

EUSTOQUIO MOLINA

Departamento de Paleontología
Universidad de Zaragoza
50009 Zaragoza, España

GERTA KELLER

Department of Geological and Geophysical Sciences
Princeton University
Princeton, NJ 08544, U.S.A.

MARINA MADILE

Dipartimento Scienze della Terra
Università di Firenze
50121 Firenze, Italia

LATE EOCENE TO OLIGOCENE EVENTS: MOLINO DE COBO, BETIC CORDILLERA, SPAIN

Quantitative analysis of upper Eocene to Oligocene planktonic foraminifers and calcareous nannofossils in the Molino de Cobo section, Betic Cordillera, Spain indicate three major extinction events: 1) in the upper Eocene at the extinction of *Globigerapsis index*, 2) at the Eocene-Oligocene boundary and 3) at the lower/upper Oligocene boundary. The *Globigerapsis index* extinction event in this area coincides with the dramatic abundance decline of the discshaped discoasters (*D. saipanensis*, *D. barbadiensis*). This faunal and floral assemblage change coincides with a carbonate dissolution interval.

The Eocene-Oligocene boundary extinction event involves five planktonic foraminiferal species, which contrary to common belief did not go extinct simultaneously, but stretched out over a 3m interval. This extinction event is probably related to the isotopic enrichment that signals the development of the psychrosphere, or two layer ocean with cold bottom and warm surface water. The lower/upper Oligocene faunal turnover event involves the extinction of surviving Eocene species and the evolution of late Oligocene to Miocene species. A short hiatus may be present at this interval. This faunal turnover is most likely related to global cooling and a major sea level drop.

El análisis cuantitativo de los foraminíferos planctónicos y nannofosiles calcáreos del Eoceno superior y Oligoceno del corte de Molino de Cobo (Cordillera Bética, España), pone de manifiesto tres importantes eventos de extinción; en el Eoceno superior, en el límite Eoceno/Oligoceno y en el límite Oligoceno inferior/superior, respectivamente. El evento del Eoceno superior implica la súbita desaparición del género *Globigerapsis*, el cual constituía el 20 por 100 del total de la población. Los discoaster en roseta (*D. saipanensis* y *D. barbadiensis*) también declinan dramáticamente en este momento. Estos cambios en las asociaciones de foraminíferos y nannofosiles, coinciden estratigráficamente con un intervalo de disolución.

El evento de extinción del límite Eoceno/Oligoceno involucra a cinco especies de foraminíferos planctónicos, las cuales contrariamente a la creencia más generalizada no se extinguen simultáneamente, sino que se producen en un intervalo de 3 metros. Este evento de extinción está probablemente ligado al desarrollo definitivo de la psicrosfera.

El último evento coincide con el límite Oligoceno inferior/superior y supone un importante relevo; la extinción de especies supervivientes del Eoceno y la evolución de especies del Oligoceno superior y Mioceno. Este relevo está seguramente ligado a un enfriamiento global y a una importante caída del nivel del mar, habiéndose detectado además, un breve hiato dentro de este intervalo.

INTRODUCTION

The late middle Eocene to Oligocene represents a time of major paleoenvironmental and paleoclimatic changes as observed by a series of stepwise extinctions (Keller, 1983, 1986) accompanied by a longterm climatic cooling trend and a permanent drop in bottom water temperatures near the Eocene-Oligocene boundary (Shackleton and Kennett, 1976; Keigwin, 1980; Keigwin and Keller, 1984; Miller and Thomas, 1985; Keigwin and Corliss, 1986; Oberhänsli and Toumarkine, 1985; Williams et al., 1985). Lowering of sea level and widespread hiatuses are frequently associated with these faunal and climatic events (Miller et al., 1985; Keller et al., 1986, 1987; Haq et al., 1987).

Faunal changes generally parallel climatic trends. Late middle Eocene to Oligocene warm water assemblages are successively replaced by planktonic foraminifera (Keller, 1983, 1985, 1986), calcareous nannoplankton (Haq and Lohman, 1976; Haq et al., 1977; Perch-Nielsen et al., 1986), ostracod faunas (Steineck et al., 1984) and mollusks (Hut et al., 1987). The climatic cooling trend is generally considered to be related to the development of the circum-Antarctic current and subsequent cooling of Antarctica initiated by the northward movement of Tasmania and Australia by middle Eocene time (Weissel and Hayes, 1972; McGowran, 1973; Kennett, 1977).

The recent discovery of three microtektite and related microspherule layers in low latitude upper Eocene marine sediments (Keller et al., 1983, 1987; Glass et al., 1985), however, has suggested that some faunal turnovers and climatic coolings may have been triggered or accelerated by extraterrestrial impact events. Investigation of microplankton in marine sections containing one or more of these microtektite or microspherule layers revealed that no planktonic foraminiferal species extinctions coincide precisely with these events, but five radiolarian species extinctions are associated with one layer (Maurasse and Glass, 1976; San-

filippo et al., 1985). One other microspherule layer is associated with a catastrophic decline in the planktonic foraminifer Genus *Globigerina* (*G. seminvolutus*, *G. luterbacheri*, *G. howei*) and the extinction of this group occurs shortly above this layer (Keller, 1986; Keller et al., 1987).

These investigations indicate that species extinctions alone may be a poor measure of the effect on a population after a sudden environmental jolt such as an impact by an extraterrestrial body. Species populations are generally rare at time of evolution and extinction and reach their apex sometime in between. Sudden adverse environmental conditions may decimate a species population to the point where only few individuals survive, but do not recover as a stable population, and eventually become extinct. Quantitative population studies based on relative abundances of individuals in a species may therefore provide a more accurate measure of the environmental effects (Keller, 1986). It is therefore important to search for good physical (microtektites) and biological (fossil) evidence in late Eocene sections, to document whether species extinctions as well as major faunal turnovers and climatic changes are triggered by large body Earth impacts.

The upper Eocene sediments of the Molino de Cobo section of the Betic Cordillera of Spain (Figure 1) offer a unique opportunity to investigate biotic events during late Eocene to early Oligocene time. We have studied the planktonic foraminifers and calcareous nannofossils of this section quantitatively to determine the stratigraphy and population changes in terms of relative abundances of dominant species. We have been able to document three major faunal events which apparently correlate with a late Eocene event, the Eocene-Oligocene boundary event and the early/late Oligocene sea-level drop. Faunal events at these time have also been observed in low latitude sections (Keller, 1983, 1985, 1986) and are thus believed to represent global events.

LOCATION AND LITHOLOGY

Geographically, the Molino de Cobo section is located in the Cañada de Jaen Ravine, in the township of El Gobernador (Granada Province), 2 km northeast from the village and 200 m west from the Molino de Cobo farmhouse. The section is exposed along the Granada-Madrid railway tracks accessible by a path from the Gobernador village to the Pedro Martinez train station.

Geologically, the Molino de Cobo section is located in the Subetic Zone of the Betic Cordillera. The section is part of the Cañada Formation (Eocene-Aquitanian) of the Cardela Group. Sediments of the Cañada Formation

are over 500 m thick and consist of detritic limestone of turbidite origin, interbedded with thick hemipelagic marls.

Upper Eocene to Oligocene sediments of the Molino de Cobo section consist of 194 m of interbedded bioclastic calcarenites and marls that dip 30 degrees north forming the southern flank of a wide syncline. The continuation towards the nucleus was named Cañada de Jaen (El Gobernador) section and biostratigraphically studied by means of planktonic foraminifers (Molina, 1979). The sediments are lithologically similar to the nearby coeval Fuente Caldera section (Comas et al., 1984-85; Molina, 1986), except that the turbidite facies are less extensive and no olistostromes are present in the Molino de Cobo section. The bioclastic calcarenites are 30-90 cm thick and range from packstones to pseudograinstones with frequent marly inclusions. The bioclasts consist mainly of smaller and larger benthonic foraminifera and calcareous algae primarily of penecontemporaneous platform origin, although some middle Eocene species have been found. The autochthonous hemipelagic marly interbeds range between 1-5 m thick and do not contain displaced larger benthonic foraminifers. Reworked middle Eocene planktonic foraminifers and calcareous nannofossils are few to common in some marl beds.

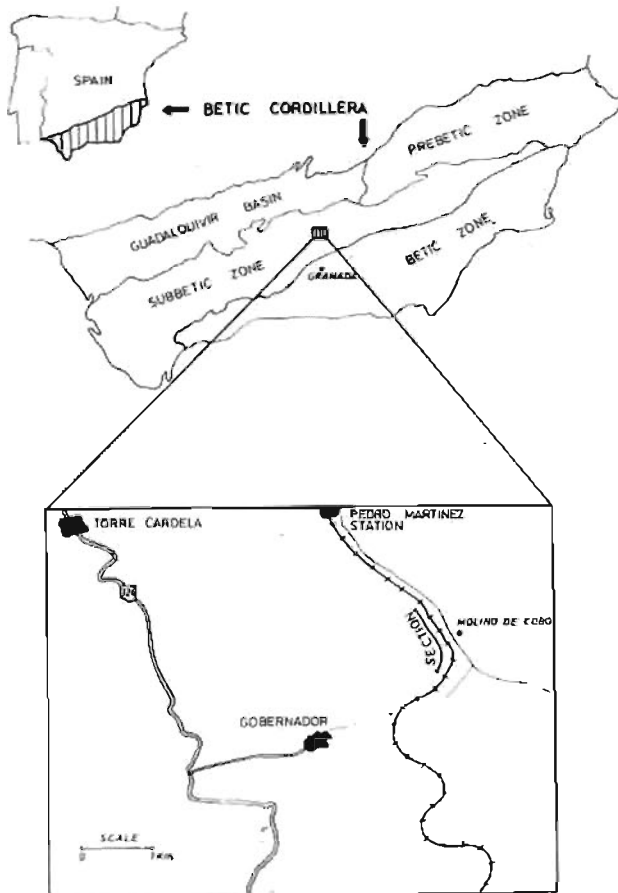


Figure 1

Location map of the Molino de Cobo section in Andalusia, southern Spain.

METHODS

Sediment samples were disaggregated by soaking in water over night with the addition of a small amount of 10 % hydrogen peroxide. Indurated samples were also heated to aid the disaggregation process. Samples were then washed over 63 and 150 micron screens with tap water. Quantitative counts for faunal analysis were obtained from aliquots (using a modified Otto microsplitter) of approximately 300-500 specimens of the size fraction greater than 150 microns. All specimens were then picked from the aliquot and mounted on a microslide for identification and permanent re-

cord. The sample was also scanned for rare species and the small size fraction was examined for smaller species.

Thin sections were made of the calcarenitic limestone beds to study the larger foraminifera and examine the lithology. Calcareous nannofossils were studied from the marly beds. A small quantity of a clean rock chip was crushed with a pestle in a mortar containing distilled water (ph 6/7). A drop of the suspension was then smeared on a cover slide, dried and embedded on a slide with Pyccolite. A semi-quantitative analyses of the abundance of dominante species was estimated using the Backmann and Shackleton (1983) method. Abundance is expressed in number of specimens per mm² at a magnification of x 1250.

BIOSTRATIGRAPHY

PLANKTONIC FORAMINIFERA

A planktonic foraminiferal biostratigraphic analysis of the Molino de Cobo section was earlier published by Martinez-Gallego (1974). We have resampled the section at closer intervals and studied the planktonic foraminifera and calcareous nannofossils based on both standard biostratigraphic techniques (first and last appearances of index species) and quantitative faunal analysis. These combined methods permit a higher resolution time control and in addition provide paleoecologic and paleoclimatic information. Quantitative faunal analysis can also minimize problems of reworked older faunas and contamination by isolating these species. It also permits a more accurate assessment of the magnitude of an extinction event by providing information on the relative portion of individuals of the population affected.

Our faunal counts are shown in Table 1. Figure 2 shows the stratigraphic ranges of species indicating where they are abundant, common or few. Figure 3 illustrates relative percent abundances of dominant species. We have used the standard low latitude zonations of

Bolli (1966) and Blow (1979) as well as a revised middle latitude zonation for this region by Molina (1979, 1986). Bolli's low latitude zonation is applicable, except that the boundary between *Cassigerinella chipolensis*-*Pseudohastigerina micra* and *Globigerina ampliapertura* Zones could not be recognized due to absence or rarity of *P. micra*. Blow's zonation was also sometimes difficult to apply because of absence or rarity of species and difficulty in identification of some index species. In some cases (Zones P15-P16) the species ranges also appear diachronous. We therefore prefer Bolli's (1966) zonation to correlate to low latitude sections and Molina's (1979, 1986) zonation for middle latitudes.

Although the aim of this paper is not to discuss the taxonomic problems of the planktonic foraminifers, some criteria of identification should be clarified. The species concept that has been followed in this work is the same as proposed by the European Working Group on Planktonic Foraminifera (Robasynski et al., 1984). Thus, no subspecies have been considered. The species are generally defined by typological criteria, and are often morphotypes with rather arbitrary boundaries due to their interspecific variations. For stratigraphic purposes morphotypes with biostratigraphical significance are chosen. Thus, some of these species may not be true biological species. Other species may include a wide variety of morphotypes of uncertain affinities such as *Catapsydrax unicavus* s.l. which includes *C. pera* and certain «*Globigerinas*» with small abortive final chambers.

Taxonomic problems in this paper also concern the genus *Pseudohastigerina*. *Pseudohastigerina micra* is a laterally compressed form which spans the Eocene/Oligocene boundary and is an important stratigraphic marker. In 1979 Blow proposed the name *P. danvillensis* for this form which we consider a junior synonym. Two similar but much smaller morphotypes of the species *P. naguewichiensis* and *P. barbadoensis* are also present, but can be distinguished only with the scanning electron

microscope. We have lumped these two small species as *P. naguwichiensis*. Also because of their small size and difficulties in identification with the stereomicroscope, biserial *Chiloguembelinas* have been lumped as *Ch. cubensis* s. l.

Upper Eocene

The lowermost 20 m (up to sample 2'4, Figure 2) of the Molino de Cobo section correspond to the *Globigerapsis semiinvolutus* Zone. The top of this zone is defined by the extinction of *G. semiinvolutus*. Blow's (1979) P15/P16 Zone boundary based in the first appearance of *Cribrohantkenina inflata* occurs at 13m from the base of the section where also *Globigerina gortanii* which defines Blow's Zone P17 was found. Both these species first appearances seem diachronous between middle and low latitudes (Boersma and Premoli-Silva, 1986).

Species characteristic of the *Globigerapsis semiinvolutus* Zone are *G. semiinvolutus*, *G. howei*, *G. index*, *G. luterbacheri*, *Globorotalia cerroazulensis*, *Gl. pomeroli*, *Globigerina transdanubica*, and abundant *G. linaperta* (Figures 2, 3, Plates 1, 2).

The uppermost part of the Eocene sediments (20 m - 68 m) correspond to the *Globorotalia cerroazulensis* Zone. The top of this zone coincides with the extinction of the *Gl. cerroazulensis* group. Molina (1979, 1986) subdivided this interval into *Cribrohantkenina inflata* and *C. lazzarii* Zones based on the last occurrences of these species respectively. These species have only been rarely observed in low latitude sections (Keller, 1983, 1985). Because the last appearance of *Gl. cerroazulensis* and *C. lazzarii* do not occur at the same time, there is a slight difference in age of the Eocene/Oligocene boundary between Molina's (1979, 1980) and Bolli's (1966) zonal systems. Characteristic species of the uppermost Eocene are *Globorotalia cocoaensis*, *Gl. cunialensis*, *Gl. increbescens*, *Gl. nana*, *Cribrohantkenina lazzarii*, *Hantkenina alabamensis*, *H. brevispina*, *Pseudohastigerina micra* larger than 150 microns, *Globi-*

gerina ampliapertura and *G. galavisi* (Figures 2, 3, Plates 1, 2).

The main biostratigraphic event in the upper Eocene occurs at the top of the *Globigerapsis semiinvolutus* Zone (sample 2, 4) where this species goes extinct. In the middle latitude Molino de Cobo section *G. semiinvolutus* is not as abundant as in low latitude sections (Keller, 1986), therefore, the population change associated with the extinction of this species is less pronounced. The *Globigerapsis* group goes extinct 23 m above the last appearance of *G. semiinvolutus* in the Molino de Cobo section and is associated with carbonate dissolution. This is considerably higher than observed in low latitude sections where *G. index*, the last surviving *Globigerapsis* species, frequently disappears shortly above *G. semiinvolutus* (Keller, 1986). Diachroneity of last appearances of these species must be assumed between middle and low latitudes.

In some low latitude sections (DSDP Sites 216 and 292) a microspherule layer of impact origin is found near the extinction of *G. semiinvolutus* and the *Globigerapsis* group disappears shortly thereafter (Keller, 1986; Keller et al., 1987). In our original sample analysis glassy microspherules were also found in the Molino de Cobo section in sample 4 near the extinction of the *Globigerapsis* group (Keller et al., 1987). However, in samples collected subsequently at the same locality we failed to find microspherules. It is possible that we missed collection the layer, or that the microspherules came from surface contamination of a yet unknown source.

Above the decline in the *Globigerapsis* group and the dissolution interval in the Molino de Cobo section there is a major decrease, relative to other species, in the abundance of *Globigerina linaperta* and an increase in *G. galavisi*, *G. ampliapertura*, *G. officinalis*, *G. ouachitaensis*, *Globorotalia nana* and *Gl. increbescens* (Figure 3). This suggests a major paleoecologic shift possibly toward cooler climatic conditions which has also been observed in low latitude section (Keller, 1986). A general cooling trend

during the late Eocene is indicated in the oxygen isotope record (Corliss et al., 1984; Oberhänsli and Toumarkine, 1985; Williams et al., 1985; Keigwin and Corliss, 1986).

Eocene-Oligocene Boundary

The Eocene-Oligocene Boundary is defined by the simultaneous extinction of the *Globorotalia cerroazulensis* group (*Gl. cerraazulensis*, *Gl. cocoaensis*, *Gl. cunialensis*) and the genus *Hantkenina* and *Cribohantkenina*. To determine the nature of these extinctions in the Molino de Cobo section a 3 m interval across the boundary was sampled at approximately 25 cm intervals. This expanded boundary section revealed that these species extinctions did not occur simultaneously (Martinez-Gallego and Molina, 1975; Molina, 1979, 1986). The *Globorotalia cerroazulensis* group disappeared before the genus *Hantkenina* (*H. alabamensis*, *H. brevispina*) which disappeared before the genus *Cribohantkenina* (*C. lazzarii*) (Table 1, Figure 2). Thus, the Eocene-Oligocene boundary extinctions appear to have occurred more gradually than previously assumed.

Although five species extinctions occurred across the Eocene-Oligocene boundary, the overall effect on the faunal assemblage appears not to have been very dramatic. This is best illustrated by the relative abundances of the dominant species in Figure 3. The species going extinct were generally less than 10% of the total fauna at the time of their demise; the same has been observed in low latitude sections (Keller, 1983, 1985, 1986). No new species evolved at this time (Figure 2). No major species abundance changes are observed (Figure 3), although there is a general increase in the deeper water species *Catapsydrax* and *Globoquadrina venezuelana*. This increase in the

deeper water dwellers has also been observed in low latitudes (Keller, 1983, 1985, 1986).

There is, however, a curious morphologic change in the size of *Pseudohastigerina micra* at the Eocene-Oligocene boundary which has also been observed in the nearby Fuente Caldera section (Molina, 1986) and in low latitude sections (Keller, 1983, 1985). *Pseudohastigerina micra* is common to abundant in upper Eocene sediments in the size fraction greater than 150 microns, but disappears from this size fraction above the Eocene-Oligocene boundary (Figure 3). In low latitudes this species is still common to abundant in the smaller than 150 micron size fraction along with *P. barbadoensis* (Keller, 1983, 1985), but in the Molino de Cobo section *P. micra* is very rare whereas *P. naguewichiensis* s.l. (which includes *P. barbadoensis*) is common (Table 1, Figure 2). The common presence or absence of *P. micra* in the larger than 150 micron size fraction is a secondary indicator to differentiate upper Eocene and lower Oligocene sediments.

Oligocene

According to Bolli's (1966) zonation the Oligocene is divided into the *Cassigerinella chipolensis*-*Pseudohastigerina micra* Zone defined by the extinction of *P. micra*, and the *Globerigerina ampliapertura* Zone defined by the first appearance of *Globorotalia opima opima*. As noted earlier *P. micra* is very rare in the Oligocene of the Molino de Cobo section and is therefore not useful as index species. The alternative middle latitude zonation of Molina (1979, 1986) provides better control here. The lowermost Oligocene *Globigerina gortanii*/*G. tapuriensis* Zone boundary is defined by the first appearance of *G. tapuriensis* and correlates to the P17/P18 Zone boundary of

Figure 2

Range chart of planktonic foraminifers from the Molino de Cobo section. Relative thickness of range lines indicates abundant, common or few specimens.

Blow (1979). The first appearance of *Globigerina angulisuturalis* defines the *G. selli*/*G. angulisuturalis* Zone boundary and corresponds to the base of Zone P21 (Figures 2, 3). All these species are rare or absent in low latitudes sections (Keller, 1983, 1985).

The lower Oligocene is marked by a relatively low diversity but stable faunal assemblage consisting primarily of Late Eocene survivors. There are no major species extinctions or abundance changes apparent. Faunal assemblages are characterized by the cool water species *Globigerina linaperta*, *G. galavisi*, *Globorotalia nana* and the surface dwellers *Globigerina ampliapertura* and *Gl. increbescens*. Except for *Gl. nana*, these species abruptly disappear between samples 11 and 11'3 marking the lower/upper Oligocene boundary (Figures 2, 3). The evolving species *Globigerina angulisuturalis*, *G. binaiensis*, *Gl. siakensis*, *Gl. pseudocontinosa*, and common typical *Globigerina ciproensis* appear above this interval (Figure 2). A short hiatus of about 1 m.y. (31.5-32.5 Ma) may be present at this faunal change as suggested by sediment accumulation rates. The major faunal turnover and short hiatus coincide with a major drop in sea level postulated by Vail and Hardenbol (1979) and Haq et al. (1987). Widespread erosion or nondeposition occurred at this time globally as observed by the widespread distribution of this hiatus (Keller et al., 1986).

CALCAREOUS NANNOFOSSILS

Calcareous nannofossils from the early intervals are generally abundant and well diversified. Preservation varies from poor to moderate. Reworked Cretaceous and Eocene nannofossils have been identified throughout this section (Figure 4).

As a result of reworked nannofossils the position of the zonal boundaries based on last occurrences are often uncertain. To circumvent this problem a semiquantitative analysis (Figure 4) to estimate the relative abundances of the dominant species has been made (Fi-

gure 5). Nevertheless, the zonal boundaries are frequently not in the standard relative position to the planktonic foraminiferal zones as reported by Berggren et al. (1986). Despite these problems a complete sequence of Late Eocene Subzone CP15a to Late Oligocene Subzone CP19a has been identified using the biozonation of Bukry (1973, 1975) and Okada and Bukry (1980).

Late Eocene

The late Eocene assemblages are characterized by abundant *Cyclicargolithus floridanus*, *Coccolithus pelagicus*, *Dictyococcites bisectus*, *Ericsonia formosa*, *Discoaster barbadiensis* and *D. saipanensis* (Figures 4, 5). The genus *Sphenolithus* ranges from the late Eocene to the early Oligocene and is represented by *S. moriformis* and *S. predistentus*. *Sphenolithus pseudoradians* used by Martini (1971) to define the base of Zone NP20 was not found. The genus *Chiasmolithus* is very rare and it is therefore not possible to calculate the *Discoaster/Chiasmolithus* ratio used by Bukry (1973) as indicator of water temperature. *Zygrhablithus bijugatus*, *Lanternithus minutus* and a few solution resistant *Pedinocyclus larvalis* were also found; all these species are considered as indicative of near shore environments.

The first appearance of *Isthmolithus recurvus* which defines the base of Subzone CP15b occurs near the base of the Molino de Cobo section (sample 1, 4 m). The extinction of *Cribrorocentrum reticulatum* occurs just below the extinction of the disc shaped *Discoasters* as also reported by Nocchi et al. (1986) and Perch-Nielsen et al. (1986).

A major biostratigraphic event is the decline in abundance and extinction of *Discoaster barbadiensis* and *D. saipanensis*. Relative species abundance analyses indicates that *Discoaster barbadiensis* is always more abundant than *D. saipanensis* and both appear to decline simultaneously. The top of Zone CP15b has been placed at sample 4 where a strong de-

crease of *D. barbadiensis* and *D. saipanensis* is observed. The number of specimens/mm² of *D. barbadiensis* decreases from 43 in sample 3 to 13 in sample 4 and to 2 in sample 4, 5. Likewise *D. saipanensis* decreases from 16 specimens in sample 3, 5 to 3 in sample 4 and to 1 in sample 4, 5. A similar decrease in these species abundances was also observed in the nearby Fuente Caldera section by Monechi (1986) and Perch-Nielsen et al. (1986). The few specimens of Discoasters above sample 4 are considered reworked (Figure 4, 5).

Interestingly, the strong decrease and probable extinction of *D. barbadiensis* and *D. saipanensis* in the Molino de Cobo section coincides with the decline and extinction of the planktonic foraminifer genus *Globigerapsis* and the dissolution interval. No quantitative analysis of nannofossils are available from low latitudes at this time. Therefore, it is not known whether the decline in the nannofossil species correlates precisely with the microspherule layer.

The uppermost Eocene layers between the extinction of *D. barbadiensis* and *D. saipanensis*, and the Eocene/Oligocene boundary (based on planktonic foraminifers) are characterized by the following variations in nannofossils.

1. A slight increase in the abundance of *Isthmolithus recurvus*, indicative of relatively cooler waters. This increase has also been observed in the nearby Fuente Caldera section by Monechi (1986) and Perch Nielsen et al. (1986), in the Umbro-Marchean Apennines (Italy) by Monechi (1986), Nocchi et al. (1986, in press), Premoli Silva et al. (in press), as well as in DSDP Site 522-522A (South Atlantic) by Backmann (1986), in Site 362-363 (Angola Basin) by Proto Decima (pers. comm.) and in several sites of the Pacific Ocean by Perch Nielsen (1986).

2. A slight decrease in the abundance of *Ericsonia formosa*.

3. An increase in abundance of *L. minutus* and *Z. bijugatus* near the Eocene/Oligocene

boundary. This event has also been observed in Italy (Nocchi et al., 1986) and in Hungary (Baldi et al., 1984).

Early Oligocene

It was not possible to subdivide the early Oligocene Zone CP16 into subzones CP16a/CP16b (*Ericsonia subdisticha*/*E. formosa*) because the acme of *E. subdisticha* which defines this subzonal boundary (Okada and Bukry, 1980) cannot be recognized. Neither could the acme of *E. obruta* be recorded which was used by Madile and Monechi in the Contessa Highway section to identify the same boundary (Premoli Silva et al., in press). The extinction of *Ericsonia formosa* which defines the top of Subzone CP16b is placed in sample 8 (89 m), although variable abundance is present throughout the early Oligocene.

In subzone CP16c an increase in abundance of *L. minutus* is observed. A similar increase in abundance of *L. minutus* and *Z. bijugatus* was observed in CP16b/c Subzones of the Contessa Highway of Italy by Premoli Silva et al. (in press) and in Hungary by Baldi et al. (1984) who interpreted this abundance change as a decrease in surface water temperature.

The extinction of *Reticulofenestra umbilica* defines the top of Subzone CP16c (*R. hillae*). As with all nannofossil last occurrences in the Molino de Cobo section, reworking of older sediments makes it difficult to determine the true extinction of index fossils. It is assumed that the extinctions of *R. umbilica* and *L. minutus* occur in sample 9'4 (112 m) near the extinction of *I. recurvus*, although rare specimens interpreted as reworked occur above this interval. In some sections where *R. umbilica* is rare (e.g. Contessa Quarry in Italy, Lowrie et al., 1982), the extinction of *I. recurvus* has been used to mark the top of Subzone CP16c. This suggests that the top of Subzone CP16c is indeed close to sample 9'4 of the Molino de Cobo section.

The first occurrence of *S. distentus* in sample 10'6 (137 m) marks the base of Zone CP18,

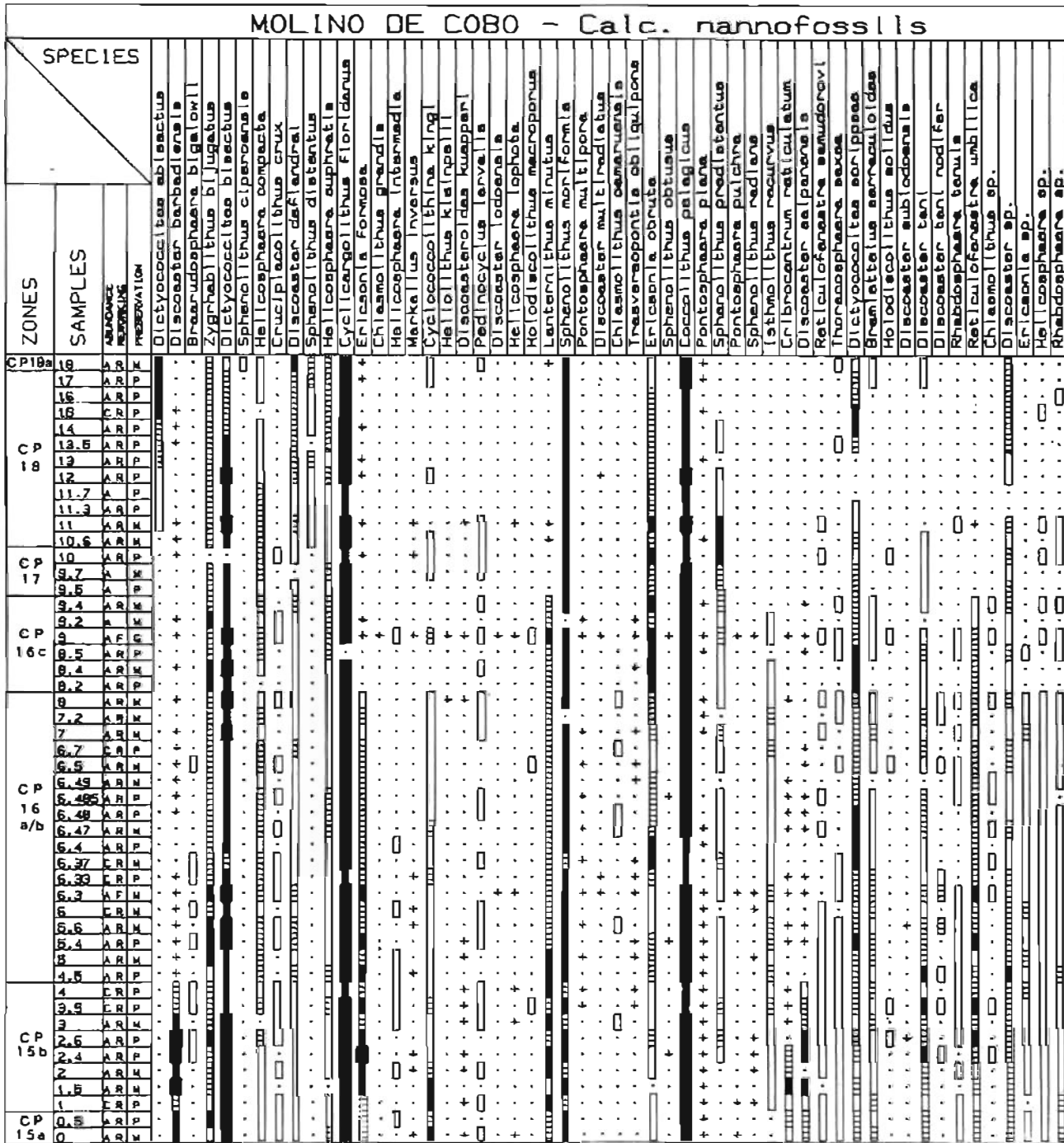


Figure 4

Range chart of calcareous nannofossils from the Molino de Cobo section. The assemblages were called abundant (A) if the relative abundances exceeded 60 % of all components, common (C) if there were more than 40 % coccoliths, few (F) for more than 10 % coccoliths and rare (R) for a relative abundance of identifiable coccolith of less than 10 %.

Relative abundance of calcareous nannofossils is based on the frequency of the species per field of view in the light microscope at a magnification of 1500.

The species was considered:

- A ■ 1 species x field of view
- C ▨ 0,5-1 species x field of view
- F ▩ 1-4 species x 10 field of view
- R □ 0,2-0,9 species x 10 field of view

+ Reworked species

and the top of this Zone is marked by the first appearance of *Sphenolithus ciperoensis* in sample 18 (191 m).

DISCUSSION

The correlation between planktonic foraminifers and calcareous nannofossils is illustrated in Figure 6 along with the corresponding European stages. Over 40 first appearances and extinctions of stratigraphically significant species (see Plates 1-3) have been identified as useful datum events. Most of these datum events cluster around three time periods: the late Eocene, at the Eocene-Oligocene boundary, and at the early to late Oligocene boundary. Several species extinctions and first appearances also occur scattered in the early Oligocene, but these species are generally very rare (Table 1).

The *Globigerapsis* extinction event in the Molino de Cobo section is associated with a dissolution interval and involves the extinction of all species of the Genus *Globigerapsis* as well as *Globigerina transdanubica* and *Globorotalia pomeroli* and coincides with a major decline in disc shaped discoasters. A catastrophic decline in the disc shaped discoasters at this level has also been observed in the nearby Fuente Caldera section (Perch-Nielsen et al., 1986) and in Umbrian sequences of Italy (Nocchi et al., 1986). These species extinctions and faunal abundance changes imply a major paleoceanographic event at this time.

Oxygen isotope data summarized by Keigwin and Corliss (1986) show that a global cooling trend occurred during middle to late Eocene time. This cooling trend resulted in gradual replacement of warm water species.

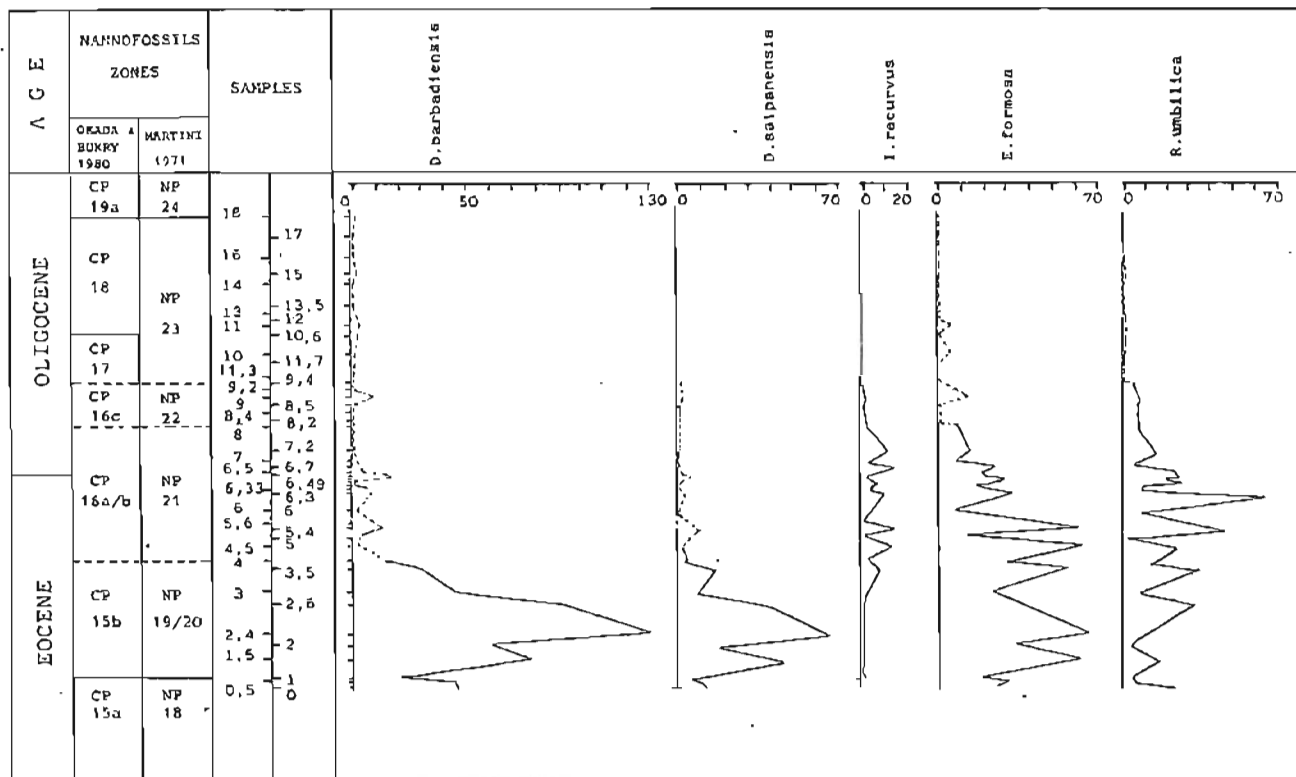


Figure 5
Relative abundances of dominant calcareous nannofossils in the Molino de Cobo section. Abundance expressed in number of specimens per mm² at a magnification of x 1250.

The abundance decline and subsequent extinction of the *Globigerapsis* group could therefore have been a consequence of this global cooling trend. However, this interpretation does not explain the near instantaneous decline in the *Globigerapsis* group from a high of more than 60 % to 1 % in low latitudes at the time of deposition of a microspherule layer, or from 20 % to zero in the Molino de Cobo section. The demise of the *Globigerapsis* group in low latitudes was probably hastened by an extra-

terrestrial impact event. It is not yet clear whether the extinction of this group in the Molino de Cobo section correlates to this event or is diachronous, especially since we failed to reconfirm our earlier microspherule discovery (Keller et al., 1987).

The Eocene-Oligocene boundary extinction event is not associated with any calcareous nanofossil species extinctions (Nocchi et al., 1986) and no major species abundance changes

MOLINO DE COBO X = < 2%	MC-0	MC-1.5	MC-1	MC-1.5	MC-2	MC-2.5	MC-2.8	MC-3	MC-3.5	MC-4	MC-4.5	MC-5	MC-5.5	MC-6	MC-6.5	MC-7	MC-7.5	MC-8	MC-8.5	MC-9	MC-9.5	MC-10	MC-10.5	MC-11	MC-11.5	MC-12	MC-13	MC-13.5	MC-14	MC-15	MC-16	MC-17	MC-18		
<i>G. angustumbilicata</i>																																			
<i>G. angulofacialis</i>																																			
<i>G. angulicostata</i>																																			
<i>G. anguliporoides</i>	X	5	6	6	X	R																													
<i>G. angulispertaria</i>																																			
<i>G. bipartita</i>																																			
<i>G. bipersonata</i>																																			
<i>G. cf. bipersonata</i>																																			
<i>G. cf. elongata</i>																																			
<i>G. corpulenta</i>	3	R	6	B	2	J																													
<i>G. socianae</i>	X	X	X	2	X	X	F	4																											
<i>G. emperiana</i>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
<i>G. galavisi</i>	6	R	5	X	6	X	R	X	F	X																									
<i>G. globularis</i>																																			
<i>G. gemma</i>																																			
<i>G. goniatitiformis</i>	X	6	5	3	X	4																													
<i>G. goniatitiformis</i>																																			
<i>G. hughii</i>																																			
<i>G. jackobensis</i>																																			
<i>G. lerysi</i>																																			
<i>G. limperla</i>	11	C	13	24	3	XI	C	21	A	29	23	5	3	3	8	3	3	5	7	11															
<i>G. limperla with bulla</i>																																			
<i>G. ocellus</i>																																			
<i>G. officinalis</i>	2	R	X	X	3	R	F	X	F	X																									
<i>G. ovoides</i>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
<i>G. pseudomplispartaria</i>																																			
<i>G. praebullisoides</i>	X	X	2	2	X																														
<i>G. praeturtilina</i>																																			
<i>G. sellii</i>																																			
<i>G. topurica</i>																																			
<i>G. transdujicica</i>	2	7	X	X	X																														
<i>G. tripertita</i>	4																																		
<i>G. vancouverensis</i>	7	11	X	10	3	2	F																												
<i>G. oerrossulem</i>	2	C	X	X	5	6	C	X																											
<i>G. cocconensis</i>	X																																		
<i>G. espinolemsis</i>																																			
<i>G. increbransensis</i>																																			
<i>G. nana</i>																																			
<i>G. cf. nana</i>	4	F																																	
<i>G. opina</i> s.s.																																			
<i>G. pomeroyi</i>	2	F	2	4	3	2	*	X																											
<i>G. pseudocantabrigia</i>																																			
<i>G. afghanensis</i>																																			
<i>G. sulzeri</i>	7	C	X	3	X	4	12																												
<i>G. index</i>	5	C	X	9	6	4	F	17	C	5																									
<i>G. basel</i>	5	F	X	4	4	6	R	X	F	10																									
<i>G. luterbacheri</i>	X	F	X	X	X																														
<i>G. semiinvoluta</i>	2	C	X	6	2	2																													
<i>Catapaydrax dissimilis</i>																																			
<i>C. dissimilis</i> s.p.																																			
<i>C. unicus</i> s.l.	15	17	6	14	7	C	10	F	5																										
<i>C. unicus</i> (no bulla)																																			
<i>H. alabasteris</i>	X	X	X		X																														
<i>H. brevispinis</i>	X	X	2		X																														
<i>Cr. inflata</i>																																			
<i>Cr. lezzarti</i>																																			
<i>P. vancouverensis</i> s.l.	6	C	X	6	4	R	C	6	C	10																									
<i>P. micra</i>	X	C	X																																

are evident among planktonic foraminifers (Keller, 1983, 1985, 1986). However, large (> 150 microns) *Pseudohastigerina micra* disappears shortly after the boundary. In addition, the five foraminifer species extinctions occur more gradually than previously thought. These faunal changes may be related to progressively adverse environmental conditions which may be related to the maximum development of the psychrosphere, or two layer ocean with cold bottom water and warm surface water at this time (Kennett and Shackleton, 1976; Keigwin, 1980).

The early to late Oligocene extinction event is somewhat obscured due to a possible 1 m.y. hiatus. Nevertheless, a major faunal turnover occurs during this interval with four species extinctions and seven first appearances including the nannofossil *Dictyococcites abisectus* and *Sphenolithus distentus* and the larger benthic foraminifer genus *Lepidocyclina* which appears at the top of the early Oligocene (Figure 6). The four planktonic foraminiferal species *Globorotalia increbescens*, *Globigerina ampliapertura*, *G. linaperta* and *G. angiporoides* going extinct are Eocene survivors which constitute between 30-40 % of the foraminiferal assemblage. Their demise occurs globally at this time (Keller, 1983, 1985). This major faunal turnover may be related to the global cooling recognized by Keigwin and Keller (1984) at this time and to the drastic sea level drop noted by Vail and Hardenbol (1979) and Haq et al. (1987).

CONCLUSIONS

Three major faunal event are observed in the upper Eocene to Oligocene strata of the Molino de Cobo section:

1. Extinction of *Globigerapsis* group and disc shaped discoasters. This faunal event involves the demise of the *Globigerapsis* group (*G. index* survives into the latest Eocene in high latitude sections). Species of the *Globigerapsis* group constitute 20 % of the total foraminiferal population at the time of extinction.

The disc shaped discoasters *D. saipanensis* and *D. barbadiensis* also decline dramatically at this time. This faunal turnover is associated with a dissolution event and a microspherule layer in low latitude deep-sea sections.

2. The Eocene-Oligocene Boundary extinction event involves 5 planktonic foraminiferal species, which did not go extinct simultaneously, but stretched out over a 3 m interval. The *Globorotalia cerroazulensis* group (*Gl. cocoaensis*, *Gl. cunialensis*) disappears before the extinction of the Genus *Hantkenina* (*H. alabamensis*, *H. brevispina*), which in turn precedes the extinction of *Cribrorhantkenina* (*C. lazzarii*) and *Pseudohastigerina micra* > 150 microns. This gradual extinction event appears to be related to adverse environmental conditions associated with the maximum development of the psychrosphere.

3. The early/late Oligocene faunal turnover event involves the extinction of Eocene survivors (*Globorotalia increbescens*, *Globigerina ampliapertura*, *G. linaperta*, and *G. angiporoides*) and the evolution of late Oligocene to Miocene species (*Globigerina binaiensis*, *G. angulituralis*, and *Gl. siakensis*) as well as two nannofossil species (*Dictyococcites abisectus* and *Sphenolithus distentus*). This faunal turnover appears to be related to paleoceanographic changes associated with a global cooling and major sea level drop.

ACKNOWLEDGEMENT

We would like to thank I. Premoli Silva and S. Monechi for their comments. This research was supported by the U.S. - Spain Joint Committee for scientific and Technological Cooperation and by M.P.I. 60 % (S. Monechi).

REFERENCES

- BACKMAN J., SHACKLETON N. J.
1983 *Quantitative biochronology of Pliocene and Early Pleistocene calcareous nannofossils from Atlantic, Indian and Pacific Oceans*. Mar. Micropaleont., vol. 8, pp. 141-170.

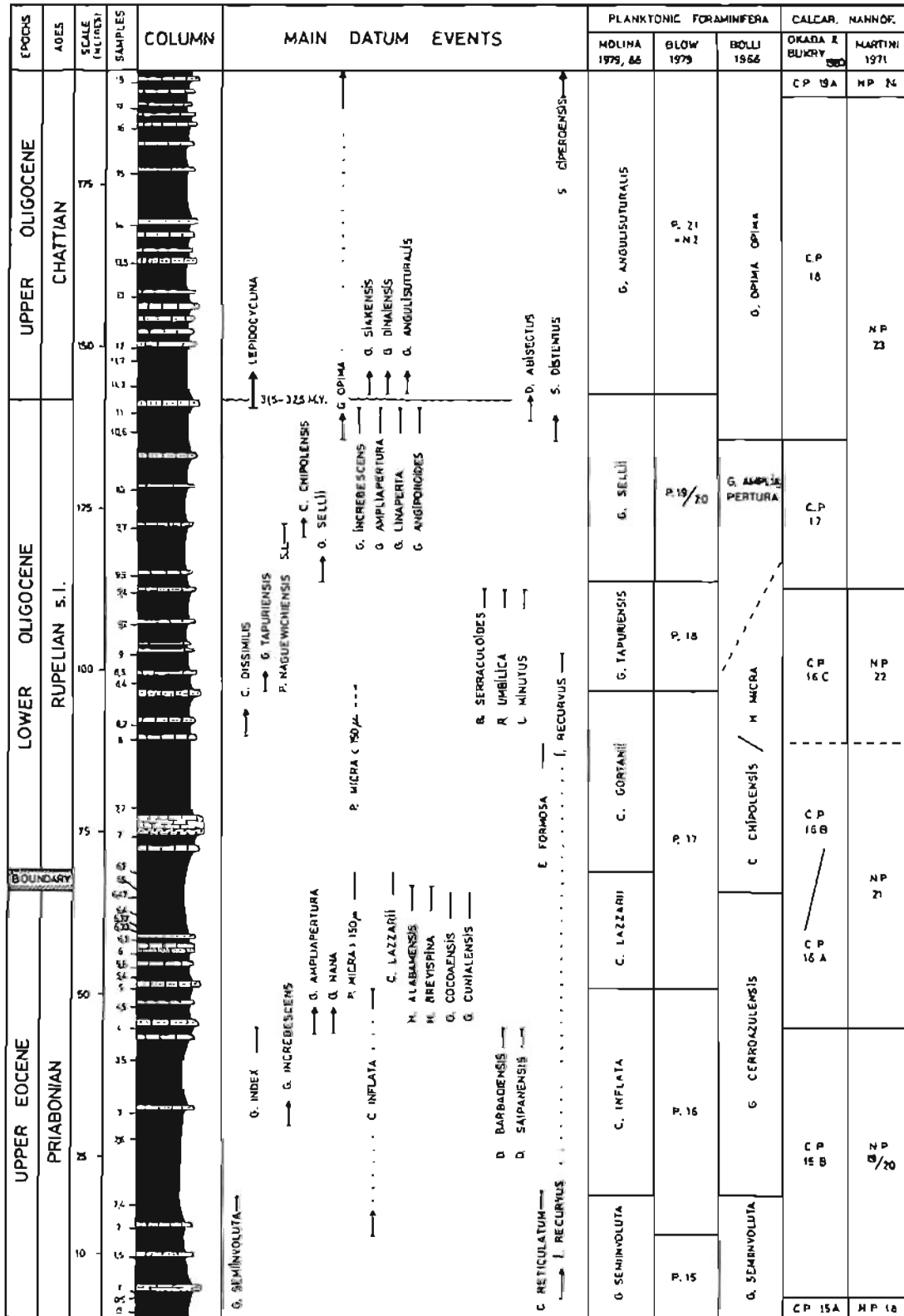


Figure 6

Summary chart of planktonic foraminiferal and calcareous nannoplankton zonation and datum events (first and last appearances) in the Molino de Cobo section.

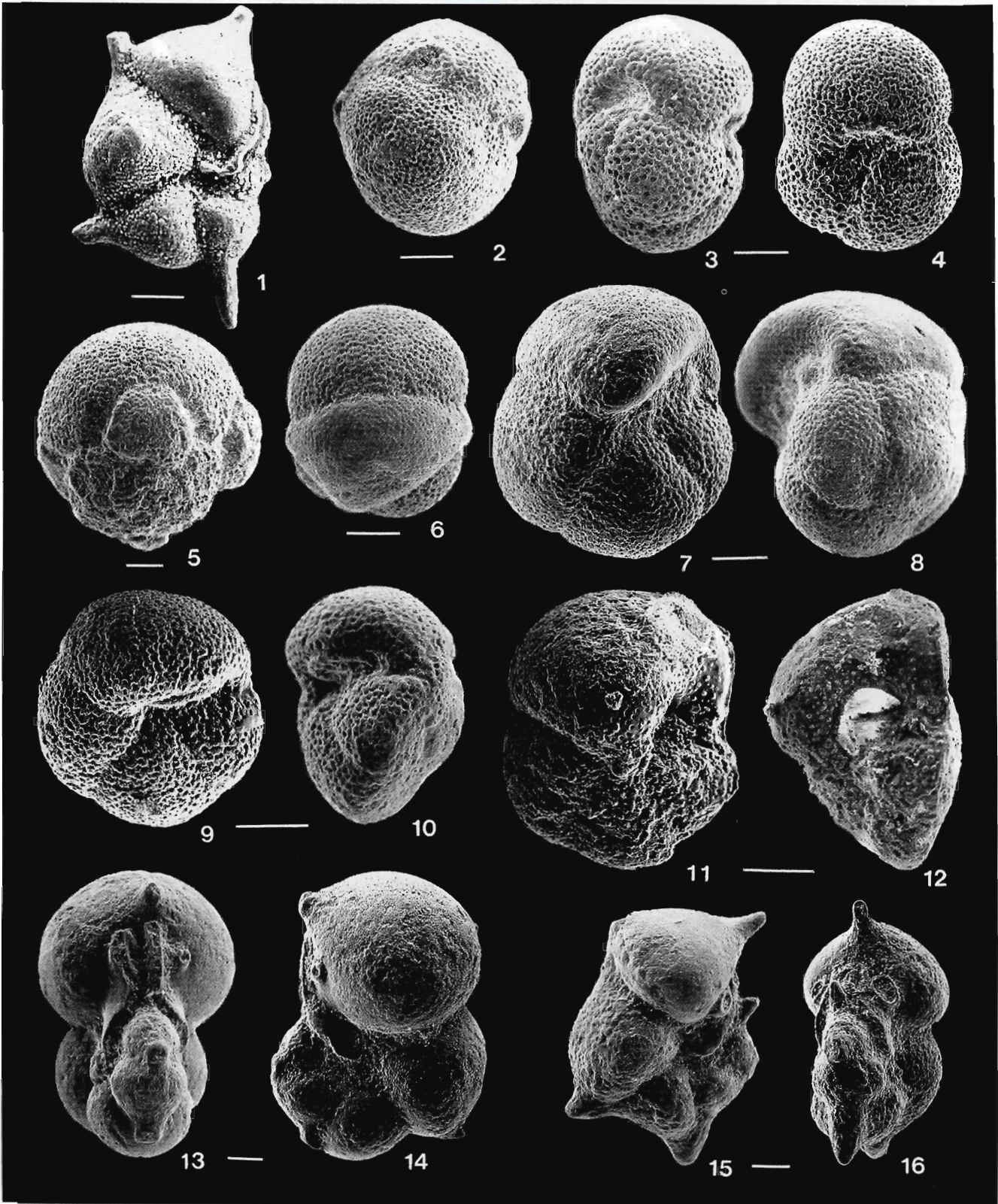
MOLINA, KELLER, MADILE

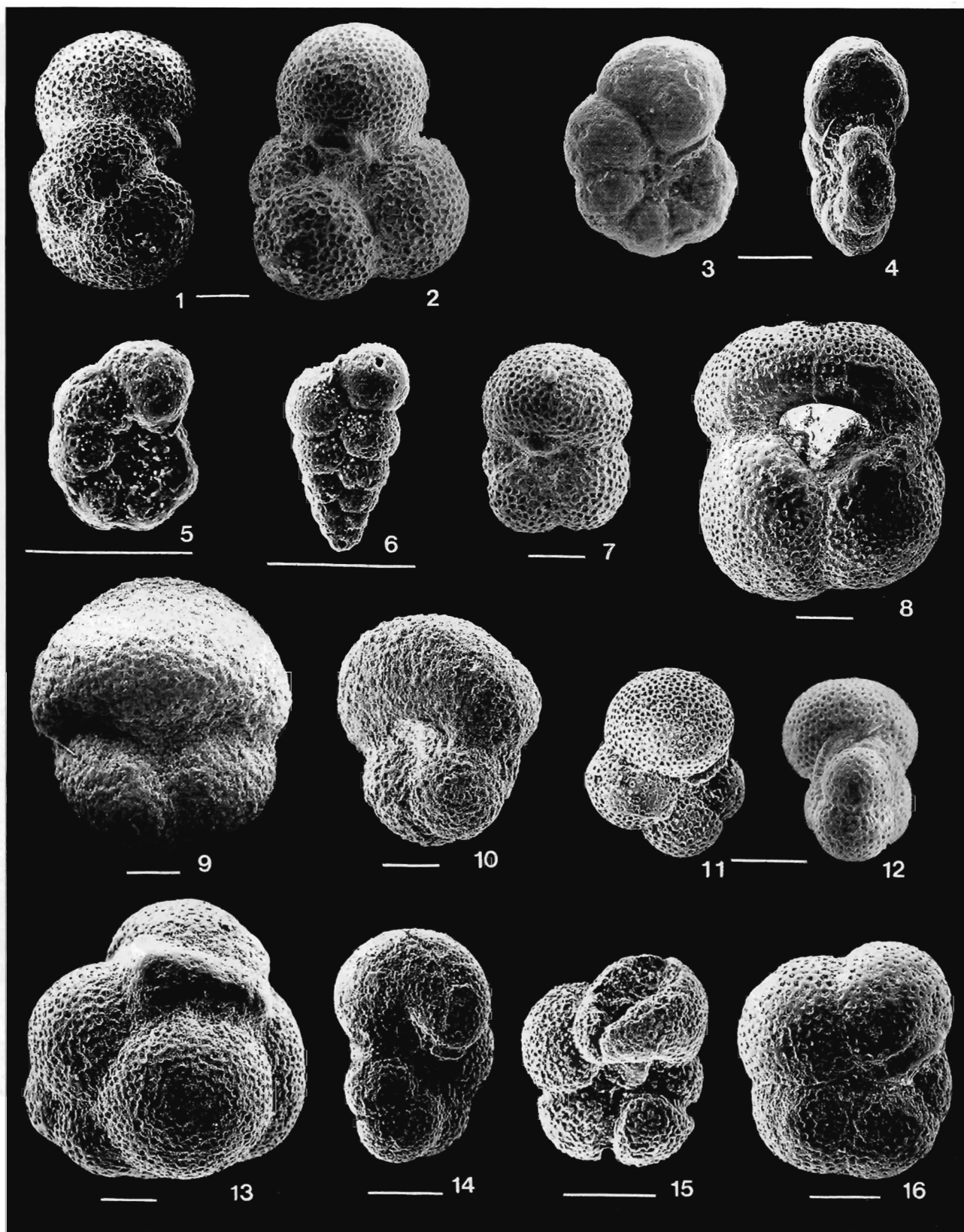
- BALDI T. et al.
1984 *The Eocene Oligocene boundary in Hungary: The Kiscellian Stage*. Acta Geol. Hung., vol. 27, pp. 41-65.
- BERGGREN W. A., KENT D. V., FLYN J. J.
1985 *Paleogene geochronology and chronostratigraphy*. Geol. Soc. Amer. Bull., vol. 96, No. 11, pp. 1419-1427.
- BLOW W. H.
1979 *The Cainozoic Globigerinida*. Leiden, Brill, 3 vol.
- BOERSMA A., PREMOLI-SILVA I.
1986 *Terminal Eocene Events: planktonic foraminifera and isotopic evidence*. Developments in Pale. and Stratig., vol. 9, pp. 213-224.
- BOLLI H. M.
1966 *Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera*. Bol. Infor. Assoc. Venez. Geol. Mine. y Petrol., volume 9, pp. 3-31.
- BUKRY D.
1973a *Coccolith and Silicoflagellate stratigraphy Tasman sea and southwestern Pacific Ocean DSDP leg 21*. In R. E. Burns et al., Initial reports of DSDP, vol. 21, pp. 885-893.
1973b *Low latitudes coccolith biostratigraphy zonation*. In Edgar N. T. et al., Initial Reports of the DSDP vol. 21, pp. 685-703.
- 1975 *Coccolith and Silicoflagellate stratigraphy, Northwestern Pacific Ocean DSDP Leg 32*. In Larson R. L. et al. Initial Reports of the DSDP, vol. 32 pp. 677-701.
- COMAS M. C., MARTINEZ-CALLEJO J., MOLINA E.
1984-85 *Lito facies y sucesión estratigráfica del Eoceno y Oligoceno al Norte del cerro Mescal (Zona Subbética Prov. de Granada)*. Cuad. Geol., vol. 12 pp. 145-155.
- CORLISS B. H., AUBREY M. P., BERGGREN W. A.,
FENNER J. M., KEIGWIN L. D. JR., KELLER G.
1984 *The Eocene Oligocene boundary Event in the Deep Sea*. Science, vol. 226, pp. 806-810.
- D'HONOT S. L., KELLER G., STALLARD R.
1987 *Major element compositional variation within and between different late Eocene microtektite strewn fields*. Meteoritics, vol. 22, No. 1, pp. 61-79.
- GLASS B. P., BURNS C. A., CROSBIE J. R., DUBOIS D. L.
1985 *Late Eocene North American microtektites and clinopyroxene-bearing spherules*. Procc. 16th Lunar and Planet Sci. Conf. Jour. Geophys. Res., vol. 90, pp. 175-196.
- HAO B. U., LOHMAN G. P.
1976 *Early Cenozoic nanoplankton biogeography of the Atlantic Ocean*. Mar. Micropaleont., vol. 1, pp. 119-194.

PLATE 1

Scale bar = 100 μ m

1. *Hantkenina alabamensis* (Cushman), sample 1.5, top of *Globigerapsis semiinvolutus* Zone.
2. *Globigerapsis semiinvolutus* (Keijer), sample 2, *G. semiinvolutus* Zone.
- 3, 4. *Globigerapsis index* (Finlay), sample 2, *G. semiinvolutus* Zone.
5. *Globigerapsis Interhacheri* (Bolli), sample 2, *G. semiinvolutus* Zone.
6. *Globigerapsis howei* (Blow and Banner), sample 0, *G. semiinvolutus* Zone.
- 7, 8. *Globorotalia pomeroli* (Toumarkine and Bolli), sample 1.5, *G. semiinvolutus* Zone.
- 9, 10. *Globorotalia cerroazulensis* (Cole), sample 2, *G. semiinvolutus* Zone.
- 11, 12. *Globorotalia cocoaensis* (Cushman), sample 5, *G. cerroazulensis* or *C. inflata* Zone.
- 13, 14. *Cribohantkenina inflata* (Howe), sample 2, *G. semiinvolutus* Zone.
- 14, 15. *Cribohantkenina lazzarii* (Pericoli), sample 6.4, *Globorotalia cerroazulensis* or *C. lazzarii* Zone.





- HAO B. H., PREMOLI-SILVA I., LOHMAN G. P.
1977 *Calcareous plankton biogeographic evidence for major climatic fluctuations in the early Cenozoic*. *Science*, vol. 235, pp. 1156-1167.
- HAO B. H., HARDENBOL J., VAIL P. R.
1987 *Chronology of fluctuating sea levels since the Triassic*. *Science*, vol. 235, pp. 1156-1167.
- HUT P., ALVAREZ W., ELDER W. P., HANSEN T., KAUFFMAN E. G., KELLER G., SHOEMAKER E. M., WEISSMAN P. R.
1987 *Comet showers as a possible cause of mass extinctions*. *Nature*, vol. 329, pp. 118-126.
- KEIGWIN L. D. JR.
1980 *Paleoceanographic change in the Pacific at the Eocene-Oligocene Boundary*. *Nature*, vol. 287, pp. 722-725.
- KEIGWIN L. D., KELLER G.
1984 *Middle Oligocene climatic change from equatorial Pacific DSDP Site 77B*. *Geology*, vol. 12, No. 1, pp. 16-20.
- KEIGWIN L. D., CORLISS B. H.
1986 *Stable isotopes in Late Eocene to Oligocene Foraminifera*. *Geol. Soc. Amer. Bull.*, vol. 97, pp. 335-345.
- KELLER G.
1983 *Biochronology and Paleoclimatic implications of middle Eocene to Oligocene planktonic foraminiferal faunas*. *Marine Micropal.*, vol. 7, pages 464-486.
- 1985 *Eocene and Oligocene stratigraphy and erosional unconformities in the Gulf of Mexico and Gulf Coast*. *Jour. Paleo.*, vol. 59, No. 4, pp. 882-903.
- 1986 *Stepwise Mass Extinction and Impact Events: Late Eocene to Early Oligocene*. *Mar. Micropal.*, vol. 10, pp. 267-293.
- KELLER G., D'HONDT S., VALLIER T. L.
1983 *Multiple microtektite horizons in upper Eocene Marine Sediments: No evidence for Mass Extinctions*. *Science*, vol. 221, pp. 150-152.

PLATE 2

Scale bar = 100 μ m

- 1, 2. *Globigerina cocaena* (Gumbel), sample 6,49, *Cribohantkenina lazzarii* or *Globorotalia cerroazulensis* Zone.
- 3, 4. *Pseudohastigerina micra* (Cole), sample 2,4, *Globigerapsis semiinvolutus* Zone.
5. *Pseudohastigerina barbadoensis* (Blow), sample 9, *Globigerina tapuriensis* Zone.
6. *Chiloguembelina cubensis* S. L. (Palmer), sample 9, *Globigerina tapuriensis* Zone.
7. *Globigerina galavisi* (Bermudez), sample 6,48, *C. lazzarii* or *Gl. cerroazulensis* Zone.
8. *Globigerina tapuriensis* (Blow and Banner), sample 9,7, *Globigerina selli* or *G. ampliapertura* Zone.
9. *Globigerina selli* (Borsetti), sample 12, *Globigerina angulisuturalis* or *Globorotalia opima* Zone.
10. *Globigerina binaiensis* (Koch), sample 11,3, *G. angulisuturalis* or *Gl. opima* Zone.
- 11, 12. *Globorotalia nana* (Bolli), sample 5,6, *C. lazzarii* or *Gl. cerroazulensis* Zone.
13. *Globigerina gortanii* (Borsetti), sample 13,5, *G. angulisuturalis* or *Gl. opima* Zone.
14. *Globorotalia siakensis* (Le Roy), sample 12, *G. angulisuturalis* or *Gl. opima* Zone.
15. *Globigerina angulisuturalis* (Bolli), sample 12, *G. angulisuturalis* or *Gl. opima* Zone.
16. *Globorotalia opima* (Bolli), sample 11,7, *G. angulisuturalis* or *Gl. opima* Zone.

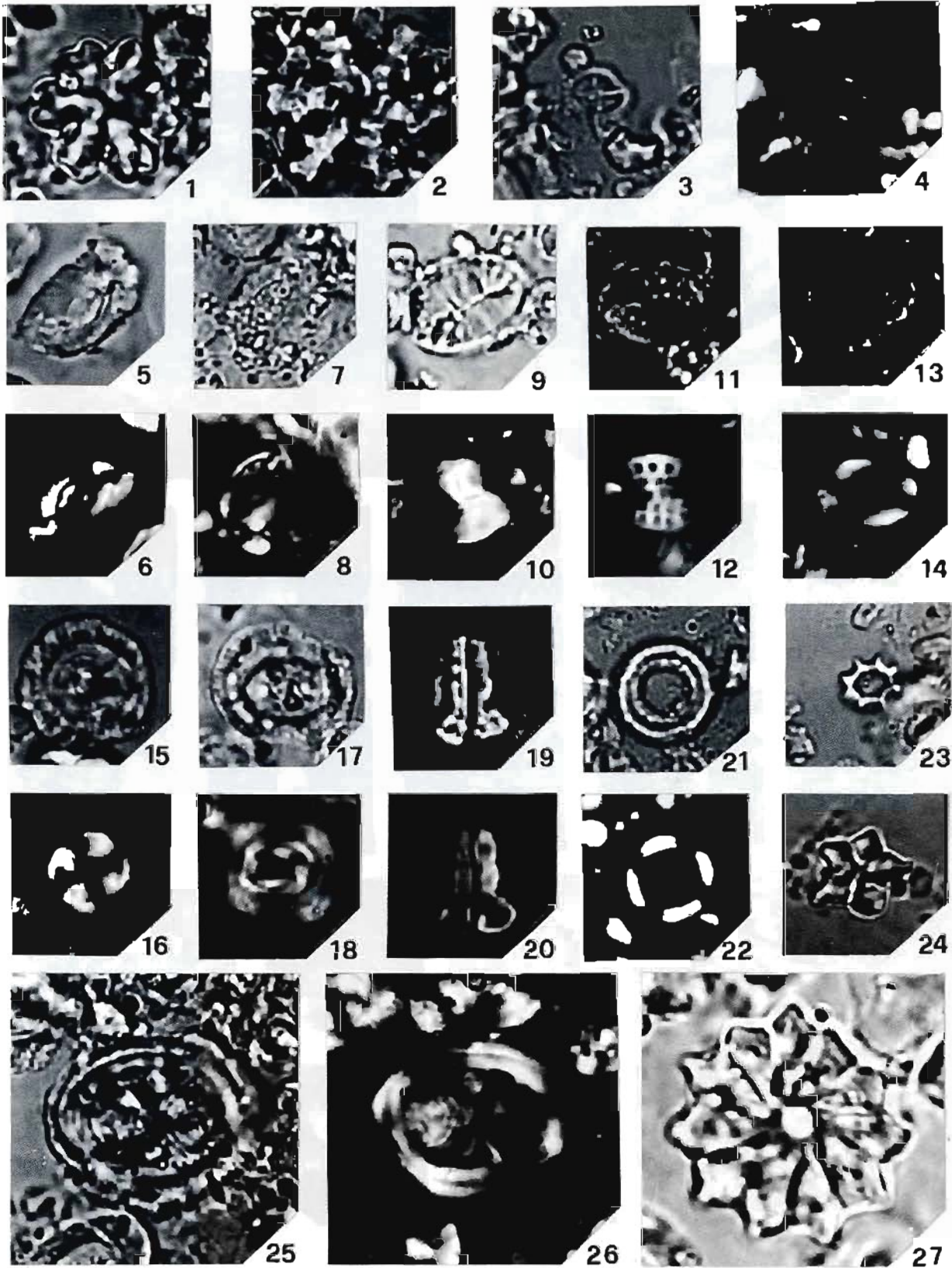
MOLINA, KELLER, MADILE

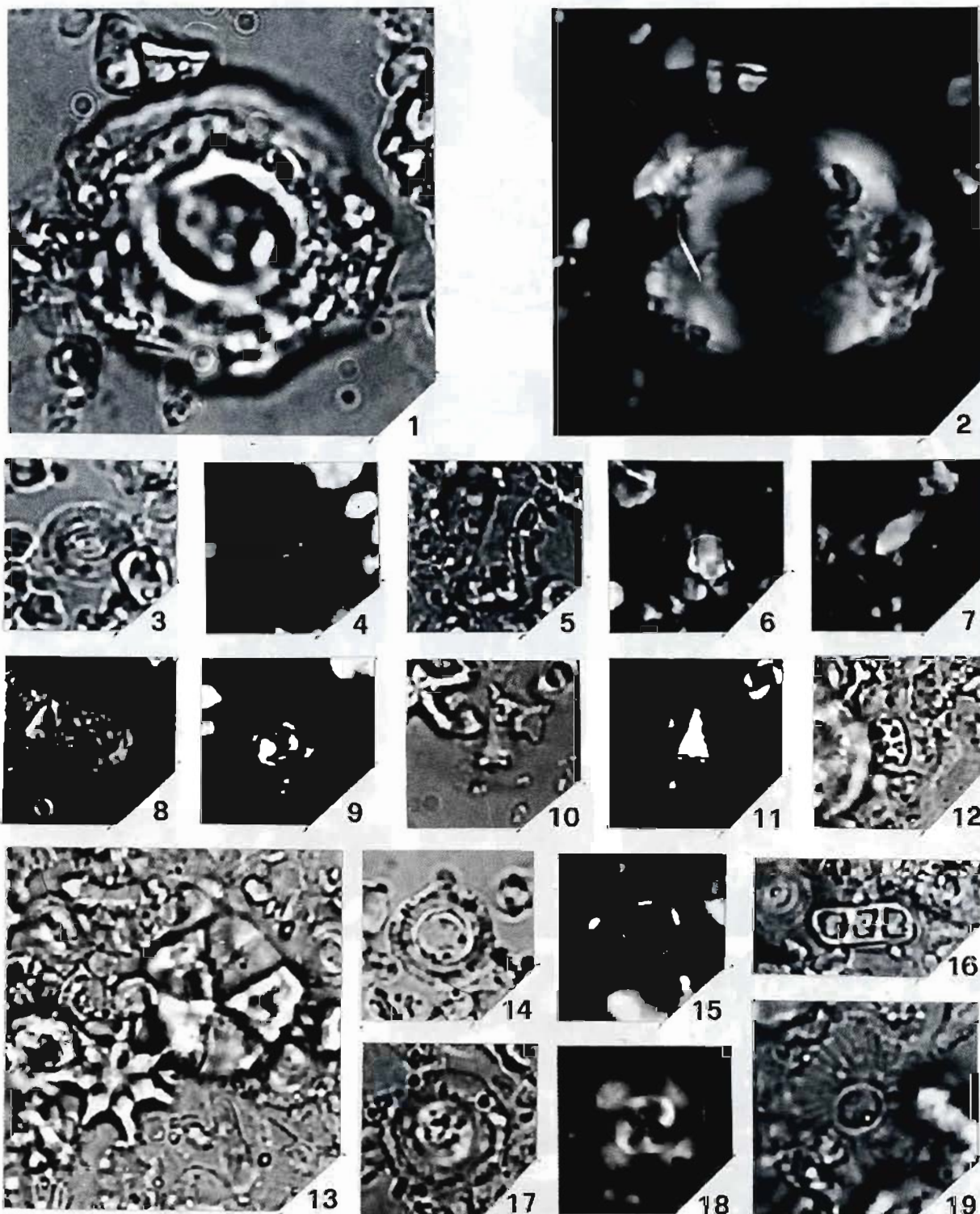
- KELLER G., HERBERT T., DORSEY R., JOHNSON M.,
CHI W. R.
1986 *Global distribution of Late Paleogene Hiatuses*.
Geology, vol. 15, No. 3, pp. 199-203.
- KELLER G., D'HONDT S. L., ORTH C. J., GILMORE J. S.,
OLIVER P. O., SHOEMAKER E. M., MOLINA E.
1987 *Late Eocene Impact Microspherules: Stratigraphy, Age and Geochemistry*. *Meteoritics*, vol. 22, No. 1, pp. 25-60.
- KENNETT J. P.
1977 *Cenozoic Evolution of Antarctic glaciation, the circum Antarctic Ocean and their impact on global Paleocyanography*. *Jour. Geophys. Res.*, vol. 82, No. 27, pp. 3843-3860.
- LOWRIE W. et al.
1982 *Paleogene magnetic stratigraphy in Umbrian pelagic carbonate rocks in the Contessa sections, Gubbio*. *Geol. Soc. Amer. Bull.*, vol. 93, pp. 321-325.
- MARTINEZ-GALLEGO J.
1977 *Estudio micropaleontológico del Nummulítico de un sector comprendido entre Moreda Piñar Pedro Martínez (Zona Subbética)*. Tesis Doct. Univ. Granada, No. 175, 264 pp.
- MARTINEZ-GALLEGO J., MOLINA E.
1975 *Estudio del tránsito Eoceno-Oligoceno con foraminíferos planctónicos al Sur de Torre Cardela (Prov. de Granada, Zona Subbética)*. *Cuad. Geol.*, vol. 6, pp. 177-195.
- MARTINI E.
1971 *Standard Tertiary and Quaternary calcareous nannoplankton zonation*. *Proc. Second Plank. Conf. Roma, 1971*, vol. 2, pp. 739-785.
- MAURASSE F., GLASS, B. P.
1976 *Radiolarian stratigraphy and North American microtektites in Caribbean Core RC9-58: Implication concerning Late Eocene radiolarian*

PLATE 3

The abbreviations XN and OL denote cross-polarized and transmitted light.

1. *Discoaster deflandrei* Bramlette and Riedel, sample 3,5 (OL) x 2200.
2. *Discoaster tani nodifer* Bramlette and Riedel, sample 3,5 (OL) x 2200.
- 3, 4. *Cruciplacolithus crux* (Deflandre and Fert) Roth, sample 3,5. (3) OL, (4) XN. x 2200.
- 5, 6. *Helicosphaera euphratis* Haq, sample 0. (5) OL, (6) XN. x 2200.
- 7, 8. *Helicosphaera bramlettei* Muller.
- 9, 10. *Pontosphaera plana* (Bramlette and Sullivan) Haq, sample 0. (9) OL, (10) XN. x 2200.
- 11, 12. *Pontosphaera multipora* (Kamptner) Roth, sample 9. (11) OL, (12) XN. x 2200.
- 13, 14. *Transversopontis obliquipons* (Deflandre) Hay, Mohler and Wade, sample 3,5. (13) OL, (14) XN. x 2200.
- 15, 16. *Ericsonia formosa* (Kamptner) Romein, sample 6,37. (15) OL, (16) XN. x 2200.
- 17, 18. *Dictyococcites abisectus* (Muller) Bukry and Percival, sample 10,6. (17) OL, (18) XN. x 2200.
- 19, 20. *Zygrhablithus bijugatus* (Deflandre) Deflandre, sample 18. (19) OL, (20) XN. x 2200.
- 21, 22. *Coronocyclus nitescens* (Kamptner) Bramlette and Wilcoxon, sample 2,6. (21) OL, (22) XN. x 2200.
23. *Corannulus germanicus* Stradner, sample 6,5, OL. x 2200.
24. *Discoaster sublodoensis* Bramlette and Sullivan, sample 5, OL. x 2200.
- 25, 26. *Chiasmolithus oamaruensis* (Deflandre) Hay, Mohler and Wade, sample 5,6. (25) OL, (26) XN. x 2200.
27. *Discoaster barbadiensis* Tan Sin Hok, sample 3,5, OL. x 2800.





- chronology and the age of the Eocene-Oligocene boundary. 7th Caribbean Geol. Conf. Proc. 1974, Guadeloupe, pp. 205-212.
- MCGOWRAN B.
1973 *Rifting and drift of Australia and the migration of mammals*. Science, vol. 180, pp. 759.
- MILLER K. G., THOMAS E.
1985 *Late Eocene to Oligocene benthic foraminiferal isotope record, Site 574, equatorial Pacific*. Initials Reports of the DSDP, vol. 85, pp. 771-780.
- MILLER K. G., MOUNTAIN G. S., TUCHOLKE B. E.
1985 *Oligocene glacioeustasy and erosion on the margin of the North Atlantic*. Geology, vol. 13, pp. 1-13.
- MOLINA E.
1979 *Oligoceno-Mioceno inferior por medio de foraminíferos planctónicos en el sector central de las Cordilleras Béticas (España)*. Tesis Doct. Public. Univ. Granada y Zaragoza, 342 pp.
1986 *Description and biostratigraphy of the main reference section of the Eocene Oligocene boundary in Spain: Fuente Caldera section*. Develop. in Paleont. and Stratig., No. 9, pp. 49-52.
- MOLINA E. et al.
1986 *Biostratigraphic correlation between the central Subbetic (Spain) and Umbro-Marchean (Italy) pelagic sequences at the E/O boundary using foraminifera*. Develop. in Paleont. and Stratig., No. 9, pp. 75-86.
- MONECHI S.
1986 *Calcareous nannofossils of the Fuente Caldera section*. Develop. in Paleont. and Stratig., vol. 9, pp. 65-70.
In press *Calcareous nannofossil events around the Eocene Oligocene boundary in the Umbrian sections (Italy)*. Submitted to Paleo. Paleo. Paleo.
- NOCCHI M., PARISI G., MONACO P., MONECHI S., MADILE M., NAPOLEONE G., RIPEPE M., ORLANDO M., PREMOLI-SILVA I., BYCE D. M.
1986 *The Eocene Oligocene boundary in the Umbrian pelagic sequences, Italy*. Develop. in Paleont. and Stratig. vol. 9, pp. 25-40.
- NOCCHI M., PARISI G., MONACO P., MONECHI S., MADILE M.
In press *Middle Eocene to Early Oligocene foraminiferal and calcareous nannofossils biostratigraphy and paleoenvironmental changes in the South Eastern sequences, Italy*. Submitted to Paleo. Paleo. Paleo.
- OBERHANSLI H., TOUMARKINE M.
1985 *The Paleogene oxygen and carbon isotope history of Sites 522, 523 and 524 from the central South Atlantic*. In: Hsu K. J., Weissert H. J. eds. South Atlantic Paleocyanography. Cambridge University Press, pp. 125-148.
- OKADA H., BUKRY D.
1980 *Supplementary modification and introduction of code numbers to the low latitudes coccolith*

PLATE 4

- 1, 2. *Reticulofenestra umbilica* (Levin) Martini and Ritzkowski, sample 3,5. (1) OL, (2) XN. x 2800.
- 3, 4. *Ericsonia* sp., sample 6,4. (3) OL, (4) XN. x 2800.
- 5, 7. *Sphenolithus distentus* (Martini) Bramlette and Wilcoxon, sample 16. (5) OL, (6) XN, (7) XN 45°. x 2800.
- 8, 9. *Ericsonia obruta* Perch Nielsen, sample 5,4. (8) OL, (9) XN. x 2200.
- 10, 11. *Sphenolithus predistentus* Bramlette and Wilcoxon, sample 5,6. (10) OL (11) XN. x 2200.
12. *Holodiscolithus solidus* (Deflandre) Roth, sample 3,5, OL. x 2200.
13. *Discoaster saipanensis* Bramlette and Riedel, and *Braarudosphaera bigelowii* (Gran and Braarud) Deflandre, sample 3,5, OL. x 2800.
- 14, 15. *Cyclococcolithina kingi* (Roth) Roth, sample 1,5. (14) OL, (15) XN. x 2200.
16. *Isthmolithus recurvus* Deflandre, sample 5,6, OL. x 2200.
- 17, 18. *Criboecentrum reticulatum* (Gartner and Smith) Perch Nielsen, sample 1,5. (17) OL, (18) XN. x 2200.
19. *Pedinocyclus larvalis* (Bukry and Bramlette) Loeblich and Tappan, sample 5,6, OL. x 2800.

MOLINA, KELLER, MADILE

- biostratigraphic zonation*. Mar. Micropaleont., vol. 5, pp. 321-325.
- PERCH NIELSEN K.
1986 *Calcareous Nannofossil event at the Eocene/Oligocene boundary*. Develop. in Paleont. and Stratig., vol. 9, pp. 275-282.
- PREMOLI SILVA L., MONECCHI S., MADILE M., NAPOLIONE G., ORLANDO M., RIPEPE M.
In press *Calcareous plankton biostratigraphy and magnetostratigraphy at the Eocene/Oligocene transition from the Gubbio area Early Paleocene through Early Oligocene*. Submitted to Palaeo. Paleont. Palaeo.
- ROBASZYNSKI F., CARON M., GONZALEZ-DONOSO J. M., WONDERS A. H.
1984 *Atlas of late Cretaceous globotruncanids*. Revue de Micropaleontologie, vol. 26, pp. 145-305.
- SANFILIPPO A., RIEDEL W. R., GLASS B. P., KYTE F. T.
1985 *Late Eocene microtektites and radiolarian extinction on Barbados*. Nature, vol. 314, pages 613-615.
- SAUNDERS J. B., BERNOULLI D., MULLER-MERZ F., OBERHANSLI H., PERCH NIELSEN K., RIEDEL W. R., SANFILIPPO A., TORRINI R. Jr.
1984 *Stratigraphy of the Late Middle Eocene to Early Oligocene in the Bath Cliff Section, Barbados, West Indies*. Micropaleontology, vol. 30, pp. 390-425.
- SHACKLETON N. J., KENNETT J. P.
1976 *Paleotemperature History of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analysis in DSDP Sites 277, 279 and 281*. Initial Reports of the DSDP, vol. 29, pp. 743-755.
- STEINECK P. L., BREEN M., NEVINS N., O'FIARA P.
1984 *Middle Eocene and Oligocene deep sea ostracoda from the oceanic formation Barbados*. J. Paleontology, vol. 58, No. 6, pp. 1463-1496.
- VAIL P. R., HILDENBOL J.
1979 *Sea level changes during the Tertiary*. Oceanus, vol. 22, No. 3, pp. 71-80.
- WEISSEL J. K., HAYES D. E.
1972 *Magnetic anomalies in the southeast Indian Ocean*. In Hayes D. E. ed. Antarctic Oceanology II. Antarctic Res. Ser., vol. 19, p. 165.
- WILLIAMS D. F., THUNELL R. C., HODELL D. A., VERGNAUD-GRAZZINI C.
1985 *Synthesis of Late Cretaceous, Tertiary and Quaternary stable isotope records of the South Atlantic based on Leg 72 DSDP core Material*. In Hsu K. J., Weissert H. J. eds. South Atlantic Paleoclimatology. Cambridge University Press, pp. 205-242.

Manuscrito recibido el 5-VI-1987