Reprinted from:
Ch. Pomerol and I. Premoli-Silva (Editors), *Terminal Eocene Events*

DESCRIPTION AND BIOSTRATIGRAPHY OF THE MAIN REFERENCE SECTION OF THE EOCENE / OLIGOCENE BOUNDARY IN SPAIN: FUENTE CALDERA SECTION

Eustoquio MOLINA*

1 INTRODUCTION

The Eocene-Oligocene boundary has been acknowledged in different Spanish regions, being located as much in continental as in continuous marine series.

In the North of Spain the limit is situated in continental facies. In the Pyrenees region of Aragón and Navarra thick sections crop out that show clearly that Eocene marine facies last as long as the Late Eocene in certain cases, with the Eocene/Oligocene limit in continental facies. In most of Catalonia and Navarra continental basins there are thick evaporitic formations that reached the top of the Eocene (Reguant, 1984). Therefore, these deposits do not allow a good biostratigrafic study of such a boundary.

In the South of Spain, geologically corresponding to the Betic Cordillera, many continuous successsions at the Eocene-Oligocene boundary can be found in marine facies. The island of Mallorca, however, is an exception; the boundary shows carbonaceous deposits with shallow marine intervals interbedding. In the region of Levante, more precisely in the area around Alicante, a continuous marine section has been quoted (Cremades, 1981) but this section does not seem to offer good possibilities due to its reduced thickness and inappropiate lithology.

The best continuous marine sections can be found in the central sector of the Betic Cordillera, more precisely in the North of the province of Granada. Most of these sections have been described by Martinez-Gallego (1977) and Molina (1979) in their doctoral theses respectively. The upper Eocene and lower Oligocene have been recognized in the sections of the Navazuelo, the Pinarejas and others. Among these, the most outstanding due to their important thickness and good exposure are: the Torre Cardela section, published by Martinez-Gallego and Molina (1975), the Molino de Cobo section, and the Fuente Caldera section, the best found so far.

---

*Department of Paleontology
University of Zaragoza (Spain)

2 LOCATION

The Fuente Caldera section is geographically located in the Gavilan ravine, in the township of Pedro Martinez (province of Granada), 6.5 km NE from the village itself and 1 km NE from the Fuente Caldera farmhouse. It can be found in the sheet of Huelma 20-39 (970) of the Spanish military map 1:50,000. The U.T.M. coordinates of the points delimiting the section are; base: 30SVG836571 and top: 30SVG835575. The section is accessible by a path from the road between Pedro Martinez and Villanueva de las Torres, which leads to the farmhouse of Fuente Caldera.

Geologically, the Fuente Caldera section is located in the Betic Cordillera that is the most western mountain system of the European

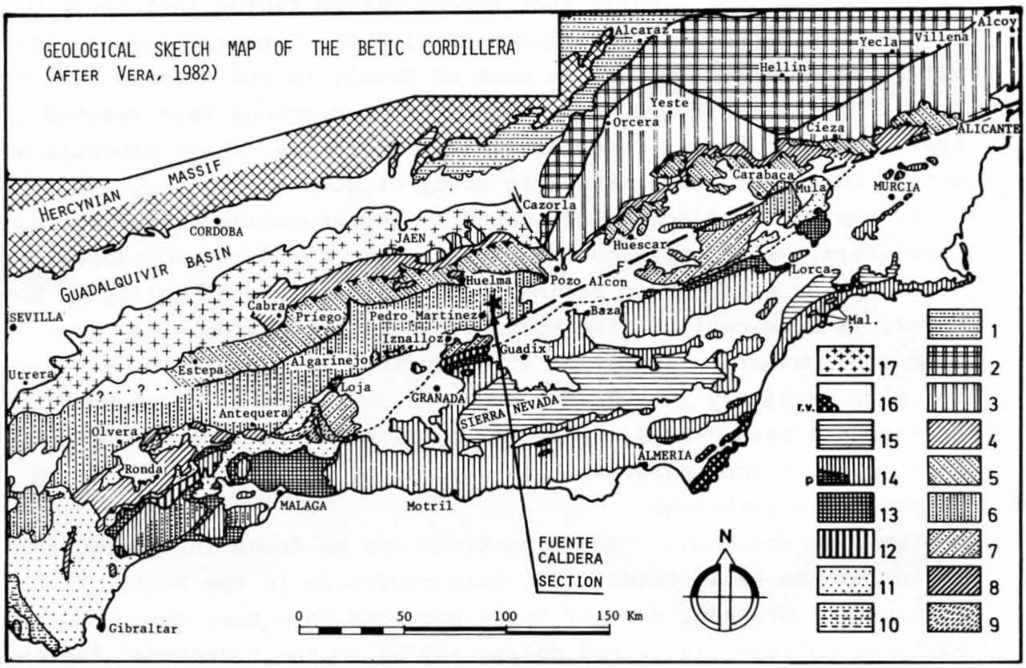

Fig. 1. Geological sketch map showing the situation of Fuente Caldera section: 1) Tabular cover of the Hercynian massif of the Meseta (Triassic and Jurassic); 2) External Prebetic; 3) Internal Prebetic; 4) Intermediate Units (or intermediate realm); 5) External Subbetic; 6) Median Subbetic; 7) Internal Subbetic; 8) Penibetic; 9) Ultra-internal Subbetic and units of dorsalian affinities and flysch substratum; 10) Tectonically underlying Campo de Gibraltar Units; 11) Campo de Gibraltar Units; 12) Rondaides or Betic dorsal; 13) Malaguide; 14) Alpujarride (p: peridotites); 15) Nevado-Filabride; 16) Upper Miocene-Pliocene-Quaternary (r.v.: volcanic rocks); 17) Guadalquivir allochtonous units (Olisthostromes of Subbetic origin inside Miocene materials).

alpine chains. It ranges all along the S and SE region of the Iberian Peninsula, with a general WSW-ENE direction. They extend along 600 Km with a variable width of about some 200 Km and it is bounded northwards, from W to E, by the Guadalquivir Basin, the tabular cover of the Hercynian massif in the Meseta and the Iberic Cordillera. Generally, the importance of folding decreases from S to N, so that in the septentrional realm (Prebetic) overthrusts cannot be individualized. Two main units can be identified from S to N: Internal Zones (or Betic Zone s. str.) and External Zones (Subbetic and Prebetic Zones).

The Fuente Caldera section is situated in the External Zones of the Betic Cordillera, more precisely within the Median Subbetic realm, which appears to be a subsident trough during the Eocene. The Palaeogene - lower Miocene marine materials are laid down in that realm and may reach up to more than 1,000 m in thickness.

The sediments of the Fuente Caldera section correspond to the Cañada Formation (Eocene-Aquitanian) of the Cardela Group established by Comas (1978) as formal lithostratigraphical units for Median Subbetic sequences of the Montes Orientales. The Cañada Formation, which may range up to a thickness greater than 500 m, is composed in general by detritic limestones of turbiditic origin interbedding rhythmically with hemipelagic marly levels.

3 LITHOLOGY AND STRUCTURE

On the flanks of the Gavilan ravine there is a thick series of materials comprised between the uppermost part of the lower Eocene and the Aquitanian. The exposure of the strata is excellent, especially in the interval corresponding to the upper Eocene and lower Oligocene, which allows a very good sampling of the boundary.

The materials of the Eocene-Oligocene boundary as a whole are generally made up of a rhythmic succession of bioclastic calcarenites and calcirudites alternating with marls, which are the predominant lithology. This light grey-greenish marly sediment shows a concoidal fracture in balls and they are easily disintegrated by the laboratory washing. The last appearance of the typical Eocene planktonic foraminifera do not correspond to any sudden lithological change.

Although less frequently there are also certain levels of marly limestones and thin calcareous conglomerate, as we go further on in to the Oligocene, where an olisthostrome is located. It involves materials of different lithologies, including volcanic rocks as well.

The series this paper is concerned with, offers in its top a mainly calcarenitic interval, which is not totally included here because it already belongs to the middle Oligocene.

The section here considered for studying the Eocene/Oligocene boundary is 200 m thick and shows an almost vertical dip, forming the North flank of a wide syncline of a general ENE-WSW direction, with its nucleus located 1 km south and delimited by two hills:Cerro Caldera and Maquina. This syncline leans on pink and white marly limestones dated as Paleocene and Late Cretaceous.

4 SEDIMENTOLOGY

The Fuente Caldera section is of great interest from the sedimentological point of view (Comas, Martinez-Gallego and Molina, 1981), due to the presence of different facies of turbidites and pelagic sediments. In this sequences the autochthonous marly interval is largely developed and they show very little reworking.

The major facies in the allochthonous interval is made up of calcareous turbidites where Bouma a interval can be recognized and sometimes a bioclastic-calciclastic coarse-grained layer appears under it, corresponding to a grain-flow episode. The bioclastic calcarenites generally range from coarse to fine types: wakestone, packstones or pseudograinstone. They show micrite intraclasts in a proportion between 3 and 20% in respect to the fragments of calcareous algae and macroforaminifera. The medium size of the grains in the basal interval is usually larger than 2 mm., and that is why they should be considered as fine calcirudites.

The recognized sequences are of the Tabade, Tab/e, Ta/c/e, types and some of them of the Tbc/e type. They show basal flat surfaces with a development of only a few sole marks: some grooves, load and tool marks. The calciruditic-calcarenitic beds are usually between 30 and 180 cm thick. For some of very incomplete sequences their thickness decreases to 7 cm. Every turbiditic bed is interbedded between marl intervals whose thickness ranges between 50 cm and 5 m, therefore autochthonous pelagic sediments are dominant. If the large quantity of interturbiditic materials alone is considered here as a indicative parameter of distality, they should consequently be considered as distal turbidites.

The origin and direction of the paleocurrent is difficult to establish due to the scarcity of structures they display, which seem to have come from the W. The place of deposit for these associated facies would be a submarine talus or slope, probably in relation to a large submarine fan.

In the upper part of the series an eight-metre thick olisthostroma is located, which is included in the biozone of *G. tapuriensis*. It is formed by a chaotic conglomerate mass, blocks and pebbles, that is the result of a gravity flow of a considerable volume, involving materials of various lithologies and origins. Taking into account the regional data, it may be assumed that the olisthostrome must have fallen from the NE.

5 GEOCHEMISTRY, MAGNETOSTRATIGRAPHY AND RADIOMETRIC DATING.

The geochemical study of the pelagic carbonates of this series have been carried out by Berthenet et al., this volume . They have analyzed the fluctuation of the chemical composition of the oceanic water, with the aim of determining the main geochemical events during the Eocene/Oligocene boundary, concluding that there is a good concordance between the chemiostratigraphy and the bioestratigraphy.

In the Fuente Caldera section five main geochemical events can be recognized. The event G 1 well marked by the $\delta^{13}C$ and $\delta^{18}O$ and moderately marked by the Sr correspond to the boundary of the foraminiferal zones. *P. semiinvoluta*/*C. inflata*. The event G 2, very neat for the Sr and moderate for the $\delta^{18}O$ corresponds to the limit of the nanno-zones NP 20/NP 21. The event G 3 (very strong for the $\delta^{13}C$ and the Sr) are situated at the boundary of the foraminiferal zones *C. inflata*/*C. lazzarii*. The event G 4 ($\delta^{13}C$ and Sr) corresponds to the boundary E/O defined by the extinction of the typical Eocene planktonic foraminifera. The event G 5 ($\delta^{13}C$ and $\delta^{18}O$, Sr) is situated in NP 21 and could eventually correspond to the boundary CP 16a/CP 16 b.

Concerning the magnetostratigraphic study, a first sampling followed by a study of the magnetization intensity in roder to determine the real possibilities of this section, was carried out in 1982 by Rasplus who observed a remanent mangnetization. Consequently, the Fuente Caldera section allows the establishment of a magnetostratigraphy.

No studies directed towards radiometric datings have been undertaken so far. Therefore, the real possibilities of the Fuente Caldera section in this sense are still unknown.

6 FLORAL AND FAUNAL CONTENT

The Fuente Caldera section is remarkable for its fossil content, mainly microfossils. However, the macrofossils such as Equinoderms Bivalves and others are very difficult to identify due to the massive fragmentation they have undergone. They appear in small proportion in the calcarenitic strata, associated with Coralline algae, Bryozoa and macroforaminifera.

The macroforaminifera forming part of this association in the turbiditic levels are mainly the following: *Discocyclina sp.*, *Asterocyclina sp.*, *Aktinocyclina sp.*, *Nummulites sp.*, *Operculina sp.*, *Heterostegina sp.*, *Spiroclypeus sp.*, *Amphistegina sp.*, and *Gypsina sp.* It must necessarily be emphasized that the percentage of the typical Eocene Discocyclinidae decreases gradually towards the upper part of the series, but nevertheless, they are still well represented in the biozone of *G. tapuriensis*.

The autochthonous marly intervals contain an extraordinarily varied quantity of calcareous nannoplankton, planktonic foraminifera, small benthonic foraminifera and some ostracoda as well. These sediments are very rich in calcareous nannoplankton and, although their preservation is not ideal, it is good enough to allow a detailed study and to establish an accurate biozonation.

The rich calcareous nannofossil content allows Monechi to recognize several events from Late Eocene to Early Oligocene. The zonation of Bukry and Okada (1980) with the designation CP were used. The zonation of Martini (1971) with the designation NP was also reported for correlation (Monechi, this volume).

To demonstrate the variation in the abundance of the most important species a semiquantitative analysis was carried out and it has been possible to identify a succession of events. The last occurrence of *C. protoannula* and *C. reticulatum* takes place before the extinction of the rosette shaped discoasters. The synchronous extinction of *D. barbadiensis* and *D. saipanensis* at the same level of the LO of *G. index*. A small increase in the abundance of the *I. recurvus*, cold water indicator, was observed between the LO of rosette shaped discoasters and the E/O boundary defined by planktonic foraminifera. The species *E. formosa* decreases around the LO of rosette shaped discoasters.

The planktonic foraminifera are especially abundant reaching 85% in almost all the samples of the marly intervals. They are quite well preserved although the chambers are filled in with sediments. They usually show no deformation whatsoever.

Taking into account the fossil content and sedimentation, it may be assumed that the paleoenvironment would be an open marine basin that would correspond to an almost 2.000 m deep bathyal zone, situated in a subtropical or temperate area.

7 BIOSTRATIGRAPHY BY MEANS OF PLANKTONIC FORAMINIFERA.

The biozonation established for the Oligocene (Molina, 1979) is still mantained in its general outline. But, nevertheless, a more detailed study is attempted in this paper, in order to determine more accurately the range of the different species and to extend the study to include the upper Eocene as well.

The vertical range of the main species, from the biostratigraphical point of view, has been shown in Figure 2. Some other species have also been identified and some of them are very abundant, but most of them appear along the whole Eocene-Oligocene transition. The following ones have been recognized among them: *Globigerina tripartita* Koch, *Globigerina venezuelana* Hedberg, *Globigerina angiporoides* Hornibrook, *Globigerina galavisi* Bermudez, *Globigerina corpulenta* Subbotina, *Globigerina officinalis* Subbotina *Globigerina praebulloides* Blow, *Globorotalia (T.) opima nana* Bolli, *Globorotaloides suteri* Bolli, *Catapsydrax unicavus* Bolli, Loeblich and Tappan, *Chiloguembelina cubensis* (Palmer), *Chiloguembelina victoriana* Beckmann, *Globigerina ouachitaensis* Howe and Wallace, and *Globorotalia (T.) increbescens* (Bandy).

The *Globorotalia cerroazulensis* group is very common throughout the upper Eocene. The author would rather consider these forms at the species level because of the different morphology between the more primitive and the evolutionary ones. In the interval studied, *G. (T.) pomeroli* became extinct at the same time as *P. semiinvoluta*; later *G. (T.) cerroazulensis* became extinct after the disappearance of *G. index*. Finally, *G. (T.) cocoaensis* and *G. (G.) cunialensis* became extinct simultaneously. *G. (G.) cunialensis* is the worst represented since it is very difficult to find good keeled specimens and it

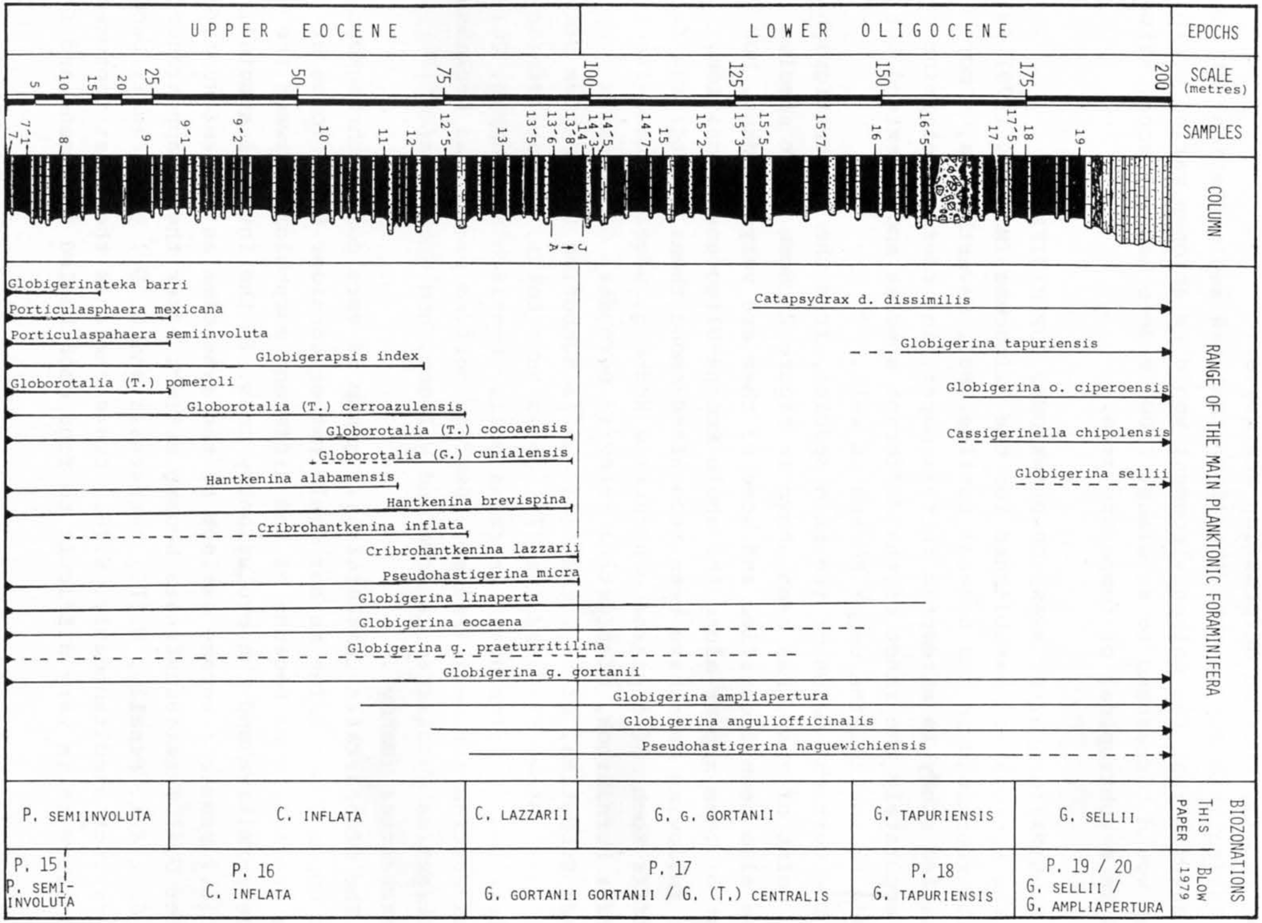

Fig. 2. Column showing the upper Eocene and lower Oligocene in Fuente Caldera section.

appears only in the uppermost Eocene.

The *Hantkenina* and *Cribrohantkenina* genera are frequent in most of the samples. The second one is well represented by the species *C. inflata*, *C. lazzarii* and probably a third one, as was pointed out by Dieni and Proto Decima (1964) in Italy. *C. inflata* has more inflated chambers than *C. lazzarii* which have almost triangular chambers with a rough surface and a few more chambers in the last whorl.

In the Spanish sections the *Pseudohastigerina micra* (Cole) extinction is a very clear datum plane. However, the range of this species does not overlap wiht that of *Cassigerinella chipolensis* Cushman and Ponton) as was pointed out in other regions of the world (Bolli, 1957,66). The explanation for such an event could be:

(1) *P. micra* extinction in low latitudes could be prior to that in mid-latitudes.
(2) *C. chipolensis* appearance in low latitudes could be prior to that in mid-latitudes.
(3) *P. micra* could be found reworked after its last extinction or could be confused with *P. n.naguewichiensis* and *P. n.barbadoensis;* these two subspecies are less compressed and smaller than *P. micra* a species typically larger than 150 microns. The small ones are very frequent from the uppermost Eocene to the lower - Oligocene.Recently, these forms larger than 150 microns have been regarded by Blow (1979), as belonging to *P.danvillensis* Howe and Wallace, 1932) but I would rather keep considering it as junior synonyms of *P. micra* (Cole, 1927) like Cordey, Berggren and Olsson (1970).

The species *Catapsydrax dissimilis* (Cushman and Bermudez) has been found only in the Oligocene, contrary to that which some specialists indicated for other regions of the world. In Spain *C.d. dissimilis* appears in the upper part of the *G.g.gortanii* zone and *C.d. ciperoensis* evolves from the former in the top of the *G. tapuriensis* zone.

The following biohorizons have been considered as the most important and used to establish the biozonation: extinction of *Porticulasphaera semiinvoluta* (Keijer), extinction of *Cribrohantkenina inflata* (Howe), extinction of *Cribrohantkenina lazzarii* (Pericoli), first appearance of *Globigerina tapuriensis* Blow and Banner, first appearance of *Globigerina sellii* (Borsetti).

Similarly, the following biohorizons can be considered clear on the scale of this particular central sector of the Betic Cordillera: extinction of *Globigerinatheka barri* Bronnimann, extinction of *Globigerapsis index* (Finlay), simultaneous extinction of *Hantkenina brevispina* Cushman, *Globorotalia* (T.) *cocoaensis* Cushman and *Globorotalia* (G.) *cunialensis* Toumarkine and Bolli, being followed inmediately by the extinction of *Pseudohastigerina micra* (Cole) at the same time as *Cribohantkenina lazzarii* (Pericoli).

The Eocene/Oligocene boundary has been sampled in detail (see Fig. 3) and therefore it has been possible to conclude that the extinction of the typical Eocene species is not simultaneous. The same conclusion has also been reached in the Torre Cardela section (Martinez-Gallego & Molina, 1975). As the *Pseudohastigerina micra* and *Cribohantkenina lazzarii* are the last typical Eocene species to became extinct, they have been chosen as the datum plane to mark out such a boundary.

The biozonation established in this paper has been correlated to that which offers more similarities (Blow, 1979), but there are some important differences; so, the top of the G. *semiinvoluta* zone, is delineated by the last appearance of the nominal species instead of by the first appearance of C. *inflata*. The zone P 17 of Blow

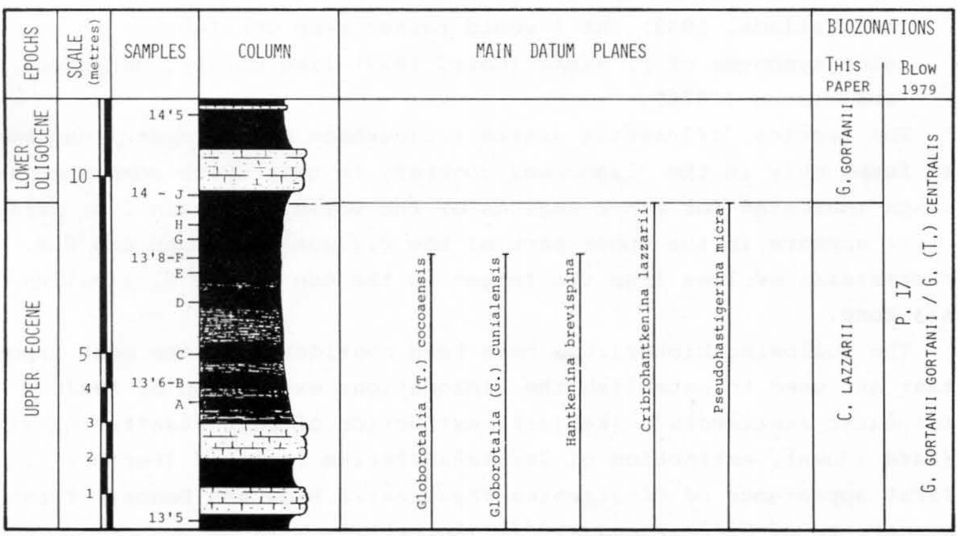

Fig. 3. Column showing a detailed sampling of the Eocene/Oligocene boundary in Fuente Caldera section.

has been divided into two zones: *C. lazzarii* and *G. g. gortanii*. The latter is an interval zone situated between the extinction of *C. lazzarii* and the first appearance of *G. tapuriensis*. Here the planktonic foraminifera bear affinity to those of the Oligocene; and the species *G.g.gortanii* has been found throughout the upper Eocene and Oligocene, contrary to what Blow pointed out.

Finally it should be noted that some biohorizons, such as *G. tapuriensis* and *G. sellii* that have been used in the biozonation, show a very gradual appearance. On the other hand, many extinction biohorizons seem very instantaneous. The typical Eocene species stand out clearly in this sense. Nevertheless, when the Eocene/Oligocene boundary is being sampled in detail, it can be observed that the extinction of the typical Eocene forms are not all simultaneous, as it could appear. Besides that, no lithological change is observed. Consequently, it can be said that there is a transition of biological and sedimentological events at the Eocene-Oligocene in the Fuente Caldera section.

REFERENCES

Berthenet, F. 1985. Evénements géochimiques á la limite E/O. Mém. DEA, option strat. Univ. P.& M. Curie, Paris, Roneo,30 p.

Blow, W.H. 1979. The Cainozoic Globigerinida. Leiden, Brill, 3 vol.

Comas, M.C. 1978. Sobre la geología de los Montes Orientales: sedimentación y evolución paleogeográfica desde el Jurásico al Mioceno inf.(Zona Subbetica, Andalucia).Tesis, Univ.Bilbao, 323 pp.

Comas, M.C., Martinez-Gallego, J., and Molina, E. 1981. Facies y sucesión estratigráfica del Eoceno y Oligoceno al N del Mencal (Zona Subbetica, Prov. de Granada). Cuad. Geol., 12, (in press).

Cremades, J., 1981. Contribución al conocimiento de los foraminiferos planctónicos y al estudio bioestratigráfico del Eoceno y Oligoceno del sector oriental de las Cordilleras Béticas. Tesis Doc.

Martinez-Gallego, J., 1977. Estudio micropaleontologico del Nummulitico de un sector comprendido entre Moreda-Piñar-Pedro Martinez (Zona Subbetica). Tesis Doct. Univ. Granada. 175.

Martinez-Gallego, J. and Molina, E. 1975. Estudio del transito Eoceno-Oligoceno con foraminíferos planctónicos al Sur de Torre Cardela (Prov. de Granada, Zona Subbetica). Cuad.Geol. 6: 177-195.

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.

Molina et al.(in press). Biostratigraphic correlation between the central Subbetic (Spain) and Umbro-Marchean (Italy) pelagic sequences at the E/O boundary using foraminifera. This volume.

Perch-Nielsen, K. et al. (in press). Calcareous nannofossils at the Eocene/Oligocene boundary. This volume.

Renard, M. 1985. Géochimie des carbonates pélagiques. Thése Univ. P.& M. Curie, n°84-16 et Mém. BRGM n°85, (1985), 660 p.

Reguant, S. 1984. The Geological events at the Eocene-Oligocene boundary in Spain. TEE News, 8.