Reprinted from Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen, Amsterdam, series B, volume 80 (4), October 21, 1977

STRATIGRAPHY/PALAEONTOLOGY

DISCOVERY OF A PLANKTONIC FORAMINIFERAL ASSOCIATION BETWEEN THE ABATHOMPHALUS MAYAROENSIS ZONE AND THE "GLOBIGERINA" EUGUBINA ZONE AT THE CRETACEOUS/TERTIARY BOUNDARY IN THE BARRANCO DEL GREDERO (CARAVACA, SE SPAIN): A PRELIMINARY REPORT. I

BY

J. SMIT

(Communicated by Prof. W. P. de Roever at the meeting of June 18, 1977)

SUMMARY

In the outcrops of the boundary described, which is found in the Loma de Solana unit of the North Subbetic zone, the section across the boundary is more complete than in any other fully marine section with pelagic sediments so far described. A thin clay layer is encountered which separates sediments with a fauna the Cretaceous Abathomphalus mayaroensis Zone from those with a fauna of the Paleocene "Globigerina" eugubina Zone. This boundary layer contains an indigenous planktonic foraminiferal association unknown from other areas. It is supposed that the extinction of the Globotruncana-Rugoglobigerina fauna may have taken place in less than 1.000 years.

INTRODUCTION

At the end of the Cretaceous (Maastrichtian) the dinosaurs, mosasaurs, plesiosaurs, ammonites, belemnites and numerous other animals of smaller systematic units became extinct. No species of the Globigerinacea are known to cross the Cretaceous-Tertiary boundary, although relations between Cretaceous and Tertiary species have been suggested (Berggren 1960, 1962, Olsson 1970); nevertheless the Globigerinacea continued to exist and, accordingly, some species must have survived the terminal Cretaceous event, whatever the cause of the mass extinctions may have been. So far investigations have failed to discover the planktonic foraminiferal "missing link".

On land continuous sections of fully pelagic sediments across the Cretaceous-Tertiary boundary from which the individual specimens of planktonic Foraminifera can be extracted are relatively scarce and most information on the boundary is based on material provided by the Deep Sea Drilling Project (D.S.D.P.) in the last eight years. All investigators of this material confirm the statement of a.o. Luterbacher and Premoli Silva (1964) that the extinctions of the Cretaceous planktonic Foraminifera took place very suddenly, as observed even in the most complete cores.

The author investigated forty localities in the Subbetic zone between Vélez-Rubio and Caravaca where an apparently continuous sequence exists across the boundary. In all these localities the transition from Cretaceous to Tertiary takes place within calcareous pelagic sediments with varying amounts of intercalated turbidites or olistostromes; indications for shallow water environments were never found; planktonic Foraminifera occur in abundance in all fine-grained deposits.

The most complete section was found in the Barranco del Gredero, four km South-West of Caravaca (Fig. 1). Everywhere else parts of the zonation found there were missing. Always part of the Paleogene (the "G". eugubina

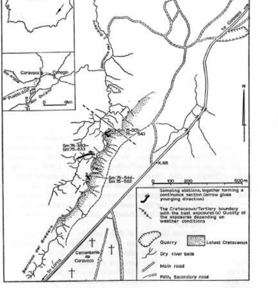


Fig. 1. Map showing the sections across the Cretaceous-Tertiary boundary in the Barranco del Gredero.

Zone at least) was lacking and in half of the sections part of the Cretaceous. In nearly all sections the Cretaceous is conformably overlain by the Paleogene. These hiatuses may be due to submarine erosion phenomena such as slumping or turbidity current action, which can be concluded from the presence of turbidites, slumpmasses and olistostromes. Alternatively they may be the result of the existence of late Cretaceous "highs" on which no sedimentation took place. The presence of similar "highs" may be deduced from the occurrence of quite different facies, or striking differences in thickness, very close together in the Almoyas area (Fig. 3).

In the Barranco del Gredero a thick and undisturbed sequence of late Cretaceous and early Tertiary age has been found in which several detailed sections were taken. These exposures were already mentioned by Fallot *et al.* (1958), Durand Delga *et al.* (1959), Paquet (1969) and Van Veen (1969). The Cretaceous-Tertiary boundary can here be followed over a distance of at least 0.8 km along the strike, and is frequently exposed. The sediments are fully marine, pelagic marls and calcilutites and only a few turbidites are intercalated.

The entire sequence from Cenomanian to middle Eocene, some 600 metres in thickness, contains abundant planktonic foraminiferal faunas; most samples yield clean wash residues with well-preserved faunas.

In the post-Cenomanian part of the section macrofossils are extremely scarce; thin-shelled irregular echinoids, sometimes with their spines preserved and thus presumably in situ, a few solitary corals and some very large flat Inoceramus shells occur.

The investigated part of the section contains all planktonic foraminiferal zones so far described from the latest Cretaceous and Paleocene (Bolli 1966); all zones are complete and unusually thick. Moreover a ten centimetres thick marly clay interval occurs (B.3, page 288), containing an indigenous planktonic foraminiferal fauna that is different both from the underlying fauna typical for the uppermost Cretaceous A.mayaroensis Zone, and from the overlying "G" eugubina Zone fauna of the lowermost Paleocene. This particular fauna has not been described as occurring in other classical areas, such as the Appennines (Luterbacher and Premoli Silva 1964) and the Joides boreholes (Legs 13 and 20). The author is at present investigating all aspects of the boundary in these outcrops in collaboration with specialists in the fields of nannoplankton (T. Romein, 1976, 1977), Dinoflagellata (De Coninck), microchemistry and mineralogy.

It is the purpose of this paper to describe the geologic setting in which the Cretaceous-Tertiary boundary occurs and to give some preliminary details on the faunas encountered. A large amount of material from the Cretaceous-Tertiary beds has been sampled. Part of this material is available to colleagues interested. The classification of Ingram (1954) has been followed to indicate the thickness of beds.

REGIONAL STRATIGRAPHY

The Betic Cordilleras along the meridian of Caravaca consist of the following units. South of the hercynian Meseta the Prebetic zone is found, consisting of shallow marine and continental deposits of Triassic to Miocene age. South of this zone follows the Subbetic zone. Triassic and lower Lias are similar to those of the Prebetic. From the upper Lias onwards deeper water facies prevail. The Cretaceous and Tertiary consist of an open marine facies of pelagic and gravitationally emplaced deposits. South of the Subbetic, the Betic zone is found, consisting of four superimposed tectonic complexes. The lower three consist of metamorphosed sediments of Triassic and older age. The uppermost, Malaguide complex is non- or hardly metamorphic and comprises Silurian to Oligocene rocks.

The Subbetic is subdivided in three subzones, the North Subbetic, the Central zone and the South Subbetic (fig. 3). In late Cretaceous and early Tertiary all three zones are characterized by the association of pelagites and gravitites. There are, however, diagnostic differences between the individual pelagic and the individual gravitite rock units of the three subzones. All Cretaceous-Tertiary boundaries known in these subzones have been examined. In the North Subbetic (Fig. 3), the boundary is well exposed in the so-called Loma de Solana unit. In the Central and South Subbetic zones, deformation has been more severe and boundaries can rarely be followed over larger distances. Some forty separate sections over the boundary have been examined in an attempt to find the most suitable one. In all these sections, however, one or more planktonic foraminiferal faunal zones were found to be missing, as indicated on the accompanying map (Fig. 3), and the sequences of pelagic rocks are thin compared with those of the Loma de Solana unit in the North Subbetic. Therefore the Gredero section from the latter unit has been selected as the object for the present investigation.

LOCAL STRATIGRAPHY

The Loma de Solana unit in the North Subbetic zone differs from other North-Subbetic units by its unusual thickness and the continuous sedimentation. Details on this unit have previously been published by Fallot *et al.* (1958), Durand Delga *et al.* (1959), Paquet (1969), Van Veen (1969) and Von Hillebrandt (1975).

We shall here follow the lithostratigraphic classification of Van Veen (1969), who divided the Late Cretaceous to Miocene deposits into the following lithostratigraphic units:

C)	Gredero formation	Lower Eocene to Miocene
B)	Jorquera formation	Lower Maastrichtian to Lower Eocene
A)	Quipar formation	Cenomanian to Campanian

All three formations consist essentially of pelagic calcilutites and marls with intercalations of calcareous turbidites in the upper two formations.

The lowermost, i.e. the Quipar formation, is developed in a Couches Rouges facies, but has only a single reddish interval in the Santonian to lower Campanian. In the Jorquera formation the pelagic rocks of the lower part are still very like the Couches Rouges, but in the upper part and in the overlying Gredero formation soft marls begin to predominate over hard calcilutites.

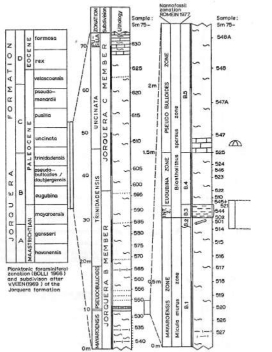
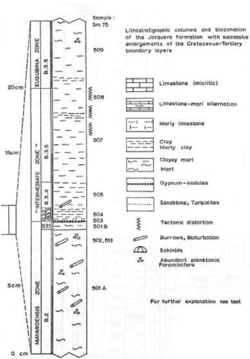


Fig. 2. Lithostratigraphic columns of the section in the Barranco del Gredero.

The turbidites of the Gredero formation contain a much higher percentage of larger benthonic Foraminifera than those of the Jorquera formation.

The Cretaceous-Tertiary boundary occurs within the Jorquera formation. Van Veen (1969) divided this formation into four parts, J^a–J^d. This subdivision is lithostratigraphically not very satisfactory, Van Veen (1969) himself considered it "somewhat artificial".



In fig. 2 the Jorquera formation is depicted, with successively higher enlargement of the Cretaceous-Tertiary boundary beds. The first column has been compiled after Van Veen (1969) for the Cretaceous and after Von Hillebrandt (1975) for the Paleocene interval.

J^a *Member*

White, relatively thick-bedded, hard calcilutites alternating with softer thin- to medium-bedded marls. The bedding planes between the two rock types are almost flat as can be observed in an old quarry along the Caravaca – Puebla de Don Fadrique road near km 67. Thickness 100 m. Early – Late Maastrichtian.

J^b *Member*

White-grey to greenish yellow calcilutites alternating with strongly dominating marls. The bedding planes are less flat than in the J^a member. Both J^a and J^b members contain intercalations of characteristically orange-coloured calcarenites, up to 1 metre thick, graded or finely laminated, with occasional sole markings. These calcarenites contain among others *Inoceramus* prisms, lime clasts, planktonic and larger benthonic Cretaceous Foraminifera. The latter are also reported from the Paleocene, where they are clearly reworked.

Within this member the Cretaceous – Tertiary boundary occurs (Fig. 2). The marls directly above the Cretaceous – Tertiary boundary exhibit a darker, more greyish colour than those from the Cretaceous. This difference is difficult to observe in the field. Thickness 70 metres. Late Maastrichtian (A. mayaroensis Zone) and Early Paleocene (up to and including the G. trinidadensis Zone).

J^c *Member*

Dark, olive-grey marls containing a ten metres thick interval of alternating red to yellow marls and hard calcilutites. This Couches Rouges-like interval serves as a marker bed within the white and grey colours of the Jorquera formation. A single, thin (10 cm) lense of fine-grained, grey arenite was found, consisting for 70% of *Microcodium* fragments. Thickness 75 metres. Early to Late Paleocene (G. trinidadensis Zone to Gl. velascoensis Zone).

J^d *Member*

Olive-green marls alternating with graded and often laminated calcarenites containing among others planktonic Foraminifera and rare *Nummulites* and *Alveolina*. Thickness 25 metres. Latest Paleocene (Gl. velascoensis Zone) to Early Eocene (Gl. rex Zone).

To facilitate the description of the Cretaceous – Tertiary boundary beds, the part of the J^b member directly above and below the boundary has been further subdivided into five beds; B.1 to B.5 (Fig. 2).

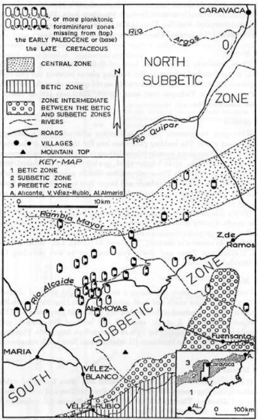


Fig. 3. Map of the Subbetic zone between Caravaca and Vélez-Rubio, showing the hiatus at the Cretaceous-Tertiary boundary in the sections investigated.

B.1 Bed

Light green to whitish marls and rare, slightly harder calcilutites of the same colour containing a foraminiferal fauna of the A. mayaroensis Zone, which in most samples consists for more than 95% of planktonic Foraminifera. Evidence for bioturbation is only rarely seen. Thickness 90 cm. The same rocktype continues more than 25 metres in the undifferentiated lower part of the J^b member, where some thin-bedded laminated calcarenites are intercalated, consisting almost entirely of planktonic Foraminifera.

B.2 Bed

The same marls as B.1, containing, however, abundant black burrows of the "*Zoophycos* and *Chondrites*" type. B.2 contains the same rich planktonic foraminiferal fauna as B.1. Thickness 5–7 cm.

B.3 Bed

The complex, thin – bedded to laminated boundary bed, which separates marls with a fauna of the A. mayaroensis Zone from marls containing a fauna of the "G". eugubina Zone. It is the interval occupied by this bed which, in my opinion, is lacking in all previously described pelagic sections across the Cretaceous-Tertiary boundary.

In this bed the sequence from bottom to top is as follows (Fig. 2):

B.3.1. 1 cm green soft marl, not laminated, containing a poor A. mayaroensis Zone assemblage; the insoluble residue (I.R.) which in the underlying interval has a mean value of 18% increases to 48%;

B.3.2. 0.1–0.5 cm rusty-red clay with small gypsum aggregates; too thin to sample without running the risk of contamination;

B.3.3. 1 cm black, thinly laminated clayey marl;

B.3.4. 2 cm dark green, faintly laminated, ductile clayey marl, with several kinds of burrows, lying with a transitional contact on B.3.3; in B.3.3. and B.3.4. the fauna shows two clearly different types of preservation: a well preserved fraction, which is assumed to be indigenous and a poorly preserved, often broken fraction, which consists of evidently redeposited Cretaceous globotruncanids and rugoglobigerinids;

B.3.5. 7 cm green to dark green clayey marl alternating with laminae of very ductile clay which do not contain planktonic Foraminifera apart from some large, probably reworked globotruncanids; smaller benthonic Foraminifera are per unit weight of sample much more numerous than in B.3.1. or B.3.6.; in proportion to the I.R. content, however, their frequency remains more or less the same; this interval is often slickensided and the planktonic Foraminifera are crushed; also slumped yellow arenitic streaks occur, which consist almost entirely of badly preserved reworked planktonic Foraminifera; the Insoluble Residue of B.3.3. to B.3.5. varies from 52% to 70%;

B.3.6. 7 cm transition of the dark green marl of B.3.5. to the light green marls of B.4.; the I.R., decreases to 16%, which coincides with a considerable increase in the amount of specimens of planktonic Foraminifera; the top of this interval contains the first, rare, *"Globigerina" eugubina* Luterbacher and Premoli Silva.

B.4 Bed

Olive-grey to-green marls, containing a rich assemblage of very small planktonic Foraminifera of the "G'" eugubina Zone. The ratio between the specimens of the various species varies; in the lower part of this bed *"Globigerina" eugubina*, *Globigerina fringa* and related species dominate, wheras in the upper part *Chiloguembelina* spp., *Guembelitria cretacea*, *Guembelitria* spp. form the greater part of the association. Thickness 40 cm.

B.5 Bed

Light grey-green marls and a single 15 cm thick layer of white, hard calcilutite, which contains small irregular echinoids with their spines preserved, and a solitary coral. Similar marls continue in the undifferentiated upper part of member J^b. Thickness 1.5 m.
G. pseudobulloides/daubjergensis Zone.

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BY

J. SMIT

(Communicated by Prof. W. P. de Roever at the meeting of June 18, 1977)

NOTES ON PLANKTONIC FORAMINIFERA

In the Cretaceous - Tertiary boundary layers of the Gredero section, assemblages of planktonic Foraminifera have been found which characterize three faunal zones. Two of these zones are well known from literature and recognized in various parts of the Tethyan - tropical regions (e.g. Spain, Italy, Trinidad, Pacific Ocean); the A. mayaroensis Zone of the Latest Cretaceous, characterized by the zonal marker *Abathomphalus mayaroensis* Bolli, *Trinitella scotti* (Brönnimann) and very large globotruncanas like *Globotruncana contusa* (Cushman), *Gt. conica* White and *Gt. stuarti* (De Lapparent) (B.1 and B.2), and the "G." eugubina Zone of the Lowermost Paleocene, characterized by extremely small „globigerinids" like *"Globigerina" eugubina* Luterbacher and Premoli Silva and *Globigerina fringa* Subbotina.

In the present section a third, "intermediate" zone can be recognized which is characterized by the absence of both true globotruncanids and the small globigerinids of the "G." eugubina Zone.
It contains a "residual" fauna of Cretaceous species.

Abathomphalus mayaroensis zone

Samples Sm 75-502, -501 and -514 yield the following species: (Fig. 4)

Abathomphalus mayaroensis Bolli
Archaeoglobigerina blowi Pessagno
Globigerinelloides sp.
Globotruncana aegyptiaca Nakkady
Globotruncana arca Cushman
Globotruncana conica White
Globotruncana contusa (Cushman)
Globotruncana aff. falsostuarti Sigal
Globotruncana aff. rosetta (Carsey)

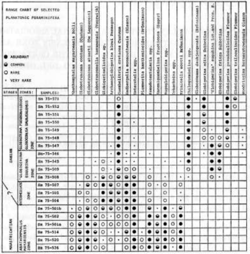


Fig. 4. Range chart of some planktonic Foraminifera from the section of the Barranco del Gredero.

Globotruncana stuarti (De Lapparent)
Globotruncana trinidadensis Gandolfi
Globotruncana spp.
Globotruncanella havanensis (Voorwijk)
Globotruncanella petaloidea (Gandolfi)
Globotruncanella messinae subcarinata (Brönnimann)
Gublerina sp.
Guembelitria cretacea Cushman
Hedbergella monmouthensis (Olsson)
Hedbergella sp.
Heterohelix spp.
Planoglobulina sp.
Plummerita hantkeninoides (Brönnimann)
Pseudoguembelina spp.
Pseudotextularia spp.
Racemiguembelina fructicosa (Egger)
Rugoglobigerina rotundata Brönnimann
Rugoglobigerina rugosa (Plummer)
Rugoglobigerina spp.

Trinitella scotti (Brönnimann)
Schackoina cenomana Schacko
Schackoina multispinata Cushman and Wickenden
Ventilabrella sp.

Further, less than 2% smaller benthonic Foraminifera and even smaller quantities of ostracods, fish-teeth and hystrichospheres are found.

The planktonic foraminiferal fauna ranges throughout member B.1, B.2 and the last 10 m of the Cretaceous without any significant changes in the number of species: up to the highest sample of the A. mayaroensis Zone (SM 75–501a) it remains strongly diversified with over forty species.

Intermediate zone

In the lower 0.5 cm of B.3.1 the number of both species and specimens decreases sharply, but they do not vanish completely. In the "intermediate" zone globotruncanas and rugoglobigerinas disappear but heterohelicids and other small to extremely small forms like *Hedbergella monmouthensis* (Olsson), *Archaeoglobigerina blowi* Pessagno and *Guembelitria cretacea* Cushman, which already occur in small quantities in the A. mayaroensis Zone suddenly become more numerous, also in relation to other species within the size fraction of up to 160 μ.

These forms could possibly be reworked, but the relatively small size, the good preservation and the relative increase in numbers oppose this view. We may conclude from these findings that after the extinction of the main globotruncanid fauna and before the appearance of the first species of the "G." eugubina fauna, during the very short period that beds B.3.2. to B.3.5 were deposited there still lived unkeeled and dwarfed species of Cretaceous origin.

Samples Sm 75–504 and –505 taken in the beds B.3.3 and B.3.4 yield (Fig. 4):

Archaeoglobigerina blowi Pessagno
Globotruncana spp. (corroded)
Globigerinelloides sp. *aff. messinae* (Brönnimann) (pl. 2, Fig. 4)
Guembelitria cretacea Cushman (Pl. 2, Fig. 6)
Hedbergella monmouthensis (Olsson) (Pl. 2, Fig. 3)
Heterohelicidae (in part corroded)
Rugoglobigerina spp. (corroded)
fish remains
pollen (rare)
hystrichospheres
smaller benthonic Foraminifera (up to 55% of the fauna in some laminae of B.3.5)
ostracods (rare)

"Globigerina" eugubina Zone

In B.3.6 the first rare and very small "globigerinids" of the "G." eugubina Zone appear (Pl. 1, Figs. 1–9). They are already fully developed and, as far as I could ascertain, they have no direct relationship with species like *Hedbergella monmouthensis* (Olsson) or *Archaeoglobigerina blowi* Pessagno together with which they occur. Such relationships have been suggested by a.o. Abtahi (1975).

The first appearance of "*Globigerina*" *eugubina* in sample SM 75–508 (B.3.6) marks the lower boundary of the "G." eugubina Zone.

The "G." eugubina Zone was established by Luterbacher and Premoli Silva (1964) in the central Appennines of Italy and later this Zone has been recognized in several regions of the world (however, nowhere in boreal regions). So far occurrences have been described from the Appennines, the Soutern Alps (Luterbacher and Premoli Silva 1966), east of the Caspian sea (Nevzorova 1971), Northern Spain (Von Hillebrandt 1965) and Joides holes in the Caribbean (Leg 15, Bolli and Premoli Silva 1973), the Pacific Ocean (Leg 20, Krashenninnikov and Hoskins 1973) and the Blake Plateau off the east coast of Florida (Leg 44, R. R. Schmidt, in press). Questionable occurrences have been found in Northern Africa (Blow, in Fisher *et al.* 1971), the Pyrenees (Von Hillebrandt 1962) and in Alabama (Olsson 1970). In most of these regions the determination of "*Globigerina*" *eugubina* is based on thin sections. Localities where detached, well-preserved specimens can be obtained are, as far as I know, the Joides legs 15 20 and 44 and the Gredero section in discussion.

Since the "G." eugubina Zone in the Gredero section is ± 40 cm thick and not disturbed by drilling operations, it should be one of the best land-based localities to examine the evolution of the earliest Tertiary globigerinid faunas step by step. For this purpose it has been sampled continuously. In the present, preliminary, report only the faunas from the basal and uppermost parts will be described.

Samples SM 75–509 and Sm, 75–521 (base "G." eugubina Zone) yield:

"*Globigerina*" *eugubina* Luterbacher and Premoli Silva (Pl. 1, Figs. 1, 3, 6)
Globigerina fringa Subbotina (Pl. 1, Figs. 8, 9)
Chiloguembelina aff, midwayensis (Cushman) (Pl. 2, Figs. 1, 2)
Chiloguembelina sp.
Hedbergella monmouthensis (Olsson)
Archaeoglobigerina blowi Pessagno
globotruncanids, rugoglobigerinids and heterohelicids (rare and broken)
Guembelitria cretacea Cushman

Sample SM 75–546 (top "G." eugubina Zone) yields;

Archaeglobigerina blowi Pessagno (rare)
Chiloguembelina spp.
"*Globigerina*" *eugubina* Luterbacher and Premoli Silva
Globigerina fringa Subbotina
Globigerina aff. edita Subbotina

PLATE 1

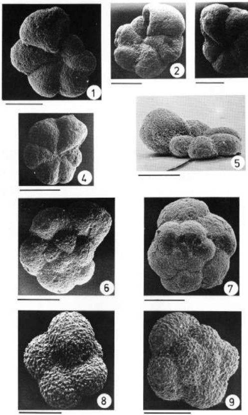
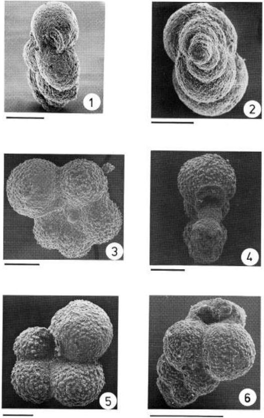


PLATE 2



Globotruncana sp. (rare and broken)
- *Guembelitria irregularis* Morozova
- *Guembelitria cretacea* Cushman
- *Hedbergella monmouthensis* (Olsson) (rare)
- *Woodringina hornerstownensis* (Olsson) (rare)

All samples from the "G." eugubina Zone contain 7–15% smaller benthonic Foraminifera, some ostracods, hystrichospheres and fish remains. In contrast with the overlying, 22 metres thick G. pseudobulloides/daubjergensis Zone, the evolution of the planktonic Foraminifera in the "G." eugubina Zone is rapid. It should even be possible to divide this Zone into some subzones, but considering the very slight thickness of this Zone, the stratigraphic value of such zonules would be doubtful. In the lower part of the "G." eugubina Zone *"Globigerina" eugubina* and *Globigerina fringa* dominate, whereas in the upper part chiloguembelinids and *Guembelitria* spp. form 80% of the fauna. *Woodringina hornerstownensis* Olsson appears in the upper part of the Zone.

The species themselves also show rapid changes; the dimensions of *"Globigerina" eugubina* increase only slightly, the number of chambers in the last whorl, however, increases from 4½–6 to 6½–8, even 10 (in rare cases) and the chambers become more rounded, with deeper depressed sutures.

The aperture in sample SM 75–509 is in most specimens a narrow rimless opening and shows a tendency to become a very long, slit-like opening in samples Sm 75–545 and –546 where it even reaches over the face of the last chamber to the periphery (Plate 1, Fig. 3). Also worth noticing is the variation in shape of the aperture, which is probably even more pronounced than in other Paleocene globigerinids (Plate 1, Figs. 1–5). The species *"Globigerina" anconitana*, *"Globigerina" umbrica* and *"Globigerina" sabina* distinguished by Luterbacher and Premoli Silva (1964) are believed to fall within the variation of *"Globigerina" eugubina* as defined above. *Globigerina fringa* Subbotina (Plate 2, Figs. 8–9) shows a fine hispid wall structure with pores in and between the tubercles, whereas the tests of *"Globigerina" eugubina* are invariably smooth, without any pores, tubercles or spines. Comparison of Scanning Electron Micrographs of specimens of *"Globigerina" eugubina* from Joides legs 15 (Bolli and Premoli Silva, (1973) and

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PLATE 1

(Bar = 0.05 mm) All figures Scanning Electron Micrographs.
Figures 1–7. "Globigerina" eugubina LUTERBACHER and PREMOLI SILVA figs. 1–4: Umbilical view, showing the long rimless opening and the variation in form of the test. The aperture reaches in fig. 3 and fig. 4 even over the periphery. Figs. 1–3: SM 75–509, Fig. 5: SM 75–508, Fig. 6–7: SM 75–545.
Figures 8–9 Globigerina fringa SUBBOTINA; fig. 8: Umbilical view, SM 75–509; fig. 9: Spiral view, SM 75–509.

20 (Krasheninnikov and Hoskins, 1973) and species collected by the author in the Appennines (the locality of Ceselli: cf. Luterbacher and Premoli, Silva, 1964), as well as specimens from the Blake Plateau (Leg 44, Schmidt in press) put at my disposal by R. R. Schmidt, reveal that the walls of the specimens from all these localities are completely recrystallized, whereas the accompanying fauna of *Globigerina fringa* and the chiloguembelinids are only partly recrystallized, or show no recrystallization at all; this may indicate that the wall structure of "*Globigerina*" *eugubina* differs from that of other globigerinids.

The appearance of *Globigerina pseudobulloides* Plummer in the fauna of sample Sm 75–547, a still rich "*G.*"*eugubina* fauna, marks the lower boundary of the G. pseudobulloides/daubjergensis Zone. "*Globigerina*' *eugubina* disappears rapidly within the first 30 cm of this Zone, but chiloguembelinids and *Guembelitria* spp. still form the greater part of the fauna for a while.

Approximately from sample Sm 75–552 the faunas consist predominantly of:

Globigerina pseudobulloides Plummer
Globigerina triloculinoides Plummer (rare)
Globigerina inconstans Subbotina
Globigerina edita Subbotina
Globigerina taurica Morozova
Globigerina varianta Subbotina

Specimens of *Globigerina pseudobulloides* are at first small and smooth, but in sample Sm 75–548 they are already among the larger specimens in the fauna and show the typical reticulate wall structure. Noteworthy is that *Globigerina triloculinoides* Plummer appears later than *Globigerina pseudobulloides*, in sample Sm 75–552; initially it is very small and then probably synonymous with *Globigerina minutula* Luterbacher and Premoli Silva.

Possible lineage relationships across the Cretaceous-Tertiary boundary

Already in samples of the lowermost part of the "G." eugubina Zone a diversified planktonic foraminiferal fauna exists, with probably up to

PLATE 2

(Bar=0.05 mm) All figures Scanning Electron Micrographs. Figures 1–2 Chiloguembelina aff. midwayensis (CUSHMAN); fig. 1: Apertural view, SM 75–509; fig. 3: Hedbergella monmouthensis (OLSSON) Umbilical view, SM 75–504; fig. 4: Globigerinelloides sp. aff messinae (BRÖNNIMANN) Side view, SM 75–504; fig. 5: Archaeoglobigerina blowi PESSAGNO. Umbilical view, SM 75–508; fig. 6: Guembelitria cretacea CUSHMAN, Oblique view, SM 75–504.

seven different species. It seems probably therefore that not one single, but several species survived the terminal Cretaceous event, evolving into different groups in the Tertiary.

In Fig. 5 an attempt has been made to establish lineages across the Cretaceous-Tertiary boundary, mainly based on the Gredero faunas. In my opinion there are arguments for at least four lineages:

Cretaceous	Tertiary
1) *Heterohelix* group	*Chiloguembelina* group
2) *Guembelitria cretacea*	*Guembelitria-Globoconusa* group
3) *Archaeoglobigerina blowi*	
Hedbergella monmouthensis	*Globigerina fringa*
4) (?) small Cretaceous taxon	"*Globigerina*" *eugubina* group

Evidence for possible descendants from the *Globotruncana* group has not been found.

The chiloguembelinids in the base of the "G." eugubina Zone (Plate 2, Fig. 1) show a flattening of the chambers, which makes them very similar to some heterohelicids of the latest Cretaceous. They do not seem to be related to the other planktonic Foraminifera in the "G." eugubina Zone.

Guembelitria cretacea Cushman passes the boundary without any changes;

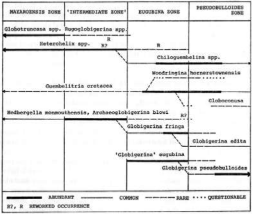

Fig. 5. Supposed lineages between Cretaceous and Tertiary taxa from the section in the Barranco del Gredero.

in the „G." eugubina Zone transitional forms have been found: to *Guembelitria irregularis* Morozova when the triserial arrangement becomes irregular; to *Woodringina hornerstownensis* Olsson when the length of the spire increases and the last chambers show a tendency to become biserial; and to *Globoconusa* when the height of the spire decreases. Both *Globoconusa* and *Guembelitria* show a typical hispid wall-structure. The first specimens of *Globoconusa daubjergensis*, however, have been found much later in the section. So it is possible that the development of *Globoconusa* took place elsewhere, presumably in boreal regions, since *Globoconusa daubjergensis* is abundant there, and rare in Tethyan regions, and that this genus returned to equatorial waters later.

More problematic is the predecessor of "*Globigerina*" *eugubina*; it does not clearly resemble any known Late Cretaceous species. However, among the many juvenile forms of *Globotruncana*, *Rugoglobigerina* and *Globotruncanella* some rare forms occur which are eugubina-like, extremely small, but unfortunately not very well preserved. "*Globigerina*" *eugubina* probably develops into the *Globigerina eobulloides* (essentially a smooth-walled pseudobulloides)-*Globigerina pseudobulloides* group.

Hedbergella monmouthensis (Olsson), *Archaeoglobigerina blowi* Pessagno and *Globigerinelloides* sp. (Pl. 2, Fig. 3–5) cross the boundary, become more numerous in the intermediate zone (B.3) and even persist into the base of the "G." eugubina Zone. As these species have a rather hispid wall structure they may be remotely related to the *Globigerina fringa-edita* group which has the same hispid wall and low trochospiral shape, although the differences between these forms are considerable. *Globigerina fringa* Subbotina increases in size in the top of the "G." eugubina Zone and passes gradually into *Globigerina edita* Subbotina.

FINAL REMARKS

All samples from the section (Sm 75–501 to SM 75–656), some 30 from the A. mayaroensis Zone, 10 from the intermediate Zone and 90 from the "G." eugubina to the Gl. pusilla Zone, were treated with hydrochloric acid (10%) and the obtained insoluble residue dried and weighed. The soluble material in the sample is nearly all of organic origin (Foraminifera, coccoliths); the insoluble residue consists almost exclusively of clayey material. The amount of hystrichospheres and other organic shells can be neglected (< 1%).

On the average the rocks below the boundary contain 20% and the rocks above the boundary 18% insoluble residue. The hard rocks, which have a considerably lower insoluble residue content, have not been included. The variation between the samples is small, at most 5%. The boundary layers B.3.2/B.3.5 on the other hand have a rather different insoluble residue content, (on the average 60%), whereas the transitional B.3.1 layer and the lowermost sample of the "G." eugubina Zone (B.3.6.) contain intermediate quantities.

If it is assumed that:

1) the insoluble residue consists of hemipelagic material;
2) the supply of hemipelagic clay was more or less constant within the time interval covered by the section in discussion (including the time in which the boundary layers were deposited) and;
3) no hiatus of importance occurs within the interval concerned;

then it would be possible to calculate the length of time necessary for the deposition of the B.3 interval, especially B.3.2 to B.3.5. The thickness of the Maastrichtian to Middle Paleocene deposits is about 210 metres, deposited in approximately 12 million years (Worsley 1975). The mean sedimentation rate is thus 1.75 cms/1,000 years. The rate of deposition of the hemipelagic material is ± 20% of this figure: 0.37 cms/1,000 years. The thickness of the interval B.3.2–B.3.5 is ± 10 cms. The insoluble material contributes 6 cm to this figure and thus may have been deposited in approximately 16,000 years. This figure should be a fair general estimate of the time evolved between the extinction of the A. mayaroensis Zone fauna and the appearance of the "G." eugubina Zone fauna. Worsley (1975) suggested that the worldwide carbonate deficiency which marks the Cretaceous-Tertiary boundary event (Bolli and Premoli Silva 1973) and the resulting uprise of the Calcium Carbonate Compensation Depth, was caused by the decreased supply of material from peneplenized continents (which, by the way, cannot be confirmed in the Gredero Section). He arrived at a figure of 2 million years for the duration of this crisis in the Braggs section in Alabama (Worsley 1975). Worsley's calculation starts from the observed rate of extinction of coccolith species in the Latest Cretaceous. In the last Cretaceous coccolith-bearing sample still a number of species are present. The time necessary for these species to become extinct is found by upward extrapolating the established rate of extinction. Thus he arrived at a figure of 2 million years. This figure is not anywhere near the 16,000 years calculated above.

With our data and assumptions also an estimate can be made for the rapidity of the terminal Cretaceous extinctions; in bed B.3.1 the globotruncanid fauna disappears in 0.5 cm, or within ± 1,000 years. In the preceding 5 m of sediment no indications for these mass extinctions were found; the faunas remain richly diversified and not even a slight increase of the quantity of insoluble residue was found.

Some sources of error may influence our figures:

- the assumed constant rate of supply of hemipelagic material is speculative; however, the insoluble residue content throughout the whole section (except B.3) does not vary much, and it is very difficult to imagine a sudden world-wide event simultaneously causing a carbonate (plankton) deficiency and an equivalent decrease of supply of hemipelagic material;

- it is not certain that the hemipelagic material was deposited in the manner assumed; other modes of supply (e.g. turbidite tails) are not impossible; however, infill of the Loma de Solana basin by bottom-hugging currents may have left some traces like lamination, size-sorting of the planktonic Foraminifera, or other sedimentological features of which as yet no evidence has been found;
- there is of course no certainty that there is no hiatus within or at the boundaries of the B.3 interval, there are, however, no indications for the existence of such a hiatus; the boundary is exposed over a distance of 0.8 km and all the beds described, even the entire B.3.1–B.3.6 subdivision, can be recognized in the exposed sequences. Furthermore all known successive planktonic foraminiferal and nannofossil Zones (Romein 1977 this volume) from the Late Cretaceous and Early Paleogene with their gradual transitions are present and exceptionally thick in the Gredero section.

Finally, there is absolutely no indication for any facies changes between the sequences below and above the boundary.

Summarizing, it should be admitted that the data at hand are not decisive, but they suggest an extremely rapid extinction of the *Globotruncana-Rugoglobigerina* fauna in less than 1,000 years and even may be in dozens of years, and a shorter duration for the presumed carbonate crisis following after the extinctions than assumed by Worsley (1975).

ACKNOWLEDGEMENTS

I wish to thank Prof. J. J. Hermes, Mr. Th. B. Roep, Prof. H. J. Mac Gillavry, Prof. W. P. de Roever and Mr. S. R. Smit for critically reading the manuscript and their advice and I wish also to acknowledge Mr. G. Brunsmann, Mr. Th. M. G. van Kempen, and Mr. F. H. Kievits for their technical assistance and moral support, Mr. A. J. T. Romein for his contribution in discussions and Mr. R. R. Schmidt for kindly providing a sample of D.S.D.P. Leg 44.

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