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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
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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

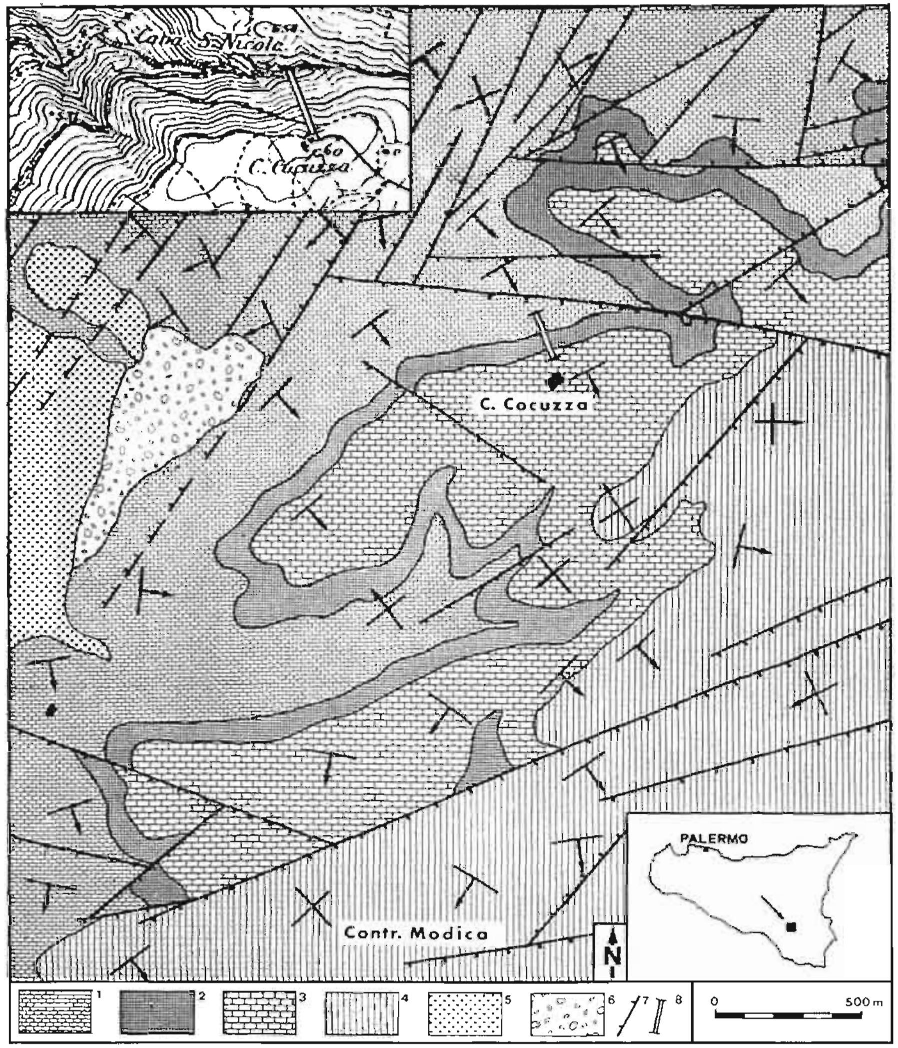

Fig. 1 – Geological map of the Case Cocuzza area.
1) Alternating marls and calcarenites (Ragusa Fm. - Leonardo Mb.). 2) Massive bedded calcarenite level (Ragusa Fm. - Irminio Mb.). 3) Alternating marls and calcarenites (Ragusa Fm. - Irminio Mb.). 4) Alternating marls and calcarenites (Tellaro Fm.). 5) 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

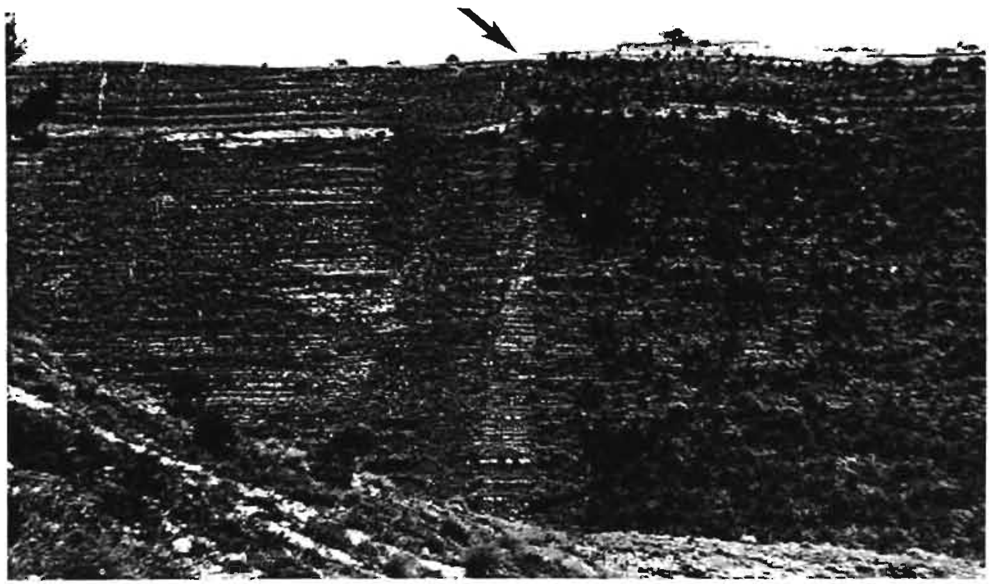

Fig. 2 – View of the Case Cocuzza section; the arrows indicate the top and the bottom.

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,

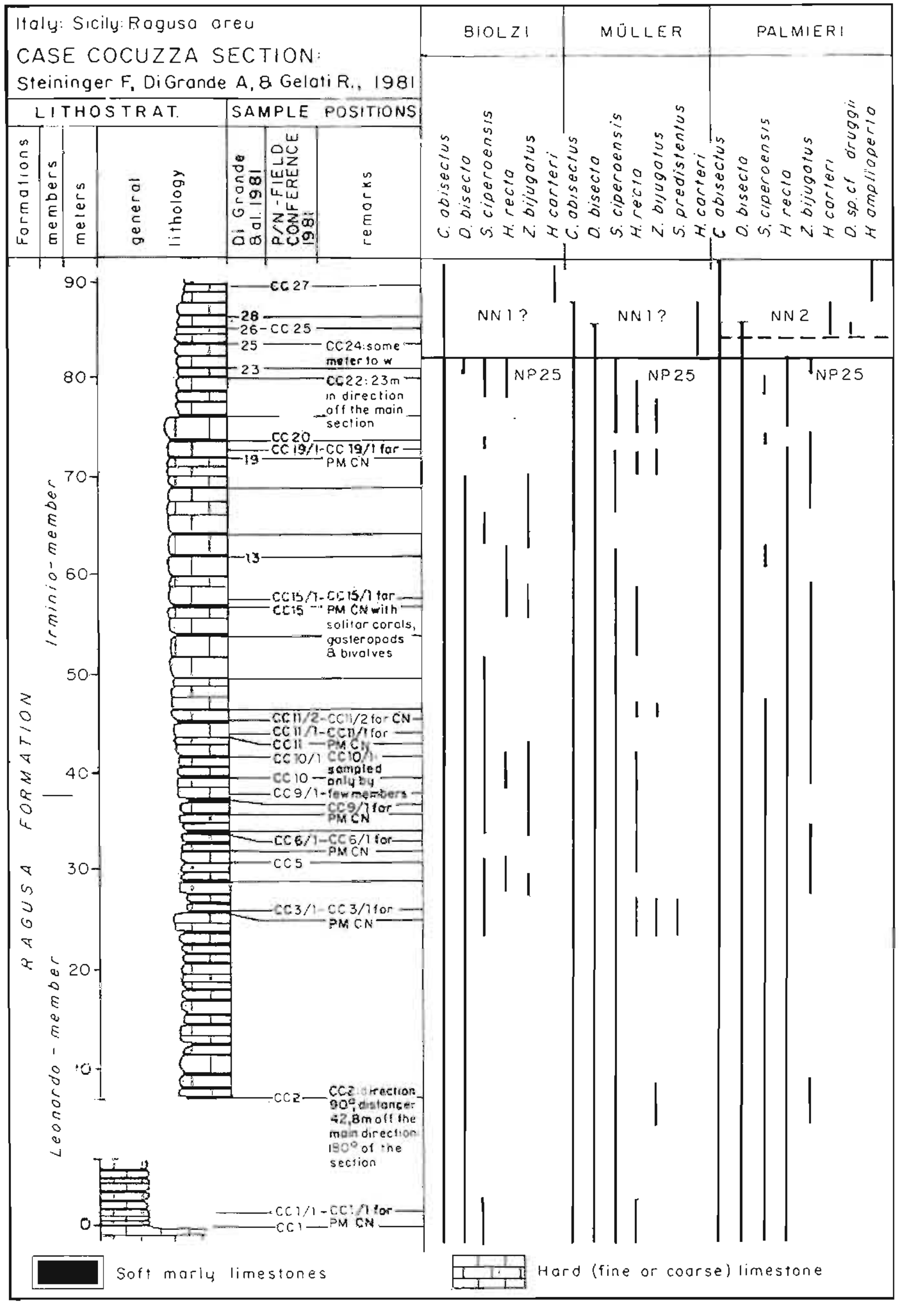

Fig. 3 – Distribution of the stratigraphically most important nannofossil species and biostratigraphic zonations (Martini, 1971) proposed by each author in Case Cocuzza section.

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.

As shown in Fig. 4 representatives of the genus *Globigerinoides* occur throughout the section. The taxa *Globigerinoides quadrilobatus triloba* (Reuss) and *G. altiapertnrus* 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 pre-

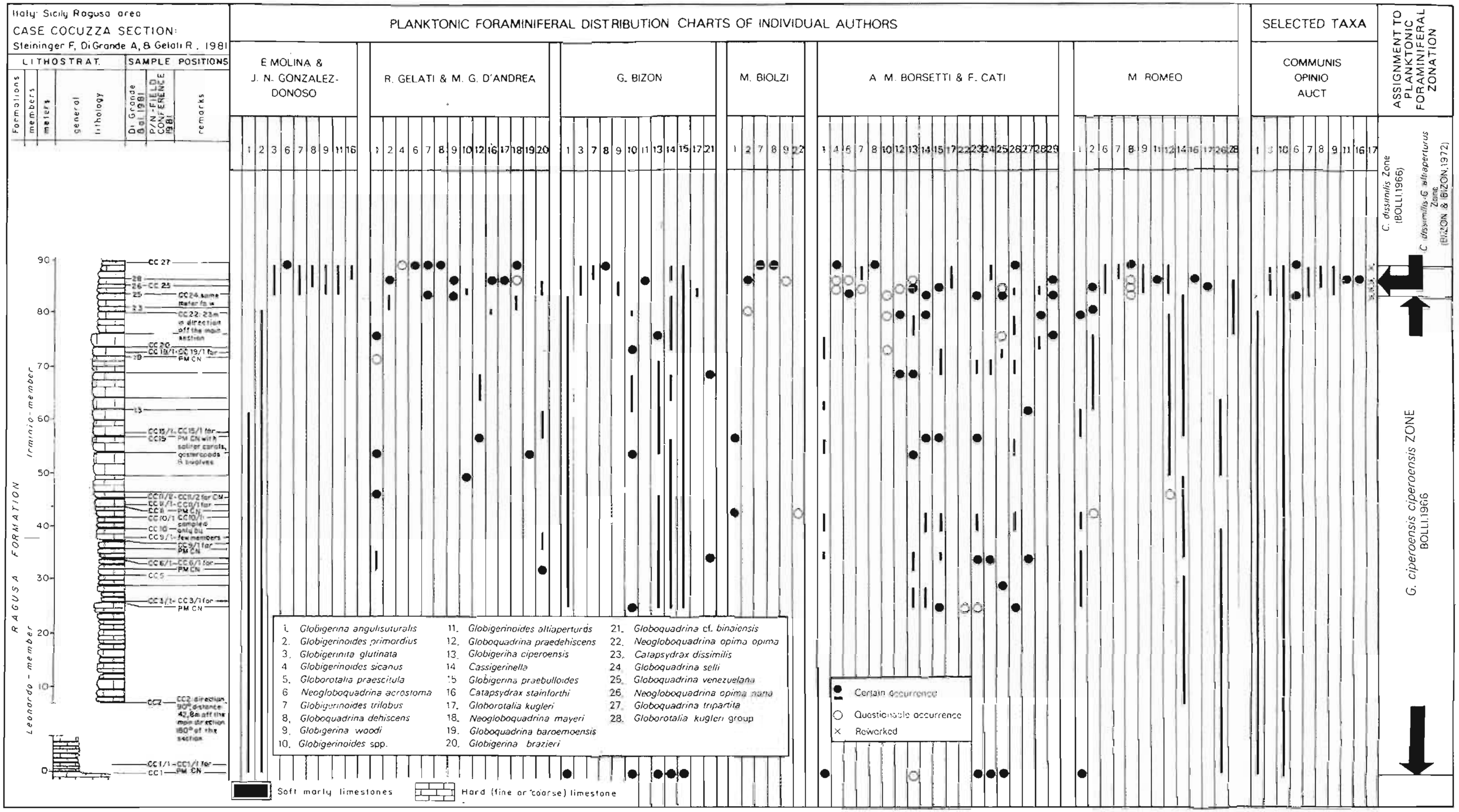

Fig. 4 – Distribution of planktonic foraminifera in Case Cocuzza section (Sicily).

sented 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).

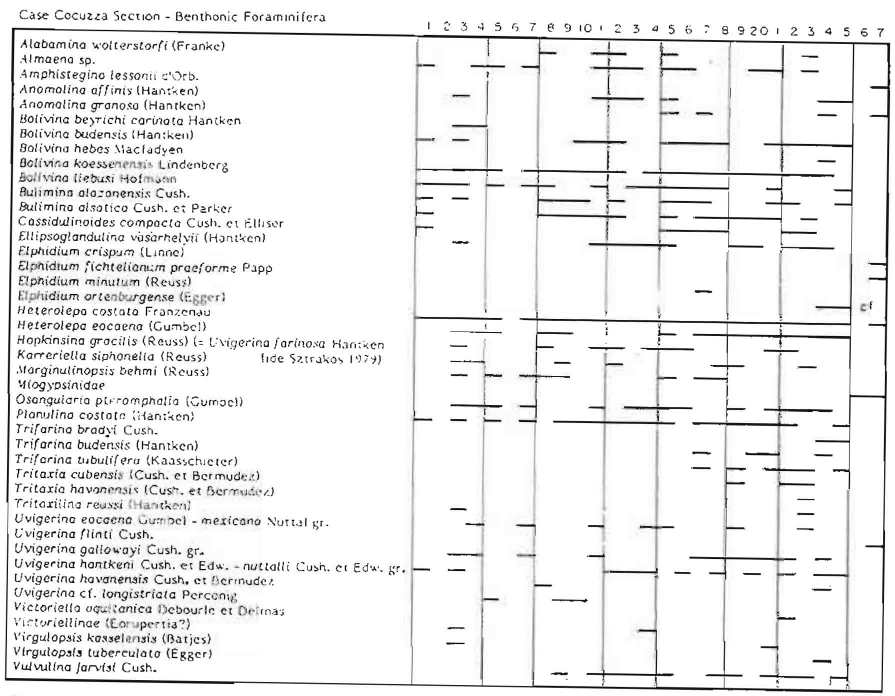

Fig. 5 – Distribution of benthonic foraminifera in Case Cocuzza section.

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

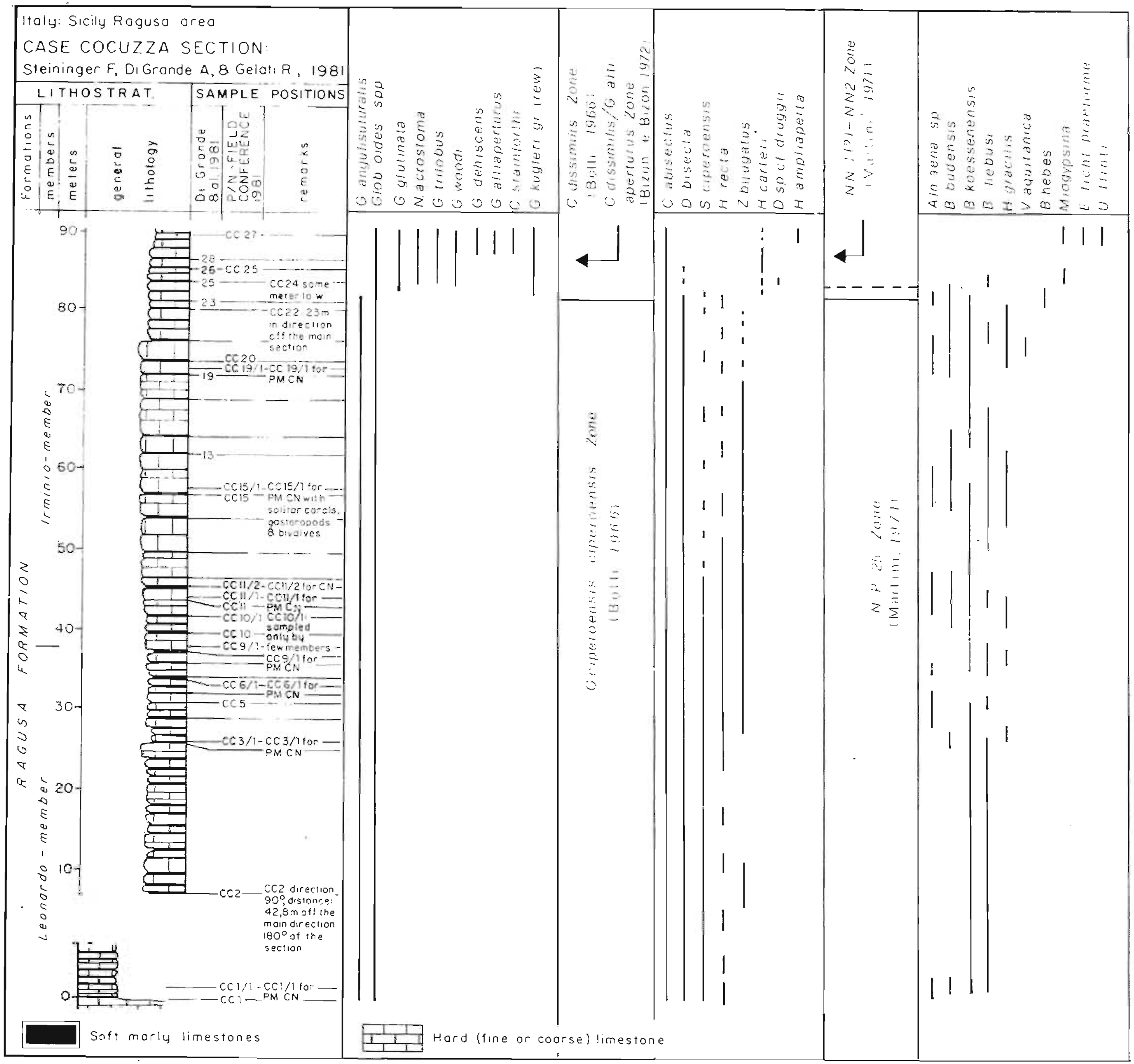

Fig. 6 – Biostratigraphy of Case Cocuzza section.

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. altiapertiurus.* 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.

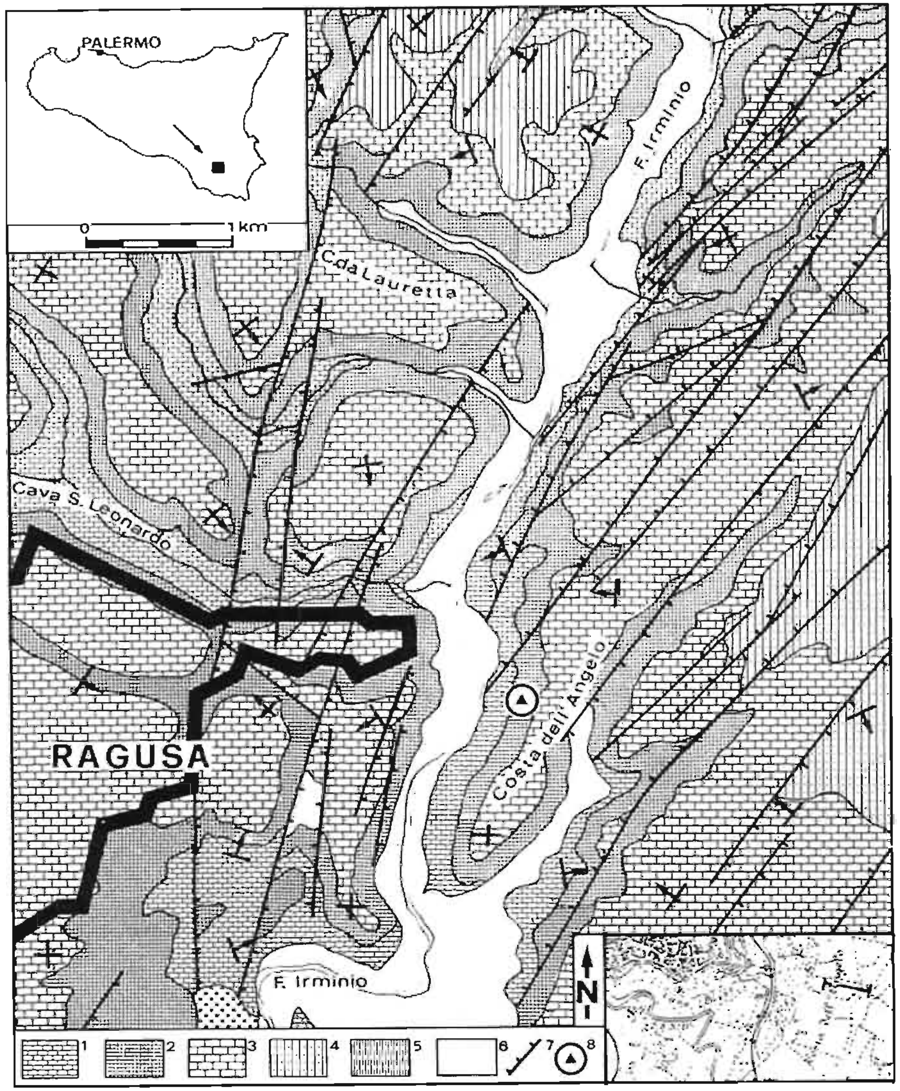

Fig. 7 – Geological map of the Costa dell'Angelo area.
1) Alternating marls and calcarenites (Ragusa Fm. - Leonardo Mb.). 2) Massive bedded calcarenite level (Ragusa Fm. - Irminio Mb.). 3) Alternating marls and calcarenites (Ragusa Fm. - Irminio Mb.). 4) Alternating calcarenites and marls (Tellaro Fm.). 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.

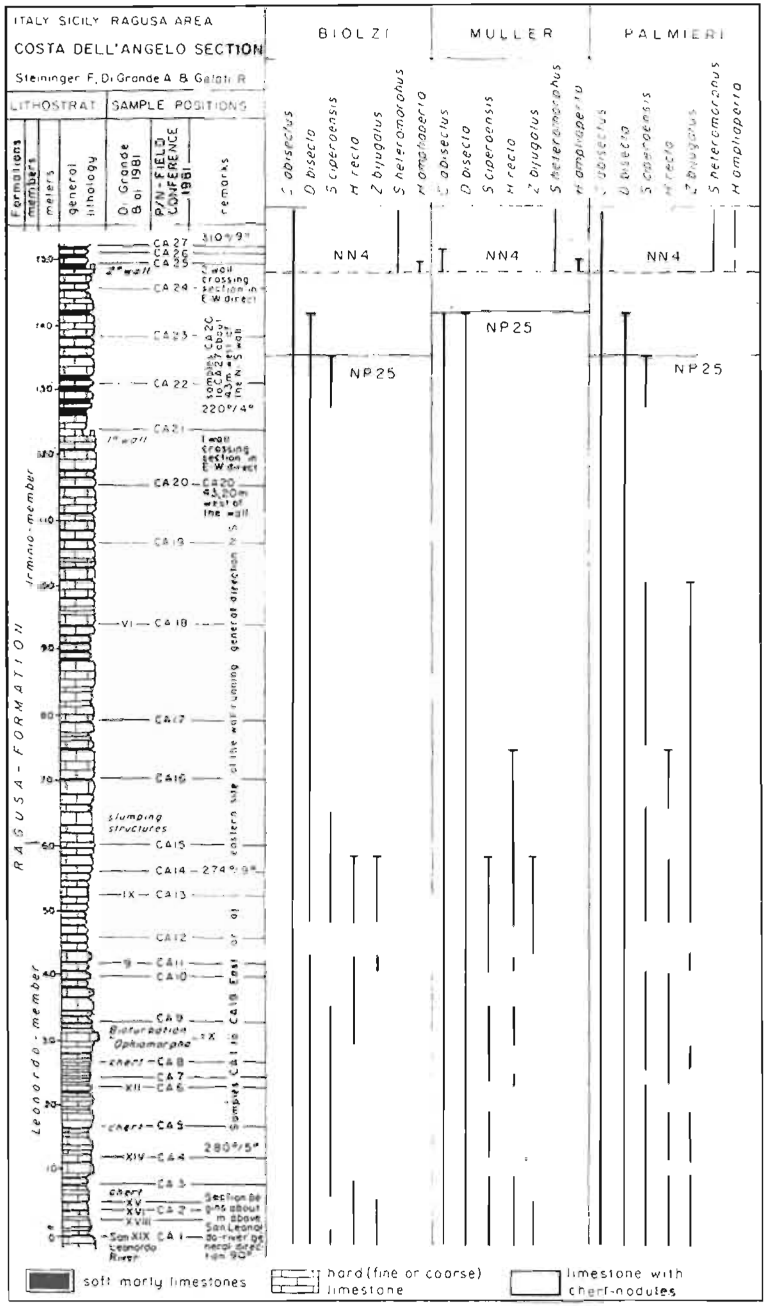

Fig. 9 – Distribution of the stratigraphically most important nannofossil species and biostratigraphic zonations (Martini, 1971) proposed by each author in Costa dell'Angelo section.

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 between 47m 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.

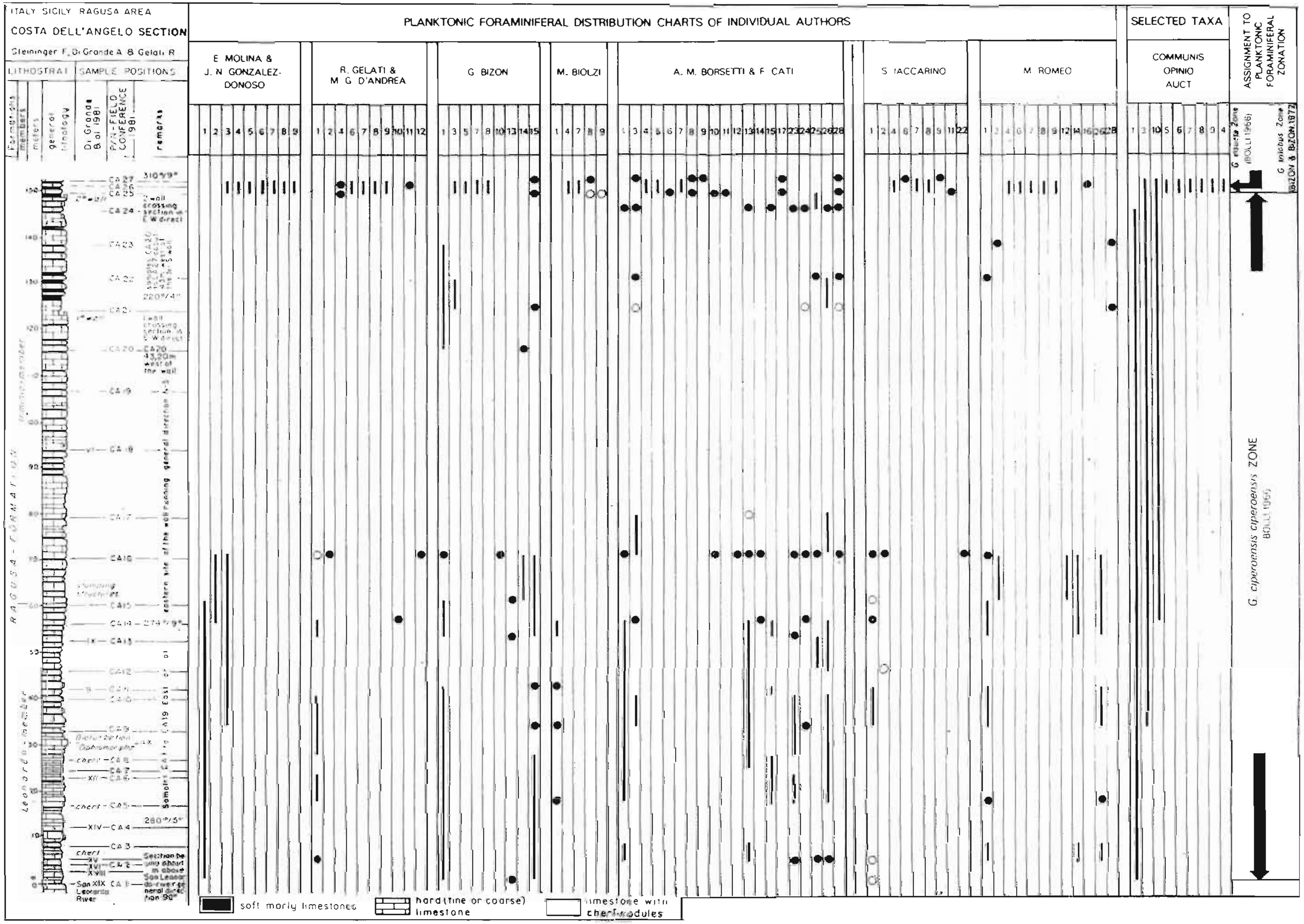

Fig. 10 – Distribution of planktonic foraminifera in Costa dell'Angelo section (Sicily). For explanation of arabic numerals, solid lines, open (closed) circles, see caption Fig. 4.

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.

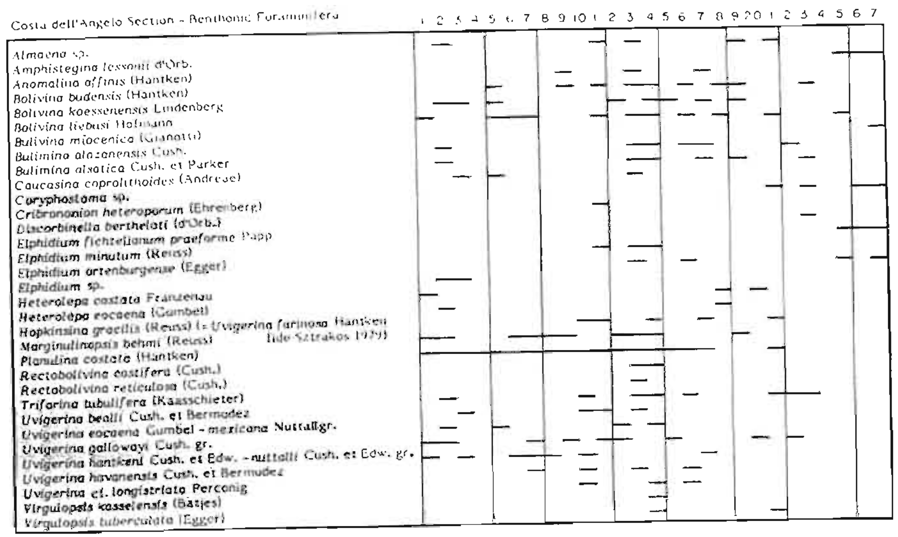

Fig. 11 – Distribution of benthonic foraminifera of Costa dell'Angelo section.

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. altiapertura* – 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.

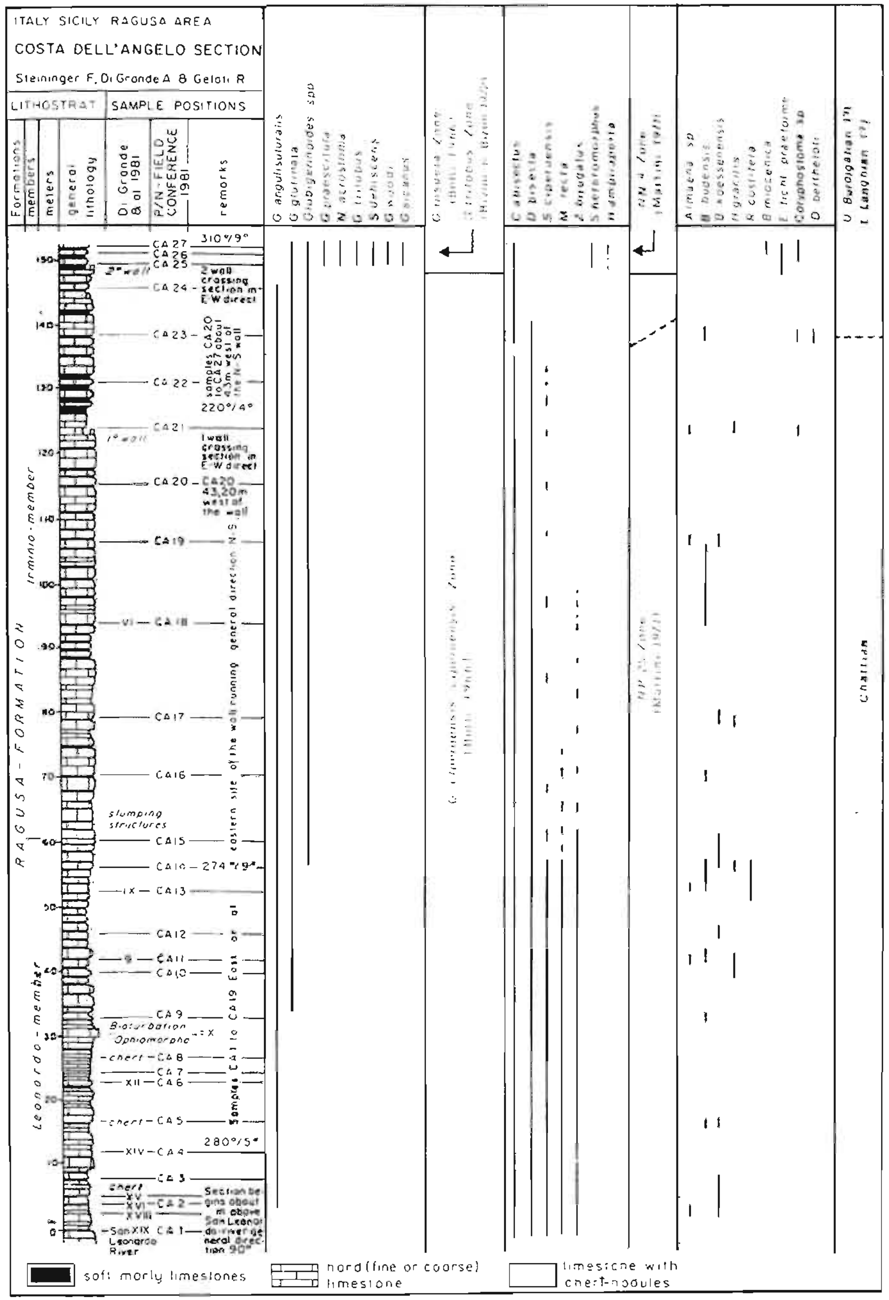

Fig. 12 – Biostratigraphy of Costa dell'Angelo section.

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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.

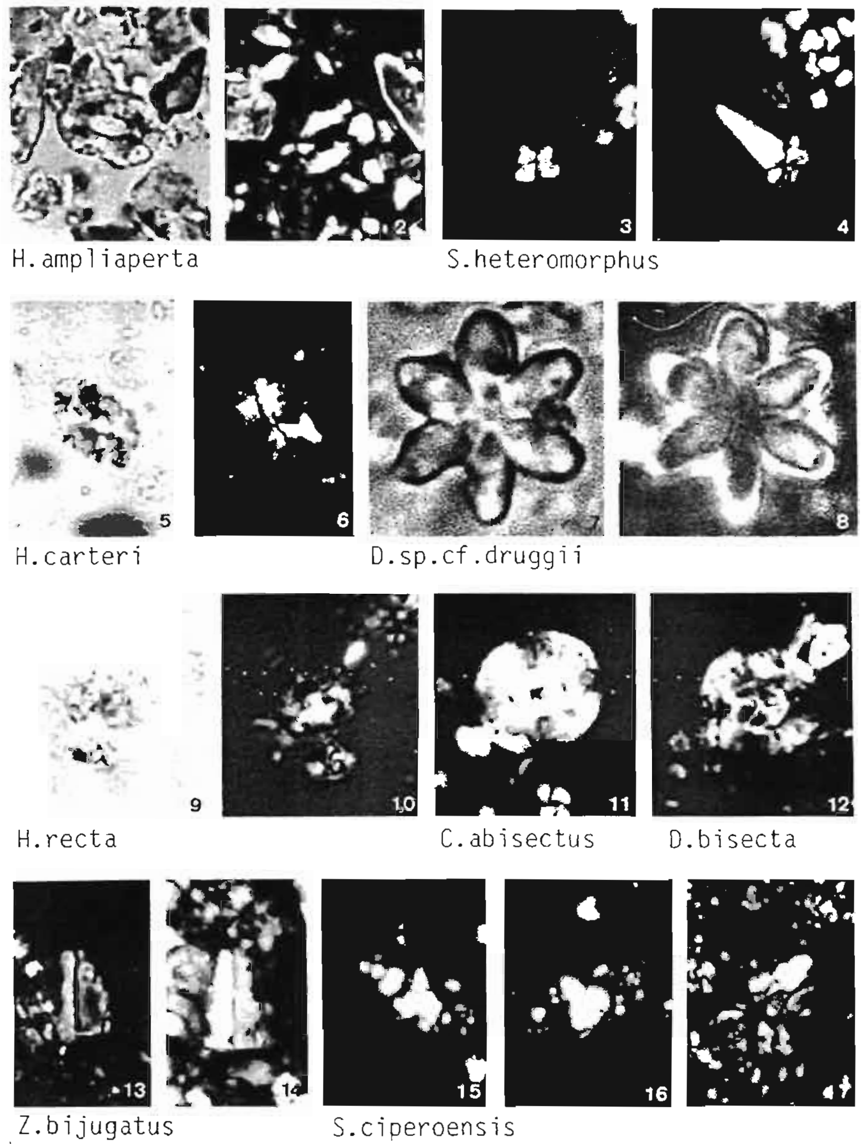

PLATE 35

Planktonic foraminifera from Case Cocuzza section.

Fig. 1 – *Globigerina woodi woodi* Jenkins. Sample CC26; x 125.

Fig. 2 – *Globigerinoides quadrilobatus triloba* (Reuss). Sample CC27; x 125.

Fig. 3 – *Globoquadrina dehiscens* (Chapman, Parr & Collins). Sample CC27; x 125.

Fig. 4 – *Globigerina angulisuturalis* Bolli. Sample CC23; x 125.

Fig. 5 – *Catapsydrax stainforthi* Bolli, Loeblich & Tappan. Sample CC26; x 125.

Fig. 6 – *Globigerinita glutinata* (Egger). Sample CC26; x 125.

Fig. 7,8 – *Globigerinoides altiaperturus* Bolli. Sample CC26; x 125.

Fig. 9,10 – *Globigerinoides quadrilobatus primordius* Blow & Banner. Sample CC12; x 75.

Fig. 11-13 – *Globorotalia kugleri* Bolli. Sample CC25; x 125.

Fig. 14 – *Neogloboquadrina acrostoma* (Wezel). Sample CC27; x 125.

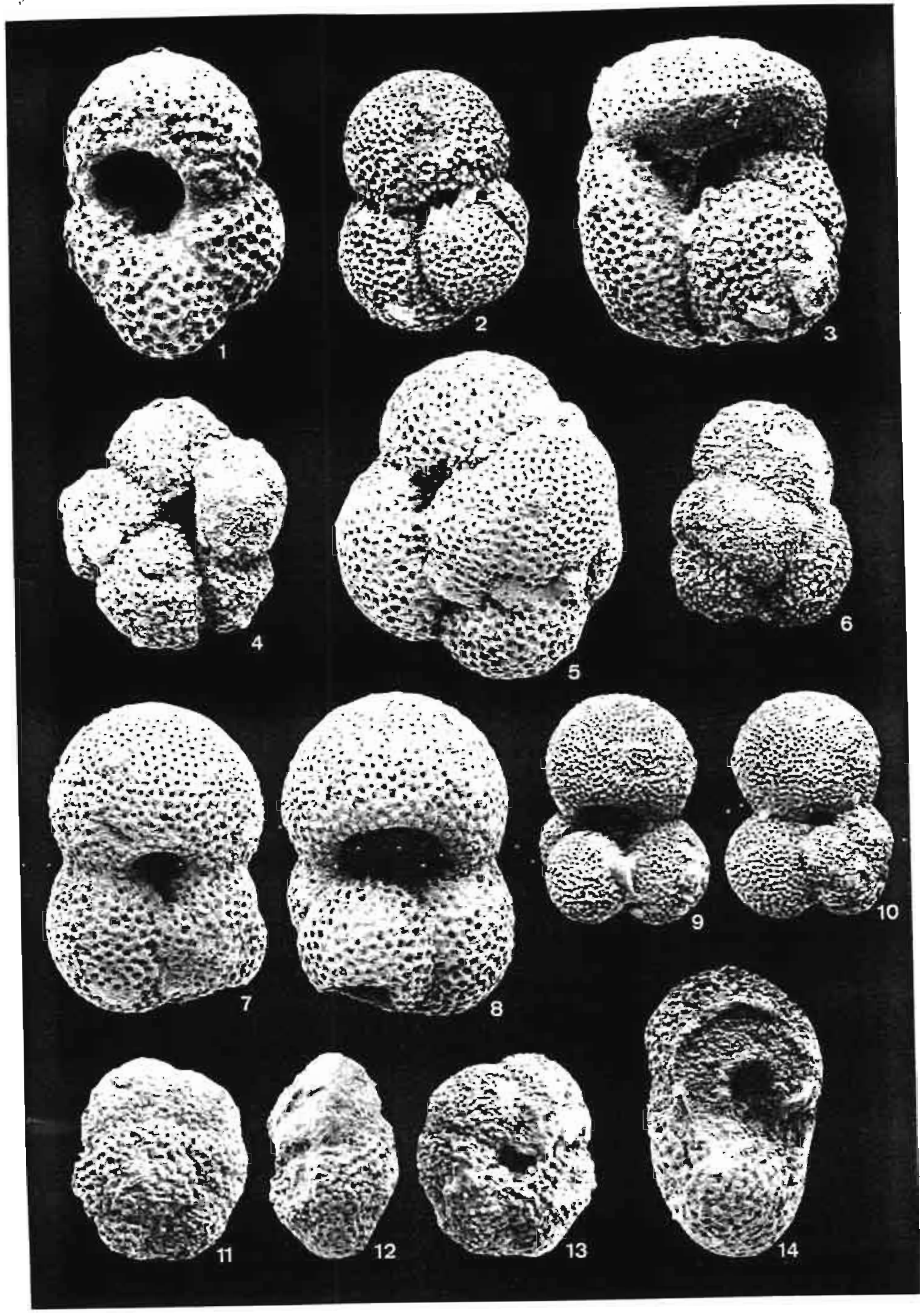

PLATE 36

Planktonic foraminifera from Costa dell'Angelo section.

Fig. 1,4 – *Globigerina angulisuturalis* Bolli. Sample CA9; x 125.

Fig. 2 – *Cassigerinella chipolensis* (Cushman & Ponton). Sample CA15: x 250.

Fig. 3 – *Globoquadrina dehiscens* (Chapman, Parr & Collins). Sample CA25: x 125.

Fig. 5 – *Globigerinoides quadrilobatus triloba* (Reuss). Sample CA27: x 125.

Fig. 6 – *Globigerina woodi woodi* Jenkins. Sample CA27; x 125.

Fig. 7,8 – *Globorotalia praescitula* Blow. Sample CA25: x 125.

Fig. 9,10 – *Globigerinoides quadrilobatus primordius* Blow & Banner. Sample CA16; x 75.

Fig. 11-13 – *Neogloboquadrina acrostoma* (Wezel). Sample CA25: x 125.

Fig. 14 – *Globigerinoides sicanus* De Stefani. Sample CA27; x 125.

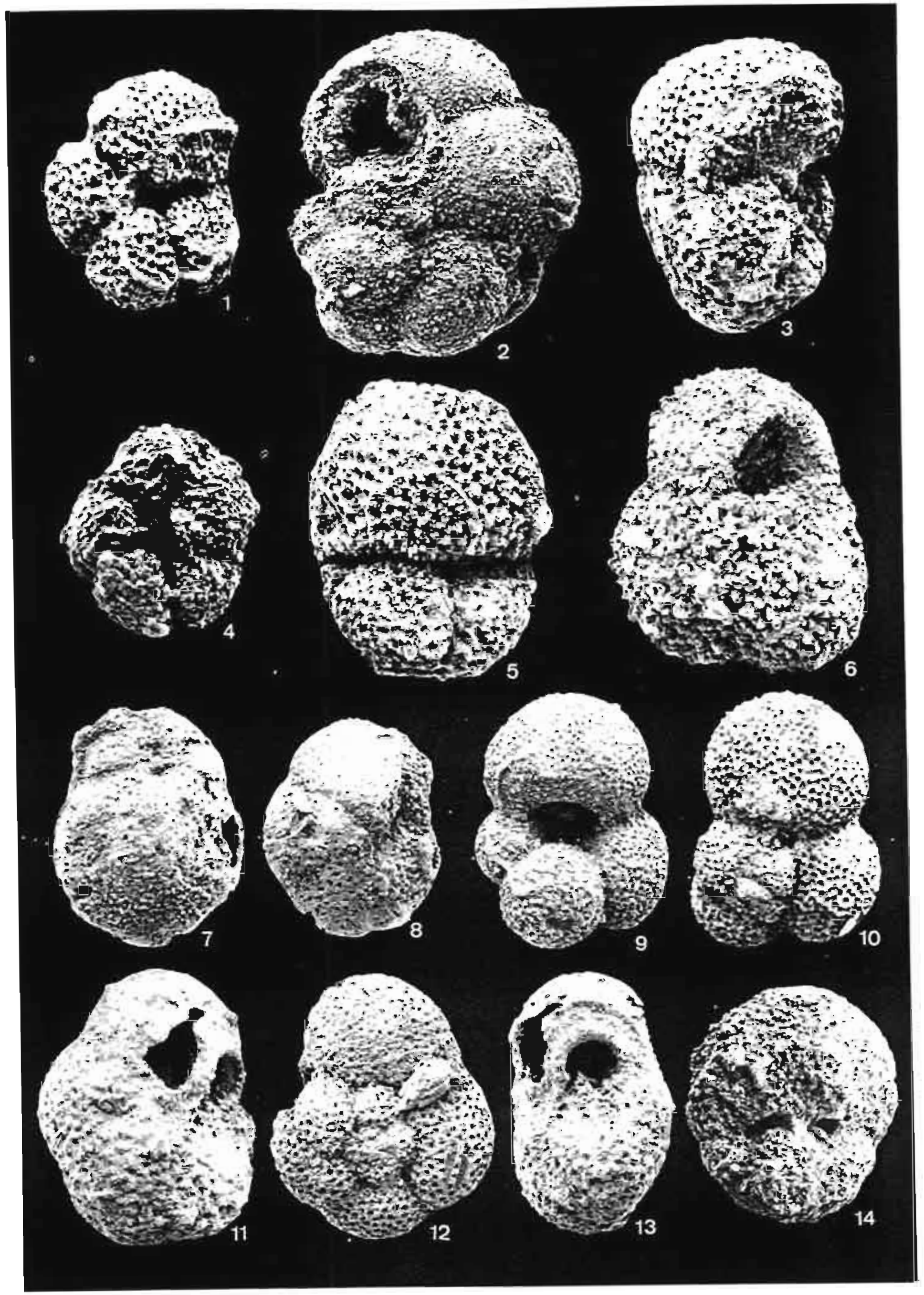

PLATE 37

Benthonic foraminifera from Case Cocuzza and Costa dell'Angelo sections.

Fig. 1 – *Marginulinopsis fragaria* (Guembel). Sample CC15; x 50.

Fig. 2 – *Vaginulina* cf. *aculeata* (Cushman & Gray). Sample CC15; x 50.

Fig. 3 – *Bolivina reticulata* Hantken. CA21; x 110.

Fig. 4 – *Bolivina hebes* Macfadyen. Sample CC25; x 150.

Fig. 5,8 – *Bolivina koessenensis* Lindenberg. Sample CC15; 5) x 100; 8) enlargement of the younger part x 300.

Fig. 6 – *Bolivina budensis* (Hantken). Sample CA19; x 150.

Fig. 7 – *Bolivina miocenica* (Gianotti). Sample CA27; x 160.

Fig. 9 – *Rectobolivina costifera* (Cushman). Sample CA13; x 95.

Fig. 10 – *Virgulopsis pupoides* (Nyiro). Sample CA14; x 210.

Fig. 11 – *Bulimina alsatica* Cushman & Parker. Sample CA13; x 160.

Fig. 12 – *Uvigerina bealli* Cushman & Bermudez. Sample CC27; x 65.

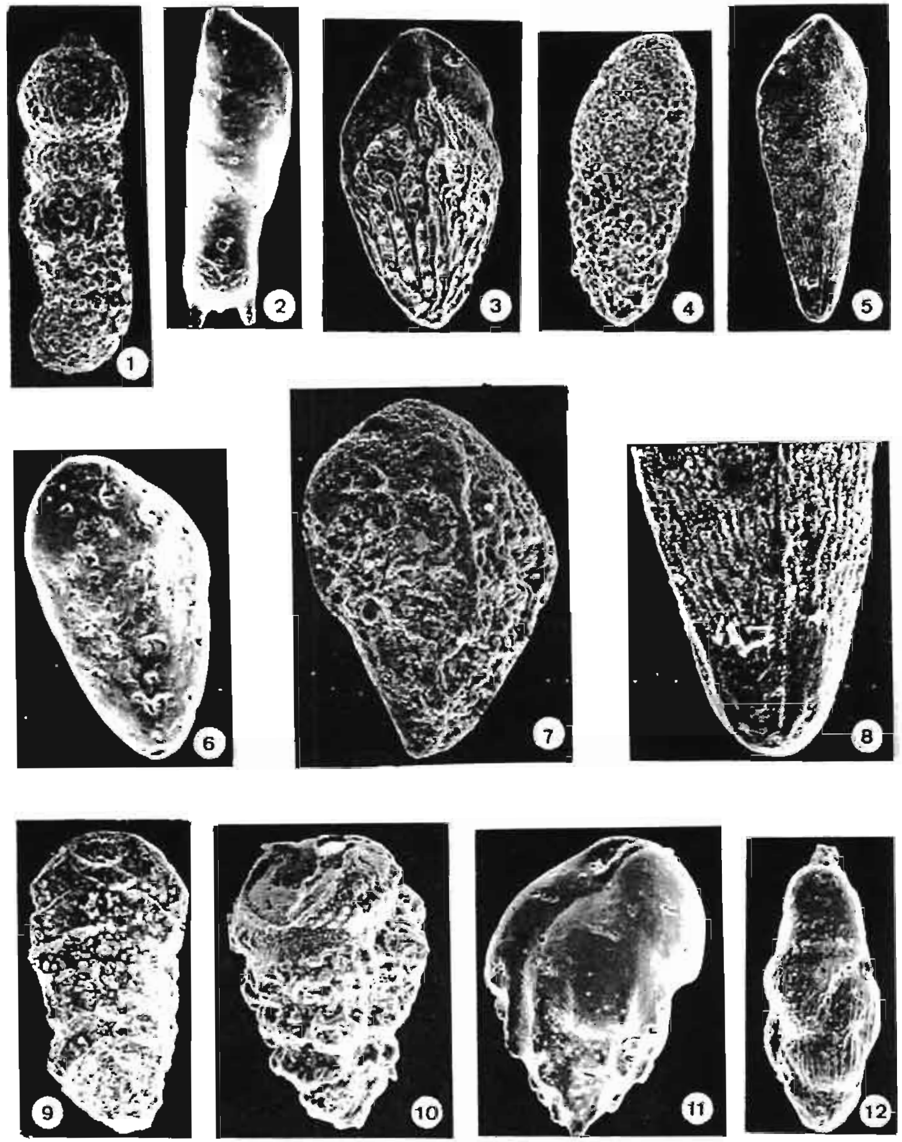

PLATE 38

Benthonic foraminifera from Case Cocuzza and Costa dell'Angelo sections.

Fig. 1 – *Uvigerina eocaena* Guembel *mexicana* Nuttal group. Sample CC15; x 125.

Fig. 2 – *Uvigerina gallowayi* Cushman group. Sample CC16; x 120.

Fig. 3 – *Uvigerina* cf. *longistriata* Perconig. Sample CA16; x 110.

Fig. 4 – *Rectuvigerina* cf. *elegans* (Hantken). Sample CC21; x 100.

Fig. 5 – *Uvigerina hantkeni* Cushman & Edwards *nuttalli* Cushamn & Edwards group. Sample CC15; x 100.

Fig. 6 – *Uvigerina flinti* Cushman. Sample CC27; x 110.

Fig. 7 – *Trifarina angulosa* (Williamson). Sample CC15; x 175.

Fig. 8 – *Siphouvigerina multicostata* (Bergquist). Sample CA13; x 130.

Fig. 9 – *Trifarina tubulifera* (Kaasschieter). Sample CA13; x 115.

Fig. 10 – *Hopkinsina gracilis* (Reuss). Sample CC22; x 100.

Fig. 11 – *Planulina costata* (Hantken). Sample CC15; x 95.

Fig. 12 – *Victoriella aquitanica* Debourle & Delmas. Sample CC23; x 30.

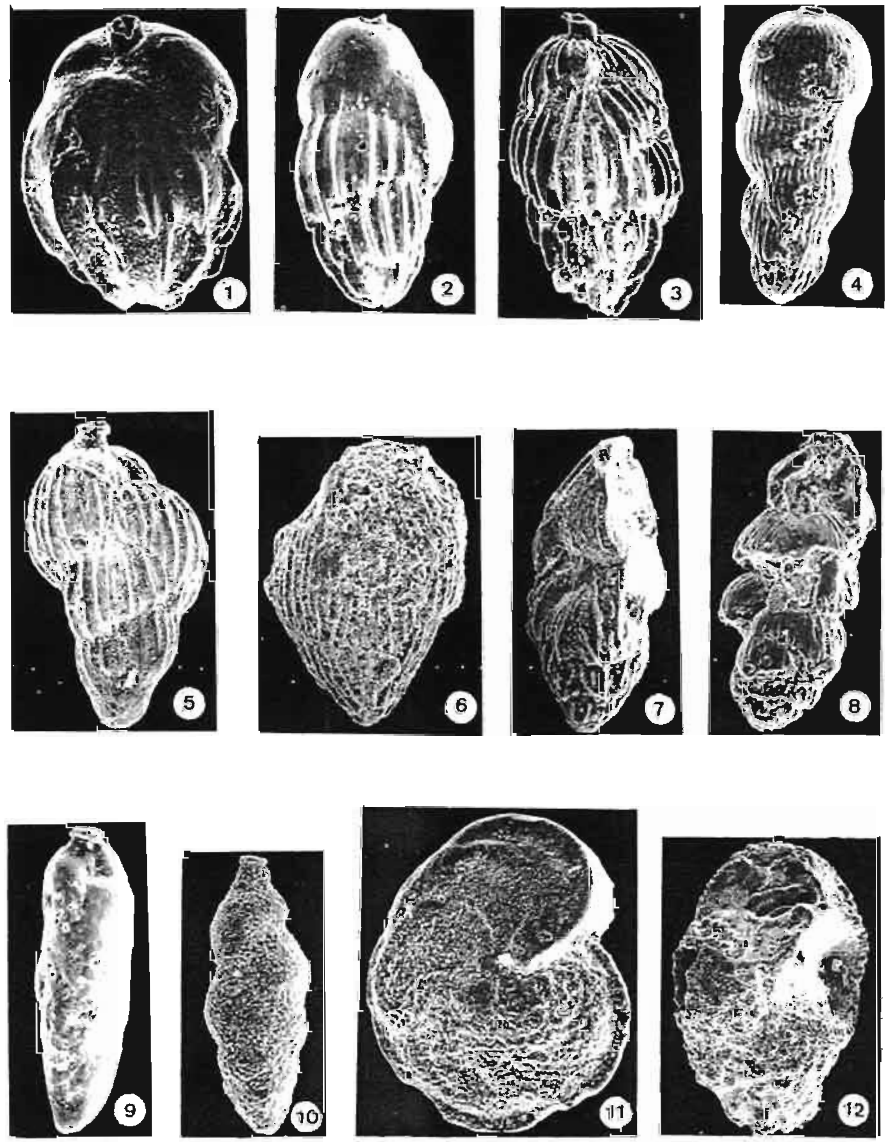

PLATE 39

Benthonic foraminifera from Case Cocuzza and Costa dell'Angelo sections.

Fig. 1 — *Elphidium crispum* (Linné). Sample CC27; x 65.

Fig 2 — *Elphidium fichtelianum praeforme* Papp. Sample CA25; x 125.

Fig. 3 — *Elphidium ortenburgense* (Egger). Sample CA16; x 150.

Fig. 4 — *Anomalina granosa* (Hantken). Sample CC15; x 50.

Fig. 5,6 — *Heterolepa costata* Franzenau. Sample CC15; x 65.

Fig. 7 — *Osangularia pteromphalia* (Guembel). Sample CC15; x 100.

Fig. 8,9 — *Almaena* sp. Both sides. Sample CC15; x 120.