läßt sich auch in Profilen sowohl im subtropischen als auch im gemäßigten Bereich erkennen. Im Oberen Yprésien (Unteres Eozän) wurden von unten nach oben folgende Biozonen ausgedehnt: *Morozovella subbotinae* Zone mit *Morozovella formosa* Unterzone, *Morozovella aragonensis* Zone mit *Morozovella aragonensis* Unterzone und *Morozovella caucasica* Unterzone, *Acarinina pentacamerata* Zone mit *Acarinina pentacamerata* Unterzone, *Subbotina boweri* Unterzone und *Truncorotaloides praetopilensis* Unterzone; im Unteren Lutétien (Mittleres Eozän): *Hantkenina nuttalli* Zone, mit *Hantkenina nuttalli* Unterzone und *Globigerapsis subconglobata* Unterzone.

Resumen: Las primeras y últimas apariciones de foraminíferos planctónicos del tránsito Eoceno Inferior-Eoceno Medio en la secciones de Alamedilla y Agost (Cordillera Bética) han permitido establecer una nueva biozonación. Esta biozonación ha sido correlacionada con los pisos estándar europeos marinos (Ypresiense y Luteciense) y puede correlacionarse con secciones situadas en latitudes subtropicales y templadas. Se han diferenciado las biozonas siguientes: Biozona de *Morozovella subbotinae* con Subzona de *Morozovella formosa*, Biozona de *Morozovella aragonensis*, con Subzona de *Morozovella aragonensis* y Subzona de *Morozovella caucasica*, Biozona de *Acarinina pentacamerata*, con Subzona de *Acaninina pentacamerata*, Subzona de *Subbotina boweri* y Subzona de *Truncorotaloides praetopilensis* (Ypresiense Superior, Eoceno Inferior), y Biozona de *Hantkenina nuttalli* con Subzona de *Hantkenina nuttalli* y Subzona de *Globigerapsis subconglobata* (Luteciense Inferior, Eoceno Medio).

Introduction

Paleogene planktic foraminiferal classic biozonations were developed in order to have a refined stratigraphical tool in the petroleum industry (BOLLI 1957, 1966, STAINFORTH et al. 1975, BLOW 1979). These zonations constituted general biostratigraphical subdivisions of the Paleogene and were originally developed for use in tropical and subtropical latitudes.

Lately, some authors made significant progress towards the development of a more detailed Paleogene biostratigraphy (BERGGREN & MILLER 1988). Furthermore, BERGGREN et al. (1995) have published zonations of the Paleogene for tropical-subtropical latitudes, and STOTT & KENNETT (1990) and HUBER (1991) for high latitudes. At present, it is still possible to establish more detailed biozonations; for instance, GONZALVO & MOLINA (1992) for the Eocene/Oligocene boundary in low latitudes.

The Ypresian-Lutetian transition in the Southeast of the Betic Cordillera has been treated by several authors such as COLOM (1954) and HILLEBRANDT (1974, 1976). These studies, mainly biostratigraphic and descriptive, were used as reference in this research. The Agost section, studied by HILLEBRANDT (1974, 1976) and CREMADES (1982), was restudied by MARQUEZ & USERA, (1984) and MARQUEZ (1975, 1983, 1991). The Alamedilla section, located in the Central area of the Betic Cordillera, was studied by MARTINEZ GALLEGO (1973, 1977).

We have studied these two sections, which are very representative of the Betic Cordillera. The Alamedilla section, in the Subbetic Zone where the planktic foraminifera were deposited in a deep environment and the Agost section located towards the Southeast in a more shallow environment. In both sections, the interval containing the Ypresian/Lutetian boundary is well

exposed and it is more expanded at Agost. In order to search for a good candidate to define the Ypresian/Lutetian boundary stratotype, a new biozonation of the Lower Eocene to the lowermost Middle Eocene has been established in this paper. Furthermore, the main chronostratigraphical aspects are analyzed.

Materials and methods

The Alamedilla section is located 1,5 km south of Alamedilla village (Granada Province), in the Barranco de Los Valencianos (Fig. 1). The Lower Eocene consists of reddish and grey marls interbedded with calcareous marls, and the Lower/Middle Eocene boundary consists of greenish-grey marls. The samples were taken every two meters throughout the lower Eocene, and every 50 cm across the Ypresian/Lutetian boundary. The Agost section is situated 1 km north of the village of Agost (Alicante Province), near the Lomas de la Beata. The section consists of turbiditic yellowish sands and white-gray hemipelagic marls. Samples were taken every meter across the Ypresian/Lutetian boundary, and every three or four meters in the upper part of the section.

The samples were disaggregated by soaking in water with Calgon overnight with the addition of a small amount of 10 % hydrogen peroxide. Samples were then washed with tap water over 63 and 100 μm screens and dried in the oven at 50°C. Quantitative counts for faunal analysis were obtained from aliquots (using a modified Otto microsplitter) of approximately 300-500 specimens in the size fraction greater than 100 μm . Finally, the remaining sample was scanned for rare species and the fractions between 63 and 100 μm were examined for smaller species. All specimens picked from the aliquot and the rare taxa from the rest of the sample were mounted on a microslide for a permanent record and identified.

Biostratigraphy

Biostratigraphy across the lower-middle Eocene transition in these two sections was not previously studied in detail. Based on detailed samplings and quantitative studies of the planktic foraminifera in both sections, we have refined the most commonly used biozonations of BOLLI (1966), TOUMARKINE & LUTERBACHER (1985), BERGGREN & MILLER (1988) and BERGGREN et al. (1995) (Fig. 4).

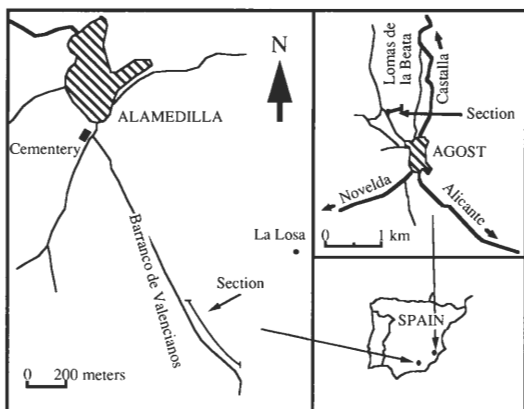


Fig. 1. Location of the Alamedilla and Agost section in the Betic Cordillera, Spain.

The following revised biozonation is proposed:

***Morozovella subbotinae* Interval Range Zone (BERGGREN (1969))**

Definition: Partial Range between the last occurrence (LO) of *Morozovella velascoensis* and the first occurrence (FO) of *Morozovella aragonensis*.

Approximate age: Early Eocene (Early Ypresian).

Remarks: This biozone has only been studied in Alamedilla section (fig. 2) and only in its upper part. Typical assemblages of this zone are characterized by the co-occurrence of such species as *Morozovella subbotinae*, *M. marginodentata*, *M. gracilis*, *M. aequa* and *M. lensiformis*.

***Morozovella formosa* Partial Range Subzone (BLOW 1979, as P 8a, BERGGREN & MILLER 1988, BERGGREN et al. 1995, as P 6b = P 6c; ARENILLAS & MOLINA 1996)**

Name abbreviated to simplify it.

Definition: Partial Range of nominate taxon between the FO of *Morozovella formosa* and the FO of *Morozovella aragonensis*.

Approximate age: Early Eocene (Early Ypresian).

Remarks: This subzone has only been studied in Alamedilla section (Fig. 2) and only in its upper part. BLOW (1979) used for this interval the name P 8a. The clear separation between the FO of *M. formosa* and *M. aragonensis*

allows to characterise this subzone easily. The FO of *M. aragonensis* is a distinct event of appearance for biostratigraphic use. BOLLI (1957) and BECKMANN et al. (1969) used the name of this biozone for another stratigraphically younger interval between the FO of *M. aragonensis* and the FO of *A. pentacamerata*.

Some authors use the FO of *M. aragonensis* as the upper boundary of their zones. TOUMARKINE & LUTERBACHER (1985) and PREMOLI SILVA & BOLLI (1973) used a *Morozovella subbotinae* Zone defining the base at the LO of *Morozovella edgari*. However, BLOW 1979, BERGGREN & MILLER 1988 and BERGGREN et al. 1995, used the same markers as we used for the interval here described.

In Spain, CANUDO & MOLINA (1992) used a *Pseudohastigerina wilcoxensis* Biozone in the Pyrenees. This zone represents a more extensive interval and only its upper part correlates with our *Morozovella formosa* Biozone. HILLEBRANDT (1974) named the same interval here described with another species, *Globorotalia lensiformis*. ARENILLAS & MOLINA (1996) named the same interval with the same boundaries, which could be mistaken for the *M. formosa formosa* Biozone (TOUMARKINE & LUTERBACHER 1985), but the latter biozone occurs between the FO of *M. aragonensis* and the FO of *Acarinina pentacamerata*.

This zone is dominated by morozovellids, represented by seven different species. The faunal assemblage consists of: *Morozovella aequa*, *M. gracilis*, *M. marginodentata*, *M. subbotinae*, *M. lensiformis*, *M. formosa*, *Acarinina interposita*, *A. quetra*, *A. mckannai*, *A. nitida*, *A. pentacamerata*, *Subbotina patagonica*, *S. pseudoeocaena*, *S. inaequispira* (at the top), *Muricoglobigerina soldadoensis*, *M. angulosa*, *M. esnehensis*, *Globigerinoides lozanoi* and *Pseudohastigerina wilcoxensis*.

***Morozovella aragonensis* Interval Range Zone (BERGGREN 1971, as P7, BLOW 1979 as P8b, CANUDO & MOLINA 1992)**

Definition: Interval between the FO of *Morozovella aragonensis* and the LO of *M. formosa*.

Approximate age: Early Eocene (Early Ypresian).

***Morozovella aragonensis* Interval Range Subzone (BERGGREN 1971, as P7, BLOW 1979, as P8b, CANUDO & MOLINA 1992)**

Herein emended at the upper limit.

Definition: Interval between the FO of *Morozovella aragonensis* and the FO of *M. caucasica*.

Approximate age: Early Eocene (Early Ypresian).

Remarks: The biostratigraphical interval from the first concurrent occurrence of *M. aragonensis* and the FO of *M. caucasica* has been described by CANUDO & MOLINA (1992) in the Pyrenees. This biozone is close to the *M. aragonensis* Biozone of BERGGREN (1971), BERGGREN & MILLER (1988). In this paper, we have divided the interval corresponding to BERGGREN & MILLER's (1988) *M. aragonensis* Biozone in two biozones: a lower *M. aragonensis* Biozone and an upper *Morozovella caucasica* Biozone.

The name *M. formosa* Biozone has been used by BECKMANN et al. (1969) and TOUMARKINE & LUTERBACHER (1985) with its top corresponding to FO of *A. pentacamerata*. The *M. formosa* biozones as used by BERGGREN (1969), BERGGREN & MILLER (1988) and BLOW (1979) are close to the interval here defined. It only differs in the definition of its top, which is marked by the LO of *M. formosa*. We use the FO of *M. caucasica* for the definition of the top because it allows to recognise, in low and low-temperate latitudes, two more detailed stratigraphic horizons, instead of only one.

In Spain, HILLEBRANDT (1974) used a *Globorotalia aragonensis* Biozone which extends from the FO of *M. aragonensis* to the FO of *Globorotalia palmerae*. MARQUEZ & USERA (1984) used a *M. formosa* Biozone but its base corresponds to the FO of *M. formosa*, and its top corresponds to the FO of *Acarinina aspensis*, following STAINFORTH et al. (1975).

This biozone has been studied in the Alamedilla section where it is about 20 meters thick. The faunal assemblage consists of: *Morozovella subbotinae* and *M. lensiformis* (only basal part), *M. formosa*, *M. aragonensis*, *Acarinina interposita*, *A. quetra*, *A. mckannai*, *A. nitida*, *A. pentacamerata*, *A. primitiva*, *Igorina convexa*, *Subbotina patagonica*, *S. pseudoeocaena*, *S. inaequispira*, *Muricoglobigerina soldadoensis*, *M. angulosa*, *M. esnehensis*, *Globigerinoides lozanoi*, *Pseudohastigerina wilcoxensis*, and *Acarinina aspensis*, *Pseudohastigerina micra*, *Muricoglobigerina senni* and *Globigerinoides higginsii* (top).

***Morozovella caucasica* Concurrent Range Subzone (BERGGREN 1971, CANUDO & MOLINA 1992)**

Upper limit emended herein.

Definition: Interval between the FO of the nominate taxon and the LO of *Morozovella formosa*.

Approximate age: Early Eocene (Middle Ypresian).

Remarks: This biozone has been introduced for a more detailed division of the middle part of the Lower Eocene. In subtropical and tropical areas, the first appearance of *M. caucasica* occurs before the LO of *M. formosa*. This interval of the co-occurrence of the two species represents 10 meters in

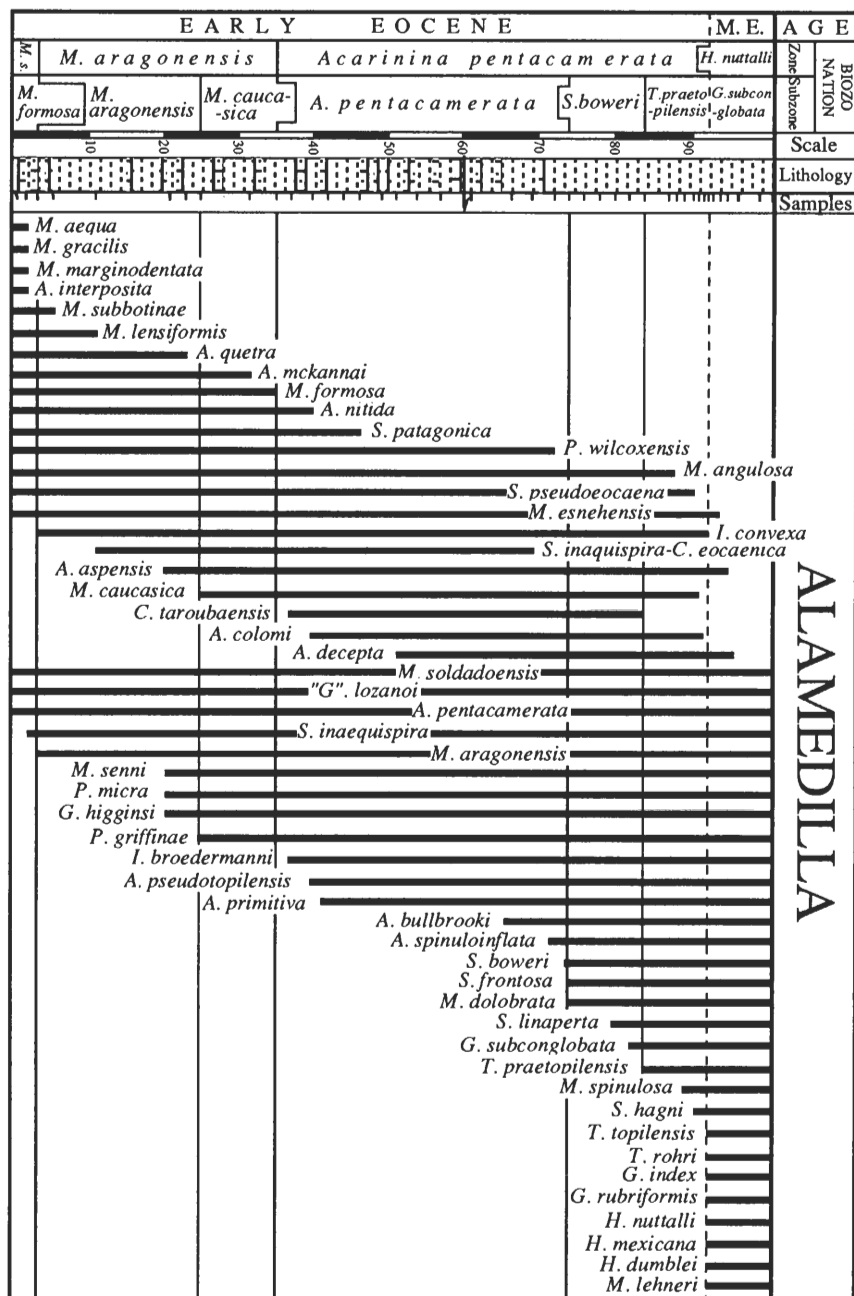


Fig. 2. Stratigraphical distribution of the planktic foraminifera in the Alamedilla section (*M. s.* = *M. subbotinae* Biozone).

the Alamedilla section (Fig. 2). In temperate or high latitudes (CANUDO & MOLINA 1992), the FO of *M. caucasica* occurs after the LO of *M. formosa*, in this case the *M. caucasica* Biozone can not be recognised.

BERGGREN (1971) defined this biozone, and more recently CANUDO & MOLINA (1992) used it in the Pyrenees, but with the FO of *S. frontosa* as marker of its top, their biozone would include the *M. caucasica* and *M. aragonensis* biozones of this paper. Also, ORUE-ETXEBARRÍA et al. (1984) used a *Globorotalia (Morozovella) caucasica* Biozone but again with different boundaries. Generally, biozonations do not use the FO of *M. caucasica* as zonal marker, and the *M. caucasica* Biozone of this paper, could be included in the *M. formosa* Biozone of PREMOLI SILVA & BOLLI (1973), STAINFORTH et al. (1975) and TOUMARKINE & LUTERBACHER (1985), or included in the P7 of BLOW (1979) and BERGGREN & MILLER (1988).

In the Betic Cordillera, MARTÍNEZ GALLEGO (1977) and HILLEBRANDT (1965) used a *M. caucasica* Biozone as the youngest biozone of the Lower Eocene, above their *Globorotalia palmerae* Zone.

This biozone in the Alamedilla section contains the following assemblage: *Morozovella formosa*, *M. aragonensis*, *M. caucasica*, *Acarinina mckannai*, *A. nitida*, *A. pentacamerata*, *A. primitiva*, *A. aspensis*, *Igorina convexa*, *Subbotina patagonica*, *S. pseudoeocaena*, *S. inaequispira*, *S. linaperta*, *Muricoglobigerina soldadoensis*, *M. angulosa*, *M. esnehensis*, *M. senni*, *Pseudohastigerina wilcoxensis*, *P. micra*, *Paragloborotalia griffinae*, *Globigerinoides lozanoi*, and *G. higginsii*.

***Acarinina pentacamerata* Interval Range Zone (Introduced by KRASHENINNIKOV 1965)**

Modified at the lower limit.

Definition: Interval between the LO of *Morozovella formosa* and the FO of *Hantkenina nuttalli*.

Approximate age: Early Eocene (Middle-Late Ypresian).

Remarks: This zone has been introduced by KRASHENINNIKOV (1965) and modified by TOUMARKINE & LUTERBACHER (1985) from the FO of *Turborotalia cerroazulensis frontosa* to FO of representatives of the genus *Hantkenina*. In this paper, we have used the LO of *M. formosa* to define its base.

***Acarinina pentacamerata* Interval Range Subzone (Introduced by KRASHENINNIKOV 1965)**

Name herein emended.

Definition: Interval between the LO of *M. formosa* and the FO of *Subbotina boweri*.

Approximate age: Early Eocene (Middle Ypresian).

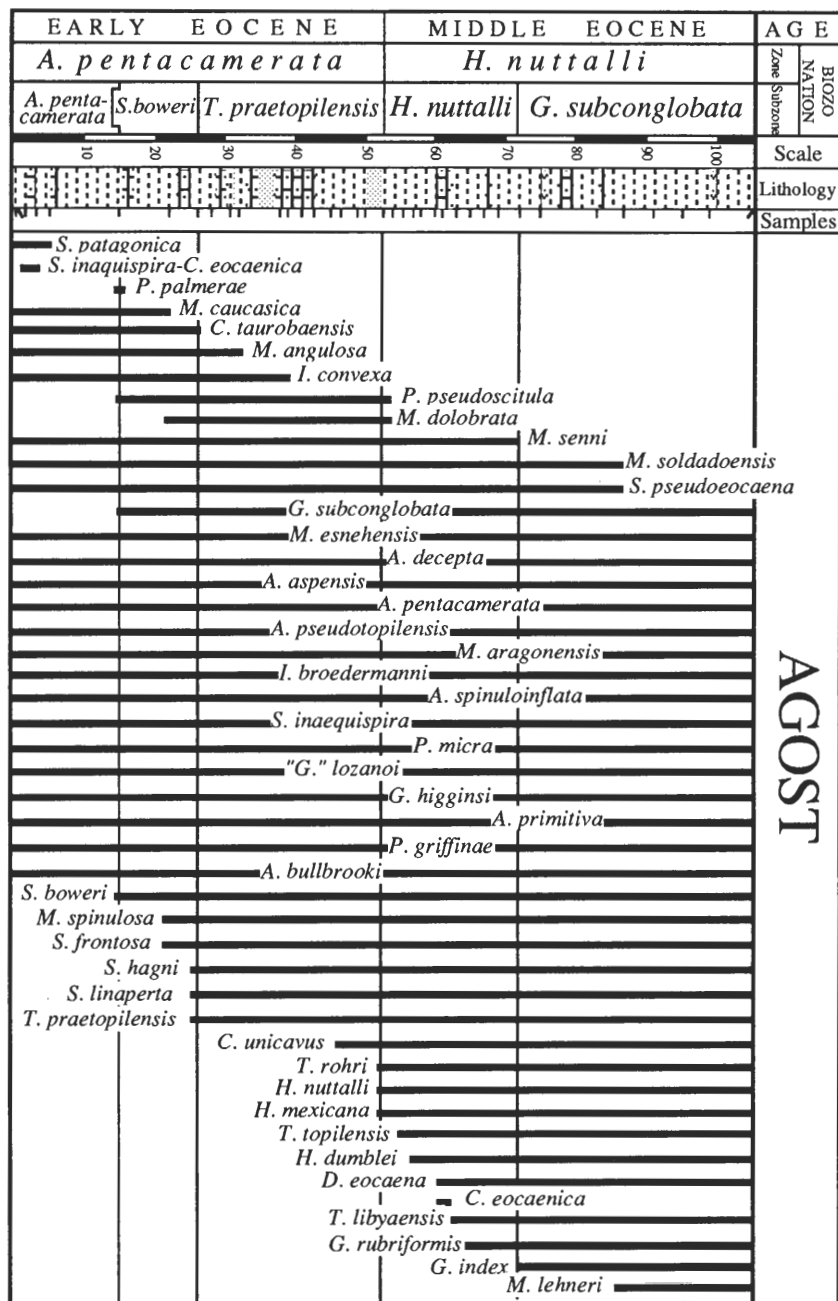


Fig. 3. Stratigraphical distribution of the planktic foraminifera in the Agost section.

Remarks: In this paper, we have used the FO of *S. boweri*, following BLOW (1979), although BLOW used the FO of *S. frontosa frontosa*, but he considered these two species as synonym, whereas we consider *S. boweri* and *S. frontosa* as separate species. Both species appear at the same time in the Alamedilla section (fig. 2), but in the Agost section (fig. 3) the FO of *S. boweri* occurs below the FO of *S. frontosa*. Both horizons are very close and both species could be used as marker.

This biozone is represented in the Alamedilla section by approximately 40 meters of sediments (Fig. 2). In Agost section, it was possible to study the 15 upper meters (Fig. 3). "*Planorotalites palmerae*" is very rare in both sections and only has been found in one sample at Agost. Therefore, it is impossible to use it as a zonal marker. Moreover, BLOW (1979) stated that the taxon *palmerae* is probably referable to the genus *Pararotalia* and is quite certain that it is not referable to the genus *Globorotalia*. If '*P. palmerae*' is most probably not a planktic form, it should not be used as biostratigraphic marker. However, it has been recognized in the Agost section by MARQUEZ & USERA (1984) and HILLEBRANDT (1976) very close to the LO of *M. formosa*. BERGGREN & MILLER (1988) used it for the definition of the top of P8 (*M. aragonensis* Biozone). This biozone corresponds rather closely to the *M. caucasica* Biozone as described here. BERGGREN & MILLER (1988) and BERGGREN et al. (1995) expand the Lower Eocene to the FO of *Hantkenina*, which corresponds to the top of Zone P9. Our *A. pentacamerata* Biozone should be the middle lower part of P9. TOUMARKINE & LUTERBACHER (1985) used the name *M. aragonensis* Biozone, but in their definition it corresponds to both the *M. caucasica* Biozone and the "*A. pentacamerata* Biozone" as used in this paper.

In the Southern Pyrenees, CANUDO & MOLINA (1992) used a *M. caucasica* Biozone, which corresponds to the *M. caucasica* and *A. pentacamerata* biozones here described. The upper part of the *M. aragonensis* and the *G. caucasica* Biozone of ORUE-ETXEARRIA & APELLANIZ (1985) correspond to the *A. pentacamerata* Biozone here described. HILLEBRANDT (1965) used a *M. aragonensis* and a *Planorotalites palmerae* Biozone to represent our *A. pentacamerata* interval. The lower boundary of these biozones is difficult to correlate satisfactorily with our *A. pentacamerata* Biozone because *S. inaequispira*, which these authors used to place the base, has some taxonomic problems hampering its recognition.

The nominate taxon, *Morozovella aragonensis*, extends throughout the entire biozone. This biozone includes the following taxa: *Morozovella caucasica*, *Acarinina nitida* (only at the base), *A. pentacamerata*, *A. aspensis*, *A. colomi*, *A. decepta*, *A. pseudotopilensis*, *A. primitiva*, *Igorina convexa*, *I. brodermanni*, *Subbotina patagonica* (only at the base), *S. pseudoeocaena*,

S. inaequispira, *S. inaequispira-Clavigerinella eocaenica*, *Muricoglobigerina soldadoensis*, *M. angulosa*, *M. esnehensis*, *M. senni*, *Pseudohastigerina wilcoxensis*, *P. micra*, *Paragloborotalia griffinae*, *Globigerinoides lozanoi*, *G. higginsii*, *Catapsydrax taroubaensis* in addition to *Acarinina spinuloinflata* and *A. bullbrooki* at the top of the biozone.

***Subbotina boweri* Partial Range Subzone (ORUE-ETXEBARRÍA 1983, 1984)**

Name herein emended.

Definition: Interval from the FO of the nominate taxon and the FO of *Truncorotaloides praetopilensis*.

Approximate age: Early Eocene (Late Ypresian).

Remarks: This biozone has a thickness of about 10 meters in the Alamedilla section (Fig. 2), and of about 12 meters in Agost (Fig. 3). The FO of *Subbotina boweri* corresponds to the FO of *Subbotina frontosa*, *Morozovella dolobrata*, *M. spinulosa* and *Globigerapsis subconglobata*. The base of the zone constitutes an important faunal turnover. The new species dominate the faunal assemblage and replace the *Muricoglobigerina soldadoensis* group.

BLOW (1979) defined his P10 Zone with the FO of *Subbotina frontosa frontosa* as the basal marker, and stated that the morphotype described by BOLLI (1957) as *Globigerina boweri* is close to the holotype of *Globigerina frontosa*. Therefore, he used *S. frontosa frontosa*, but he identified the two forms as separate subspecies. In this paper both species with the stratigraphic level of their FO very close have been identified (figs. 2 and 3).

BLOW (1979), STAINFORTH et al. (1975) and TOUMARKINE & LUTERBACHER (1985) used the FO of *S. frontosa* for the definition of the base of the *Acarinina pentacamerata* Biozone, which comprises the *S. boweri* and *T. praetopilensis* subbiozones as described here. The top of BLOW's biozone is after the FO of *Hantkenina*, whereas all other use the FO of *Hantkenina* as the base of the next younger biozone. BOLLI (1957) proposes the name *G. palmerae* Biozone.

In Spain, CANUDO & MOLINA (1992) and ORUE-ETXEBARRÍA (1983; 1984) used the FO of *Subbotina* (or *Eoglobigerina*) *frontosa* instead of that of *S. boweri* as the base. In the Betic Cordillera, CREMADES (1982) also used the subspecies *S. frontosa* in his biozonation.

Faunal assemblage: *Morozovella aragonensis*, *M. caucasica*, *M. dolobrata*, *Acarinina pentacamerata*, *A. aspensis*, *A. colomi*, *A. decepta*, *A. pseudo-topilensis*, *A. bullbrooki*, *A. spinuloinflata*, *A. primitiva*, *Igorina convexa*, *I. broedermanni*, *Subbotina boweri*, *S. frontosa*, *S. pseudoeocaena*, *S. inaequispira*, *Muricoglobigerina soldadoensis*, *M. angulosa*, *M. esnehensis*, *M. senni*, *Pseudohastigerina micra*, *Paragloborotalia griffinae*, *Globigerinoides*

lozanoi, *G. higginsii*, *Globigerapsis subconglobata*, *Planorotalites pseudo-scitula*. *Catapsydrax taroubaensis* and *Planorotalites palmerae* at the base.

***Truncorotaloides praetopilensis* Partial Range Subzone (ORUE-ETXEBARRÍA & APELLANIZ 1985)**

Definition: Partial range between the FO of *Truncorotaloides praetopilensis* and the FO of *Hantkenina nuttalli*.

Approximate age: Early Eocene (Late Ypresian).

Remarks: In the Betic Cordillera, an interval between the FO of *S. boweri* and *T. praetopilensis* and the FO of *Hantkenina* has been recognized. Its thickness in the Agost section is about 26 meters (Fig. 3), and in the Alamedilla section (Fig. 2) at least 9 meters. This biozone allows a more detailed subdivision of the upper part of the Lower Eocene. The same interval is recognized in the Pyrenees as *T. praetopilensis* Zone, where it was defined by ORUE-ETXEBARRÍA & APELLANIZ (1985).

This biozone has been also recognized in the Pyrenees by CANUDO & MOLINA (1992), but with the top defined by the FO of *Hantkenina dumblei*, because this species is more frequent than the others hantkenids. Other authors did not distinguish the interval of the *T. praetopilensis* Biozone. It could correspond to the upper part of the *A. pentacamerata* Biozone of TOUMARKINE & LUTERBACHER (1985) and STAINFORTH et al. (1975), and also to the upper part of the *S. inaequispira* Biozone of BERGGREN & MILLER (1988), of the *P. palmerae* Biozone of PREMOLI SILVA & BOLLI (1973) and to the *Sphaeroidinellopsis senni* Biozone of BENJAMINI (1980). These authors situated the Lower/Middle Eocene boundary at the first appearance of *Hantkenina*, except BLOW (1979) whose P10 Zone includes the *S. boweri*, *T. praetopilensis*, *H. nuttalli* and the *G. subconglobata* biozones discussed in this paper (Fig. 4).

In the Betic Cordillera, it seems that the *T. praetopilensis* Biozone could correspond to the upper part of HILLEBRANDT'S (1976) *M. caucasica* Biozone and to the *Acarinina angulosa* Biozone of MARQUEZ & USERA (1984). CREMADES (1982) used an *Eoglobigerina frontosa* Biozone which could include the *T. praetopilensis* Biozone in its middle to upper part.

The faunal assemblage is: *Morozovella aragonensis*, *M. dolobrata*, *M. spinulosa*, *A. pentacamerata*, *A. aspensis*, *A. colomi*, *A. decepta*, *A. pseudotopilensis*, *A. bullbrooki*, *A. spinuloinflata*, *A. primitiva*, *Igorina convexa*, *I. broedermanni*, *Subbotina boweri*, *S. frontosa*, *S. pseudoeocaena*, *S. inaequispira*, *S. hagni*, *S. linaperta*, *Muricoglobigerina soldadoensis*, *M. angulosa*, *M. esnehensis*, *M. senni*, *Pseudohastigerina micra*, *Paragloborotalia*

EARLY EOCENE		M. EOCENE		AGE	
<i>M. aragonensis</i> <i>M. caucasica</i> <i>M. formosa</i>		<i>S. boweri</i> <i>T. praetopilensis</i> <i>H. nuttalli</i> <i>G. index</i>		F.O. and L.O. of planktic foraminifera	
<i>M. sub-bothae</i>	<i>Morozovella aragonensis</i>	<i>Acarinina pentacamerata</i>		This work	Zone
<i>M. formosa</i>	<i>M. aragonensis</i> <i>M. caucasica</i>	<i>Acarinina pentacamerata</i>			Subzone
<i>P. wilcoxensis</i>	<i>Morozovella aragonensis</i>	<i>Morozovella caucasica</i>		Canudo & Molina, 1992	
<i>M. formosa</i> <i>M. lensiformis</i>	<i>Morozovella aragonensis</i> <i>Morozovella formosa</i> P.7 P.6b	<i>Morozovella aragonensis</i> P.8 P.9 P.9 <i>H. nuttalli</i>	<i>Pt. palmerae</i> <i>H. nuttalli</i>	Berggren et al., 1995	
<i>M. subbotinae</i>	<i>Morozovella formosa</i>	<i>Morozovella aragonensis</i>	<i>Acarinina penta-camerata</i>	T. & L., 1985	
<i>M. subbotinae</i>	<i>Morozovella formosa</i>	<i>Morozovella aragonensis</i>	<i>Acarinina angulosa</i>	Marquez, 1983; 1991	
P8a	P8b	P9	P10	Blow, 1979	
<i>M. subbotinae</i>	<i>Morozovella formosa</i>	<i>Morozovella aragonensis</i>	<i>Acarinina penta-camerata</i>	Bolli, 1957; 1966	
<i>"G" lensiformis</i>	<i>Morozovella formosa</i> / <i>A. angulosa</i>	<i>Morozovella aragonensis</i>	<i>"G" caucasica</i>	Hillebrandt, 1974; 1976	

Fig. 4. Correlation of the proposed biozonation with others established for the Lower-Middle Eocene transition (T. & L., 1985 is TOUMARKINE & LUTERBACHER 1985).

griffinae, *Globigerinoides lozanoi*, *G. higginsi*, *Globigerapsis subconglobata*, *Planorotalites pseudoscitula*, *Catapsydrax unicavus* and *Truncorotaloides praetopilensis*.

***Hantkenina nuttalli* Partial Range Zone (BOLLI 1957)**

Definition: Partial range between the FO of *Hantkenina nuttalli* and the FO of *Globigerapsis kugleri*.

Approximate age: Middle Eocene (Early Lutetian).

Remarks: This biozone was already defined by BOLLI (1957) and emended by STAINFORTH et al. (1975) as *Hantkenina aragonensis* Zone and renamed by TOUMARKINE (1981) as *H. nuttalli* Zone. We advise to use the FO of *H. mexicana* instead of *H. nuttalli* as marker of its base when *H. nuttalli* is a rare species, as in temperate areas. *H. mexicana* has its initial appearance at the same time as *H. nuttalli* (Figs. 2 and 3) but can be more abundant. The top is defined either by the FO's of *G. subconglobata*, *G. kugleri*, *G. mexicana* or *G. index*.

***Hantkenina nuttalli* Partial Range Subzone (BOLLI 1957)**

Top herein emended.

Definition: Partial range between the FO of *Hantkenina nuttalli* and the FO of *Globigerapsis index*.

Approximate age: Middle Eocene (Early Lutetian).

Remarks: This biozone has been recognized only in the Agost section, it corresponds to 13 meters of sediments. In Alamedilla, the interval corresponding to this biozone and also the base of the *G. subconglobata* Biozone is almost completely covered. Nevertheless, it is possible to recognize it because the species that characterize the beginning of the Middle Eocene, have their initial appearance at the same time: three species of *Hantkenina*, *Truncorotaloides topilensis*, *T. rohri*, *Morozovella lehneri* and *G. index*.

PREMOLI SILVA & BOLLI (1973) and STAINFORTH et al. (1975) used the name of *Hantkenina aragonensis* (= *H. nuttalli*) for this zone. Also, TOUMARKINE & LUTERBACHER (1985) and BERGGREN & MILLER (1988) used *H. nuttalli*. These biozones differ from the *H. nuttalli* Biozone as defined here mainly by the use of the FO of *G. index* as marker of the top. The first appearance of *Hantkenina* is the event used by all of them. The top marker depends on the species of *Globigerinatheka* chosen, *G. index* in this paper, or *G. kugleri* by BERGGREN & MILLER (1988).

In the Betic Cordillera, HILLEBRANDT (1974), MARTÍNEZ GALLEGO (1977), CREMADES (1982) and MARQUEZ & USERA (1984) used the *H. aragonensis* Biozone following BOLLI's (1966) zonation. Therefore, the *H.*

nuttalli Subzone would be included in the lower middle part of the *H. aragonensis* Biozone. In the Pyrenees, CANUDO & MOLINA (1992) used the *Aragonella dumblei* (= *H. dumblei* in this paper) Biozone, because it is the most abundant species of *Hantkenina*.

The FO of *Hantkenina mexicana* and *H. nuttalli* coincides with the FO of *Truncorotaloides rohri*. Later appear: *T. topilensis*, *H. dumblei*, *Dentoglobigerina eocaena*, *T. libyaensis*, and at the top of these biozone *Globigerapsis rubrifformis*. The rest of the faunal assemblage is composed by *Morozovella aragonensis*, *M. dolobrata*, *M. spinulosa*, *Acarinina pentacamerata*, *A. aspensis*, *A. decepta*, *A. pseudotopilensis*, *A. bullbrooki*, *A. spinuloinflata*, *A. primitiva*, *Igorina broedermanni*, *Subbotina boweri*, *S. frontosa*, *S. pseudo-eocaena*, *S. inaequispira*, *S. hagni*, *S. linaperta*, *Muricoglobigerina soldadoensis*, *M. angulosa*, *M. esnehensis*, *M. senni*, *Pseudohastigerina micra*, *Paragloborotalia griffinae*, *Globigerinoides lozanoi*, *G. higginsii*, *Globigerapsis subconglobata*, *Catapsydrax unicavus*, *Truncorotaloides praetopilensis* and *Clavigerinella eocaenica*.

***Globigerapsis subconglobata* Interval Range Subzone (BOLLI 1957, BERGGREN 1969, BOLLI 1972)**

Limits herein emended.

Definition: Interval range between the FO of *Globigerapsis index* and the FO of *Globigerapsis kugleri*.

Aproximate age: Middle Eocene (Early-Middle Lutetian).

Remarks: The subzone studied contains in Agost about 35 meters (Fig. 3) of sediments, and in Alamedilla (Fig. 2) only 8 meters.

The *Globigerapsis kugleri* Zone of BOLLI (1957) is marked by the FO of *Globigerinatheka mexicana mexicana* at the base. Later, PROTO DECIMA & BOLLI (1970) emended BOLLI's (1957) zone and named it *Globigerinatheka subconglobata curryi* Zone. BOLLI (1972) renamed the zone as *G. subconglobata subconglobata* Zone in order to avoid further confusion. The biozone here defined is starting earlier than BLOW's (1979) P11 Zone, although the base of his biozone is traced at the FO of *G. kugleri*. As BERGGREN & MILLER (1988), we were not able to recognize the different subspecies of the *G. subconglobata* group as discussed by PROTO DECIMA & BOLLI (1970). In the *G. subconglobata subconglobata* Zone, TOUMARKINE & LUTERBACHER (1985) used *G. mexicana mexicana* as zonal marker. Therefore, we use the FO of *G. index* as base of the subzone, because it is easy to recognize and its initial appearance represents the beginning of the typical Middle Eocene assemblages, and it allows to define a new and more detailed interval at the Middle Eocene base.

In the Betic Cordillera, HILLEBRANDT (1974) recognized a *G. subconglobata* Zone, as also CREMADES (1982), MARQUEZ (1983) and MARQUEZ & USERA (1984). However, the latter authors place the base of this zone at the FO of *G. index*, because *G. kugleri* appears later. Our *G. subconglobata* Subzone corresponds the base of their zone.

The FO of *Globigerapsis index* is followed closely by the appearance of *Morozovella lehneri*. The faunal assemblage contains: *M. aragonensis*, *M. spinulosa*, *Acarinina pentacamerala*, *A. aspensis*, *A. colomi*, *A. decepta*, *A. pseudotopilensis*, *A. bullbrooki*, *A. spinuloinflata*, *A. primitiva*, *Igorina convexa*, *I. broedermanni*, *Subbotina boweri*, *S. frontosa*, *S. pseudoeocaena*, *S. inaequispira*, *S. hagni* and *S. linaperta*. *Muricoglobigerina soldadoensis*, *M. esnehensis* and *M. senni*, in the lower part. *Pseudohastigerina micra*, *Paragloborotalia griffinae*, *Globigerinoides lozanoi*, *G. higginsii*, *Globigerapsis subconglobata*, *G. rubriformis*, *Catapsydrax unicavus*, *Truncorotaloides praetopilensis*, *T. rohri*, *T. libyaensis*, *Hantkenina nuttalli*, *H. mexicana* and *H. dumblei*.

Chronostratigraphy

According to the International Subcommittee on Paleogene Stratigraphy, the Lower Eocene/Middle Eocene boundary corresponds to the base of the Lutetian stage (JENKINS & LUTERBACHER 1992). During the International Geological Congress in Washington (1989), the Lutetian and Ypresian were officially established as the standard stages of this interval. Subsequently, a working group has been organized in order to search for a Ypresian/Lutetian Boundary stratotype. Several sections in different countries have been sampled and evaluated as possible candidates for the Ypresian/Lutetian boundary stratotype. In order to find a candidate for the Boundary Stratotype, two Spanish sections have been studied: the Alamedilla and the Agost sections which are the best known sections located in the Betic Cordillera.

The Ypresian has its type-region in the hills around Yeper (Ypres), Belgium (DUMONT 1849, WILLEMS et al. 1981). The Ypresian stage (Ieper Formation) extends from the North of France, through a larger part of Belgium, to the South of the Netherlands. Unfortunately this formation is poorly fossiliferous and only twelve foraminiferal species have been recorded by WILLEMS (1980). According to PARDO (1993) in the Yeper Formation (Knokke borehole) it is possible to recognize the P6a and P6b Zones (planktic foraminifera) of BERGGREN & MILLER (1988). Some authors have correlated their zonations with the Ypresian stage and in terms of calcareous nannofossils it is characterized by the NP11, NP12 and NP13 Biozones (MARTINI

1971) and the lower part of the NP14 Biozone (ROCHE 1982). In terms of planktic foraminifera, the Ypresian should be characterized by the P.6a, P.6b, P.7, P.8 and P.9 Biozones of BERGGREN et al. (1995). The Ypresian overlaps in part with the top of the Cuisian. The base of the Cuisian corresponds to the base of the NP12 Biozone (CAVELIER & POMEROL 1986). The Ilerdian was defined in the Spanish Pyrennees by HOTTINGER & SCHAUB (1960) and overlaps with the lower Ypresian and the Cuisian *sensu lato* (MOLINA et al. 1992, 1994, 1995, 1996).

The Lutetian was defined by DE LAPPARENT (1883) and revised by BLONDEAU (1981) who proposed a new stratotype 50 km North of Paris. According to BLONDEAU (1981) planktic foraminifera are present in the new stratotype, but are infrequent and not typical, though it is possible to recognize the P.10, P.11 and most of P.12 zones of BLOW (1979), and in terms of calcareous nannoplankton it comprises the interval from the NP14 Biozone (upper part) to the NP16 Biozone. Some authors still often use stage names such as the Bruxelian, Ledian and Wenmelian, which are now obsolete since they cover small intervals that are completely within the Lutetian (CAVELIER & POMEROL 1986).

Consequently, the Ypresian/Lutetian boundary should be placed in the NP14 Biozone and could coincide with the base of the P.10 Biozone of BERGGREN et al. (1995) or the base of the *Hantkenina nuttalli* Biozone of this paper. At present, the most frequently used biostratigraphic criteria for the base of the Middle Eocene is the FO of representatives of the genus *Hantkenina* (BOLLI 1957, 1966, BERGGREN 1969, BERGGREN & MILLER 1988, PREMOLI SILVA & BOLLI 1973, STAINFORTH et al. 1975, TOUMARKINE & LUTERBACHER 1985), the base of the biozones of *Nummulites laevigatus* and *Alveolina stipes* (SCHAUB 1988, CAVELIER & POMEROL 1981), and the top of the NP14 Zone in terms of the calcareous nannoplankton zonation (AUBRY 1983). The boundary between the magneto Chron 22 and 21 has been interpolated and the age of the boundary should be about 49 million years (BERGGREN et al. 1995) (Fig. 5).

Conclusions

The continuous marine sections in the Betic Cordillera are rich in planktic foraminifera from the Cretaceous-Palaeocene boundary to the middle Eocene. The best two sections, Alamedilla and Agost, so far known to contain the Lower-Middle Eocene boundary have been studied in detail. The Alamedilla section presents a continuous Lower Eocene except at the Ypresian/Lutetian boundary, and the Agost section shows an expanded Lower-

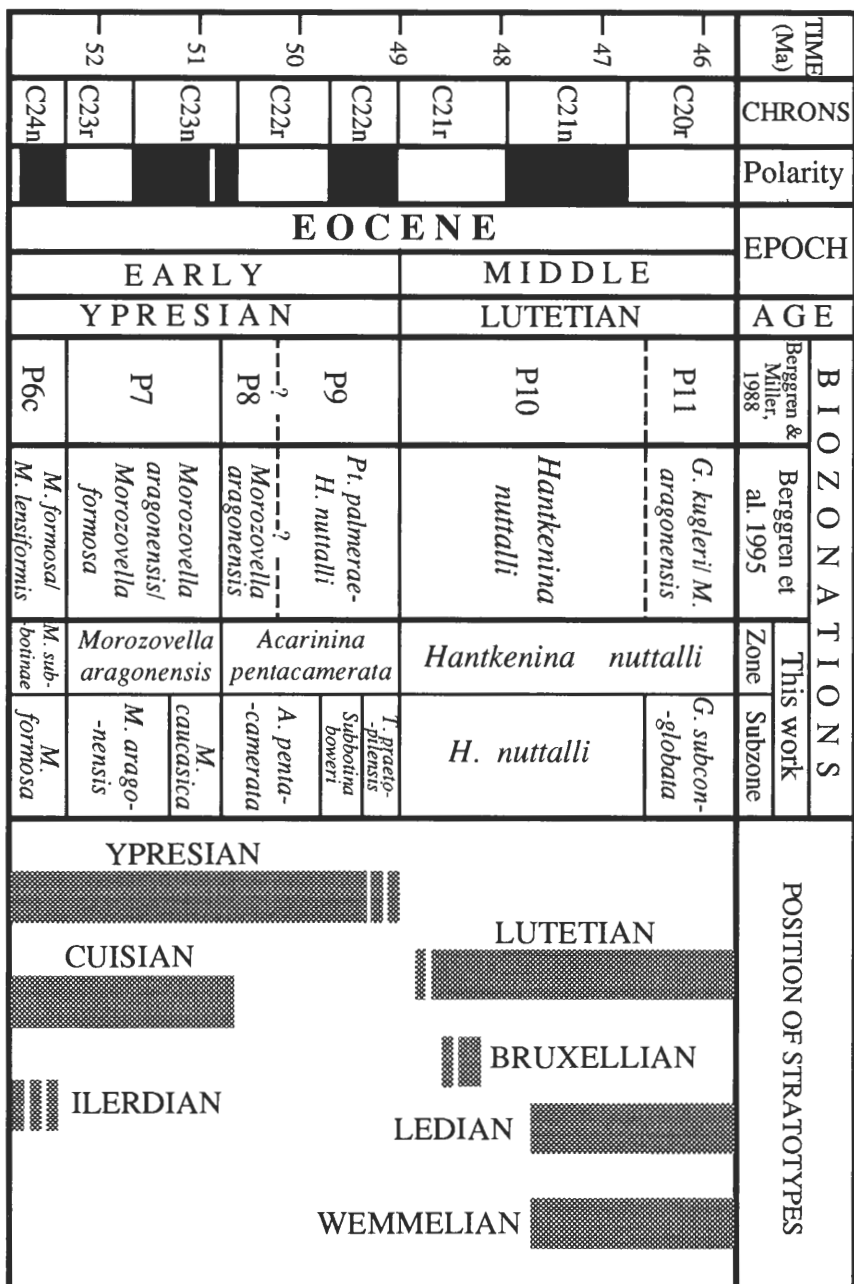


Fig. 5. Chronostratigraphical correlation of planktic foraminifera biozonation and the position of the stratotypes (Time, Chrons and Polarity based on BERGGREN et al. 1995).

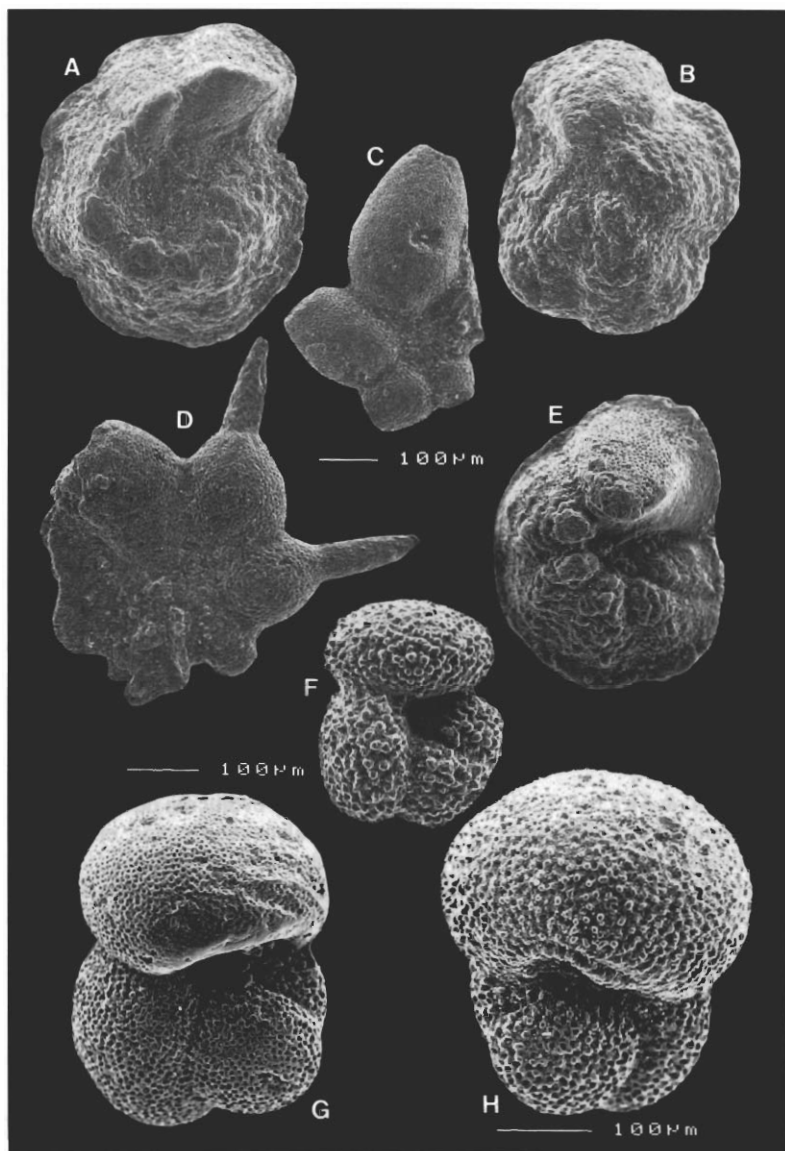


Fig. 6
A: Umbilical side of *Morozovella caucasica*. Sample of Alamedilla section. **B:** Umbilical side of *Morozovella formosa*. Sample of Alamedilla section. **C:** Umbilical side of *Hantkenina nuttalli*. Sample of Alamedilla section. **D:** Umbilical side of *Hantkenina mexicana*. Sample of Alamedilla section. **E:** Umbilical side of *Morozovella aragonensis*. Sample of Agost section. **F:** Umbilical side of *Truncorotaloides praetopilensis*. Sample of Agost section. **G:** Umbilical side of *Subbotina frontosa*. Sample of Agost section. **H:** Umbilical side of *Subbotina bowyeri*. Sample of Agost

Middle Eocene transition where it is possible to study the gradual faunal turnover across the boundary.

Based on the first and last occurrences of planktic foraminiferal species as observed in both sections, we propose a new biozonation correlatable with the international standard stages and valid for subtropical latitudes. The correlation of our biozonation with the stages accepted by the Subcommission on Paleogene Stratigraphy, Ypresian and Lutetian, is the following: Ypresian (*Morozovella subbotinae* Biozone with *Morozovella formosa* Subzone, *Morozovella aragonensis* Biozone with *Morozovella aragonensis* Subzone and *Morozovella caucasica* Subzone, *Acarinina pentacamerata* Biozone with *Acarinina pentacamerata* Subzone, *Subbotina boweri* Subzone and *Truncorotaloides praetopilensis* Subzone) and lower Lutetian (*Hantkenina nuttalli* Biozone with *Hantkenina nuttalli* Subzone and *Globigerapsis subconglobata* Subzone).

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