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IN SEARCH OF THE PALAEOGENE/NEOGENE BOUNDARY STRATOTYPE

Part 2

POTENTIAL BOUNDARY STRATOTYPE SECTIONS IN ITALY AND SPAIN

A COMPARISON WITH RESULTS FROM THE DEEP SEA AND THE ENVIRONMENTAL CHANGES

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International Union of Geological Sciences
Commission on Stratigraphy
Working Group on the Palaeogene/Neogene Boundary

Key—words: Palaeogene/Neogene, Oligocene/Miocene, lithostratigraphy, biostratigraphy, chronostratigraphy, potential boundary stratotype section, Italy (Sicily), Spain (Betic Cordilleras), equatorial Pacific Ocean, planktonic foraminifera environments, paleoecology of micromammals.

CONTENT

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PREFACE

In publishing the first results of its research works (Giornale di Geologia, vol. XLIV, fasc. I–II, 1981) the Palaeogene/Neogene Boundary Working Group, while not having defined any final object yet, has nonetheless enabled us to: a) recall attention to the existence of lithofacies (e. g. turbidites, volcanoclastic rocks) of great significance with respect to the geodynamical situation of the Mediterranean; b) to clarify the significance of some first class faunal markers, particularly as regards planktonic foraminfera.

These results permitted to direct the course of subsequent research works carried out by the Group, in the way of giving to the International Commission on Stratigraphy, some objective data for a satisfactory solution of the problem.

Results of a second research series, coordinated by the Group in Sicily and Spain, are illustrated hereafter.

In Sicily, M. Romeo and A. Di Grande of Catania University have presented to the Working Group two sections across relatively soft carbonatic rocks of the Iblean Foreland which outcrop around Ragusa.

In Spain, J. M. Gonzalez–Donoso, D. Linares, E. Molina and F. Serrano from the Universities of Malaga and Zaragoza have offered the possibility to study two sections in terrigenous rocks from the Betic Cordilleras which outcrop to the NE of Granada.

Although all investigated sections are across the critical time span, the opinion of the Working Group is that none of them can be classified as stratotypical; in the area of the Mediterranean they surely are reference point for the reconstruction of the geological events at the boundary between Palaeogene and Neogene, but they lack some essential features which would allow them to be considered references of absolute value.

The results presented in this volume must therefore be considered only as a further step towards the possible solution of the problem which has been dealt with by the Paleogene/Neogene Boundary Working Group. It will be necessary to organize future activities taking into consideration both new areas, accepting also suggestions from colleagues who so far did not participate in the activities of the Group, and exploring areas already known, taking account of any negative elements that past experience has allowed to identify.

The editors are grateful to all active members of the Working Group, especially to those that contributed to the success of this volume. They would like to acknowledge also the ever flexible assistance of the late Prof. Dr. A. Martinsson, Chairman of the IUGS–Commission on Stratigraphy, and Dr. M. G. Bassett, the Secretary General of this commission. Their warmest thanks go to the editorial staff of the Rivista Italiana di Paleontologia e Stratigrafia for having accepted this paper; they are particularly grateful to Prof. C. Rossi Ronchetti for the critical review of all manuscripts and to Dr. C. Albanesi for the careful editing.

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The Editors

ITALY: SICILY, IBLEAN REGION

Abstract. Two sections proposed as Palaeogene/Neogene Boundary stratotype have been studied in the foreland of the Iblean region. The distribution of selected calcareous nannoplankton, planktonic and benthonic foraminifera taxa has been studied.

The Case Cocuzza section is broken by a hiatus covering the entire *Globorotalia kugleri* Zone. The Costa dell'Angelo section is broken by a hiatus covering the *G. kugleri – Catapsydrax dissimilis – Catapsydrax stainforthi* zones of Bolli (1966).

Both sections are not suitable to serve as a Palaeogene/Neogene Boundary stratotype.

General Geology (Fig. 1). (A. di Grande).

Foreword. The Iblean area, in southeastern Sicily, lies between the Catania Plain, the Vittoria Plain, and the Mediterranean and Ionian Seas.

In recent papers, Sicily is considered as a natural continuation of the E–W trending Apennine Chain because of its present physiography and mainly due to tectonic–structural similarities and paleogeographic evolution. Some geological analogies are also found to the North–African mountain chains, at least with regard to the sedimentological features and structural arrangement of certain formations.

From a paleogeographic point of view, the Iblean region, that corresponds to the Ragusa «plateau», is considered as being stratigraphically and structurally a foreland domain, laterally continuing northward to the Apulo–Garganic platform and southward through the Maltese archipelago to the northeastern African chains.

At present the Iblean area is an uprised structure bounded by tensional faults, chiefly trending in a NE–SW and NW–SE direction, having been active at least since the Upper Miocene to the Present, with recently recognized strike–slip characters (Ghisetti & Vezzani, 1981).

Tectonic–sedimentary evolution. In the Iblean area sedimentary and eruptive terrain are known ranging in age from Mesozoic to Quaternary. The levels older than Upper Cretaceous are only known by bore–hole data (Rigo & Cortesini, 1959; Rocco, 1959; Kafka & Kirkbride, 1959; Caflysch & Schmidt Di Friedberg, 1967); the Oligo–Miocene succession makes up the bulk of the outcropping rocks, while the Plio–Quaternary ones are found at its periphery over limited areas.

According to Catalano, D'Argenio & Montanari (1982), three larger depositional episodes related to the tectonic evolution can be recognized in the Mesozoic succession of the Iblean area. The oldest one is represented by the Gela Fm. dolomites, calcarenites and evaporites grading upward to shales and laminated dolomitic limestones (Noto Fm.); this is Upper Triassic (Norian–Rhaetian) in age and indicates rapidly subsiding platform (restricted tidal

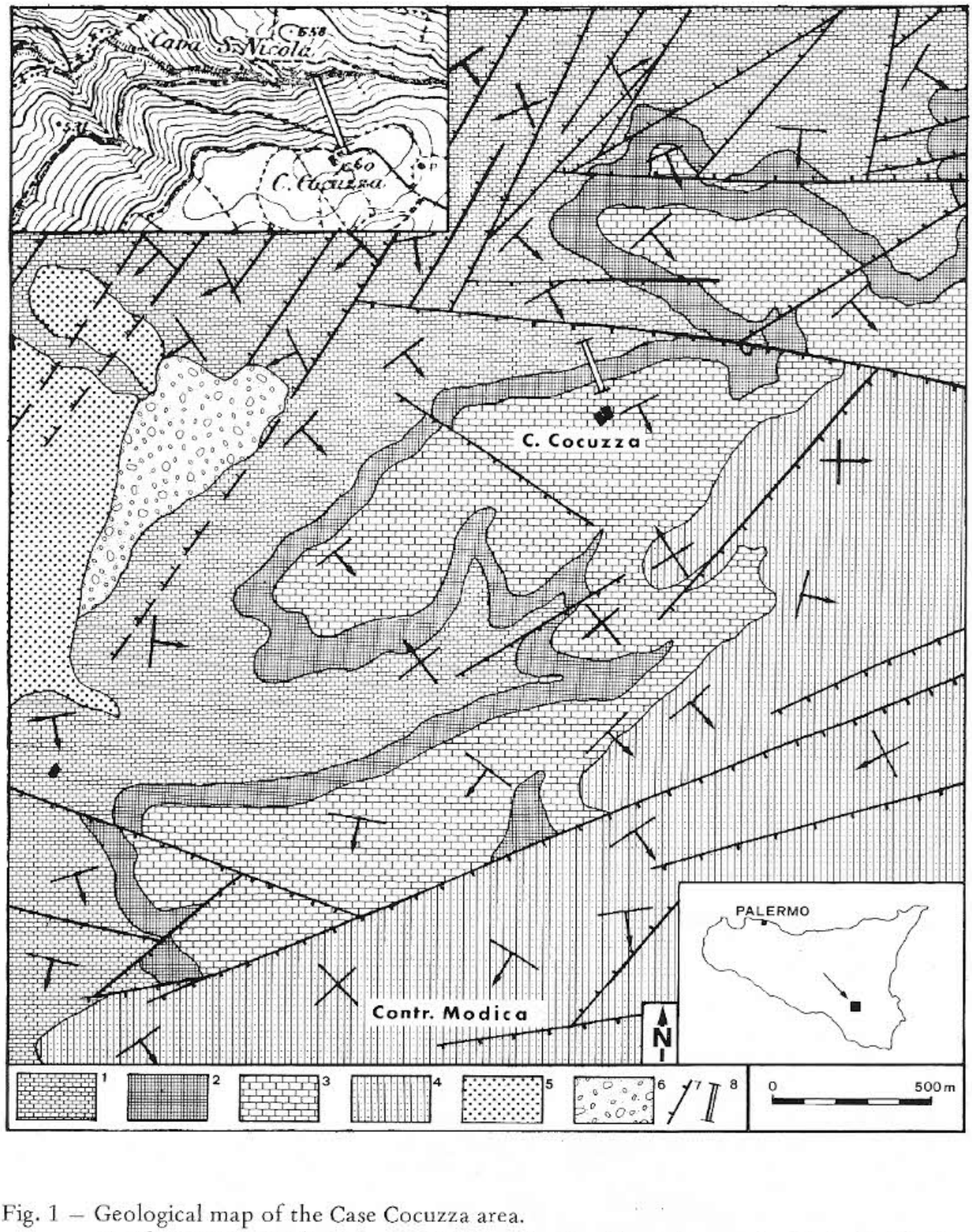


Fig. 1 — Geological map of the Case Cocuzza area.

1) Alternating marls and calcarenites (Ragusa Fm. - Leonardo Mb.). 2) Massive bedded calcarenite level (Ragusa Fm. - Irminio Mb.). 3) Alternating marls and calcarenites (Ragusa Fm. - Irminio Mb.). 4) Alternating marls and calcarenites (Tellaro Fm.). 5) Gravel, conglomerates, sands and calcarenites of the Quaternary age. 6) Actual debris. 7) Fault. 8) Section.

plain) conditions. The tectonic events at the Triassic–Jurassic boundary allow a western (Ragusa sector) and eastern (Syracuse sector) domain to be distinguished.

During the second depositional cycle, in Liassic times, the differences between the two domains become larger, with an open limestone platform environment (algal and oolitic limestones of the Syracuse Fm.) in the eastern sector and subsiding basin conditions (Streppenosa Fm. p.p. and Modica Fm. p. p.) in the western sector.

A third Middle–Jurassic to Upper Cretaceous episode is marked by the almost complete disappearance of the Syracuse eastern platform followed at first by condensed sequences (Buccheri Fm. p.p.) with radiolarite marls and marly limestones then by pelagic calcilutites, deposited in the Ragusa western basin. At the end of this depositional cycle a tectonic phase, combined with subaqueous and volcanic activity (Capo Passero Mb. of the Amerillo Fm.), followed by rudistid limestones (Portopalo Mb. of the Amerillo Fm.), again allows partial identification of distinct eastern and western sectors. This distinction becomes more evident from the Eocene to the Miocene until the time of the general uprising of the Iblean area (Messinian, according to Di Grande & Romeo, 1980).

In the Ragusa sector, during the Tertiary, the pelagic sedimentation (Amerillo Fm.) is replaced by sedimentation with detrital features (calcarenites, calcilutites and marls of the Ragusa Fm.) (Fig. 1) in a subsiding basin of moderate depth, with depth increasing later in the Lower to Middle Miocene as indicated by the deposition of the Tellaro Fm. marls. These are followed by the Palazzolo Fm. calcarenites and calcilutites, related to a regressive episode. Immediately afterwards, in the Messinian, the present configuration of the Iblean Mountains became outlined with the central part emerging and with evaporitic basins being formed at the periphery as a result. During the same time (Eocene–Tortonian) the eastern sector shows stable open sea platform conditions, with both a moderate depth and a condensed sedimentation compared to that in the Ragusa area. The emerging central part of the Iblean region leads to the formation of lagoon basins at the periphery of the sector, these correspond with the evaporitic ones in the western sector.

In the above mentioned Neogene interval, tectonic phases controlled the sedimentation in both sectors. An important episode in the Syracuse sector is transgressive deposition due to an uplifting of the Palazzolo Fm. limestones, the latter reach the Oligocene–Miocene boundary here. In the western sector the deposition of the thick calcarenite beds, marking the transition between the Leonardo and Irminio Members of the Ragusa Fm., corresponds with this episode.

The upper part of the analyzed sections probably shows the influence of this tectonic–sedimentary episode which led to a decreasing basin depth with increasing detrital input and possible local emersions; this episode could be responsible for the sedimentation gaps and the subsequent lack of certain biostratigraphic intervals.

The Case Cocuzza Section.

Location and lithology (Fig. 2). (A. Di Grande & M. Romeo).

Location. According to I.G.M. official cartography, this section is in the south–eastern part of the Licodia Eubea quadrangle (F. 273, III NE), 6 km NW of the Monterosso Almo town with the following coordinates: long. (Rome M. Mario) 2° 14' 30", lat. 37° 6' 30". It has been measured and sampled mainly along the left side of Cava S. Nicola, starting upslope from Case Cocuzza at an altitude of 690 m a.s.l.

Only the lower part has been sampled along the right side; the continuity between the two parts is certain.

Lithologic sequence (Fig. 2). The analyzed lithostratigraphic interval is entirely within the Ragusa Fm., lying here below the Tellaro Fm.; both units are part of a monoclinal structure, dipping at an average angle of 15° to the S or SSE and interrupted by tensional faults that trend mainly in a NE–SW but also in a E–W and NW–SE direction.

The sequence is rather uniform, composed mainly of soft marls and hard calcarenites, cherty at places. The overall measured thickness is 90.10 m.

Three lithologic intervals can be recognized. In the lowest one whitish weak marls, calcareous marls and marly limestones are found in layers 5 to 30 cm thick, regularly interlayered with hard, whitish, finegrained calcarenites in 20–40 cm thick layers; thicker beds, up to 1 m, are occasionally found. This interval is 38.25 m thick and corresponds with the upper part of the Leonardo Mb. (Ragusa Fm.) of Rigo & Barbieri (1959).

The middle interval is made up of hard mainly fine–grained, sometimes coarser, calcarenite beds interlayered with thin layers of white–yellowish, sometimes sandy, marls. This interval is 38.45 m thick in its entirety and correponds with the lower part of the Irminio Mb. (Ragusa Fm.) and with the level with thick calcarenitic beds (Di Grande & Grasso, 1977).

The highest interval is similar to the lowest one and consists of yellowish coarse calcarenites in layers 20 to 40 cm thick alternating with yellowish to white–yellowish sandy marls in layers of equal thickness. The harder layers in the lower part, thicker than the soft ones, include macroforaminifera (*Miogypsina* sp., etc.). This interval is 8.4 m thick and corresponds with the top part of the Irminio Mb.

Calcareous Nannoplankton (Fig. 3; Pl. 34). (M. Biolzi, R.H. Lehotayova, C. Mueller & G. Palmieri).

Low diversity characterized the nannofossil association in the Case Cocuzza section: *Dictyococcites bisecta, Cyclicargolithus abisectus, C. floridanus, Coccolithus pelagicus* and *Sphenolithus moriformis* are the most common species throughout the section. Nannofossils are common in samples CC1 to CC15, and are less frequent from sample CC16 to CC27. They are slightly to

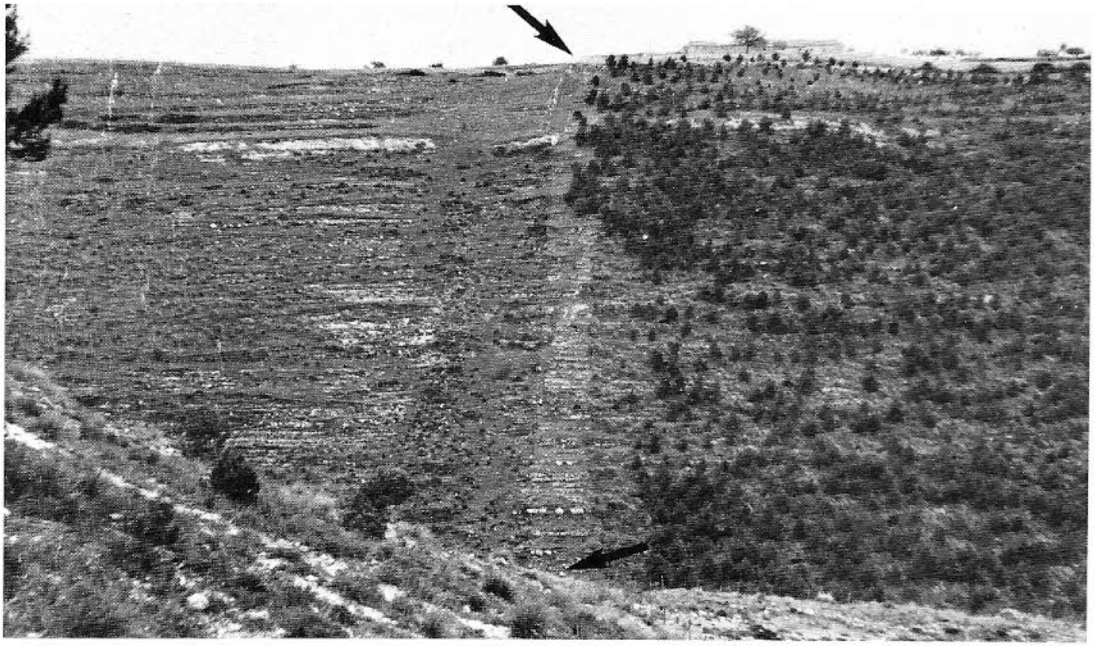


Fig. 2 — View of the Case Cocuzza section; the arrows indicate the top and the bottom.

heavily overgrown and often broken. In some samples, reworked Cretaceous and Eocene species occur sporadically.

The distribution of the stratigraphically most important species (see: In Search of the Palaeogene/Neogene Boundary Stratotype, part 1) according to the different authors and the biostratigraphic zonation they proposed are given in Fig. 3. Lehotayova could study only few samples, therefore her results are not included in the chart.

According to all authors samples CC1 to CC23 belong to the *Sphenolithus ciperoensis* Zone (NP 25 of Martini zonation, 1971), therefore to the Late Oligocene. The upper boundary of this zone is defined by the highest occurrence of *Sphenolithus ciperoensis, Helicosphaera recta* and *Zygrhablithus bijugatus. Dictyococcites bisecta* is common in sample CC22 and CC23, whereas only one specimen was found by Mueller and Palmieri in sample CC24 and CC25. Mueller actually uses *Dictyococcites dictyodus* and not *Dictyococcites bisecta* but since the authors agreed that the two names correspond here to the same form they keep *Dictyococcites bisecta.*

Helicosphaera carteri indicating an Early Miocene age is found from sample CC24 upwards. At the same level a decrease in size of the nannofossils can be observed. The specimens are larger up to sample CC23 than in samples CC24 to CC27. This change has been observed also in other regions (Atlantic,

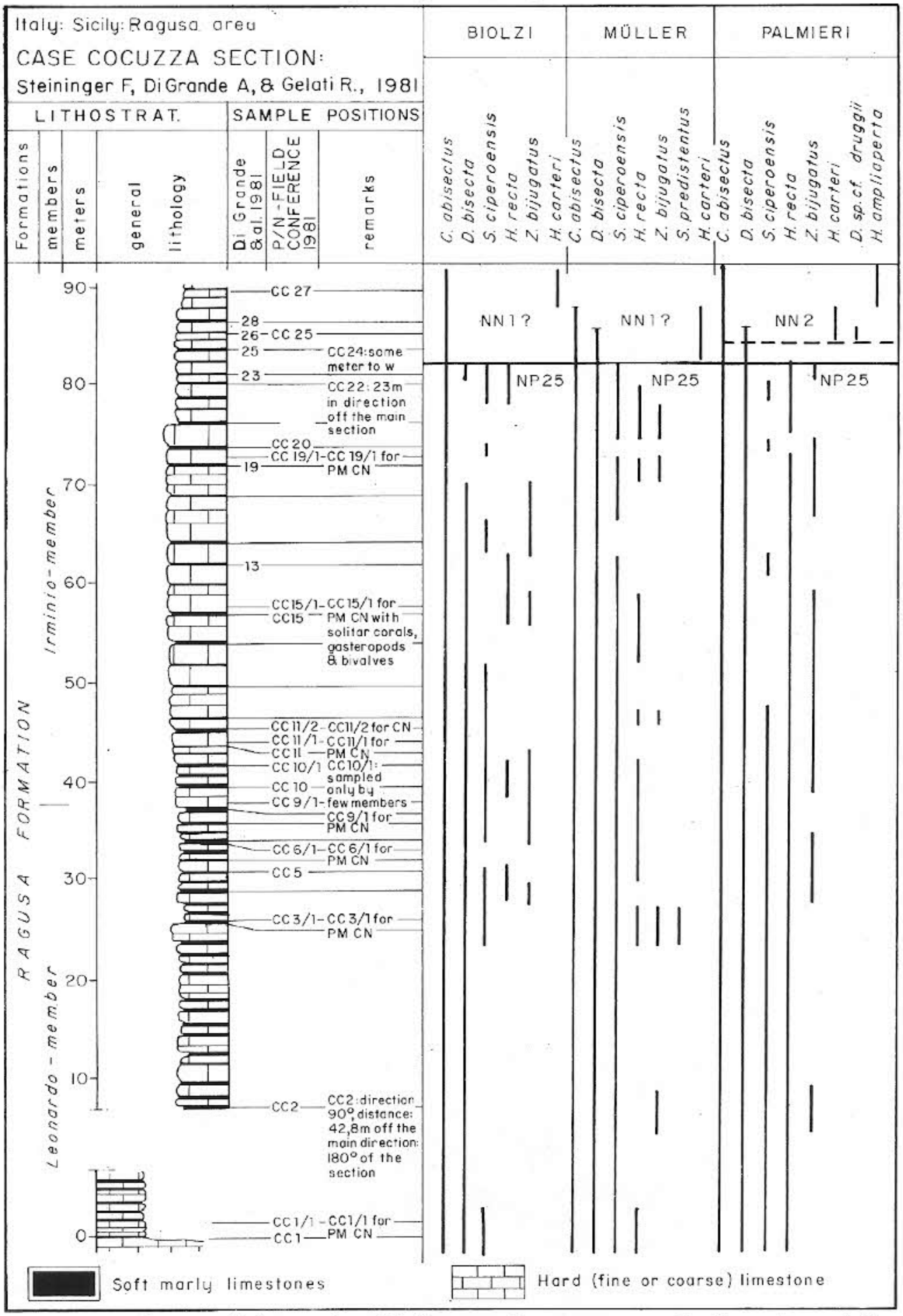


Fig. 3 — Distribution of the stratigraphically most important nannofossil species and biostratigraphic zonations (Martini, 1971) proposed by each author in Case Cocuzza section.

Mediterranean, north Germany) between zones NP 25 and NN 1. On these observations Biolzi and Mueller dated the sediments from sample CC24 to CC27 Early Miocene but no definite evidence exists to assigne the last portion of the sequence to the nannofossil Zone NN1. The possibility of a hiatus between samples CC23 and CC24 is very likely. Palmieri found a form of *Discoaster* sp. cf. *druggii* in sample CC25 (see Pl. 34, fig. 7, 8) therefore, he assigned the sequence from this sample to the top to the *Discoaster druggii* Zone (NN2). Typical *D. druggii* is generally missing or very rare in most part of the Mediterranean area. However, both in the western and in the eastern Mediterranean, in surface and/or outcropping sections, six rayed *Discoaster* with a broad central area, resembling *D. druggii* but not typically developed, are usually detected in sediments referred to the Lower Miocene Zone NN2, on the basis of other stratigraphical data, and are indicated as *D.* sp. cf. *druggii*. The presence of *Helicosphaera ampliaperta* usually found from the upper part of Zone NN2, in sample CC27 would support Palmieri's assumption.

Planktonic Foraminifera (Fig. 4; Pl. 35). (J. W. Zachariasse, M. Biolzi, G. Bizon, A. M. Borsetti, F. Cati, M. G. D'Andrea, R. Gelati, J. M. Gonzalez–Donoso, S. Iaccarino, E. Molina & M. Romeo).

Planktonic foraminifera are poorly preserved throughout the section Case Cocuzza. Due to post–burial processes of dissolution and reprecipitation of carbonate most planktonic foraminifera are recrystallized, overgrown or even partially dissolved.

The small average size of the specimens in combination with the poor state of preservation severely hinders a reliable determination of the individual faunal components.

Faunal analyses were initially carried out by M. Romeo who correctly concluded that the stratigraphic range of the section extends from the Oligocene up into the Miocene. Later, some 27 samples, collected during the P/N Boundary meeting on Sicily (1981), were throughly studied by the other participants. Their distribution charts are presented in Fig. 4. Even though most authors refrained from making a total fauna analysis, the scattered distribution of selected taxa along with the great number of questionable determinations readily portrays the poor state of preservation of the planktonic foraminiferal fauna.

During the P/N–meeting held in Malaga (1982), the distribution charts of the Sicilian sections were compared with one another to verify the degree of correspondance in the stratigraphic ranges of biostratigraphically important taxa. In cases discrepancies occurred the true stratigraphic ranges were established through cross–checking the material of individual authors by the whole group. In this way we could reach a consensus on the stratigraphic distribution of selected taxa the result of which is given in the rightmost column of Fig. 4. Selected taxa are figured on Plate 35.

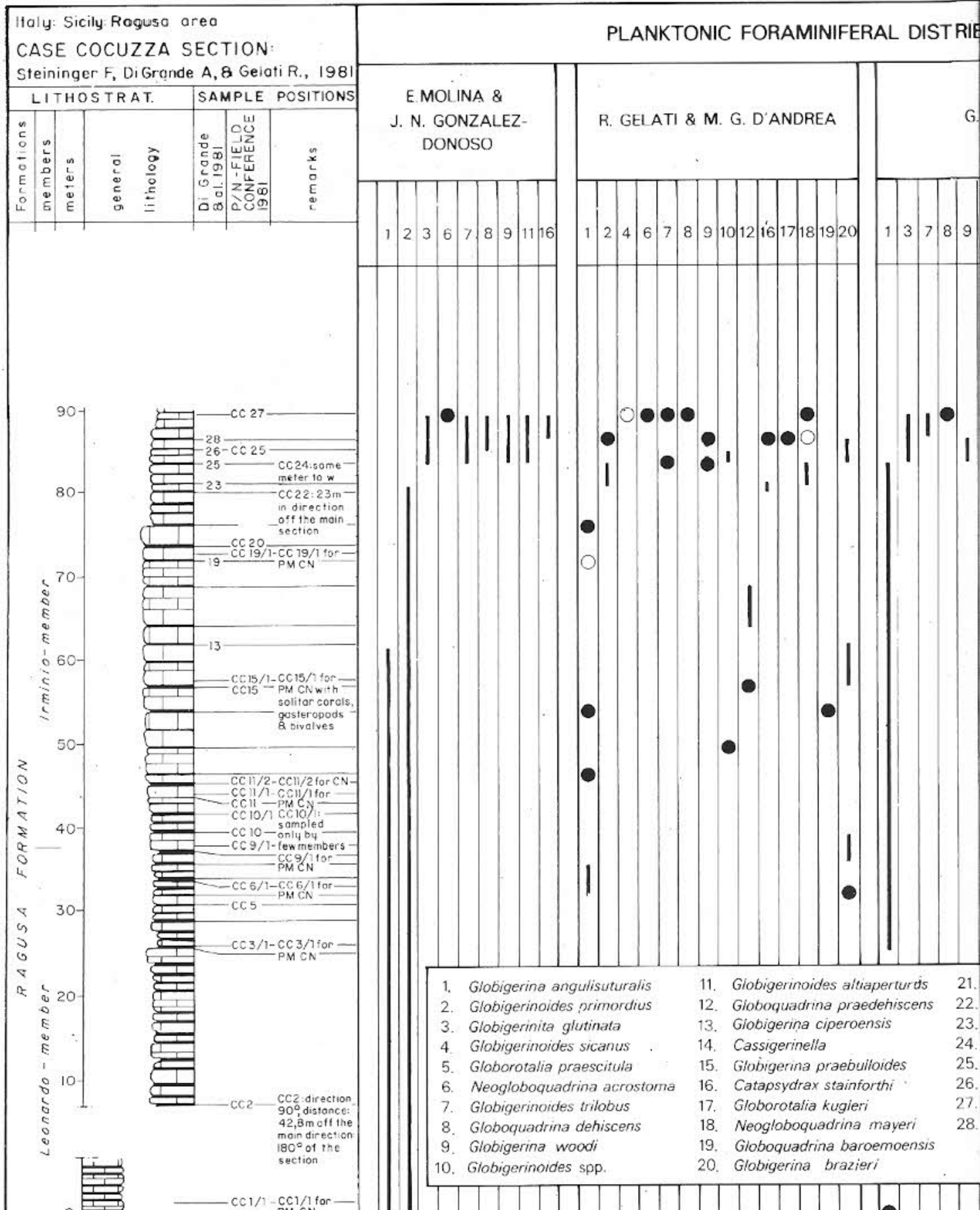
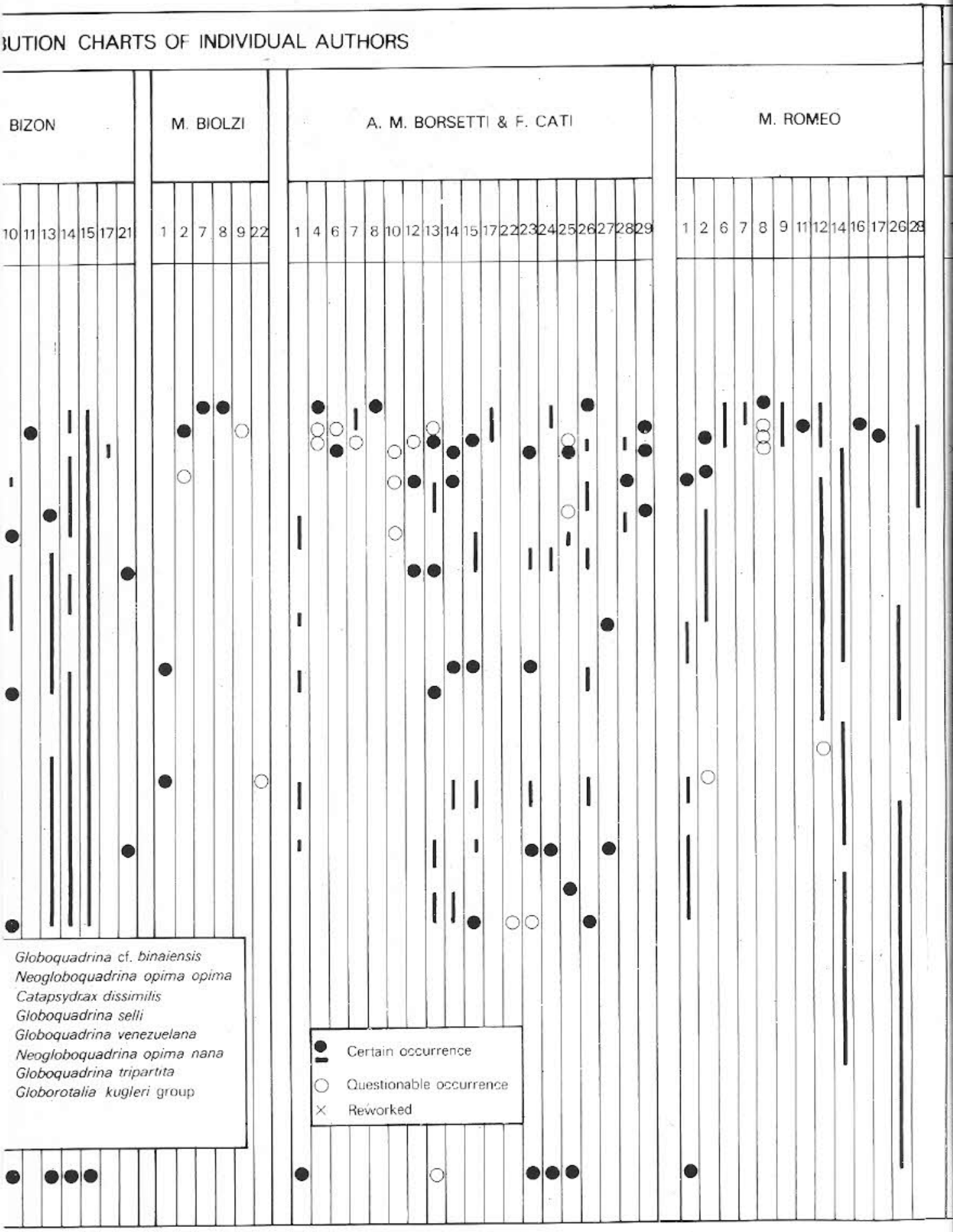
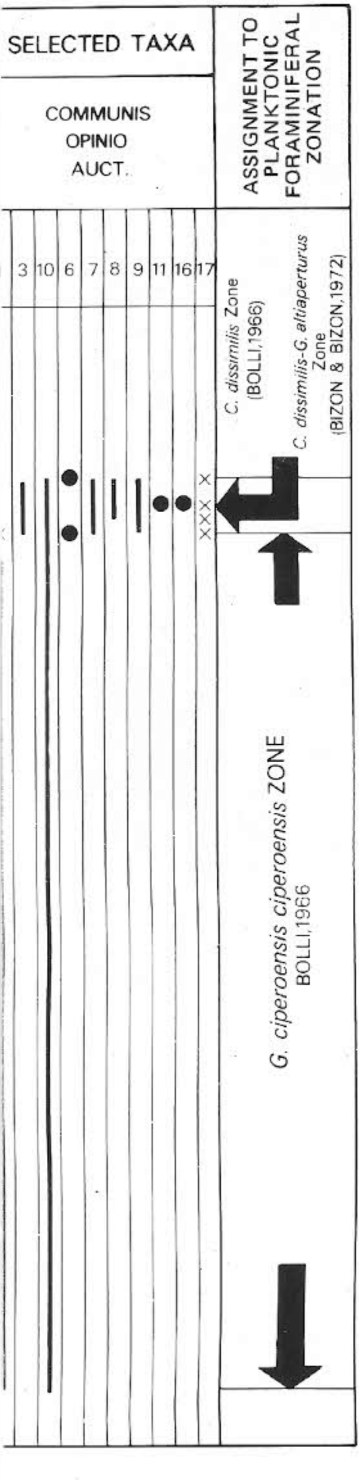


Fig. 4 — Distributio



n of planktonic foraminifera in Case Cocuzza section (Sicily).



SELECTED TAXA
COMMUNIS OPINIO AUCT.
ASSIGNMENT TO PLANKTONIC FORAMINIFERAL ZONATION
3 10 6 7 8 9 11 16 17
C. dissimilis Zone (BOLLI,1966)
C. dissimilis-G. altiaperturus Zone (BIZON & BIZON,1972)
G. ciperoensis ciperoensis ZONE BOLLI,1966

As shown in Fig. 4 representatives of the genus *Globigerinoides* occur throughout the section. The taxa *Globigerinoides quadrilobatus triloba* (Reuss) and *G. altiaperturus* Bolli were differentiated within the group of *Globigerinoides. G. quadrilobatus triloba* is the label strictly used for specimens having (almost) three chambers in the final whorl. Specimens meeting this definition are found by all authors in the interval delimited by the samples CC24 – CC27. *G. altiaperturus* is rarely registered by Molina and Gonzalez–Donoso in samples CC24 – CC27, and by Bizon and Romeo in sample CC26. The general opinion is that typical *G. altiaperturus* occurs only in sample CC26 and that specimens reported from samples CC24, 25, and 27 are either too poorly preserved or have too small a supplementary aperture; they fit in better with the definition of *Globigerinoides parawoodi* (Keller, 1981).

It is to be noted that in all cases the poor preservation hinders a certain discrimination between *G. altiaperturus* and *Globigerina woodi woodi* Jenkins. *G. woodi woodi* is reported by most authors from sample CC24 upwards. Specimens labelled by Gelati and D'Andrea as *Globigerina brazieri* Jenkins in samples CC24 and 25 were considered indistinguishable from specimens assigned here to *G. woodi woodi.* In samples CC15–16, CC9–10, and CC6 these authors used the label *G. brazieri* for specimens considered to be of indefinite taxonomic affinity.

The highest occurrence of *Globigerina angulisuturalis* Bolli is reported by Bizon from CC24. Checking the specimens collected by Bizon confirms the continuous presence of this species up to sample CC24.

Globigerinita glutinata (Egger) is reported only by Molina and Gonzalez–Donoso and by Bizon. These authors find the species from sample CC24 up to CC27.

Globoquadrina dehiscens (Chapman, Parr & Collins) is found by all authors in sample CC27. Its presence in samples CC25 and 26, reported by Molina and Gonzalez–Donoso, is accepted by the other authors. The lowermost stratigraphic occurrence of *Neogloboquadrina acrostoma* (Wezel) is reported by Borsetti and Cati and Romeo from sample level CC24.

Specimens assignable to *Catapsydrax stainforthi* Bolli, Loeblich & Tappan occur sporadically in samples CC26 and 27 (Molina and Gonzalez–Donoso; Romeo).

Representatives of the *Globorotalia kugleri* group (including morphotypes labelled by Blow (1969) as *Globorotalia mendacis* and *G. pseudokugleri*) are extremely rare in the upper part of the section. *G. mendacis* and *G. pseudokugleri* are reported by Borsetti and Cati to occur discontinuously from sample CC20 up to CC26. A few specimens assigned to *Globorotalia kugleri* Bolli are reported by Gelati, D'Andrea, Bizon, Borsetti and Cati, and Romeo from various samples above level CC24.

Finally, some questionable occurrences of *Neogloboquadrina opima opima* (Bolli) were verified and subsequently omitted from the record.

Conclusions. The distribution patterns of the planktonic foraminifera presented in Fig. 4 indicate a discontinuity in the upper part of section Case Cocuzza. A number of taxa, which in continuous sequences have successive first occurrences, abruptly appear at or immediately above sample level CC24.

The (almost) continuous presence of *G. dehiscens, G. quadrilobatus triloba,* and of *G. woodi woodi,* together with the occasional occurrences of *G. altiaperturus* and *C. stainforthi* and the absence of *Globorotalia praescitula* Blow from level CC24 upwards permit us to position this higher interval biostratigraphically within the *C. dissimilis* Zone (Bolli, 1966) or within the lower part of the *C. dissimilis/ G. altiaperturus* Zone of the Mediterranean scheme of Bizon & Bizon (1972). The reported sporadic occurrences of *G. angulisuturalis* in CC24 (Bizon), of *G. ciperoensis* in CC25 (Borsetti and Cati; Romeo), and of the *G. kugleri* group at various levels above CC24 (Bizon; Borsetti and Cati) are considered to be due to reworking.

The association found below level CC24 is characterized by the joint presence of *G. angulisuturalis* and *Globigerinoides* spp. and without *N. opima opima.* It is indicative for the *G. ciperoensis* Zone of Bolli (1966) and Bizon & Bizon (1972).

The analysis of the planktonic foraminifera thus reveals a hiatus in between sample levels CC23 and 24, the extent of which corresponds with one planktonic foraminiferal zone (the *G. kugleri* Zone of Bolli, 1966).

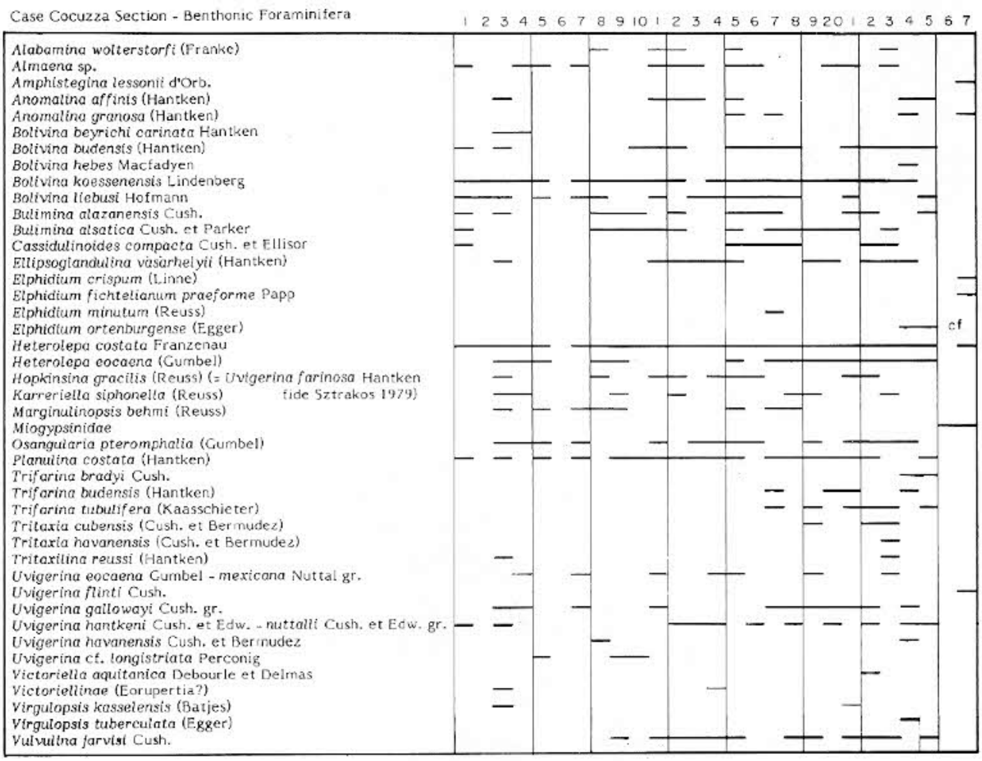


Fig. 5 – Distribution of benthonic foraminifera in Case Cocuzza section.

Benthonic Foraminifera (Fig. 5; Pl. 37–39). (A. Poignant).

Benthonic foraminifera are rather abundant and well preserved in marly levels; they are scarce and badly preserved in calcareous ones.

On the whole, the microfauna mainly contains hyaline species and few agglutinated ones.

Nodosariidae: Lenticulina, Chrysalogonium, Marginulinopsis, Frondicularia, Plectofrondicularia, Vaginulinopsis ... and *Eouvigerinidae: Siphonodosaria, Stilostomella*, are fairly common until sample 25, but their specific assignment is always difficult and most of them do not have any biostratigraphical significance.

The other predominant genera with the largest specific diversity are: *Bolivina, Uvigerina, Trifarina, Elphidium, Heterolepa.*

Many species exist both in Oligocene and Miocene or have a wide stratigraphical range in the Tertiary. The most interesting species for the interpretation of the Oligocene–Miocene boundary belong to *Bolivina, Uvigerina, Hopkinsina, Trifarina, Victoriella, Elphidium, Miogypsina, Heterolepa, Almaena.*

According to some papers, a few species of *Almaena* persist in the Lower Miocene, nevertheless it is a rather Oligocene genus. *Bolivina budensis, B. koessenensis, B. liebusi, Hopkinsina gracilis* are reported from Oligocene. *Trifarina tubulifera*, described in the Eocene of Belgium, is found in the French and Hungarian Oligocene. *Victoriella aquitanica* was described in the Oligocene of southwestern France, *Heterolepa costata* is widespread in Oligocene.

On the contrary, *Bolivina hebes* is reported from Miocene, *Uvigerina flinti* appears in the Miocene of the Po Plain, *Elphidium fichtelianum praeforme* is recorded in the Aquitanian stratotype and in the Miocene of Austria, at last, *Miogypsina* indicates the Miocene.

From these data, it implies that the boundary could be placed approximately towards samples CC24–25.

With regard to the paleobathymetry, in the lower and middle part of the section, the presence of *Victoriellinae* in three samples, the relative abundance of *Almaena*, the lesser number of *Pullenia, Pleurostomella*, the absence of *Oridorsalis. Cibicidoides, Nodosarella*, suggest a sea–depth of about 100–200 m. In the upper part of the section, *Miogypsina, Elphidium, Amphistegina* point to shallow deposition with sea–depth probably not exceeding 50 m.

Biostratigraphy of Case Cocuzza section (Fig. 6). (M. Romeo).

The stratigraphic distribution of some selected taxa of planktonic and benthonic foraminifera as well as calcareous nannoplankton species has been studied by several specialists of the «Working Group on the Palaeogene/Neogene Boundary» and are plotted here in a tentative correlation chart to evaluate the biostratigraphic correlation for the Case Cocuzza section (Fig. 6.).

The uppermost Oligocene level, characterized by the last occurrence of *Globigerina angulisuturalis*, falls within sample position CC23 and is recognized as the *G. ciperoensis ciperoensis* Zone (Bolli, 1966). Within the same sample the last occurrence of *Helicosphaera recta, Zygrhablithus bijugatus* and *Sphenolithus ciperoensis* was recorded in this section; all these taxa are limited to the calcareous nannoplankton Zone NP25 of Martini (1971).

Several meters above this, at sample position CC24 and CC25, the last occurrence of *Bolivina koessenensis, Hopkinsina gracilis* and other taxa typical for Oligocene benthonic foraminifera associations were recovered.

The following–higher–interval of the section – sample position CC24 – is characterized by the presence of *Globigerinoides quadrilobatus triloba, Globigerina woodi woodi, Globoquadrina dehiscens* together with *Catapsydrax stainforthi* and *G. altiapertus*. This fauna allows the recognition of the *Catapsydrax dissimilis* Zone of Bolli (1966) or the lower part of the *C. dissimilis / G. altiaperturus* Zone of Bizon & Bizon (1972). This result is in good agreement with the observed occurrence of the calcareous nannoplankton *Discoaster* cf. *druggii* and *Helicosphaera ampliaperta*, taxa reported in general from the NN2 Zone interval of Martini (1971).

This foraminiferal and nannoplankton record revealed a major discontinuity of this section across the Palaeogene / Neogene boundary. The entire *G. kugleri* Zone of Bolli (1966) seems to be missing, as is the larger part of nannoplankton Zone NN1. This result cannot be controlled using the benthonic foraminifera record, since *Uvigerina flinti, Elphidium fichtelianum praeforme* and *Miogypsina* sp. are significant Miocene taxa and indicate an Aquitanian age only.

This sedimentation gap between sample position CC23 and CC24/25, detected by planktonic foraminifera and calcareous nannoplankton associations only, is situated in the uppermost part of the «Livello a banchi calcarenitici» and could be the reason for the absence of an entire planktonic foraminifera zone – the «*G. kugleri* Zone» – straddling the Palaeogene/Neogene boundary.

The analysis of the Case Cocuzza section within the wider Iblean area revealed a major discontinuity covering the interval between the Oligocene/Miocene boundary and reaching up into the Burdigalian. This phenomenon was already noticed elsewhere, in several other sections studied in detail as potential Palaeogene/Neogene boundary stratotype sections (Cati et al., 1981; Borsetti et al., 1983).

This general conclusion is supported further by the paleobathymetric study carried out by A. Poignant on the benthonic foraminifera of this section. A. Poignant reconstructed a basin evolution from the upper epibathyal zone at a paleodepth of about 100 to 200 meters during Oligocene time, decreasing to about 50 meters into the inner neritic zone in the Early Miocene part of the section (Wright, 1978).

The hiatus recognized in the Oligocene/Miocene transitional part of the «Irminio member» of the «Ragusa formation» (Rigo & Barbieri, 1959), identified as «Livello a banchi calcarenitici» by Di Grande & Grasso (1977) is probably due to a sedimentation gap in the course of an emersion of the entire Iblean area beginning in the Upper Oligocene and lasting until the Early Miocene.

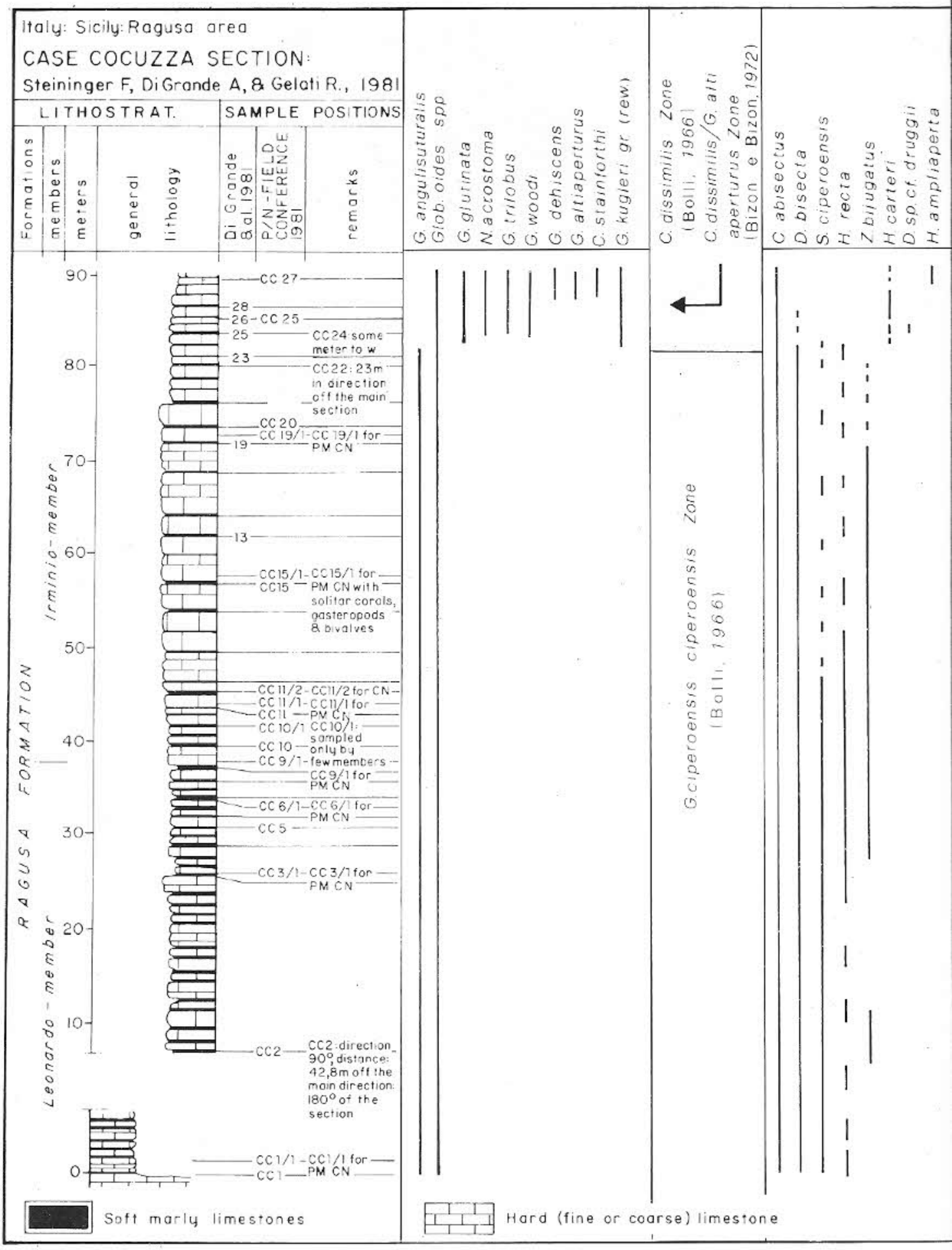
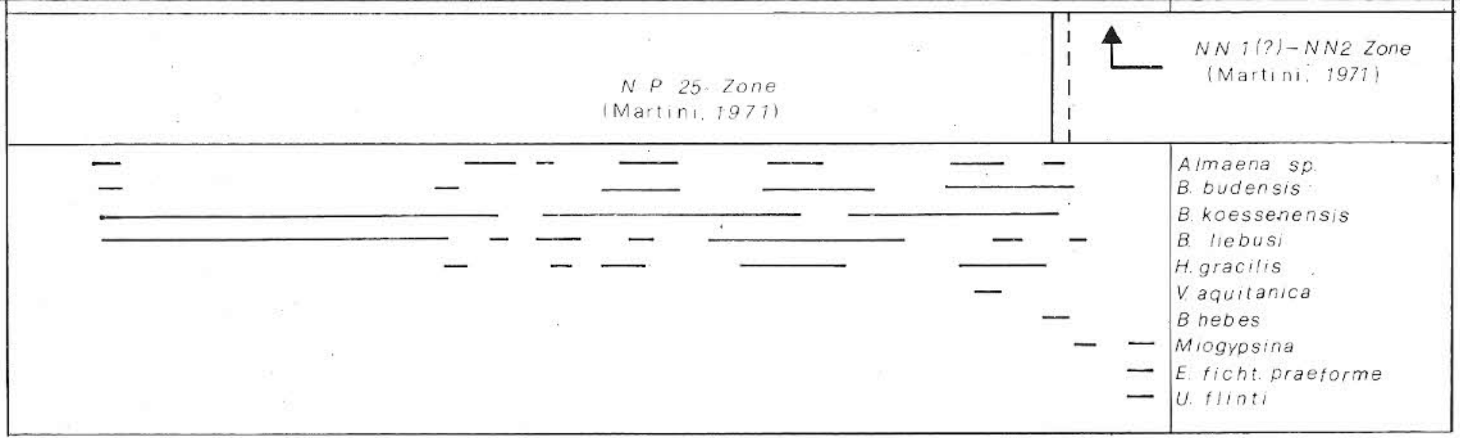


Fig. 6 — Biostratigraphy of Case Cocuzza section.



N P 25- Zone
(Martini, 1971)
NN 1(?)–NN2 Zone
(Martini, 1971)
Almaena sp.
B. budensis
B. koessenensis
B. liebusi
H. gracilis
V. aquitanica
B. hebes
Miogypsina
E. ficht. praeforme
U. flinti

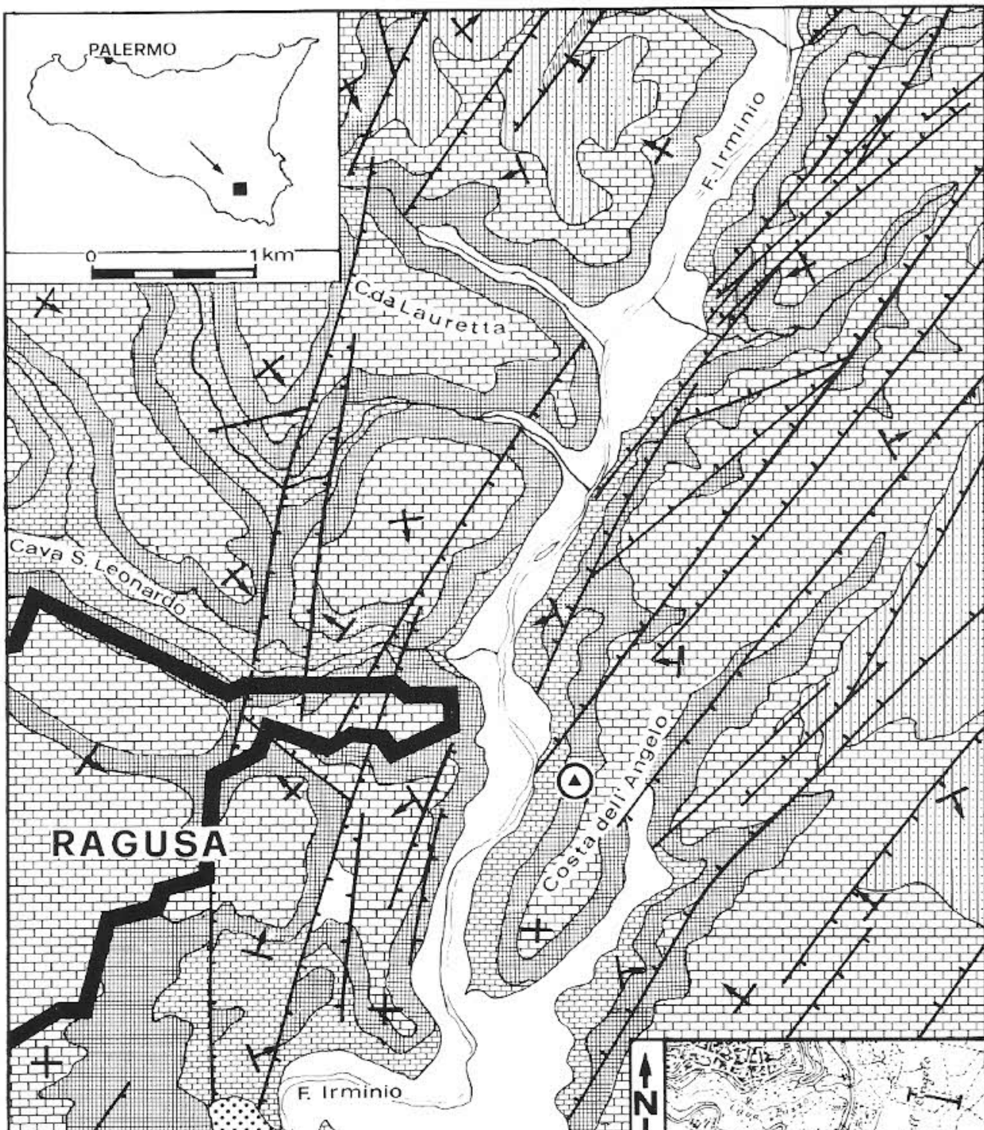


Fig. 7 — Geological map of the Costa dell'Angelo area.
1) Alternating marls and calcarenites (Ragusa Fm. - Leonardo Mb.). 2) Massive bedded calcarenite level (Ragusa Fm. - Irminio Mb.). 3) Alternating marls and calcarenites (Ragusa Fm. - Irminio Mb.). 4) Alternating calcarenites and marls (Tellaro Fm.). 5) Whitish marls (Tellaro Fm.). 6) Recent and actual alluvium. 7) Fault. 8) Section.

The Costa dell'Angelo Section.

Location and lithology (Fig. 7, 8). (A. Di Grande & M. Romeo).

Location (Fig. 7). According to I.G.M. official cartography this section is in the central–southern part of the Ragusa quadrangle (F. 276, I NO), 0.5 km to the east of Ragusa Ibla, and has the following coordinates: long. (Rome M. Mario) 2°·18' 20", lat. 36° 55' 30". The section has been sampled along the left side of the Irminio River valley starting from the confluence with the Cava S. Leonardo valley at 502 m a.s.l. down to about 350 m a.s.l.

Lithologic sequence (Fig. 8). The section has been wholly sampled within the Ragusa Fm. which lies almost horizontally, dips gently to the E, and is cut by a dense pattern of tensional faults, mainly trending in a NE–SW direction; occasionally different and variable dips are found.

The sampled section is 152 m thick and the lithologic sequence is composed of hard, fine or coarse–grained calcarenites and soft marls.

Three intervals can be recognized based on the manner in which the above–mentioned lithologic types are associated.

In the lowest interval hard, fine–grained, whitish calcarenites in 20–40 cm thick layers regularly alternate with thinner layers of soft whitish marls. Hard calcarenite beds up to 1.5 m in thickness and brown cherty nodules are

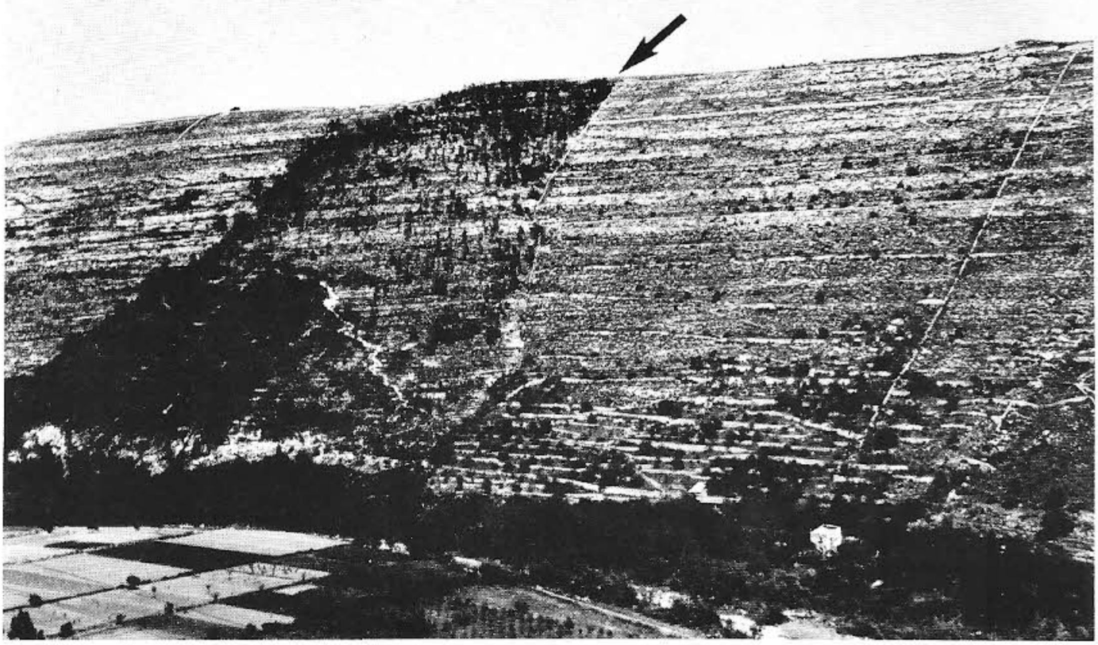


Fig. 8 – View of the Costa dell'Angelo section; the arrows indicate the top and the bottom.

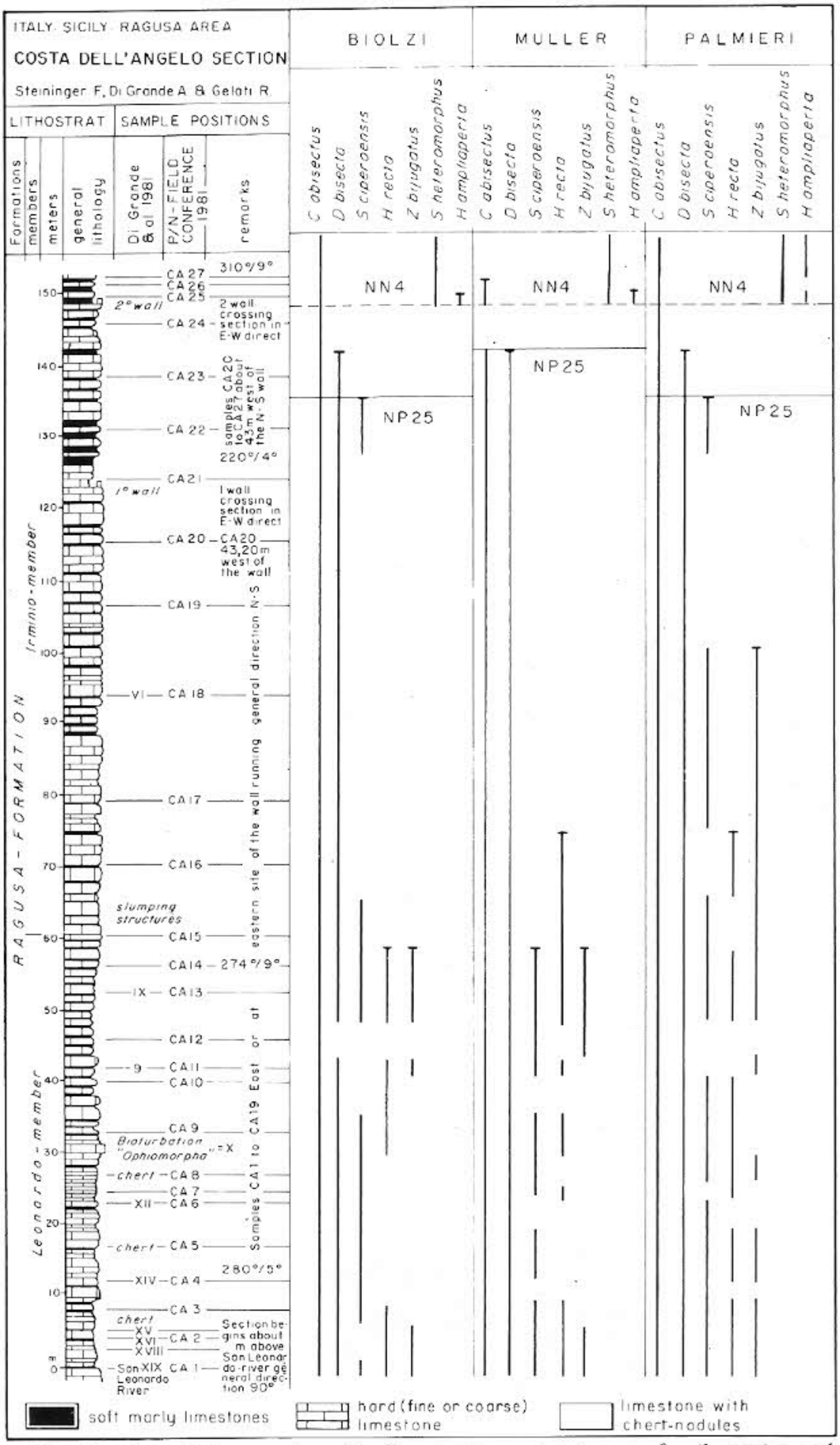


Fig. 9 – Distribution of the stratigraphically most important nannofossil species and biostratigraphic zonations (Martini, 1971) proposed by each author in Costa dell'Angelo section.

also found at its bottom. This interval corresponds with the upper part of the Leonardo Mb. (Ragusa Fm.).

The middle interval consists of hard calcarenite beds, grading upward from fine–to coarse–grained interlayered with lenticular bodies of sandy marls or with alternating layers of calcarenites and sandy marls. Each of the beds, at times showing slumping structures, has a variable thickness of up to 20 m laterally; three of such beds have been observed along the surveyed section. The interval corresponds with the lower part of the Irminio Mb.

The highest interval is 6.6 m thick entirely and is made up of hard, coarse-grained yellowish calcarenite layers 20–60 cm thick and of yellowish, relatively hard sandy marls in layers of the same thickness. This interval is distinct from the lowest one because the marl layers are thicker, harder and coarser–grained; it corresponds with the top of the Irminio member.

Calcareous Nannoplankton (Fig. 9; Pl. 34). (M. Biolzi, C. Mueller & G. Palmieri).

The calcareous nannofossils present in the Costa dell'Angelo section strongly vary in abundance and preservation. In the lower part of the sequence up to sample CA15, the change is mainly related to recristallization and fragmentation due to diagenesis, which is expecially strong in the carbonate rich layers. Nannofossils are rare in samples CA16 to CA20, and become more common again in samples CA21 to CA23. In sample CA24 they are almost absent and in samples CA25 to CA27 are very rare.

The assemblages are generally of low diversity: *Dictyococcites bisecta, Cyclicargolithus abisectus, C. floridanus, Coccolithus pelagicus* and *Sphenolithus moriformis* are the most common species throughout the section. In Fig. 9 the biostratigraphic zonations proposed by the different authors and the distribution of the stratigraphically most important species (see: In Search of the Palaeogene/Neogene Boundary Stratotype, part 1) are given.

All three authors assigned the sequence from the bottom up to sample CA22 to the Late Oligocene *Sphenolithus ciperoensis* Zone (NP25 of Martini zonation, 1971). At this level, coinciding with the highest occurrence of *Sphenolithus ciperoensis* Biolzi and Palmieri traced the upper boundary of zone NP25. Mueller used *Dictyococcites bisecta* (= *dictyodus*) as index fossil (she didn't detect any *Sphenolithus ciperoensis* higher than sample CA14), therefore she placed the same boundary one sample higher, between CA23 and CA24. Actually, *Dictyococcites bisecta* has a continuous distribution, whereas *Sphenolithus ciperoensis*, common up to sample CA14, becomes rare and discontinuous in the upper part of its range. However, since its determination is doubtless (see Pl. 34, fig. 16) and since its highest occurrence level, slightly lower than the level of extinction of *Dictyococcites bisecta*, is tipical, *Sphenolithus ciperoensis* is here considered a reliable marker of the upper boundary of Zone NP25. *Helicosphaera recta* and *Zygrhablithus bijugatus* are useless for the definition of the Oligocene/Miocene boundary in the Costa dell'Angelo section because they have their highest occurrence in levels far lower (somewhere be-

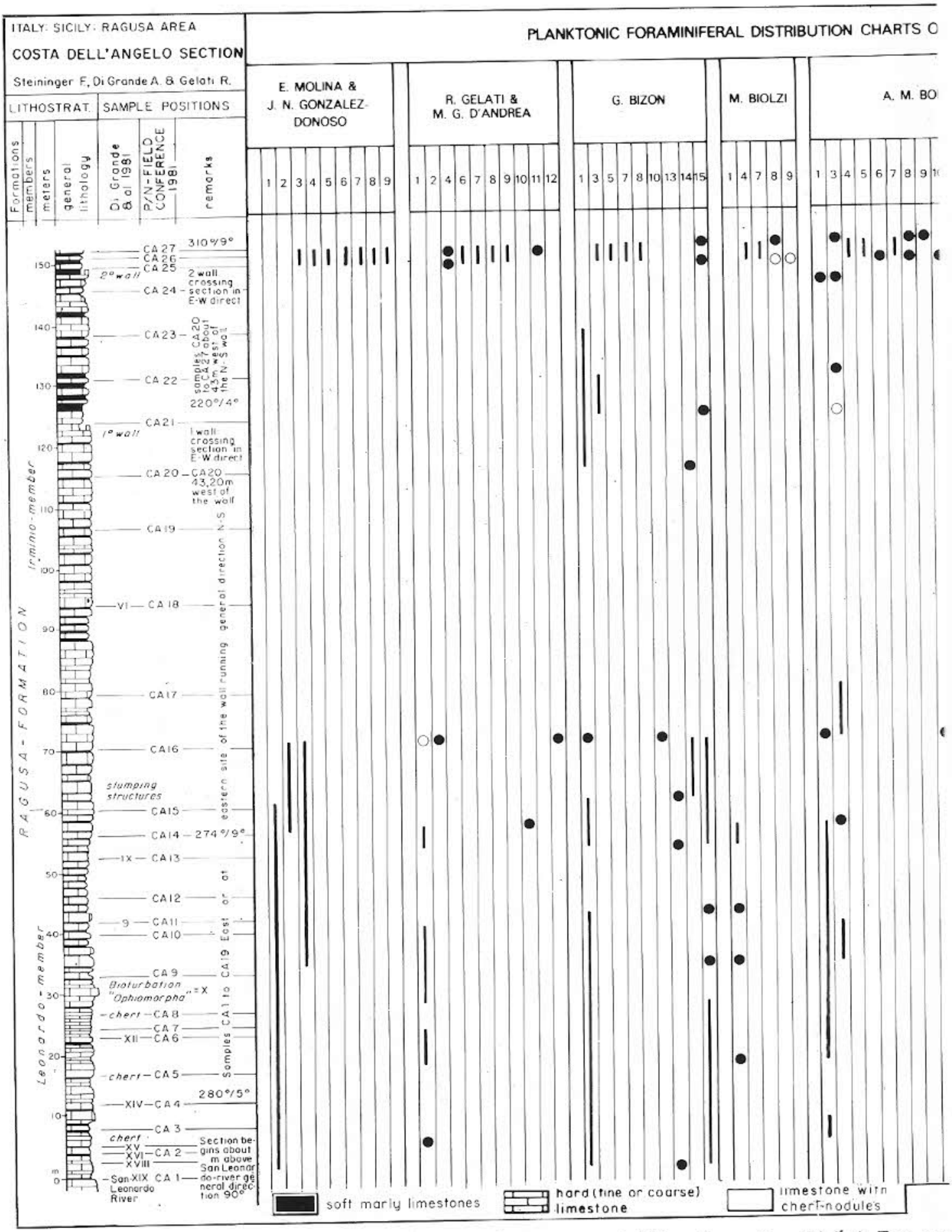
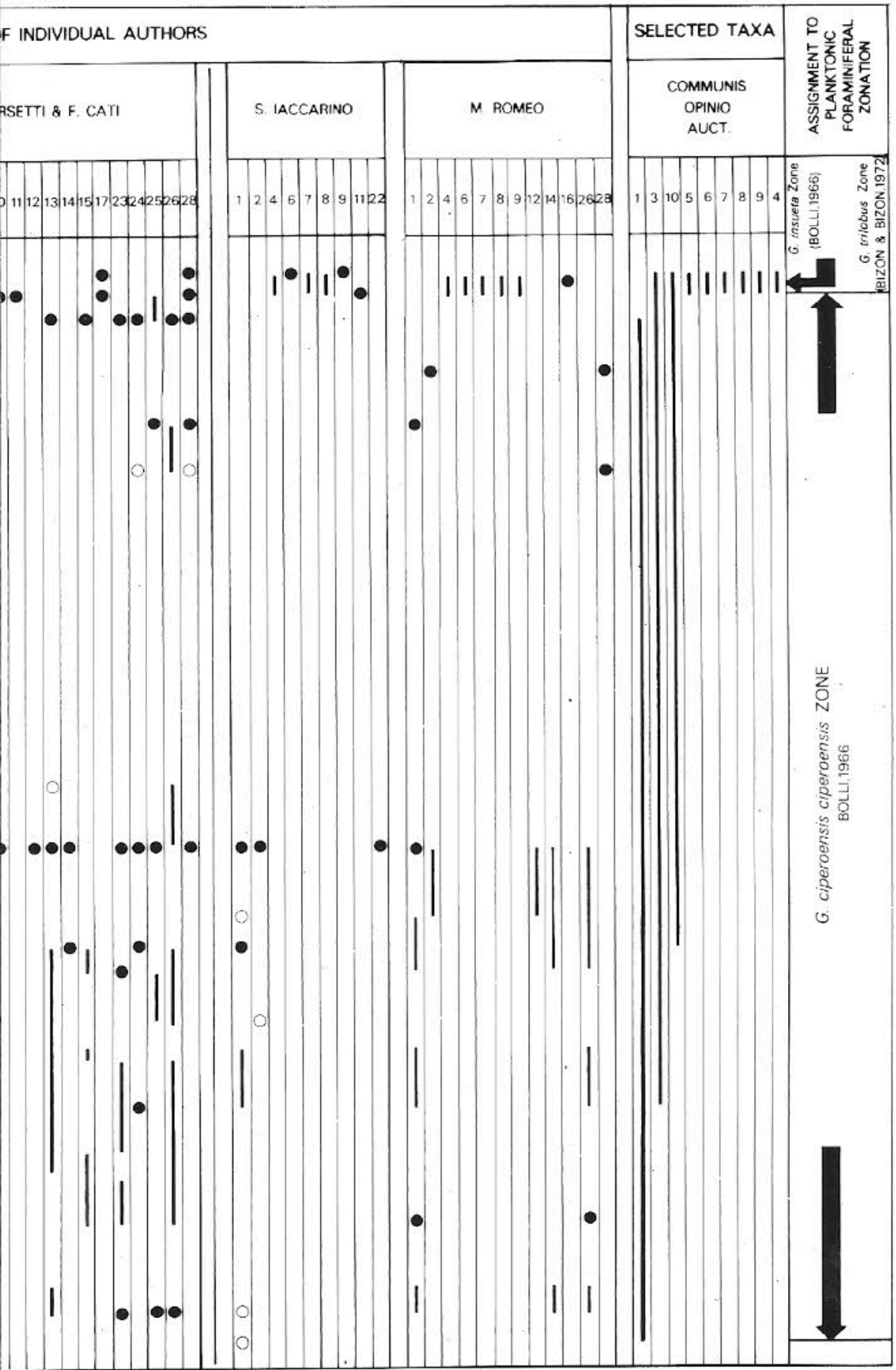


Fig. 10 – Distribution of planktonic foraminifera in Costa dell'Angelo section (Sicily). For exp



lanation of arabic numerals, solid lines, open (closed) circles, see caption Fig. 4.

tween 47 m and 82 m, according to the different authors) than those of *Sphenolithus ciperoensis* and *Dictyococcites bisecta*. No age determination was possible for sample CA24, because of the scarsity of nannofossils. The presence of *Sphenolithus heteromorphus* and *Helicosphaera ampliaperta* in sample CA25 assignes this sample to the *Helicosphaera ampliaperta* Zone (NN4). The last occurrence of *Helicosphaera ampliaperta* would actually define the boundary between NN4 and NN5, however, because of the absence of other significant species and because one of the authors detected *Helicosphaera ampliaperta* also in sample CA27, it seems better to assigne the upper part of the sequence from sample CA25 to the Early Miocene Zone NN4.

A hiatus representing about 5 million years exists between samples CA23 and CA25.

Very few Eocene reworked species have been observed.

Planktonic Foraminifera (Fig. 10; Pl. 36). (J. W. Zachariasse, M. Biolzi, G. Bizon, A. M. Borsetti, F. Cati, M. G. D'Andrea, R. Gelati, J. M. Gonzalez–Donoso, S. Iaccarino, E. Molina & M. Romeo).

The state of preservation and the overall aspect of the planktonic foraminiferal fauna in section Costa dell'Angelo is similar to that reported from section Case Cocuzza.

The pilot study of M. Romeo, demonstrated the Oligo–Miocene age of the section. Late, some 27 samples were studied by the working group the results of which are presented in Fig. 10. Following the procedure described earlier, the general opinion on the stratigraphic ranges of selected taxa is given in the rightmost column of Fig. 10. Selected taxa are figured on Plate 36.

The poor state of preservation of the planktonic foraminiferal associations is accentuated by the extreme poverty of data in the middle/upper part of the section. Thanks to the perseverance of some authors we could ascertain a definite turn–over in the planktonic foraminiferal composition in the upper part of the section.

From sample level CA25 upwards, all authors reported various occurrences of *Globigerinoides quadrilobatus triloba* (Reuss), *Globoquadrina dehiscens* (Chapman, Parr & Collins), and *Globigerina woodi woodi* Jenkins. In addition, most authors registered *Neogloboquadrina acrostoma* (Wezel), while some authors (Molina and Gonzalez–Donoso; Bizon; Borsetti and Cati) documented the presence of *Globorotalia praescitula* Blow.

A lengthy discussion was held on the taxonomic status of specimens labelled as *Globigerinoides sicanus* De Stefani by Molina and Gonzalez–Donoso, Gelati and D'Andrea, Biolzi, Borsetti and Cati, and Romeo. The final conclusion was that these forms are indistinguishable from *G. sicanus* and consequently we added the label *G. sicanus* in the combined distribution chart of Fig. 10.

With respect to *Globigerinoides altiaperturus* Bolli no consensus could be reached. The specimens collected by Gelati and D'Andrea from sample CA26, and by Borsetti and Cati from CA25 did not allow a certain determination.

None of the taxa listed above was found below level CA25. The most characteristic element in the associations from below CA25 is *Globigerina angulisuturalis* Bolli the highest occurrence of which has been fixed at sample level CA24. Up to the same sample level scattered occurrences of *Globigerina ciperoensis* Bolli are reported by Bizon and by Borsetti and Cati.

Although some authors collected a few specimens which were questionable assigned to *Neogloboquadrina opima opima* (Bolli) they did not meet sufficiently well the operational definition.

The lowermost stratigraphic occurrence of the genus *Globigerinoides* could be fixed at sample level CA14.

Conclusions. The distribution patterns of planktonic foraminiferal taxa in section Costa dell'Angelo undoubtly indicate the presence of a prominent discontinuity in the upper part of the section.

The occurrence of *G. sicanus* and *G. praescitula* in the interval delimited by the samples CA25 – CA27 indicates that this part of the section can be correlated with the upper part of the *G. insueta* Zone of Bolli (1966) and with the upper part of the *G. trilobus* Zone of Bizon & Bizon (1972). The interval below sample level CA25 is attributable to the *G. ciperoensis* Zone of Bolli (1966) and of Bizon & Bizon (1972).

Hence a hiatus is present in our record in between sample levels CA24 and CA25 the extent of which is greater than in section Case Cocuzza.

Benthonic Foraminifera (Fig. 11; Pl. 37–39). (A. Poignant).

The benthonic foraminiferal assemblage is not essentially different from that of the Case Cocuzza section; it is, however, a little less abundant and diversified.

As in Case Cocuzza, calcareous hyaline species are predominant and agglutinated ones rather scarce. *Nodosariidae* and *Eouvigerinidae* are numerous. The other predominant genera are the same as in the Case Cocuzza section.

The species apparently most interesting for the biostratigraphy belong to the genera: *Bolivina, Rectobolivina, Hopkinsina, Discorbinella, Elphidium, Coryphostoma* and *Almaena.*

Almaena is mainly an Oligocene genus: *Bolivina budensis, B. koessenensis, B. liebusi, Rectobolivina costifera* and *Hopkinsina gracilis* are reported from the Oligocene.

Bolivina miocenica and *Elphidium fichtelianum praeforme* are recorded in the Miocene. *Coryphostoma* sp. is found in the Lower Miocene of southwestern France and *Discorbinella bertheloti* in the French Burdigalian.

The boundary between the Oligocene and Miocene is not obvious because the last levels are highly calcareous marls and contain a poor and badly preserved fauna.

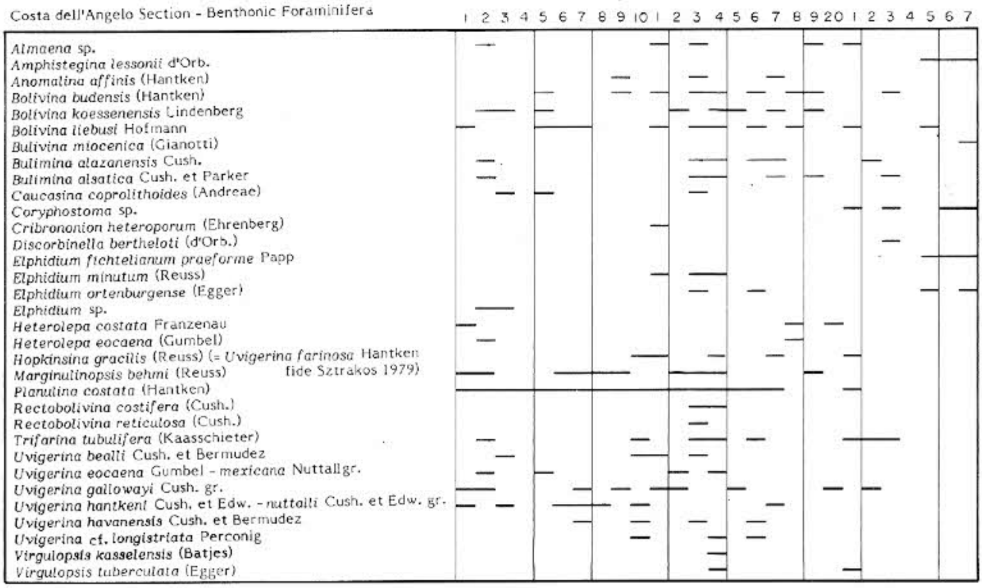


Fig. 11 — Distribution of benthonic foraminifera of Costa dell'Angelo section.

Because according to the AGIP book *Bolivina miocenica* appears in the Langhian, certain levels in the Lower Miocene are possibly missing.

As far as paleobathymetry is concerned, representatives of *Almaena* and *Elphidium* in most of this section and similarly in the Case Cocuzza section, as well as the absence or scarcity of genera such as *Oridorsalis, Cibicidoides, Nodosarella, Pullenia, Pleurostomella* indicates a depth similar to that in Case Cocuzza, i. e. 100 to 200 m. The top levels of the section point to a decreasing depth of deposition approaching 50 m.

Compared with the sections of the Piedmont (Lemme) and Marche regions (Ca' Fusconi, Montebello D'Urbino, Casa di Tosi), the Sicilian sections are not as rich in benthonic foraminifera. In the Lemme section the richest nearly 120 species belonging to 62 genera were found, while in Case Cocuzza only 64 species and 43 genera were recorded. On the whole, foraminifera are better preserved in the Sicilian sections.

In general, the depth of the Sicilian deposits is lower than in northern Italy as indicated by the lack of both agglutinated species (*Karreriella, Tritaxilina, Eggerella, Dorothia, Martinottiella*) and *Oridorsalis, Cibicidoides, Nodosarella,* the presence of *Almaena, Elphidium* and *Victoriella,* and in the upper levels numerous *Elphidium, Miogypsina* and *Amphistegina.*

Biostratigraphy of Costa dell'Angelo section (Fig. 12). (**M. Romeo**).

The stratigraphic distribution of some selected taxa of planktonic and benthonic foraminiera as well as calcareous nannoplankton species has been studied by several specialists of the Palaeogene Neogene Boundary Working Group and are plotted here in a tentative correlation chart (Fig. 12).

The larger part of the section belongs to the Late Oligocene since *G. angulisuturalis* is present up to sample CA24. This entire interval of the section therefore can be correlated to the *G. ciperoensis* Zone of Bolli (1966). The uppermost occurrence of *Sphenolithus ciperoensis* and *Dictyococcites bisecta*, indicative for the calcareous nannoplankton Zone NP25 of Martini (1971), was recorded slightly lower in sample CA22 or CA23. Towards sample CA23 the latest occurrence of *Bolivina budensis, B. liebusi, Rectobolivina costifera* and *Hopkinsina gracilis* also indicates the Late Oligocene age of this part of the section.

A sudden faunistic change is recognized at sample position CA25 by the occurrence of *G. sicanus* and *G. praescitula* along with *G. quadrilobatus triloba, G. dehiscens* and *G. woodi woodi*. This association is typical for the *G. insueta* Zone of Bolli (1966) and the uppermost part of the *G. trilobus* Zone in the Mediterranean biostratigraphic zonation of Bizon & Bizon (1972). Together with these planktonic indicators we can follow the appearance of *Sphenolithus heteromorphus* and *Helicosphaera ampliaperta*, indicative of nannoplankton Zone NN4 of Martini (1971).

This major hiatus between sample CA23/24 and CA25 stretches over a time interval of approximately 7 million years and contains the plankton foraminifera zones *G. kugleri* – *C. dissimilis* – *C. stainforthi* – and part of the *G. insueta* Zone in the zonation of Bolli (1966) or the *G. kugleri* – *G. primordius* – *C. dissimilis/G. altiaperturus* – and the lower part of the *G. trilobus* – zones in the Mediterranean zonation scheme of Bizon & Bizon (1972). In terms of calcareous nannoplankton zonation, parts of the NP25 – NN1 – NN2 – NN3 and even parts of the NN4 Zone in terms of Martini's (1971) zonation are missing. Benthonic foraminifera indicate that the Aquitanian and nearly the entire Burdigalian is missing in this section.

This major hiatus in the Costa dell'Angelo section must be seen in connection with the evolution of entire Iblean area and is again recorded in the «Irminio member» of the « Ragusa formation» in the uppermost beds of the so–called «Livello a banchi calcarenitici» (Di Grande & Grasso, 1977). The sedimentation gap may be due to a complete emersion of the area. The benthonic foraminifera record at least again points to a paleodepth evolution of the area similar to that recorded in the Case Cocuzza section.

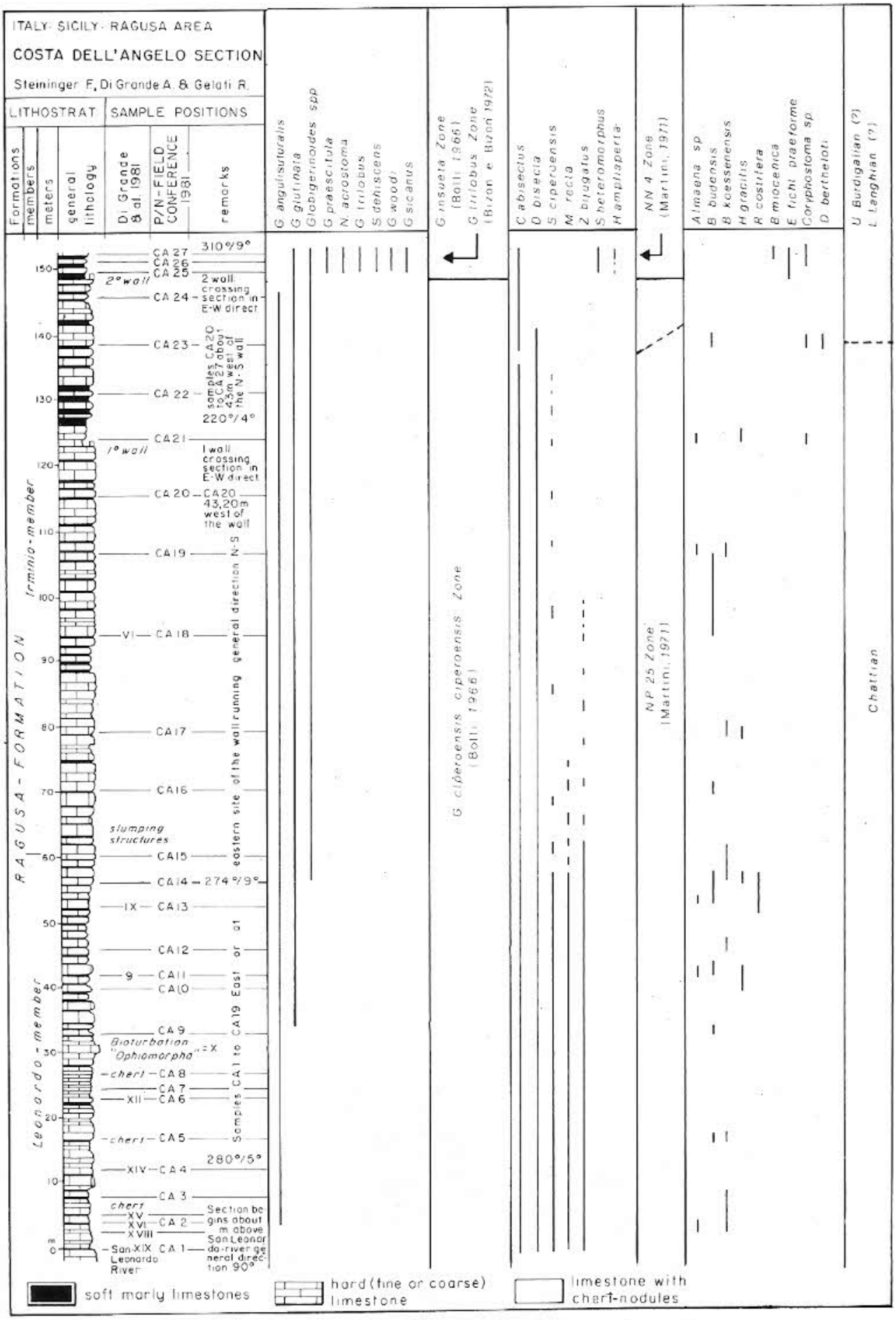
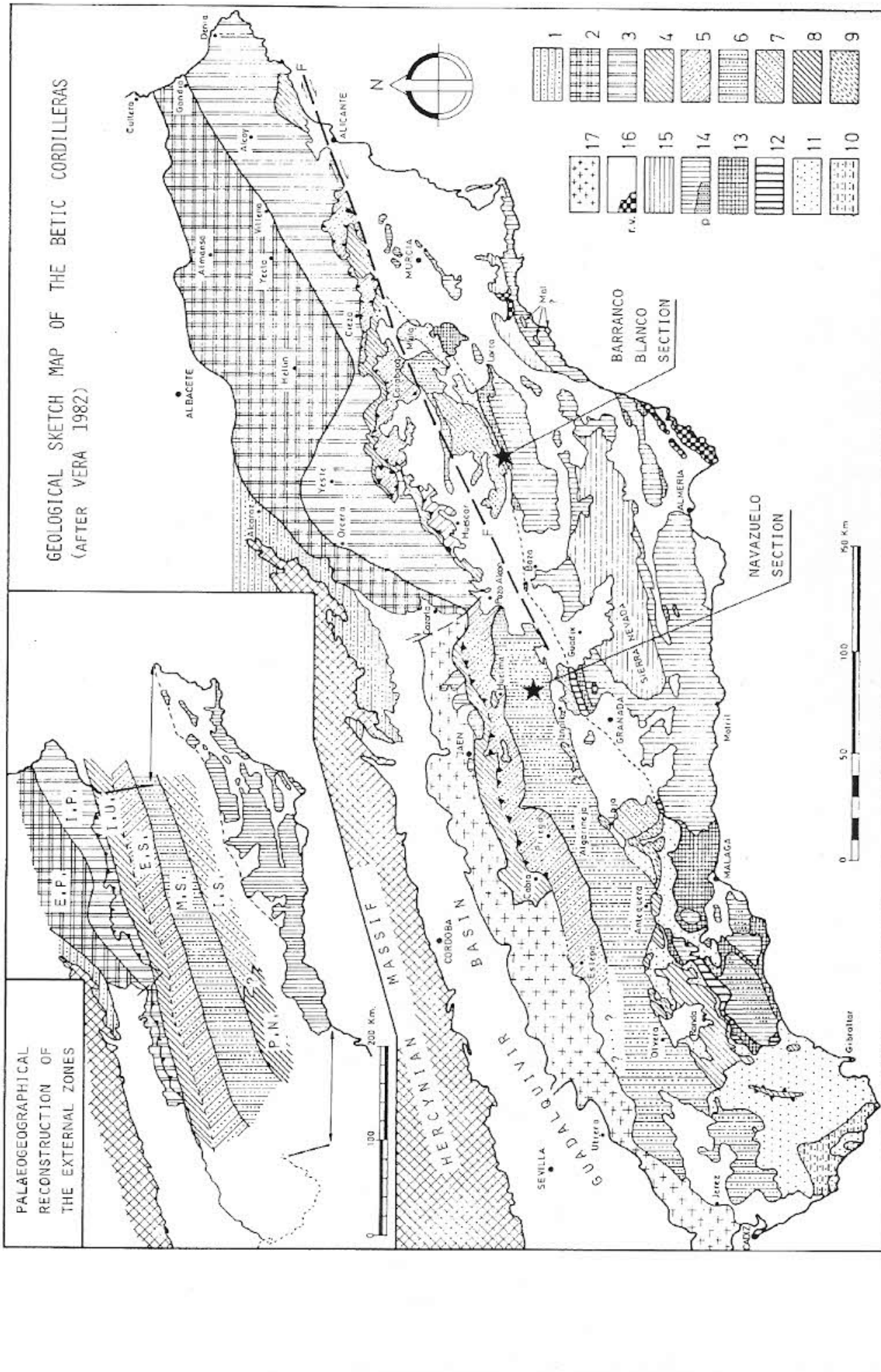


Fig. 12 – Biostratigraphy of Costa dell'Angelo section.


GEOLOGICAL SKETCH MAP OF THE BETIC CORDILLERAS
(AFTER VERA 1982)
PALAEOGEOGRAPHICAL RECONSTRUCTION OF THE EXTERNAL ZONES
E.P.
I.P.
I.U.
E.S.
M.S.
I.S.
P.N.
200 Km.
100
0
HERCYNIAN MASSIF
GUADALQUIVIR BASIN
BARRANCO BLANCO SECTION
NAVAZUELO SECTION
SIERRA NEVADA
N
F
ALBACETE
ALICANTE
MURCIA
ALMERIA
GRANADA
JAEN
CORDOBA
SEVILLA
MALAGA
CADIZ
Gibraltar
Jerez
Utrera
Estepa
Antequera
Cabra
Priego
Guadix
Baza
Huescar
Orcera
Yeste
Hellin
Cieza
Yecla
Villena
Almansa
Alcoy
Gandia
Cullera
Denia
Lorca
Mula
Caravaca
Alcaraz
Motril
Loja
Olvera
Ronda
Alcala la Real
Pozo Alcon
Cazorla
Huelma
Iznalloz
Algarinejo
Mol
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SPAIN: BETIC CORDILLERAS

Abstract. Two sections proposed as Palaeogene/Neogene Boundary stratotype have been studied in the Betic Cordilleras. The distribution of selected calcareous nannoplankton, planktonic and benthonic foraminifera taxa has been studied.

The Navazuelo section reaches up into the *Globorotalia kugleri* Zone; however the boundary to the *Globigerina ciperoensis* Zone is debatable and the *Catapsydrax dissimilis* Zone is not reached. In the Barranco Blanco section the *Globigerina ciperoensis* and *Globorotalia kugleri* zonal boundary is also unclear; the *Catapsydrax dissimilis* Zone is reached but the boundary to the *Globorotalia kugleri* Zone is represented by a hiatus, respectively a tectonic contact. The section itself is heavy tectonized.

Both sections are not suitable to serve as a Palaeogene/Neogene Boundary stratotype.

General Geology (Fig. 13). (J.M. Gonzalez–Donoso, D. Linares, E. Molina & F. Serrano).

Betic Cordilleras are the furthest west mountain systems of the european alpine chains. They range all along S and SE of the Iberian Peninsula, with a WSW–ENE general direction; they are bounded northwards, from W to E, by the Guadalquivir Basin, the tabular cover of the Hercynian massif in the Meseta and the Iberic Cordillera. They extend along 600 km with a variable width of about some 200 km.

In short, it can be said that the Betic Cordilleras are composed of a series of superimposed overthrusts dipping towards the north foreland, that is, the Meseta. Generally, the importance of folding decreases from S to N, so that in the septentrional realm (prebetic) overthrusts cannot be individualized:

Several geographical units can be identified from S – to N:

a) Internal Zones (or Betic Zone s. str.), characterised by the presence of overthrusts affecting basement and cover. Within these units three superimposed tectonic complexes, composed on the whole of overthrusts, can be distinguished: Nevado–Filabride, Alpujárride and Maláguide; the first two are formed by paleozoic and triassic–metamorphic materials, whereas the third

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Fig. 13 – Geological sketch map of the Betic Cordilleras (after Vera, 1982): 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) Ultrainternal 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) Maláguide; 14) Alpujárride (p: peridotites); 15) Nevado–Filabride; 16) Upper Miocene–Pliocene–Quaternary (r. v.: volcanic rocks); 17) Guadalquivir allochthonous units (Olisthostromes of Subbetic origin inside Miocene materials).

In the Paleogeographic reconstruction: E. P.: External Prebetic; I. P.: Internal Prebetic; I. U.: Intermediate Units; E. S.: External Subbetic; M. S.: Median Subbetic; S. I.: Internal Subbetic; P. N.: Penibetic.

one is formed by little or non–metamorphic paleozoic and triassic materials as well as post–triassic sedimentary materials. Furthermore, a fourth unit can be locally identified: Betic dorsal unit or Rondaide, formed by sedimentary materials of Permian and more recent age.

Internal Zones actually display some difficult problems, mainly those concerning their former relative paleogeographic positions occupied by the different tectonic complexes integrating them before their actual arrangement; there exists, however, some agreement on the fact that they could be part of a microplate (Alborán), situated much to the E of its actual position.

b) External Zones, characterized by a basement, probable continuation of the Hercynian massif of the Meseta, not affected by the alpine overthrusts and not cropping out; a Triassic unit which acts as detaching level and a sedimentary, mesozoic and cenozoic cover, except a few and localized volcanic interbeddings.

Within the External Zones two major units can be distinguished: an autochthonous or parautochthonous Prebetic at north, formed by off–shore platform and even subaerial environment materials and Subbetic overthrusting the former, further south and formed by pelagic materials from the Carixian. The so called intermediate units can be paleogeographically and tectonically inserted between these two major units.

Each of the major units, Prebetic and Subbetic can be divided into a series of minor ones, with different stratigraphic series being laid down in separate realms differing by their bathimetry and distance from the continent.

Thus, in the Prebetic, outer and inner parts extending north and southwards respectively can be individualized; the first one less thick, with a higher number of detected stratigraphic gaps and mostly integrated by shallower sediments than the second one.

In the Subbetic the features of either typically «threshold» or «subsident trough» Jurassic series lead to the differentiation of three separate realms from N to S: an External Subbetic (threshold extending southwards of the trough in which the intermediate units were laid down), Median Subbetic (trough) and Internal Subbetic (threshold); in the Lower Cretaceous the most western part of the latter became individualized as a single block that even partially emerged, as can be inferred by the presence of the series of stratigraphic discontinuities, making it possible to separate a western realm (Penibetic) and an eastern one (Internal Subbetic s. str.).

It should finally be noted that Subbetic materials appear disposed in a set of overthrustings which would roughly correspond to the above described units.

c) A series of mesozoic and cenozoic units, which have been hitherto interpreted in quite different ways develops between the Internal and External Zones; these are the units of Campo de Gibraltar as well as several others appearing strongly similar to Subbetic or Rondaide.

The Campo de Gibraltar units are a set of gravitatory overthrusts, consisting mainly of turbidites, ranging from Cretaceous to Lower Miocene. There is no agreement whether they still occupy their original relative position or they come from a further – southern area such as that realm of the Internal Zones or even another one much further south yet.

Units showing Subbetic affinities (Ultra–internal Subbetic) could have been laid down in a sedimentary trough extending southwards the inner subbetic threshold.

Units displaying rondaide (or dorsalian) affinities could constitute the basement for at least part of Campo de Gibraltar units.

d) Finally, a series of intramountaneous basins (Ronda, Granada, Guadix–Baza, etc.) infilled with neogene materials laid down after the main folding phase (s) as well as another marginal one extending northwards, that of Guadalquivir, may be also recognized.

The Navazuelo Section.

Location and lithology (Fig. 13). (J. M. Gonzalez–Donoso, D. Linares, E. Molina & F. Serrano).

The Navazuelo section is situated near the village of Guadahortuna within the area of Montes Orientales in the northern part of Granada province. It falls inside the sheet of Huelma 20–39 (970) of the Spanish military map 1:50.000.

The studied series crops out 2 km eastwards of the Cortijo «El–Navazuelo», along Arroyo Piletas, between Cortijo de Fuente de los Potros and Cerro Granado (altitude 1240).

The section is bounded by the following U.T.M. coordinates: Cortijo de Fuente de los Potros: 30SVG649539, Cerro Granado 30SVG655526.

The section is accessible by a path from km 176 of National Road 324 (Cordoba to Almería through Jaen) which leads to Cortijo de Fuente de lo Potros.

The Navazuelo section belongs to the external zones of Betic Cordilleras, more precisely within the Median Subbetic realm, which appears to be a subsident trough during the Eocene.

Palaeogene–Lower Miocene materials laid down in that realm may reach up to more than 1.000 m thickness and, during Eocene–Aquitanian times may be commonly found as flysch facies; olisthostromes being usually found inside them as well. A angular unconformity is common at the Aquitanian–Burdigalian boundary, in which deep marine environments were replaced by a shallower ones.

Comas (1978) established a formal lithostratigraphic nomenclature for median subbetic sequences of the Montes Orientales. The Navazuelo section falls accordingly within Cardela group, Cañada formation (Eocene–Aquitanian).

The Cañada formation, which may range up to a thickness greater than 500 m, is composed in general by interbedding of detritic, micritic and marly limestones as well as massive marly interval. The alternation appears strongly rhythmic and the successions seem to be of turbiditic origin. Furthermore east of Navazuelo section, olisthostromes and olistolites are included in the sections. The deposition took place in a deep marine environment, however above carbonate compensation depth level, with an important supply of turbidites; the turbiditic beds interbedding with hemipelagic levels (Comas, op. cit.).

Lithologic sequence. The series dips some 20° southwards; the exposed part with a thickness of 250 m.

As far as the lithology is concerned the section appears quite uniform, mainly composed of a rhythmic interbedding of calcarenites and marls, with a variable predominance of some components over the others throughout the different levels in the section.

Most of calcarenitic layers display quite unclear parallel bedding with a massive aspect; although from time to time some internal sedimentary structures such as graded bedding, parallel bedding and current–ripples can be observed. In these same levels organic structures («Lebensspuren») and load structures may be observed. All these data suggest the possibility that the calcarenitic layers could correspond to turbidites.

In order to avoid the danger of reworking, typical in such deposits, samples used for the study of planktonic microfauna have been collected at the top of marly intervals, that is, in the autochthonous part of the deposit. However, several samples have also been collected at the lower part of marly intervals; their study prooved that heterochrony inside planktonic microfauna is almost inexistent.

The following lithologies have been identified from base to top of the section (Gonzalez–Donoso, 1977/78; Molina, 1979): a) 20 m mainly marls, dark grey; b) 60 m rhythmic interbedding of calcarenites and marls becoming more calcareous towards the upper part; c) 70 m mainly limestones, with some marly interbeddings; d) a typical unit, composed of 45 interbeds of calcarenites and marls; e) at the top of the section, in Cerro Granado, 50 m, very rhythmic flyschoid facies with strong development of parallel and convolute bedding. The share of sand appears quite high, and light–coloured marly intervals appear fairly impoverished in planktonic microfauna.

Calcareous Nannoplankton (Fig. 14). (M. Biolzi, M. Baldi Beke & C. Mueller).

No typical Miocene form is recorded in the Navazuelo section; all the thirteen samples collected belong to the Oligocene Zone NP25. Samples NA13 to NA10 and samples NA5 to NA1 are rich in nannofossils but are characterized by low diversity of the assemblages and poor preservation, with frequent overgrowth.

In samples NA9 to NA6 nannofossils are less frequent. *Cyclicargolithus floridanus, C. abisectus, Sphenolithus moriformis, Coccolithus pelagicus, Helicosphaera parallela, H. perchnielsenianae, Dictyococcites bisecta* and

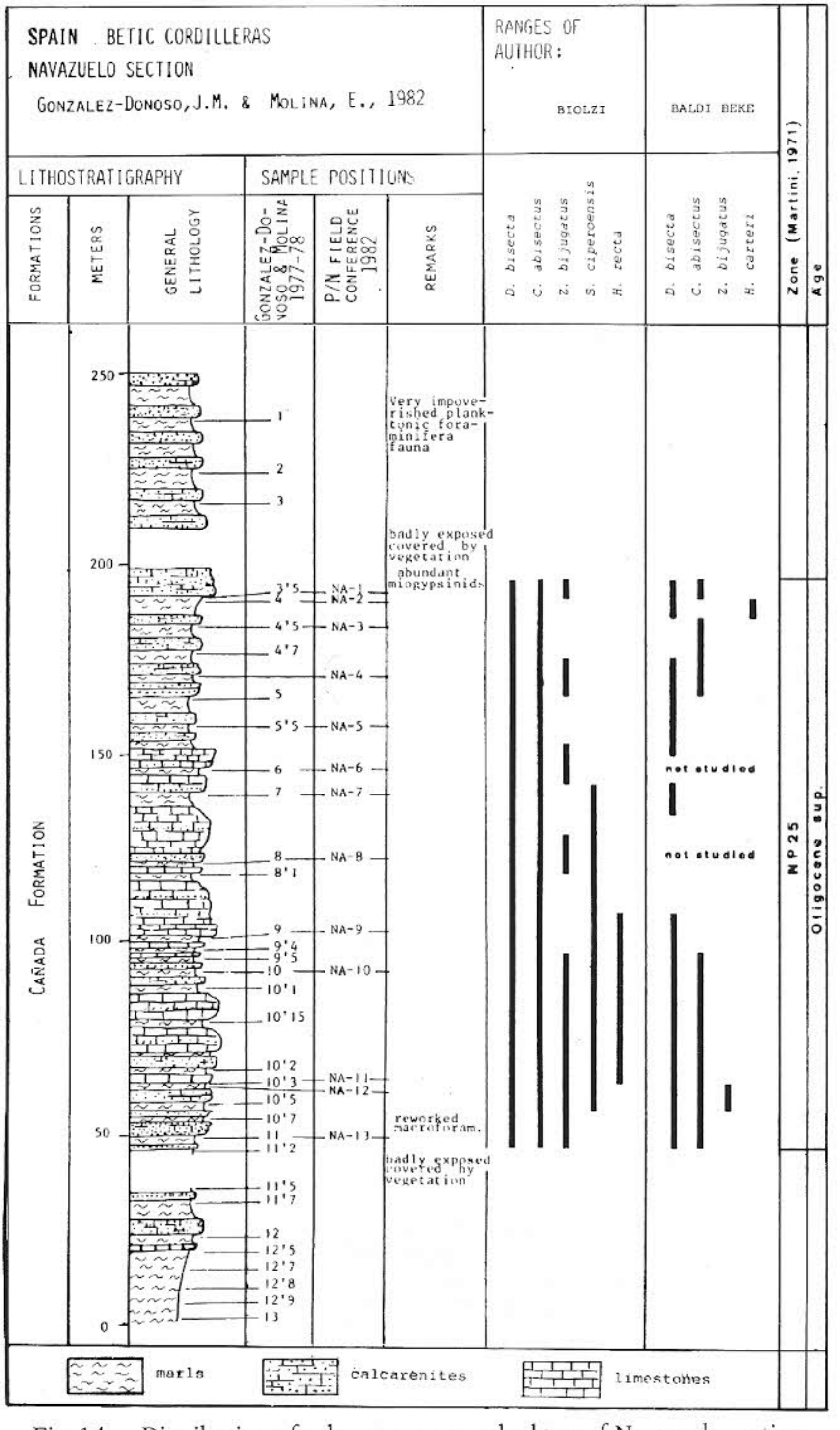


Fig. 14 — Distribution of calcareous nannoplankton of Navazuelo section.

Zygrhablithus bijugatus are the most common species observed.

Among the stratigraphically important species *Helicosphaera recta* has the highest occurrence in sample NA9 (M. B.), *Sphenolithus ciperoensis* in sample NA8 (M. B. and C. M.) and *Dictyococcites bisecta* is recorded throughout the section (M. B. and M. B. B.).

One of the authors (C. M.) suggests that the uppermost part of the section might belong to the Early Miocene (NN1 ?); the top of the Oligocene would be either at sample NA4, according to the highest occurrence of *Ericsonia fenestrata* and *Zygrhablithus bijugatus*, or at sample NA2, using the last occurrence of *Dictyococcites dictyoda* (= *D. bisecta*). But *Zygrhablithus bijugatus* and *Dictyococcites bisecta* have been found higher than NA4 by the other authors and no Miocene species is recorded to confirm such an age.

Reworked Cretaceous and Eocene species have been observed.

Planktonic Foraminifera (Fig. 15; Plate 40). (J.W. Zachariasse, M. Biolzi, G. Bizon, A.M. Borsetti, F. Cati, R. Gelati, J.M. Gonzalez–Donoso, S. Iaccarino, D. Linares, E. Molina, M. Romeo & F. Serrano).

The marly intervals of the Navazuelo section contain high relative numbers of planktonic foraminifera most of which are poorly preserved (i.e. recrystallized and partly cracked).

The results of an earlier study on planktonic foraminifera (Molina, 1979) indicate that the stratigraphic range of the Navazuelo section extendes from the Upper Eocene up into the Lower Miocene.

In view of the objectives of the working group, resampling of the Navazuelo section focused on the interval which could contain the so–called "critical time–span". Altogether some 13 samples were taken, 9 of which were studied for their planktonic foraminiferal content. The results were discussed in Milano (1982) and are presented in Fig. 15. Selected taxa are figured on Plate 40.

Consensus could be reached on the (local) stratigraphic ranges of *Globigerina angulisuturalis* Bolli, *Neogloboquadrina opima opima* (Bolli), *Globigerinita glutinata* (Egger), *Globorotalia kugleri* group, and of representatives of the genus *Globigerinoides*.

The highest occurrence of *G. angulisuturalis* is fixed at sample level NA8. As is the case in the Barranco Blanco section, specimens assignable to *G. angulisuturalis* are small–sized and tightly coiled and are outnumbered by larger–sized specimens of *Globigerina ciperoensis* Bolli.

Specimens assignable to *G. glutinata* have been recorded by Gonzalez–Donoso et al. and Zachariasse from sample level NA10 upwards.

The lowermost occurrence of representatives of the genus *Globigerinoides* is recognized by all, but one author (Gonzalez–Donoso et al.) at sample level NA8. Forms belonging to *Globigerinoides* were differently labelled by the various partecipants. Phylogenetically primitive forms, displaying a loose chamber

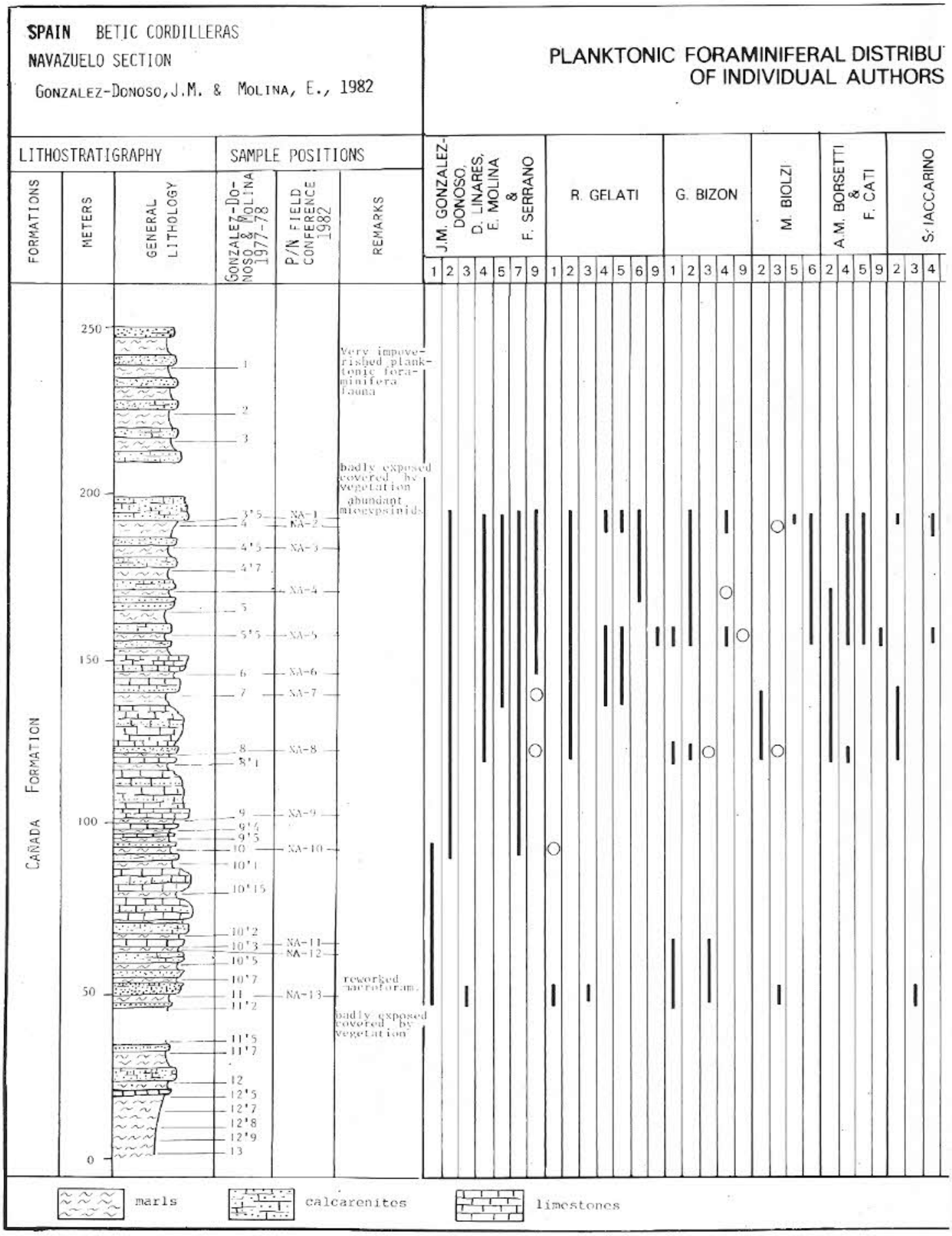
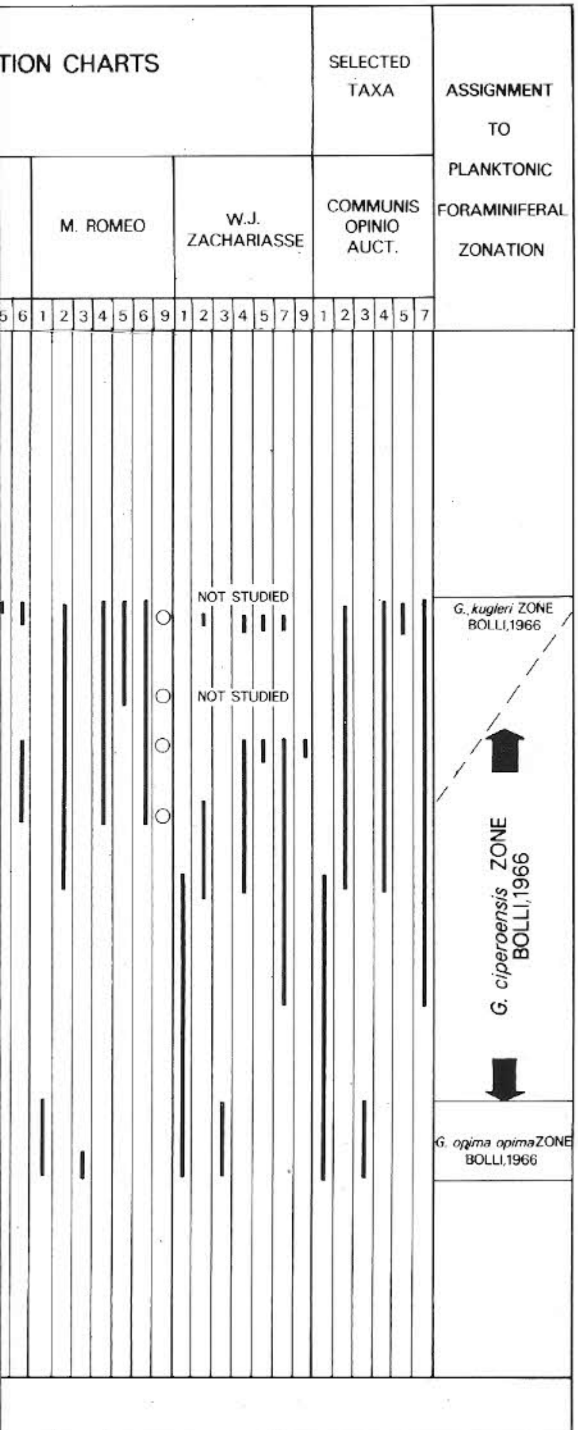


Fig. 15 — Distribution of planktonic foraminifera of Navazuelo s



TION CHARTS
SELECTED TAXA
ASSIGNMENT TO PLANKTONIC FORAMINIFERAL ZONATION
M. ROMEO
W.J. ZACHARIASSE
COMMUNIS OPINIO AUCT.
5 6 1 2 3 4 5 6 9 1 2 3 4 5 7 9 1 2 3 4 5 7
NOT STUDIED
NOT STUDIED
G. kugleri ZONE BOLLI,1966
G. ciperoensis ZONE BOLLI,1966
G. opima opima ZONE BOLLI,1966

section.

arrangement and an incipient cancellate wall–structure, are referred to as *Globigerinoides primordius* Blow & Banner or kept in open nomenclature. Such forms have been registered up to the top of the sampled interval. In addition to the forms lumped into the category of *G. primordius* and *Globigerinoides* sp., morphotypes labelled as *Globigerinoides trilobus immaturus* Le Roy were singled out by Biolzi, Gelati, Iaccarino, and Romeo in the interval delimited by the sample NA8 and NA1. Although supplementary apertures are mostly not perceptible, it was decided that specimens showing a more compact coiling and more pronounced reticulate wall–topography could belong to *G. trilobus immaturus* and occur from sample level NA5 upwards. The label *G. trilobus immaturus*, however, may include forms belonging to *Globigerina woodi connecta* Jenkins.

No consensus could be reached as to the range of *Globorotalia kugleri* Bolli and the same holds true for the occurrence of *Globoquadrina dehiscens* (Chapman, Parr & Collins).

Representatives of the *G. kugleri* group occur from sample NA8 upwards. Morphotypes assignable to *G. kugleri* are reported from samples NA1 and NA2 by almost all authors but there is no agreement on the lowermost occurrence of *G. kugleri* types. Therefore the FOD of *G. kugleri*, and thus the base of the *G. kugleri* Zone, is placed somewhere in between sample level NA7 (Gelati; Gonzalez–Donoso et al.) and sample level NA2.

Forms close or identical to *G. dehiscens* are reported from sample level NA5 by all authors. Gonzalez–Donoso et al. and Zachariasse consider these forms to fit in with the original definition of *G. dehiscens*, but, according to Borsetti and Cati, Gelati, Iaccarino, and Romeo these forms are not fully reconcilable with the above–mentioned species. Specimens registered as *G. dehiscens* from below sample level NA5 (Gonzalez–Donoso et al.) are considered to be atypical; they resemble *Globoquadrina venezuelana* (Hedberg) but differ in having more compressed chambers. The finding of such morphotypes may indicate that *G. venezuelana* is a serious candidate amongst the taxa considered to be the predecessor of *G. dehiscens*.

Specimens close or identical to *G. dehiscens* are severely reduced in relative number above sample level NA5. Trace occurrences are reported by Romeo in samples NA4 and NA2, and by Gonzalez–Donoso et al. in samples NA4, NA2, and NA1.

Finally it is observed that representatives of the *Globoquadrina* group (including *G. sellii* Borsetti, *G. binaiensis* (Koch), *G. tripartita* (Koch), *G. venezuelana* (Hedberg), and *G. globularis* Bermudez) and representatives of the genus *Catapsydrax* are frequent throughout the section. Specimens of *G. globularis* close to *Globoquadrina altispira globosa* Bolli occur in the top–part of the sampled interval (e.g. samples NA5 and NA2).

Conclusions. The results of our team–work indicate that the lower part of the Navazuelo section (i.e. sample levels NA13 and NA11) can be correlated with the *G. opima opima* Zone (Bolli, 1966), whereas the interval from level NA10 through level NA1 contains the *G. ciperoensis* Zone and *G. kugleri* Zone.

The boundary between the latter two zones is placed roughly in between levels NA7 and NA2. Hence, the "critical time–span" cannot be fully documented in the Navazuelo section.

Benthonic Foraminifera (Fig. 16; Pl. 42–45). (A. Poignant).

Smaller foraminifera, and in certain levels, numerous larger ones are present throughout the section.

On the whole, the microfauna of smaller foraminifera is not as abundant as in the Barranco Blanco section; the fauna is not very well preserved and is always recrystallized. However there are numerous and various species in samples NA2, NA3, NA7, NA8, NA13.

The assemblage of smaller foraminifera shows an Oligocene age with species also found in the Barranco Blanco section: *Almaena hieroglyphica*, *Anomalina granosa*, *Bolivina crenulata*, *B. fastigia*. *B. liebusi*, *Bulimina alazanensis*, *Globocassidulina globosa*, *Heterolepa costata*, *Karreriella siphonella*, *Tritaxia cubensis*, *T. szaboi*, and also *Anomalinoides ammophylus*, *Chilostomella cylindroides*, *Nonion elongatum*, *N. grateloupi*, *Reussella oligocaenica* etc.

Larger foraminifera are particularly abundant in samples NA7 and NA13, but are very poorly preserved and seem to be partly reworked. They are chiefly lepidocyclinids (*Eu*– and *Nephrolepidina*), *Nummulites tournoueri*, rare *N. vascus*, *Operculina complanata*, *Grzybowskia*, *Spiroclypeus*, *Cycloclypeus*, *Amphistegina lessonii*, *Pararotalia viennoti*, *Victoriella aquitanica*, *Biarritzina* sp. etc. Both levels NA7 and NA13 show striking similarities with the well–known exposure of Escornebéou in southwestern France (Upper Oligocene) which except for *Cycloclypeus* contains the same larger foraminifera.

As far as paleobathymetry is concerned, the water–depth is estimated at about 100 m, except in the levels with larger foraminifera (*Victoriella* and *Biarritzina*) in which it probably did not exceed 50 m.

A nummulite possibly reworked from the Eocene was found in sample NA13.

The larger foraminifera: *Nummulites tournoueri*, *N. vascus*, *Grzybowskia*, *Spiroclypeus* have been identified by Dr. A. Blondeau, Université P. et M. Curie, Paris.

Cycloclypeus was said by C.W. Drooger (1979): "(to be) present in some areas... possibly southern Spain".

Biostratigraphy of Navazuelo section. (J. M. Gonzalez–Donoso, D. Linares, E. Molina & F. Serrano).

Some of the most interesting biohorizons related to Palaeogene/Neogene boundary have been identified in Navazuelo section (Cañada Formation). These are the following, from older to more modern:

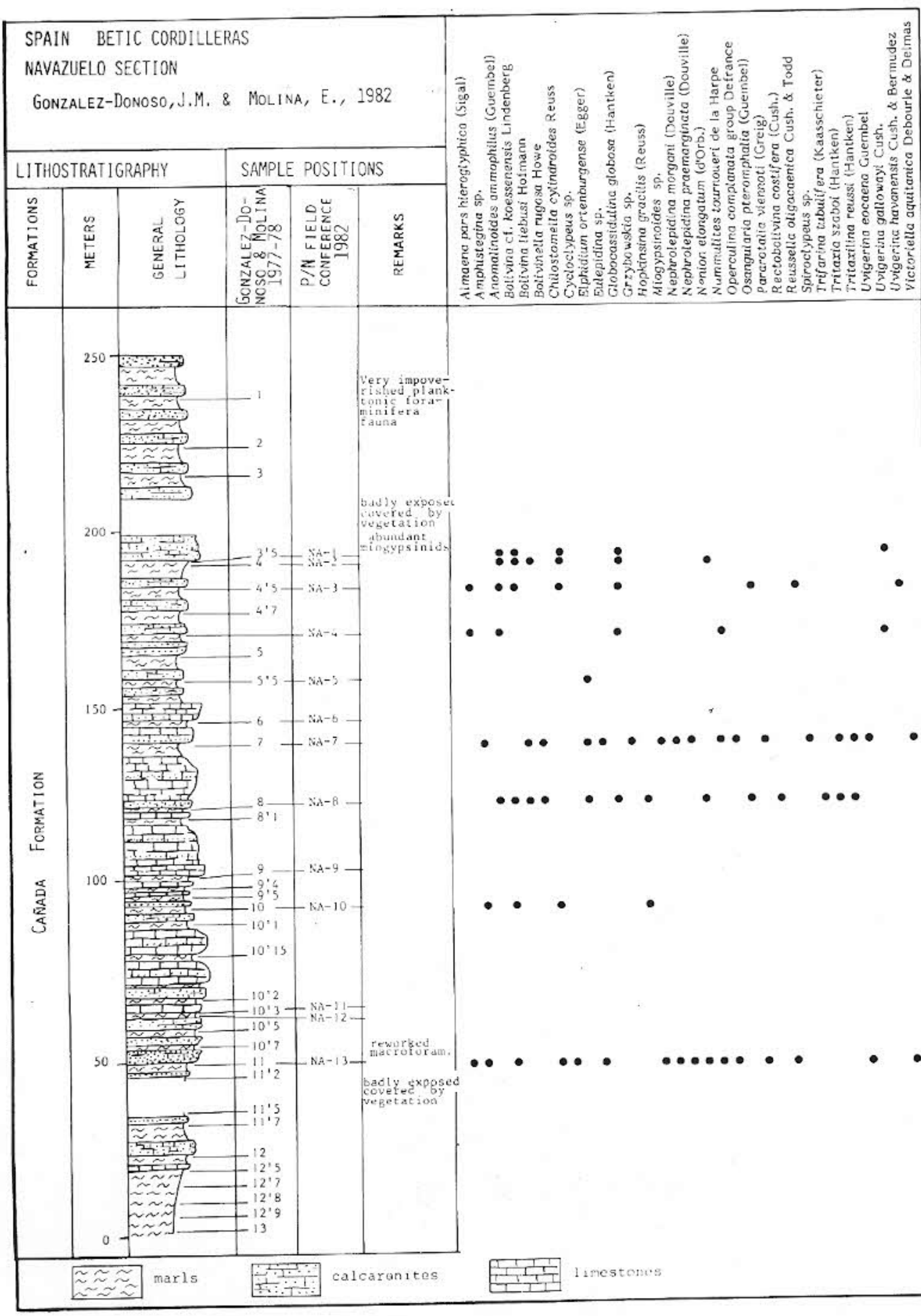


Fig. 16 – Distribution of benthonic foraminifera of Navazuelo section.

1. Biohorizon of extinction of *Globorotalia opima opima* in sample NA13.
2. Biohorizon of the first appearance of *Globigerinoides primordius* in the sample NA10; the species becoming much more abundant from NA8.
3. Biohorizon of extinction of *Globigerina angulisuturalis.*
4. The *Globorotalia kugleri* group appears in the sample NA18.
5. Biohorizon of appearance of *Globorotalia kugleri* s. str. is placed between samples NA7 and NA2.

Finally, *Globoquadrina dehiscens*, was recorded at sample NA5. *Globigerinoides primordius* and *Globorotalia kugleri* are still present in the last sampled level NA1; beyond that point the series appears poorly exposed due to vegetation.

In terms of biozonation of Blow (1969) the sampled part of Navazuelo section would comprise the zones N. 2 (part), N. 3 and N. 4 (part).

According to Molina (1979), zonation established in the central sector of Betic Cordilleras, it would comprise *G. angulisuturalis* (part) and *G. primordius* (part) zones. In terms of Bolli (1966) zonation the *G. opima*, *G. ciperoensis* and part of the *G. kugleri* – zones are recorded.

As far as nannoplankton is concerned, data appear slightly contradictory, according to Biolzi and Baldi Beke the whole section belongs to NP25 Zone, whereas, according to Mueller, sample NA1 already belongs to NN1 Zone.

The Barranco Blanco Section.

Location and lithology (Fig. 13). (J. M. Gonzales–Donoso, D. Linares, E. Molina & F. Serrano).

The Barranco Blanco section is situated in Chirivel (Almería). The studied sequence is easily sampled in the Barranco Blanco ravine, which crosses National Road 342, from Granada to Vélez Rubio, at km 121.7. It is located in Chirivel sheet 23–29 of the Spanish military map (E. 1:50.000). The section is bounded by the following U.T.M. coordinates: 30SWG697632 (base) 30SWG693634 – (top).

It should be noted that some toponimic contradictions affect the area in which the section is located. The two nearby villages are called, according to the map, Ciudad Granada and Rambla de Abajo, but they are most popularly known as Cortijo Granada and Las Nogueras by their inhabitants. Furthermore, two more or less parallel ravines named Blanco, appear on the map; the above quoted one and another one crossing the road at km 119 and 120. One is known as Barranco de la Cantera on Soediono's map (1971), – and the other as Barranco Blanco. To make matters worse the inhabitants know the ravine in which the section crops out as Barranco de las Pozas.

As it has been commented above in many areas of the Betic Cordilleras, no direct contact between the internal and external zones may be observed; a series of uncertain and long debated units are situated between them, namely: units of Campo de Gibraltar, units of subbetic affinities and units of rondaide affinities.

The Barranco Blanco section is just located in one of these contact areas in which materials coming from internal zones (Maláguides), external zones (Internal Subbetic) and a series of units whose relation with these zones has been long subject of debate, are found to crop out. These units were formally defined by Soediono (1971), namely: Ciudad Granada Group (Ciudad Granada Formation, Frac. Formation, Cortijo del Perro Malo Formation), Fuente Formation, Espejos Formation and Pinar Formation (or Solana Formation; Geel, 1973).

Regardless the discussion of arguments, which should be detailed elsewhere, the authors will assume the Ciudad Granada Formation as belonging to the Maláguide complex; Espejos and Fuente formations as equivalent to some others laid down somewhere else in the internal zones after their definitive structural arrangement, and Pinar Formation as one of the Campo de Gibraltar units.

In the northern part of Barranco Blanco several lithological units, upwards the ravine, may be observed: a) Alpujárride complex materials, with some volcanic interbeddings, b) Ciudad Granada Formation, c) lower part of Espejos Formation.

The Ciudad Granada Formation displays a thickness of about 180 m at our locality. On the ravine floor, after the Maláguide materials and after a non–observable part, the first level cropping out is a thick conglomerate stratum; further westwards some materials probably corresponding to that non–observable interval seem to be visible: they appear to be formed by a sequence of marls and sandstone–conglomerate interbedding. Again on the ravine floor, after the conglomerate interval, a series including sandstones and calcarenites interbedding with marls and clays, may be observed. Finally, a thick sequence of brownish red clays with very scarce calcarenitic interbeddings in its lower part, crops out.

This part is followed by the Fuente Formation, with an approximate thickness of 30 m; the formation is mainly composed of greyish marls, with numerous coarse–grained detritic interbeddings at its lower part; its base being of olisthostromic character. Towards the upper part "silexitic" and "tuffaceous" materials are commonly found.

The transition – respectively the contact – from the Ciudad Granada and to the Fuente Formation crops out by a sudden lithological change and contact points to a major unconformity. The Ciudad Granada Formation extends in E–W direction, with a dip of 60°N. Olisthostromic part of Espejos Formation extends with a 80°E direction and 30°N dip, subsequently changing to a 120°E direction and 60°N dip.

Paleoecology. From the basal transgressive levels from Ciudad Granada Formation a impoverished fauna of planktonic foraminifera was recorded; however, fragmentary invertebrate remains (mainly echinoderms and mollusca) as well as benthonic foraminifera, appear fairly common; furthermore *Miogypsinidae* identified by Soediono (1969), as well as some specimens of *Heterostegina* sp., *Operculina* sp., *Amphistegina* sp., some *Miliolidae* and calcareous algae, have been identified. Such an association points to a shallow marine environment with high energy and warm waters.

A deeper environment (perhaps more than 200 m), in which macroforaminifera did not develop any more, but on the contrary, planktonic foraminifera as well as small–sized benthonic ones became very abundant, was progressively replacing the former. This fauna appears quite well preserved and highly diversified; among benthonics the most meaningful genera are: *Alabamina, Almaena, Bolivina, Bulimina, Cassidulina, Gyroidina, Uvigerina, Pullenia, Cibicides,* and *Eponides*. The planktonic/benthonic ratio enables to infer, for 2/3 of Ciudad Granada Formation, a depth ranging from the outer shelf to the upper bathyal.

Towards the upper parts of Ciudad Granada Formation pteropods (mainly *Vaginella* sp. and *Clio* sp.) as well as holothurian sclerites become common in these levels.

The best indicators for water temperature are the planktonic foraminifera: some subtropical, although never abundant forms as *Globorotalia kugleri, G. mendacis, G. pseudokugleri*, and *Globigerina binaiensis* have been recorded. Several others such as *Globigerina sellii, G. venezuelana, G. angulisuturalis, G. praebulloides occlusa, Cassigerinella chipolensis* and *Globigerinoides primordius*, are most common. On the other hand, the groups of *Catapsydrax dissimilis* and *Globoquadrina dehiscens* appear to be very rare. This association would indicate a temperate–warm water environment transitional from tropical to temperate areas.

The Fuente Formation could have been deposited in a much deeper basin, though in a tectonic very instable interval, specially as far as the first part of the formation is concerned. The recorded fauna displays a high share of radiolaria as well as numerous planktonic and small benthonic foraminifera. Both radiolarians and "silexitic levels" appear related to some volcanism evidenced by the presence of tuffs in some parts of the Betic Cordilleras. However, studies carried out on samples of this section showed a very small share of volcanic glass (Ardanese, oral communication), therefore they could not be considered as typical silexitic or tuff levels.

Calcareous Nannoplankton (Fig. 17). (M. Biolzi, M. Baldi Beke, C. Mueller & A. Romein).

The transition Oligocene–Miocene is not continuous in the Barranco Blanco section; a hiatus exists, probably including the uppermost part of the Oligocene and the lowermost part of the Miocene.

Samples BB1 to BB18 have rich Late Oligocene (NP25) nannofossil assemblages: *Cyclicargolithus abisectus, C. floridanus, Coccolithus pelagicus, Helicosphaera parallela, Discolithina enormis, Dictyococcites bisecta (=dictyodus), Zygrhablithus bijugatus, Sphenolithus ciperoensis, S. moriformis, Ericsonia fenestrata, Coronocyclus nitescens.*

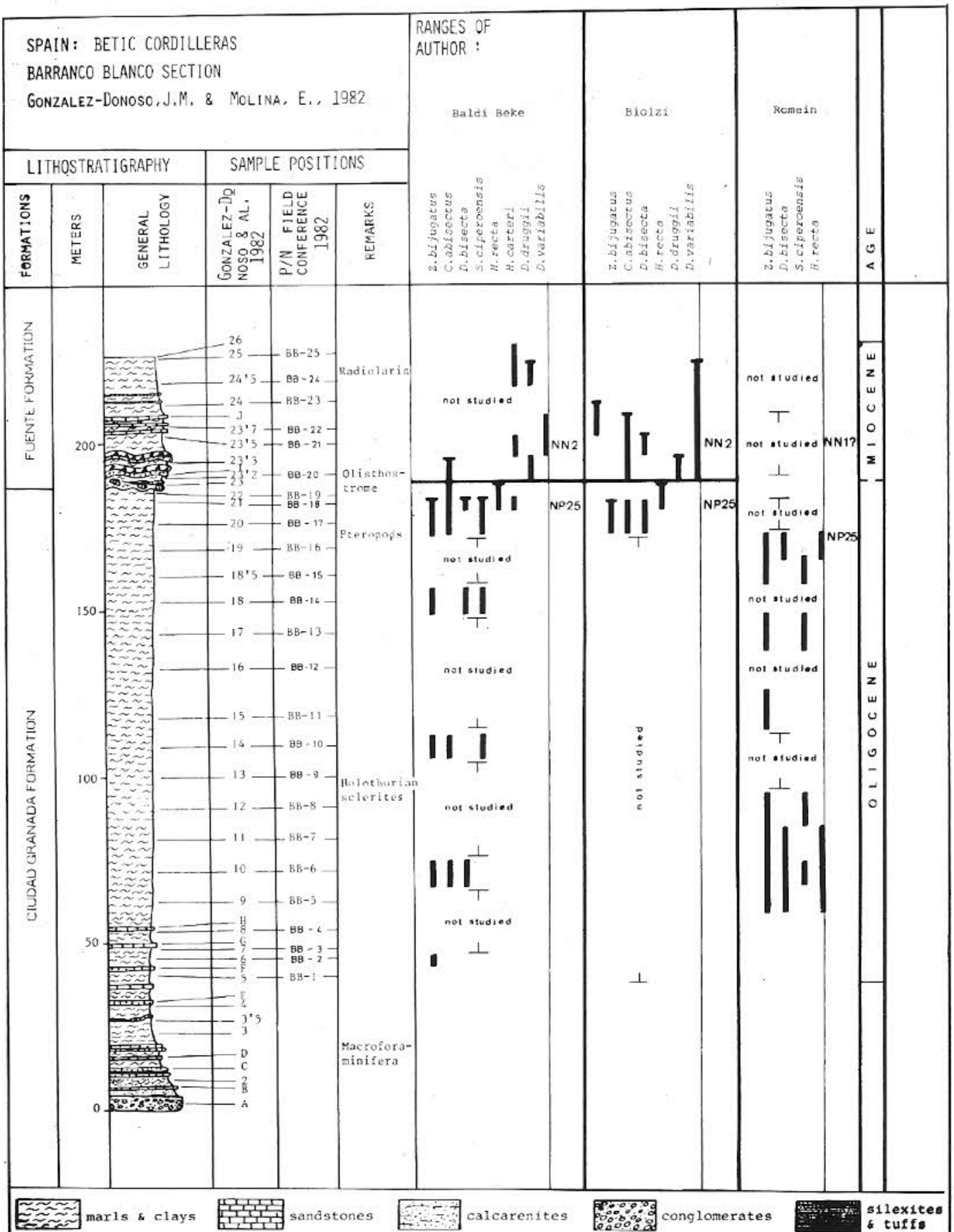


Fig. 17 – Distribution of calcareous nannoplankton of Barranco Blanco section.

Sample BB19 is situated immediately below an olisthostrome easily recognizable in the field. It is very poor in nannofossils but contains *Helicosphaera recta* and thus is assigned to Zone NP25. The overlying sediments belong to the Early Miocene. Samples BB20 to BB25 contain poorly preserved, broken and overgrown nannofossil assemblages of lower diversity than the underlying Oligocene sequence. Rare *Discoaster druggii* and *D. variabilis* suggest that the upper part of the section belongs to Zone NN2.

Two authors (C.M. and A.R.) found no *Discoaster druggii* in sample BB20 and therefore assigned the upper part of the sequence to the Early Miocene (NN1?), based on the absence of Oligocene markers. One author (A.R.) did not study all the samples in the critical interval and therefore placed the Oligocene/Miocene boundary somewhere between samples BB16 and BB19. He found no *Helicosphaera recta* in sample BB19.

Only very few reworked Cretaceous and Eocene specimens were observed.

The unconformity between samples BB19 and BB20 which probably contains the Oligocene/Miocene boundary, might also be indicated by the alteration of the nannofossils in sample BB19 and by the distinct red color of the sediments.

Planktonic Foraminifera (Fig. 18; Plate 41). (J.W. Zachariasse, M. Biolzi, G. Bizon, A.M. Borsetti, F. Cati, M.G. D'Andrea, R. Gelati, J.M. Gonzalez–Donoso, S. Iaccarino, D. Linares, E. Molina, M. Romeo & F. Serrano).

Amongst the sections investigated by the working group, the spanish Barranco Blanco section contains the best preserved planktonic foraminiferal fauna. Notwithstanding the strongly tectonized sediment succession, planktonic foraminifera show surprisingly little distortion and their wall–structure can be fully utilized for correct specific determinations.

The results of a pilot survey, carried out by Gonzalez–Donoso, Linares, Molina, and Serrano, suggested that the Barranco Blanco section could contain a well–documented record across the Palaeogene/Neogene boundary interval. This is why this section was resampled during the Palaeogene/Neogene meeting in Malaga (1982).

Some 11 samples were analyzed in detail for their planktonic foraminiferal content. The results were discussed in Milano (1982) and are presented in Fig.18. Selected taxa are figured on Plate 41.

Globigerina angulisuturalis Bolli is recognized from sample BB1 up to and including sample BB11 by almost all authors. It is noted, however, that specimens labelled here as *G. angulisuturalis* are more tightly coiled and possess less prominent U–shaped sutures than do the notorious low–latitude assemblages.

Representatives of the *Globorotalia kugleri* group first occur in sample BB8 and extend their range up into sample level BB19. Their presence in sample BB23 recorded by Borsetti and Cati is questionable: The features of the species *Globorotalia mendacis* Blow and *G. pseudokugleri* Blow cover almost the entire

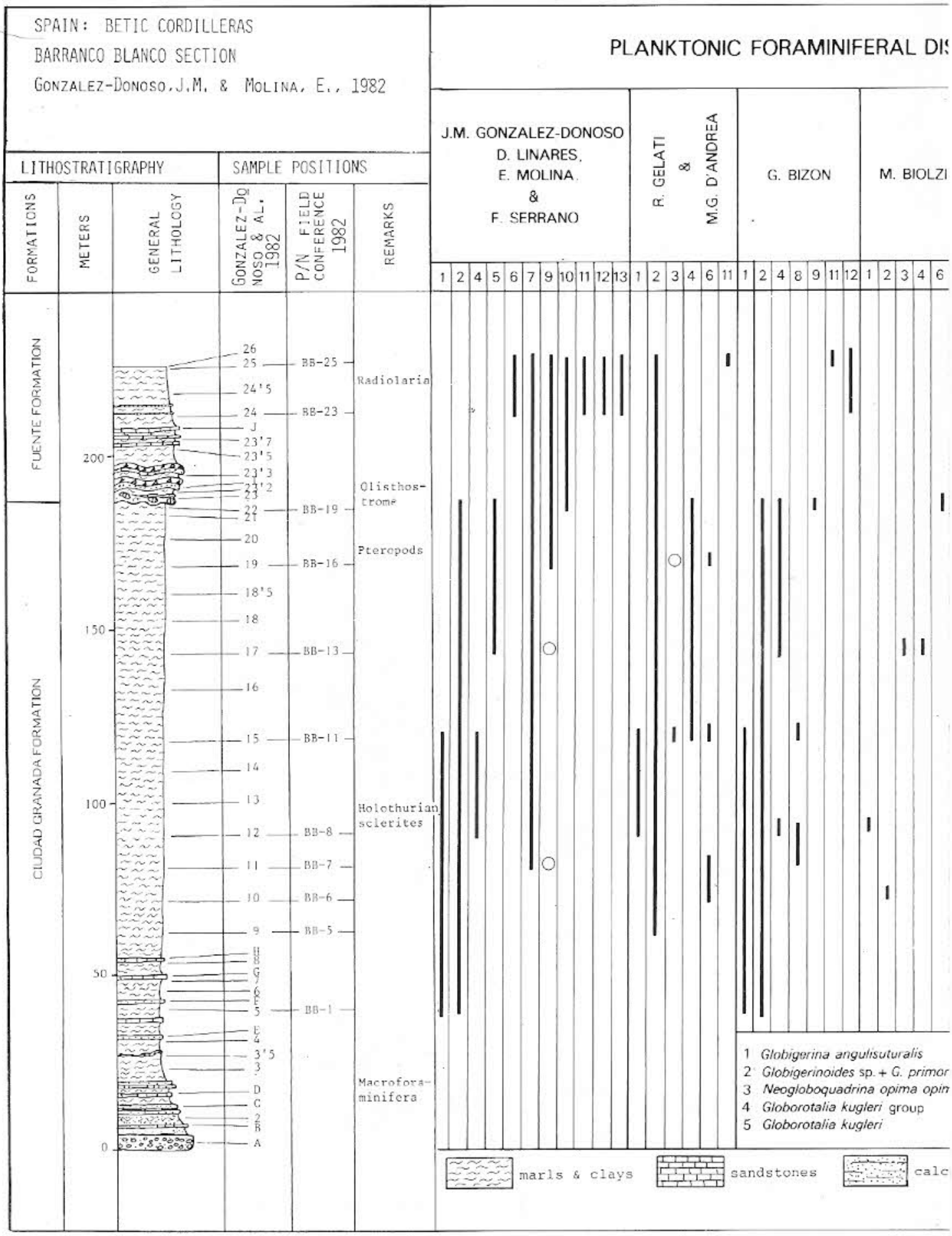
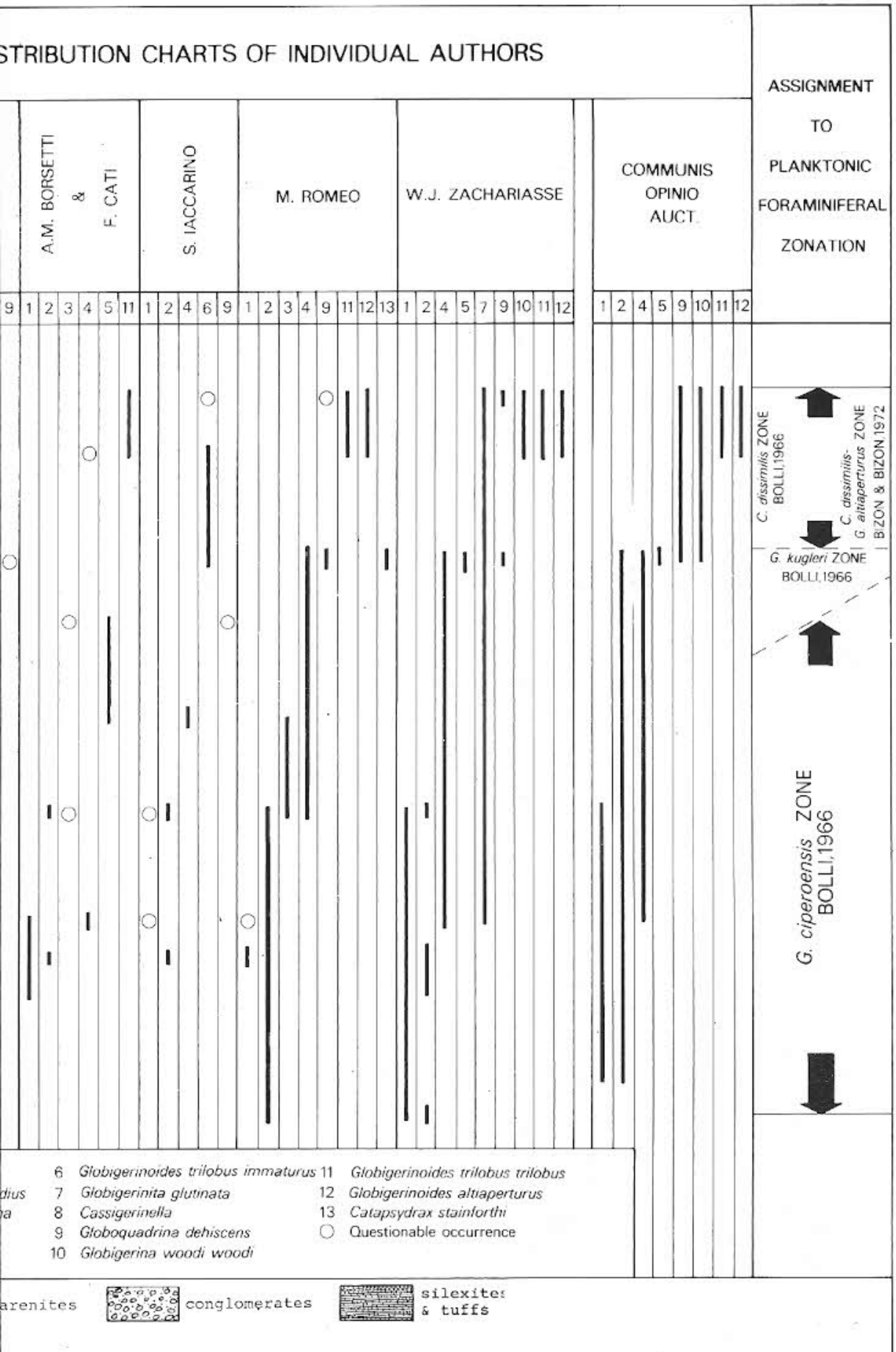


Fig. 18 — Distribution of planktonic foraminif



era of Barranco Blanco section.

morphological range of the *G. kugleri* group. No consensus could be reached as to the lowermost occurrence of true *Globorotalia kugleri* Bolli. According to Borsetti and Cati, and Gonzalez–Donoso et al. specimens assignable to *G. kugleri* occur as low as sample level BB13, whereas Zachariasse does not report this taxon until sample level BB19. Considering these differences in the lowermost occurrence of *G. kugleri* the base of the *G. kugleri* Zone (Bolli, 1966) is placed somewhere in between sample levels BB13 and BB19.

Representatives of the genus *Globigerinoides* have an extremely low frequency up to sample level BB19 but are common in samples BB23 and BB25. Phylogenetically primitive forms are recorded as *Globigerinoides* sp. and *G. primordius* Blow & Banner and are lumped here into one category the highest occurrence of which is fixed at sample level BB19. Associated with this category are forms resembling *Globigerinoides trilobus immaturus* Le Roy but lacking a supplementary aperture. The latter forms are close or identical to *Globigerina woodi connecta* Jenkins and are probably registered as *G. trilobus immaturus* by Gelati and D'Andrea, in samples BB6, BB7, and BB11 and by Gonzalez–Donoso et al. and Iaccarino in sample BB19. Typical *G. trilobus immaturus* together with *Globigerinoides trilobus trilobus* (Reuss) and *Globigerinoides altiaperturus* Bolli occur in samples BB23 and BB25.

Another discussion focused on the reported occurrence of *Neogloboquadrina opima opima* (Bolli) in samples BB11, BB13, and BB16. Comparison with topotypes, brought along by Biolzi, showed some specimens to be virtually identical with *N. opima opima*. These have either been reworked or represent end–morphologies of *Neogloboquadrina mayeri* (Cushman & Ellisor). The latter species proliferates with large–sized specimens from sample level BB11 up to level BB19.

Globoquadrina dehiscens (Chapman, Parr & Collins) is recorded from sample level BB19 by almost all participants and only by Gonzalez–Donoso et al. from samples BB23 and BB25. Trace occurrences of this taxon, reported by Gonzalez–Donoso et al. and by Iaccarino from below sample level BB19 are attributed to downstream contamination, since the state of preservation of these specimens is distinctive for the upper lithological unit.

Globigerina woodi woodi Jenkins first occurs in sample BB19, whereas the lowermost occurrence of *Catapsydrax stainforthi* Bolli, Loeblich & Tappan is fixed at sample level BB23. The first occurrence of *Globigerinita glutinata* is registered in sample BB7 (Gonzalez–Donoso et al.).

A few specimens of *Neogloboquadrina acrostoma* (Wezel) are found by Gonzalez–Donoso et al. in samples BB23 and BB25 and by Bizon in sample BB25. Trace occurrences of *Cassigerinella chipolensis* (Cushman & Ponton) are reported solely by Bizon (samples BB7, BB8, and BB11).

Finally it is observed that the group of *Globoquadrina tripartita* (Koch), including *G. binaiensis* (Koch) and *G. sellii* Borsetti, is a very characteristic element in the associations up to sample level BB19.

Conclusions. The lower lithological unit, delimited by samples BB1 through

BB19, contains a fairly well–diversified and excellently preserved planktonic foraminiferal fauna which is correlatable with the *G. ciperoensis* Zone and *G. kugleri* Zone of Bolli (1966). The boundary between the two zones is placed somewhere in between sample levels BB13 and BB19. The associations obtained from the upper lithological unit are less diversified, more poorly preserved and are admixed with high relative numbers of radiolaria. The co–association of *G. altiaperturus* and *C. stainforthi*, along with the absence of *Globorotalia praescitula* Blow, indicate that these associations are assignable to the *C. dissimilis* Zone of Bolli (1966) and to the lower part of the *C. dissimilis / G. altiaperturus* Zone of Bizon & Bizon (1972).

The change in preservation, diversity, species composition, and radiolaria content on either side of the lithological break above sample level BB19, together with the limited thickness of the *G. kugleri* Zone, point to a discontinuity in the sedimentary and faunistic record in the so–called "critical time–span".

Benthonic Foraminifera (Fig. 19; Pl. 42–45). (A. Poignant).

Two parts can be distinguished in the Barranco Blanco section:

(1) from the base to sample BB19:

The microfauna is rich, diversified, rather well preserved homogenous. About 100 species belonging to 50 genera have been collected. They are agglutinated taxa *(Textularia, Karreriella, Cyclammina, Tritaxia, Vulvulina...)*, *Nodosariacea (Lenticulina, Dentalina, Marginulina, Nodosaria, Planularia...)*, often characterized by their large size. Various *Stilostomella*, *Bolivina*, and *Heterolepa* are also found in abundance.

This assemblage is typical of the Oligocene and it is impossible to enumerate all the species. Among the most commonly representatived we can note: *Almaena delmasi*, *A. escornebovensis*, *A. hieroglyphica*, *Anomalina affinis*, *A. cryptomphala*, *A. granosa*, *Bolivina budensis*, *B. fastigia*, *B. liebusi*, *B. reticulata*, *B. semistriata*, *Bulimina alazanensis*, *B. alsatica*, *Cyclammina acutidorsata*, *Gaudryina difformis*, *Heterolepa costata*, *Hopkinsina gracilis*, *Karreriella siphonella*, *Marginulinopsis asperuliformis*, *M. fragaria*, *Miogypsinoides* sp., *Nummulites tournoueri*, *Rectobolivina szigmondii*, *Textularia lanceolata*, *Tritaxia cubensis*, *T. szaboi*, *Tritaxilina reussi*, *Uvigerina eocaena*, *U. gallowayi*, *Victoriella aquitanica*.

All the encountered species are well–known in Oligocene deposits; particularly the Spanish levels are closely similar to the Rupelian and lower Egerian of Hungary (cf. K. Sztrakos, 1979). The small benthonic foraminifera correspond well and it is of interest to point out the presence in Barranco Blanco of *Planctostoma oligocaena* Sztrakos, a species described in the lower Egerian of Hungary and never recorded elsewhere.

(2) Above sample BB19:

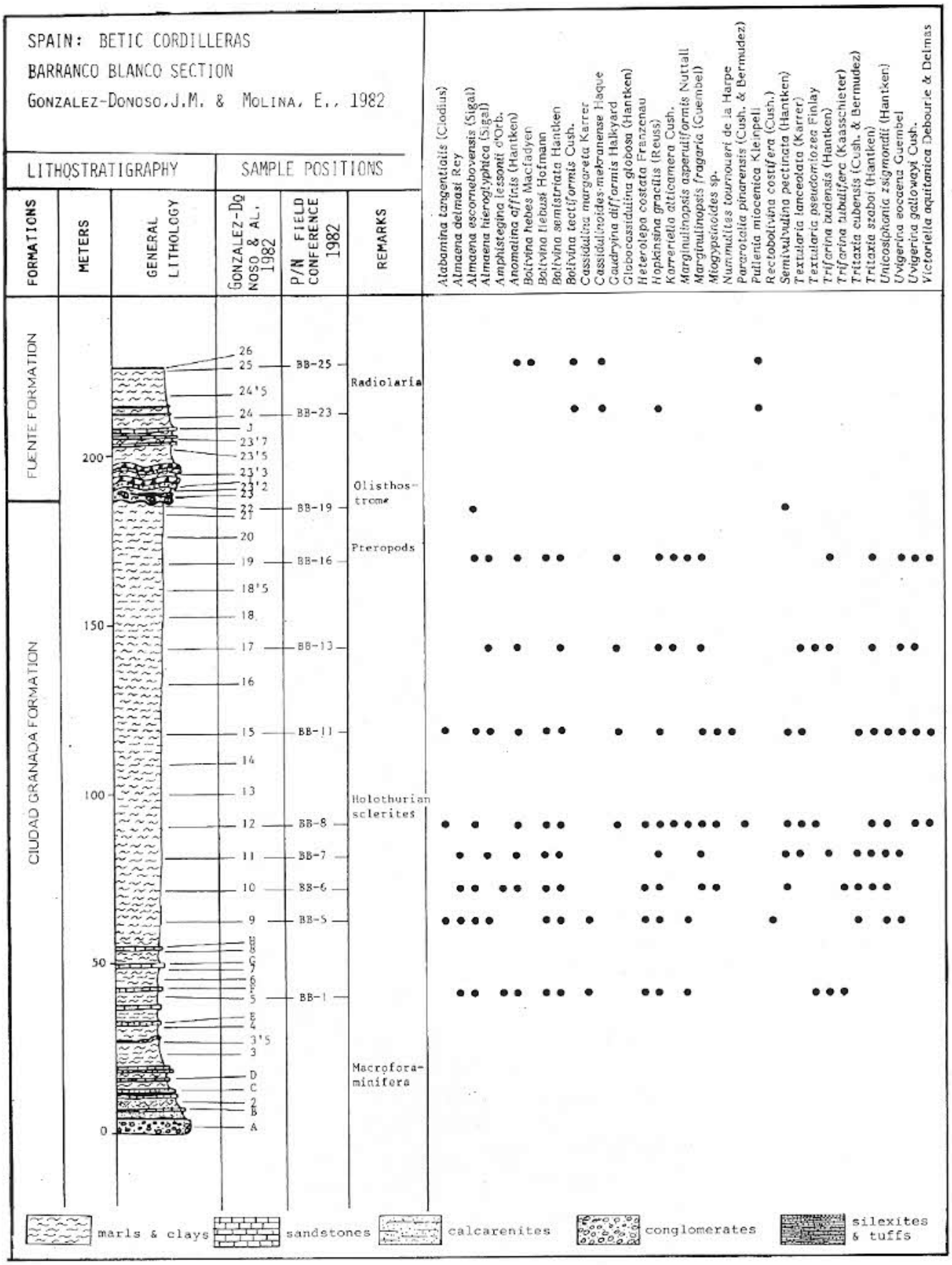


Fig. 19 – Distribution of benthonic foraminifera of Barranco Blanco section.

There is a change in the last levels with an increasing abundance of Radiolaria and Foraminifera such as *Gyroidina*, *Oridorsalis*, *Melonis*, *Pullenia*, *Globocassidulina*, *Pleurostomella*, *Heterolepa*. Some new species appear: *Bolivina hebes*, *B. tectiformis*, *Pullenia miocenica*, *Cassidulinoides mekranense*.

The upper levels belong to Lower Miocene.

As far as paleobathymetry is concerned, we can say that in the lower levels the water–depth of deposition did probably not exceed 50 m (beds with *Nummulites*, *Miogypsinoides*, *Amphistegina*, *Operculina*, *Victoriella*); in the remaining ones it must have been more than 100 meters. The water was tropical with normal salinity.

There was an increase in the water–depth during the Lower Miocene (samples BB23, BB25), enabling the appearance of radiolaria and numerous foraminifera (such as *Gyroidina*, *Oridorsalis*, *Melonis* etc.); these forms suggest a water–depth between 800 and 1000 m.

Compared to the Sicilian sections, the Barranco Blanco section shows a microfauna of benthonic foraminifera which, while not differing significantly, is better preserved, richer and more diversified.

Biostratigraphy of Barranco Blanco section. (J.M. Gonzalez–Donoso, D. Linares, E. Molina, & F. Serrano).

A succession of first and last appearances, more or less interesting for different reasons, are observed all along the Barranco Blanco section, Ciudad Granada and Espejos formations.

These are, from older to more recent:

1. *Globigerinoides primordius*, identified from the first studied sample BB1 up to sample BB19.

2. *Globoquadrina dehiscens*, the sporadic appearance in the lower levels (BB5, Romeo; BB7, Gonzalez–Donoso, Linares, Molina and Serrano) is due to downstream contamination; a regular appearance is recorded in sample BB19.

3. *Globorotalia kugleri* group, represented by rare, small–sized specimens, which appears from sample BB8 upwards; *Globorotalia kugleri* s. str. (after Borsetti, Gonzalez–Donoso, Linares, Molina and Serrano) appears first on sample BB13, according to Zachariasse on sample BB19.

4. *Globigerina angulisuturalis* seems to be extinct from sample BB11 upwards.

5. *Globigerina woodi* appears in the last sample BB19 of Ciudad Granada Formation.

An angular and erosive unconformity, meaning a quite important stratigraphic gap, appears between Ciudad Granada and Espejos formations; thus, the relative position of some biohorizons cannot be accurately set in the Barranco Blanco section. *Globigerinoides primordius* and *Globorotalia kugleri* are recorded only up to unconformity. *Globigerinoides trilobus*, *Globigerinoides altiapertus* and *Catapsydrax stainforthi* (the latter already present in Ciudad Granada

Formation according to Romeo) appear in Espejos Formation.

According to the biozonation of Blow (1969), Ciudad Granada Formation can be placed into Zone N. 4 (part) and Espejos Formation into Zone N. 5 (part).

In terms of Bolli (1966) zonation the *G. ciperoensis* and part of the *G. kugleri* Zones are present below the hiatus and the lower part of the *C. dissimilis* Zone in Espejos Formation.

According to the biozonation of Molina (1979), Ciudad Granada Formation would comprise the *G. primordius* Zone (part) and Espejos Formation would comprise the *G. altiaperturus* Zone (part). The stratigraphic gap between both formations would comprise, at least, the subzone of *G. trilobus* s. l. (last part of *G. primordius* Zone).

As far as nannoplankton is concerned, there exists some disagreement among the authors; according to Baldi Beke, the Ciudad Granada Formation belongs to NP25 and Espejos Formation to NN2; Mueller assigns Ciudad Granada Formation to NP25 and Espejos Formation to NN1 with some reservation. Romein identified the NP25 Zone up to sample BB16 and the NN1 Zone, with some reservation, in the Espejos Formation.

Finally, as far as other groups of microfossils is concerned, Poignant has studied the very abundant and well preserved benthonic foraminifera. Macroforaminifera are frequent at the base of the section and become extremely rare towards the top of Ciudad Granada Formation. In sample BB11 several interesting species of *Almaena*, *Bolivina* and *Miogypsinoides* are present; one species of *Nummulites* (? *N. tournoueri*) and *Victoriella aquitanica* have been identified as well. At Espejos Formation (BB23 to 25) a change to a deeper water species has been detected.

Conclusions on the biostratigraphic results of the proposed potential Palaeogene/Neogene Boundary stratotype sections in Italy (Sicily) and Spain (Betic Cordilleras) (Fig. 20). (F.F. Steininger).

During two field seasons (Sicily 1981 and Spain 1982) the members of the Working Group sampled two proposed potential boundary stratotype sections in Sicily and two other ones in Spain (see above). Calcareous nannoplankton, planktonic and benthonic foraminifera have been studied independently by several specialists from these jointly sampled, identical sample sites. The results have been discussed and the samples compared on the microscopes at meetings in Malaga (1982) and Milano (1982).

For each of these four sections the biostratigraphic results of each group of organisms have been discussed separately and this discussion is followed by a general concluding discussion on the biostratigraphy of the section itself

In the following these results will be evaluated by their meaning in respect of the biochronologic datum levels of the Palaeogene/Neogene Boundary within the so–called "critical time–span" and on their bearing in function of a boundary stratotype for the Palaeogene/Neogene Boundary (for the general goals and ideas see Cati et al., 1981 and Steininger, 1982).

Italy: Sicily, Iblean Region.

Case Cocuzza Section (Fig. 20).

Consistent calcareous nannoplankton results of four specialists assign the lower part of the section including sample CC23 to the *Triquetrorhabdulus carinatus* - NP25 Zone. From sample CC24 upwards the presence of *Helicosphaera carteri* indicates a Miocene age. G. Palmieri assigned samples CC25 to CC27 to the *Discoaster druggii* - NN2 Zone because of the presence of *Discoaster* aff. *druggii* and *Helicosphaera ampliaperta*. A hiatus is likely according to the nannoplankton preservation, size and distribution between sample CC23 and CC24.

Ten specialists studied independently the distribution of planktonic foraminifera. Including sample CC23 the section represents the *G. ciperoensis* Zone. In sample CC24 the abrupt FOD af *G. dehiscens*, *G. woodi woodi* and *G. quadrilobatus triloba* together with *G. altiaperturus* and *C. stainforthi* till to the end of the section indicates the presence of *C. dissimilis* Zone. By these results a hiatus could be detected between samples CC23 and CC24 covering the entire *G. kugleri* Zone. This opinion is supported by the scattered appearance of reworked specimens of *G. angulisuturalis*, *G. kugleri* and *G. ciperoensis* in samples CC24 and CC25.

An Oligocene/Miocene faunal change is recorded by benthonic foraminifera close to the sample position CC24/25.

This indicates that the most important part of the "critical time–span" and the important biochronologic datum levels in relation to the Palaeogene/ Neogene boundary are missing in this section.

Summarizing all these facts the Case Cocuzza section is *not* suitable to serve as a Palaeogene/Neogene boundary stratotype section.

Costa dell'Angelo Section (Fig. 20).

The lower part of the section including sample CA22 is assigned by all three calcareous nannoplankton specialists to the *Triquetrorhabdulus carinatus* - NP25 Zone. C. Mueller also assignes sample CA23 to this zone. Sample CA24 is to poor in nannofossils to give an age indication. Unanimously samples CA25 to CA27 are assigned to the *Helicosphaera ampliaperta* - NN4 Zone since the nominating taxon was also recorded in sample CA27 by one author. According to these results a major hiatus covering the calcareous nannoplankton Zones NN1 and NN2 to NN3 exists between samples CA24 and CA25.

The same results were achieved by eleven specialists working on the planktonic foraminifera of this section. Up to sample CA24 the continuous occurrence of *G. angulisuturalis* and the scattered occurrence of *G. ciperoensis*

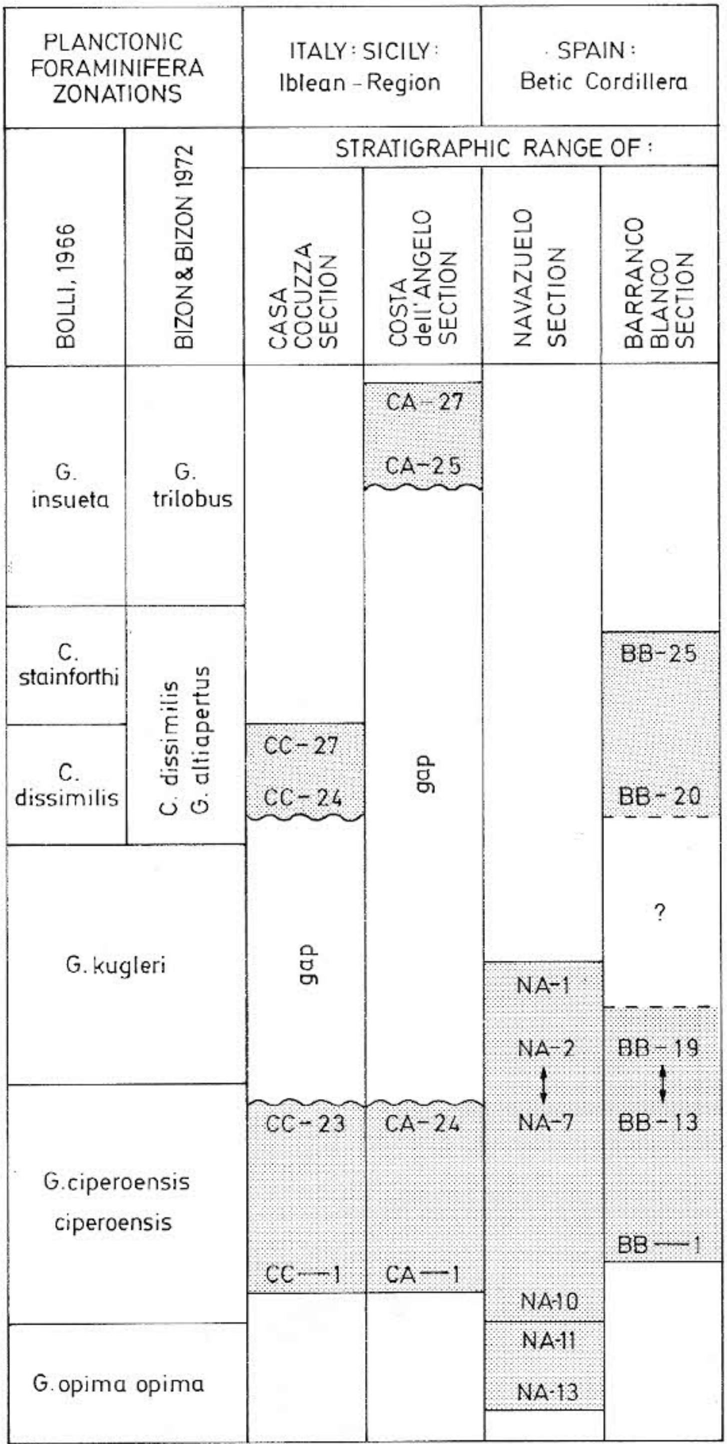


Fig. 20 — Biostratigraphic range of Italian and Spanish sections in relation to the "critical time–span" of the Palaeogene/Neogene Boundary.

assign this part of the section to the *G. ciperoensis* Zone. In sample CA25 the occurrence of *G. quadrilobatus triloba*, *G. dehiscens*, *G. woodi woodi* and others together with the unanimously agreed upon occurrence of *G. sicanus* places the upper part of the section into the *G. insueta* Zone of Bolli (1966) respectively into the upper part of the *G. trilobus* Zone of Bizon & Bizon (1972).

The major hiatus between CA24 and CA25 covers at last the *G. kugleri*, the *C. dissimilis*, the *C. stainforthi* Zones of Bolli (1966) respectively the *G. kugleri*, *G. primordius*, *C. dissimilis / G. altiapertus* and parts of the *G. trilobus* Zones of Bizon & Bizon (1972). A time–span of several - five to six - million years.

Benthonic foraminifera also indicate Oligocene age to sample CA23 and Middle Miocene forms are recorded from sample CA25.

This indicates that the most important part of the "critical time span" and the important biochronologic datum levels in relation to the Palaeogene/Neogene boundary are completely missing in this section.

Summarizing all these facts the Costa dell'Angelo section is *not* suitable to serve as a Palaeogene/Neogene boundary stratotype section.

Spain: Betic Cordilleras.

Navazuelo Section (Fig. 20).

Calcareous nannoplankton results are more or less consistent; according to three specialists the entire section belongs to the *Sphenolithus ciperoensis* - NP25 Zone. C. Mueller suggested that *Triquetrorhabdulus carinatus* - NN1 Zone might be represented in the uppermost part of the section (sample NA4 upwards). However, since NP25 markers occur till to the top of the section and no Miocene indicators are present it was generally agreed upon that only NP25 Zone is present in the studied part of the section.

In contrary results of the eleven specialists studying the planktonic foraminifera record are more inconsistant, especially as far as the "critical-time span" is concerned: the lower part of the section (sample position NA13–11) belongs to the *G. opima opima* Zone of Bolli (1966). In the upper part (sample position NA10 to NA1) the *G. ciperoensis* Zone and the *G. kugleri* Zone were recorded. However, no agreement was found on the boundary position between these two zones. According to the different authors the boundary would fall between sample position NA7 and NA2. All authors agreed that sample position NA2 and NA1 for sure belong to the *G. kugleri* Zone.

It is most important to remark that *G. dehiscens* was unanimously identified with typical forms by all specialists frequently in sample NA5 and a serious candidate considered as a predecessor of it, *G. venezuelana*, in samples below (to this question compare also Borsetti et al., 1983).

Benthonic foraminifera indicate an Oligocene age throughout the entire section.

One of the most important biochronologic datum levels for the Palaeogene/Neogene boundary the FOD of *Globoquadrina dehiscens* (Chapman, Parr & Collins) is present at sample NA5 in the *G. kugleri* Zone. However, the boundary between the *G. ciperoensis* Zone and the *G. kugleri* Zone is debatable and the boundary between the *G. kugleri* Zone and the *C. dissimilis* Zone was not recorded, since the upper part of the section is partly covered and the continuity of outcrops is very doubtful. Therefore the "critical time-span" could not be recorded. The section itself shows various internal sedimentary complications and tectonic structures.

Summarizing all these facts the Navazuelo section is *not* suitable to serve as a Palaeogene/Neogene boundary stratotype section.

Barranco Blanco Section (Fig. 20).

Calcareous nannoplankton studies of four specialists are consistent and record inclusive sample BB19 the *Sphenolithus ciperoensis* - NP25 Zone. Associations between samples BB20 to BB25 seem to belong already to the *Discoaster druggii* - NN2 Zone. Since *D. druggii* was not recorded in sample BB20 C. Mueller suggested that this part of the section might correlate to the *Triquetrorhabdulus carinatus* - NN1 Zone.

Results of twelve specialists of planktonic foraminifera came to a biostratigraphic picture comparable to the Navazuelo section: *G. ciperoensis* Zone was recorded from the base upwards, the boundary to the *G. kugleri* Zone falls according to the different authors in between samples BB13 and BB19.

Two important markers were recorded nearly by all specialists in sample BB19: the FOD of *G. dehiscens* and the FOD of *G. woodi woodi.* The upper part of the section (BB20 to BB25) belongs according to all authors to the *C. dissimilis* Zone of Bolli (1966) respectively to the *C. dissimilis/G. altiaperturus* Zone of Bizon & Bizon (1972).

Benthonic foraminifera studies gave the same result: up to sample BB19 Oligocene forms and from sample BB20 upwards Miocene forms. Unfortunately a major event with an abrupt change of facies and a hiatus separates the lower part (BB1 to BB19 - the "Ciudad Granada Fm.") from the upper part (BB20 to BB25: Espejos Fm.) of the section. The upper part might even belong to an other tectonic unit and therefore be only in tectonic contact with the lower part.

Two of the most important biochronologic datum levels for the Palaeogene/Neogene boundary, the FOD of *Globoquadrina dehiscens* (Chapman, Parr & Collins) and the FOD of *Globigerina woodi woodi* Jenkins, have been recorded in sample BB19 within the *G. kugleri* Zone. However, the boundary between the *G. kugleri* Zone and the *C. dissimilis* Zone is represented in this section by a hiatus and the boundary between the *G. ciperoensis* Zone and the *G. kugleri* Zone is not clear. In this respect the "critical-time span" was not recorded in its biochronologic sense. The section itself is heavily tectonised in its lower part.

Summarizing all these facts the Barranco Blanco section is *not* suitable to serve as a Palaeogene/Neogene Boundary stratotype section.

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PLATE 34

Nannoplankton from Case Cocuzza and Costa dell'Angelo sections.

Fig. 1,2 – *Helicosphaera ampliaperta* Bramlette & Wilcoxon. Sample CA25.

Fig. 3,4 – *Sphenolithus heteromorphus* Deflandre. Sample CA25. 3) Long axis at 0° to crossed nicols; 4) long axis at 45° to crossed nicols.

Fig. 5,6 – *Helicosphaera carteri* (Wallich) Kamptner. Sample CC26.

Fig. 7,8 – *Discoaster* sp. cf. *druggii* Bramlette & Wilcoxon. Sample CC25.

Fig. 9,10 – *Helicosphaera recta* (Haq) Martini. Sample CC4.

Fig. 11 – *Cyclicargolithus abisectus* (Mueller) Bukry. Sample CA13.

Fig. 12 – *Dictyococcites bisecta* (Hay, Moher & Wade) Bukry & Percival. Sample CA3.

Fig. 13,14 – *Zygrhablithus bijugatus* Deflandre. 13) From Costa dell'Angelo section, sample CA13; 14) from Case Cocuzza section, sample CC4.

Fig. 15-17 – *Sphenolithus ciperoensis* Bramlette & Wilcoxon. 15) and 16) from Costa dell'Angelo section, sample CA3: 15) long axis at 0° to crossed nicols; 16) long axis at 45° to crossed nicols; 17) from Case Cocuzza section, sample CC4: long axis at 45° to crossed nicols.