UTRECHT MICROPALEONTOLOGICAL BULLETINS

A. A. H. WONDERS

MIDDLE AND LATE CRETACEOUS PLANKTONIC FORAMINIFERA OF THE WESTERN MEDITERRANEAN AREA

24

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A. A. H. WONDERS

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ABSTRACT

Planktonic foraminifera from sections in predominantly pelagic and hemipelagic sediments of Late Albian to Late Maastrichtian age in southern Spain, central Tunisia and northern Italy were studied. Their vertical distribution allows for the recognition of 21 zones. They are correlated with the calcareous nannofossil zonation of Verbeek (1977), which was essentially based on the same material.

Recent data from stratotypes allow for a rather detailed correlation with the chronostratigraphic scale.

An improved calibration of the planktonic biozonations and the Middle and Late Cretaceous magnetostratigraphic scale is proposed. Late Aptian, Late Albian and Cenomanian reversals are documented with micropaleontological evidence from the actual cores.

The systematics and phylogeny of several groups of Cretaceous planktonic foraminifera are discussed. The subdivision of post-Cenomanian globotruncanids into genera, as now widely accepted, is shown to be unrealistic from an evolutionary point of view. The genus *Globotruncana* Cushman is shown to be polyphyletic.

Turonian and younger globotruncanids can be subdivided into a number of natural groups by means of *conservative* diagnostic features, which remain constant throughout the ranges of the groups. Generic features appear to be *progressive* and develop analogously in each of the groups.

The evolution of Middle and Late Cretaceous planktonic foraminifera appears to be closely related to the occurrence of two major crises in the oxygenation of the World's ocean waters. Entirely new associations of keeled forms appear immediately after these anoxic events, which occurred during most of the Aptian and Albian and at the Cenomanian-Turonian boundary. A third event, close to the Santonian-Campanian boundary, is thought to be due to fundamental changes in the oceanic circulation pattern in relation with the opening history of the Atlantic Ocean. The Cretaceous-Tertiary boundary extinction is briefly discussed. Its explanation must be essentially different from that of the other three major events.

Taxonomic notes are made on the most important species. New generic names for apparently natural groups have not been introduced and incorrect names for important zonal markers have not been altered as this would hamper the comparison between the zonal scheme as proposed here and previous ones.

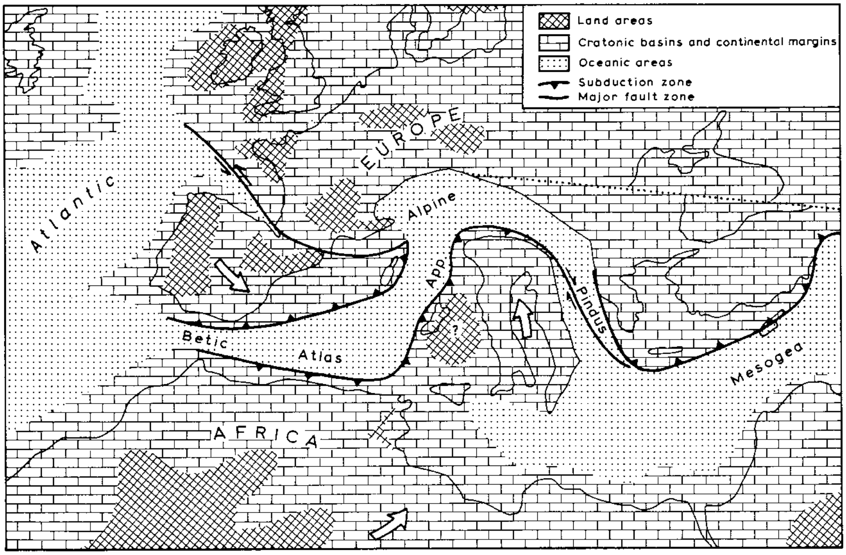

Fig. 1 Tentative reconstruction of the position of main continental blocks and oceanic areas (geosynclines) for the Late Santonian (80 Ma). Modified after VandenBerg (1979): the Balkan – Turkey block is situated about 400 km. farther E, as it is in his Early Tertiary reconstructions.

Chapter I

INTRODUCTION

During Cretaceous times, the configuration of continents, continental margins and oceanic areas was rapidly changing by successive transgressions and regressions, tectonic activity in general and plate tectonics in particular. These geologic events left their traces in Cretaceous rocks, both in their composition and fossil content.

Large areas of what is now Europe, the Mediterranean Sea and Northern Africa were covered by seas. Three main paleogeographic realms existed (fig. 1). One is the old European continental mass and shows a rather stable pattern of land areas and relatively shallow seas such as the Paris-Hampshire basin, the North Sea basin and the Aquitaine basin. The second realm was situated in what is now the European and North African Alpine belt, where a great variety of paleogeographic units are recognized, from terrestric to oceanic, and from basins situated on stable continental blocks to geosynclines. The third realm is the large stable continent of Africa, where terrestric areas and shallow marine basins existed.

It is the sedimentary history of the European realm which led the geologists of the 19th century to subdivide the Cretaceous into a number of stages, separated from each other by breaks that were originally explained as being the result of catastrophic events, concurrent with drastic changes in fossil content. We now know that some of the supposedly catastrophic changes in fossil communities are due to hiatuses in the fossil record.

During the quiet transgressions and regressions on the European continent, the Alpine realm was the theatre of the creation and deformation of continental margins and geosynclines, of flysch deposition and of folding. This was caused by the differential movements of large crustal blocks in connection with the opening of the Atlantic Ocean. Consequently, the geological history of this realm may be subdivided into a number of episodes which have tectonic events as natural separations rather than being defined by sealevel changes.

The African Cretaceous resembles the European both in facies and fossil content, although it was deposited at the other side of the Tethys sea. Roughly the same transgression and regression phases may be recognized here, as they are reflected in a comparable succession of faunas. Differences between contemporaneous African and European fossil communities are mainly due to differences in paleolatitude. The fact that these differences are small points to a more equable climate over large areas than in recent times.

GEOLOGICAL AND PALEOGEOGRAPHICAL SETTING OF THE STUDIED SECTIONS IN THE WESTERN MEDITERRANEAN CRETACEOUS

Cretaceous marine rocks in the Western Mediterranean region may be subdivided into four major facies associations:

1. Carbonate platform facies with varying amounts of terrigenous clastics,
2. Continental slope facies,
3. Pelagic basin facies,
4. Flysch facies.

All facies associations were formed in a complex arrangement of depositional basins both inside and surrounding the "Tethys", which trended roughly E-W between Europe and Africa. Convergence of both continents since the Late Cretaceous has caused the closing of most Tethyan basins. Flysch type and associated sediments were squeezed out and now are almost invariably found in allochthonous positions in Alpine nappe systems. A good example is found in the western Alps and the northern Apennines, where the northern continental margin (carbonate platform sediments of the subalpine chains and the Provence, and more or less pelagic sediments of the Briançonnais and the Provence) is very close to the southern continental margin (Scaglia formations in the southern Alps and northern Apennines), with large nappes of Cretaceous flysch (mainly of the Helminthoid Flysch complex) thrusted towards both sides over these margins.

Our sections in Italy and Tunisia are on the southern continental margin bordering the Tethys. In contrast, the section in Spain is in sediments deposited on the northern basin margin, as suggested by the sequence of facies from North (Prebetic: carbonate platform to pelagic) to South (North Subbetic and Subbetic: mainly pelagic). However, the Spanish faunas are hardly different from those from Italy and Tunisia.

All material is from facies associations 2 and 3. The Spanish and Italian sections are in pelagic limestones which may be considered as fossil planktonic foraminiferal and nannoplankton oozes, whereas the Tunisian sediments rather are hemipelagic and assignable to continental slope and associated facies.

PLANKTONIC MICROFOSSILS AND THEIR IMPORTANCE IN BIOSTRATIGRAPHY

Planktonic foraminifera and calcareous nannofossils are marine organisms which thrived in all three paleogeographic realms. Their pelagic habitat in the upper water layers allowed them to become preserved in marine sediments of various types and of a wide range of depositional depths: from sublittoral to the Calcite Compensation Depth (CCD). In time, pelagic faunas and floras rapidly changed in composition and they provide a good tool in interregional correlation. Moreover, they are particularly abundant in pelagic sediments, which, unlike most other rocks, are apt to give a continuous record of contemporaneous pelagic life.

The aim of this study is to give a detailed record of the succession of planktonic foraminiferal faunas in the Albian and the Upper Cretaceous and to update the systematics and taxonomy of some major groups. A similar study on calcareous nannofossils was recently carried out by Verbeek (1977) on the same material from Spain, Tunisia and France. This enabled the present author to give a detailed integration of calcareous nannofossil and planktonic foraminiferal zonations. Correlations with the numerical, chronostratigraphic and magnetostratigraphic scales for the Cretaceous are proposed.

A BRIEF REVIEW OF THE EVOLUTION OF THE KNOWLEDGE OF CRETACEOUS PLANKTONIC FORAMINIFERA

Rather than to enumerate extensively all previous studies, which would fill this book with authors and titles, the main episodes in the development of our knowledge of Cretaceous foraminifera are summarized to illustrate the changing status of the group in micropaleontology and other geosciences.

Already in 1963, Cita signalized two main periods, one before and one after the beginning of intense study of Cretaceous foraminifera on behalf of petroleum industry. In our opinion, we might as well distinguish a period before and after the discovery of the biostratigraphic importance of Cretaceous planktonic foraminifera by Thalmann (1934) and the first extensive biostratigraphic application by Renz (1936). Before the publication of Renz's excellent work, based on thin sections only, species and genera were only incidentally described, somewhat "at random", and often as accessory elements in faunas dominated by benthic forms. One exception is the interesting study of De Lapparent (1918), who already described the enormous morphologic variation in *Rosalina linnei* and its significance for biostratigraphy. French paleontologists still commonly refer to globotruncanids as "les Rosalines".

The relative ignorance of the importance of the group is characteristically illustrated by the various generic assignments of new species during this period: *Pulvinulina, Rotalia, Planulina, Rosalina* – all benthic genera. The period ended with the eventual recognition of the planktonic nature, the worldwide distribution and the Late Cretaceous age of the group, at first by Thalmann (1934), and later on by all subsequent authors, although not immediately. Brotzen (1934) still described the species *elevata* and *concavata* as *Rotalia* and the same author (1942) considered *Rotalipora* as the predecessor of the Cymbaloporidae.

After 1934, descriptive studies of Cretaceous planktonic foraminifera became more and more frequent, in Europe mainly as a result of scientific interest as first (Renz, 1936; Gandolfi, 1942), later also as a result of the interest of petroleum geologists, which, in turn, activated scientific workers. During the fifties, numerous new species and genera were described, e.g. by Mornod (1950), Sigal (1952), Hofker (1956), Bolli, Loeblich & Tappan (1957), Reiss (1957), Gandolfi (1957) and Bronnimann & Brown (1958). This descriptive period continued in the sixties, partially with new studies of the same authors, partially by others. More stress was put on the biostratigraphic value of the group and detailed zonations of the Upper Cretaceous were proposed (Bolli, 1966; Pessagno, 1967; Van Hinte, 1963, 1969; and others). Cretaceous planktonic foraminifera were also studied biometrically, a field of study which has never become very popular because of the immense variability in forms during growth and the ensuing complexity of the results, even when only small groups of species were involved (Klaus, 1960; Caron, 1966). Pessagno (1967) gave biometrical values to characterize rather than to differentiate between taxa.

At the end of the sixties, the knowledge had increased enormously, as had the number of synonyms and the resulting amount of taxonomic confusion. Cita (1963) already pleaded for a thorough revision, which, to some extent, was given by Pessagno (1967). Subsequent descriptions of new taxa, however, have shown that Cita's fear of such a revision to be premature was justified.

The start of the Deep Sea Drilling Program in 1968 marked the beginning of a third period. Planktonic foraminifera turned out to be of enormous utility in dating cores, estimating depositional depths by their differential resistance against solution at great depths, and in reconstructions of paleocirculation systems. Authors who had already been working on the paleoecology of Cretaceous planktonic foraminifera (e.g. Douglas & Sliter, 1966) were provided with a wealth of new data and by invoking new tools such as Oxygen and Carbon isotope analysis and extrapolating the paleoecology of recent planktonic foraminifera, new conclusions could be drawn (Douglas & Savin, 1978). The Cretaceous and Paleocene geomagnetic reversal sequence, already known from magnetic anomaly profiles across parts of the oceans, were recognized in a land section in pelagic sediments at Gubbio, Italy (Alvarez et al., 1977) and a revision of the ages of marine magnetic anomalies could be given (Larson, 1977).

Some authors continued the inventarization work (Wonders, 1975; Lamolda, 1976, 1977; Longaria & Gamper, 1976) and others gave extensive revisions of taxonomy (Linares Rodriguez, 1977; Masters, 1978), or revisions of individual taxa and smaller groups (Caron, 1977; Wonders, 1978).

PURPOSE OF THE INVESTIGATION

The aims of this study are fourfold. Recently, Verbeek (1977) proposed a detailed calcareous nannofossil zonation for the Albian and Upper Cretaceous of the Western Mediterranean area, based on the same material that was used for planktonic foraminiferal investigation here. This allows in the first place a detailed first order correlation of planktonic foraminiferal and calcareous nannofossil zonations.

Secondly, it was tried to improve the correlation with the classical Cretaceous European stratotypes by introducing planktonic foraminiferal evidence in addition to the calcareous nannofossil data of Verbeek.

In the third place, it appeared to be possible to improve the correlation of planktonic biozonations and the Cretaceous magnetostratigraphic scale. The present author was involved in a series of studies on paleomagnetism of Cretaceous and Paleogene pelagic limestones (VandenBerg et al., 1975, 1978; VandenBerg & Wonders, 1978, 1979), which provided additional data for a more detailed Cretaceous magnetic reversal scale.

Finally, some ideas concerning the development of Cretaceous planktonic foraminiferal faunas and the evolution of individual groups in relation to major Cretaceous "events" in the history of oceanic life were developed. A model, including both "Oceanic Anoxic Events" (OAE; Arthur & Schlanger, 1979) and Cretaceous plate movements is proposed as a working hypothesis in further research.

At the time the present author started the study which is published here, the enormous increase in the application of planktonic foraminifera during the seventies was still ahead. During the study, a continuous influx of new data and ideas of others had to be incorporated. The rapid succession of new publications may soon cause the conclusions presented here to be out of date. Nevertheless, it is hoped that the correlation schemes, the morphological subdivision of Cretaceous planktonic foraminifera and the evolutionary considerations as offered in this paper may contribute to a better understanding and a more effective practical application of this important and interesting group of Protista.

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PROVENANCE OF MATERIAL

Much of the investigated material is from the same sections and samples as used by Verbeek (1977). The detailed descriptions of the sections by Verbeek will be summarized here. The additional sections used for this study are described in somewhat greater detail.

El Burrueco, province of Jaén, southern Spain (figs. 2, 3, 4)

This section consists of a lower marly and an upper carbonatic part, separated by a fault. The lower part (28 metres) is composed of apparently homogeneous, greenish gray marls. It represents most of the Upper Albian (*subticinensis* Zone to *appenninica* Zone) and the basal Cenomanian (up to part of *globotruncanoides* Zone). The upper part consists of alternating white, pink and red friable nannofossil-foraminiferal chalk and represents the Upper Santonian and most of the Campanian (*carinata* Zone to *calcarata* Zone). The thickness of this part is 136 metres.

Tjalsma (1971) was the first to mention the locality. Marks (1972) studied *G. calcarata* from the upper part of the section; Wonders (1975) described the *P. buxtorfi* group from the lower part and gave a detailed zonation of the Upper Albian. The same author used material from El Burrueco in a study of the keeled Rotaliporinae (1978). VandenBerg (1979) tentatively compared the magnetostratigraphy of the Santonian and basal Campanian parts of the section with that of the Gubbio section in northern Italy and showed that the top of the Cretaceous Long Normal Zone at El Burrueco is at a somewhat lower biostratigraphic level than it is in Gubbio.

The planktonic foraminifera are very well preserved in most of the samples

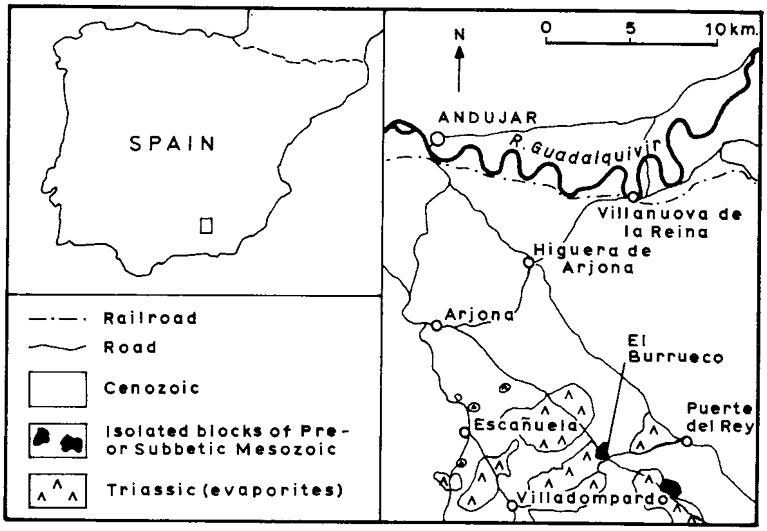


Fig. 2 Location of El Burrueco, with geological sketch, indicating the position of the allochthonous mesozoic blocks between triassic evaporites and cenozoic sediments. (Modified after Tjalsma, 1971).

from El Burrueco. The close sampling allows for detailed observations on gradual morphological changes through the section.

Sedimentary history

It is difficult to reconstruct the sedimentary history of the Cretaceous of El Burrueco, because the record is rather fragmentary and the lower part of the section tectonically overlies Triassic evaporites. The facies of both the Albian and Santonian to Campanian parts of the section is pelagic and without coarse terrigenous material. A rough estimate of the sedimentation rate (not corrected for compaction) of the Albian part, applying the numerical values for this interval of Van Hinte (1976) gives 6 m/Ma, which is

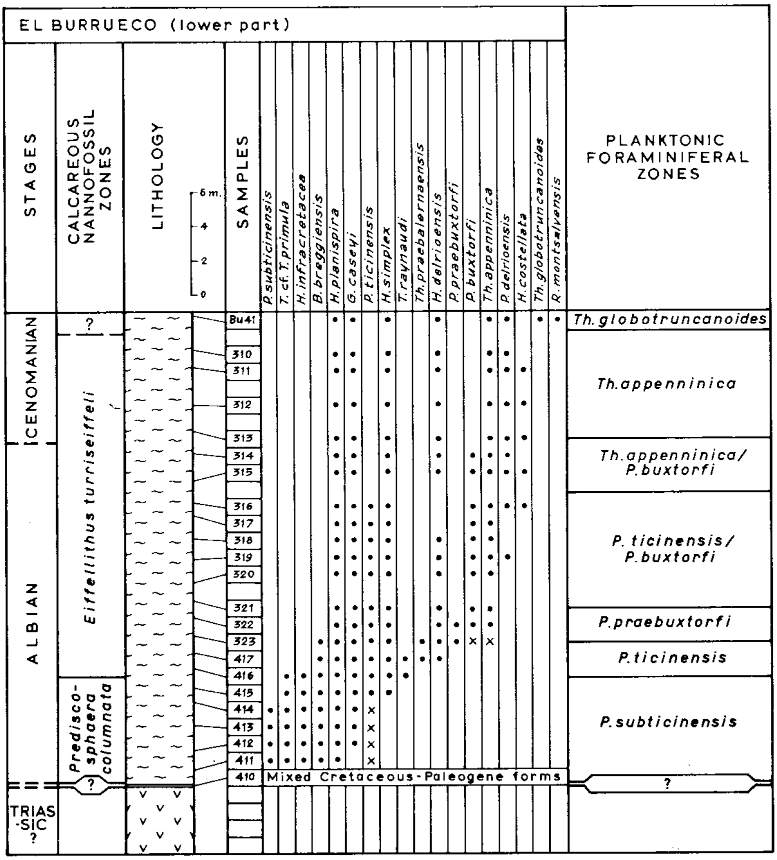


Fig. 3 Columnar section El Burrueco, lower part, with distribution chart and zonation. Calcareous nannofossil zonation after Verbeek (1977). Both zonations refer to the column "lithology", not to the column "samples".

about the same as that calculated for the pelagic Fucoid Marls in Italy by Premoli Silva & Paggi (1977). The upper 136 metres were deposited during approximately 9 Ma, which would give a average sedimentation rate of about 15 m/Ma. This figure rises somewhat if the hiatus which is indicated by the absence of the *Broinsonia parca* Zone (Verbeek, 1977) is taken into account. The average value of 15 m/Ma exceeds the one that was found for the Campanian part of the purely pelagic Umbrian Scaglia in Italy (Premoli Silva &

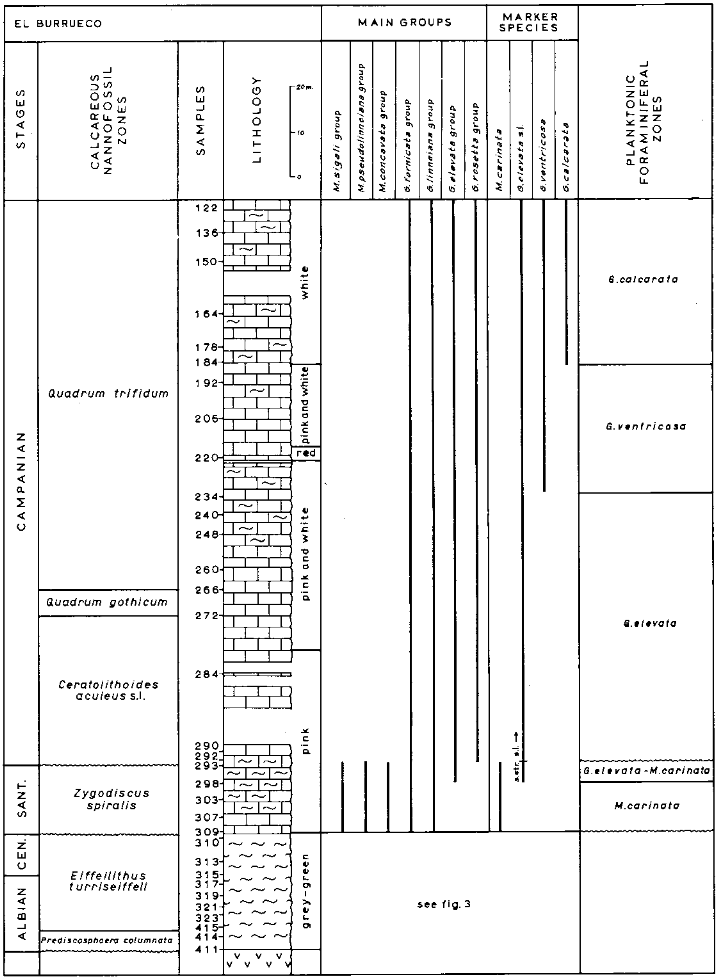


Fig. 4 Columnar section El Burrueco, upper part, with distribution of main groups and marker species, and zonation. Calcareous nannofossil zonation after Verbeek (1977). Both zonations refer to the column "lithology", not to the column "samples".

Paggi, 1977) by a factor two. Most of this may be due to postdepositional compaction of the Scaglia, a feature which is virtually absent in the friable, chalky Burrueco sediments. In fact, we believe that the facies of the Santonian to Campanian of El Burrueco is like an unaltered Scaglia limestone.

An estimate of depositional depth is hard to give, as there is no information on the regional facies distribution, the El Burrueco section being in an allochthonous, isolated block. The absence of aragonitic fossils (Ammonites) may point to a depth below the Aragonite Lysocline (ALy) or even the Aragonite Compensation Depth (ACD), the position of which would be below 1000 metres today according to Bosellini & Winterer (1975).

The intermittent presence of red colours in the sediments is caused by Fe^{III} oxides. The greenish grey marl facies of the lower part of the section may reflect a relatively low oxidation of the seafloor during deposition (Arthur, 1977) and may be considered to be a Spanish equivalent of the Italian Fucoid Marls.

Dyr El Kef area, Tunisia (figs. 5–8)

The Upper Cretaceous of the area of Dyr El Kef is developed in a hemipelagic marl and limestone facies of considerable thickness. A figure of 2,800 metres was given by Verbeek. It seems that the relatively high sedimentation rate was caused by the influx of clay; calcareous parts of the section appear to be relatively condensed.

Three sections W of El Kef together cover the entire Upper Cretaceous. In the section *Koudiat el Hamra* three lithologic units are recognized. An alternation of marls and limestones (ca. 250 metres) is overlain by a limestone unit (60 metres), again followed by 250 metres of marls. The bottom of the section is Early Cenomanian in age (*globotruncanoides* Zone), the limestone unit is above the Cenomanian-Turonian boundary (*archaeocretacea* and *helvetica* Zones) and the top is Coniacian (*primitiva* Zone). 16 samples, collected by R. R. Schmidt in 1975, were studied.

The second section is that of *Oued Zerga,* where a thick sequence (ca. 1,300 metres), mainly composed of gray marls is discontinuously exposed. Minor limestone intercalations are present. The base is of Coniacian age (*primitiva* Zone), the top Early Campanian (base *elevata* Zone). 21 samples, also collected by R. R. Schmidt, were studied.

The section *El Haria* offers continuous outcrops of the Campanian and Maastrichtian, with a total thickness of about 850 metres. Three marly units alternate with two limestone units. The latter are found in the lower part of the Campanian and in the Lower Maastrichtian. The bottom of the section is in the *elevata* Zone. The Cretaceous-Tertiary boundary is found within the upper marly unit, 240 metres above the upper limestone unit.

The Cretaceous of El Kef has been the subject of several micropaleontological studies. Salaj (1977) proposed it as a "faciostratotype" of the Tethyan marine pelagic Cretaceous. Verbeek (1977) and Sissingh (1977) studied the calcareous nannofossils.

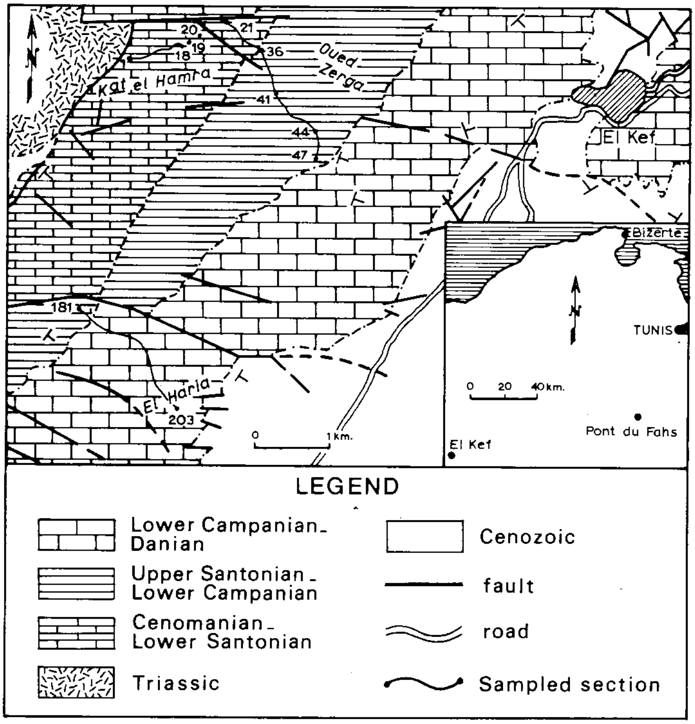


Fig. 5 Geological sketchmap of the area of El Kef, with location of the three sampled sections.

Sedimentary history

The Cretaceous of El Kef was incorporated in an extensive stratigraphic study by Burollet (1956), who pointed to a close relation between lithology and depositional environment. In his opinion, the marly parts of the sequence were deposited at greater ("bathyal-abyssal") depths than the limestone units ("infranéritique", "épinéritique"). Consequently, the Cretaceous of El Kef was considered to reflect phases of rapid subsidence alternating with periods of uplift.

There is no substantial evidence that marl sedimentation should always take place in a deep marine environment, and carbonate sedimentation at shallower depths. A much more simple model is possible, if, in a limestone-marl sequence, the marl sedimentation is explained by extra supply of terrigenous clay in an environment where, normally, carbonate sedimentation would prevail. Apport of clay may occur at any depth, at does the deposition of micritic limestones. Application of this model to the composite section of El Kef leads to a logical succession of lithofacies without the necessity of a jojoing basement.

The model can be tested by constructing a sedimentary history diagram of the section (fig. 9). In such a diagram, the building-up of the sedimentary column through time is visualized. Time is plotted on the horizontal axis, depth (c.q. sediment thickness, depth of burial, depth below sea level) on the vertical. Van Hinte (1978) extensively described this method of data-processing.

The diagram for the composite Kef section is based on four main assumptions:

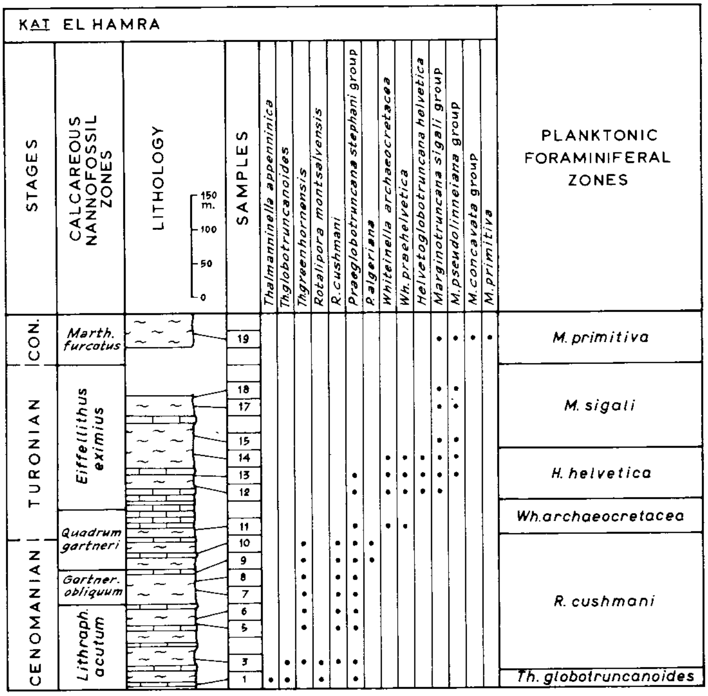


Fig. 6 Columnar section Koudiat El Hamra, with distribution of important species and zonation. Calcareous nannofossil zonation after Verbeek (1977). Both zonations refer to the column "lithology", not to the column "samples".

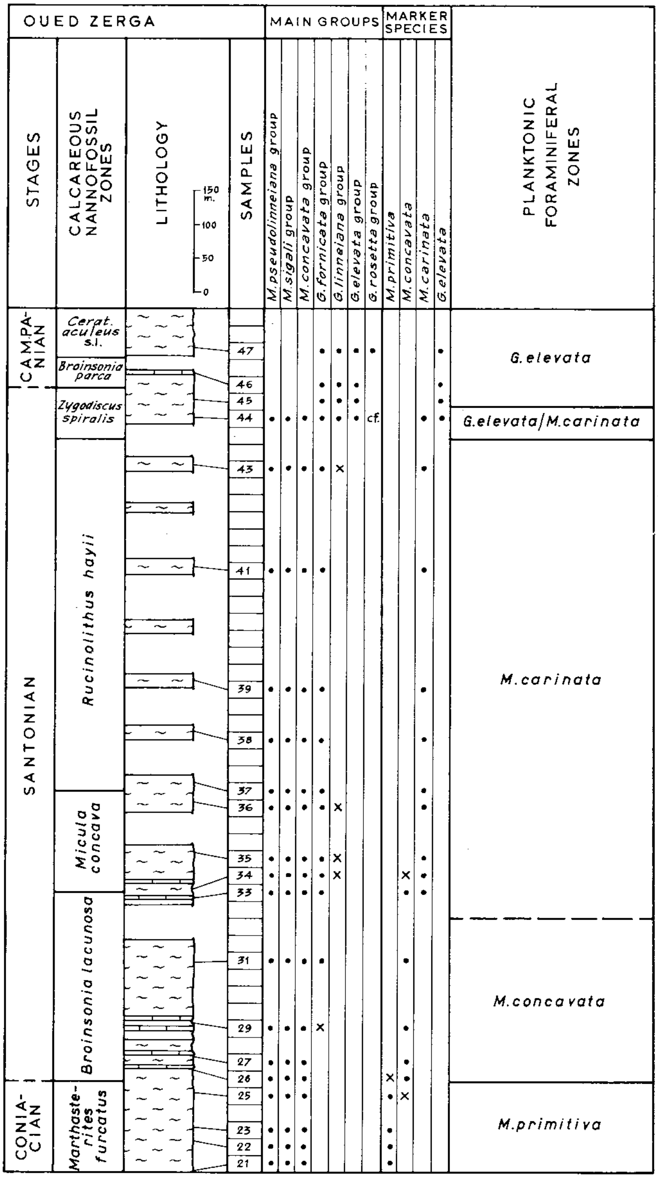


Fig. 7 Columnar section Oued Zerga, with distribution of main groups and marker species, and zonation. Calcareous nannofossil zonation after Verbeek (1977). Both zonations refer to the column "lithology", not to the column "samples".

1) The Cenomanian marls and subordinate pelagic limestones were deposited at considerable depth, but above the ACD; the depth which was estimated by Burollet at 600 metres may be a realistic one;

2) The two main limestone units in the Campanian and in the Lower Maastrichtian part of the section are thought to be of relatively shallow water origin;

3) Active basement subsidence was constant during the Late Cretaceous;

4) Isostatic subsidence of the basement was in the order of half the thickness of the sediment load.

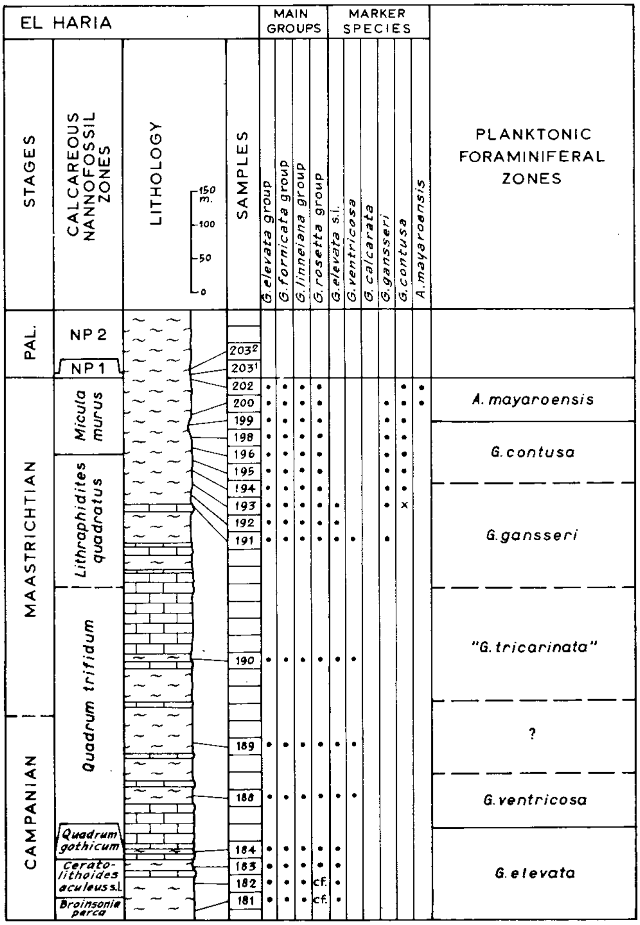


Fig. 8 Columnar section El Haria, with distribution of main groups and marker species, and zonation. Calcareous nannofossil zonation after Verbeek (1977). Both zonations refer to the column "lithology", not to the column "samples".

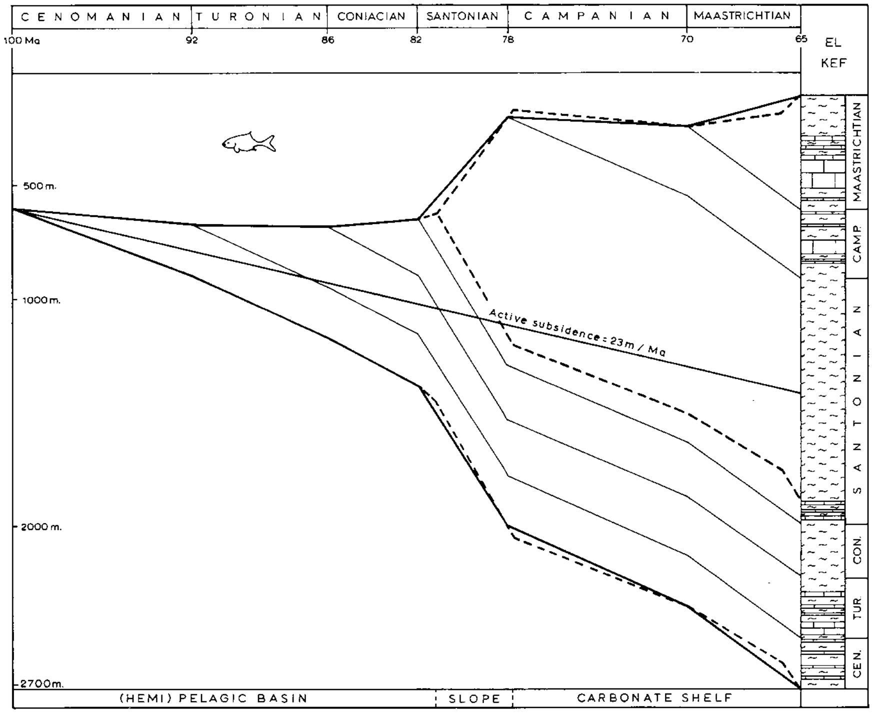


Fig. 9 Sedimentary history diagram of the composite section El Kef. For basic assumptions see text. Full lines: basement subsidence and bathymetry history per stage. Dashed lines: same, corrected for lithology.

The numerical scale is according to the correlation scheme of fig. 21, mainly after Van Hinte (1976). Assuming an initial (Early Cenomanian) water depth of 600 metres and a final (Late Maastrichtian) depth of 100 metres, we find an average rate of total subsidence of the basement of 60 metres/Ma and an average net sedimentation rate of 74 m/Ma, after compaction. The active subsidence "curve" of the basal Cenomanian is a straight line according to assumption 3. The accumulation of sediments is represented per stage (full line) and per lithologic unit (dashed line), with application of the apparent sedimentation rate of the Santonian marls. This extrapolation of Santonian sedimentation rate into the Campanian gives a numerical age of the base of the Campanian limestones of 77 Ma, which agrees with their position in the lower part of the *elevata* Zone. On the average, the Campanian and Maastrichtian sediment accumulation compensated the subsidence, with minor fluctuations in depositional depth due to differences in sedimentation rates and possibly to submarine erosion as indicated by two minor hiatuses (Sissingh, 1977). As may easily be seen, even markedly different estimates of depositional depths of the Cenomanian and the Campanian-Maastrichtian would not change the picture essentially if the constant subsidence rate is maintained. A constant great depth of deposition of the Santonian-Campanian marls, as suggested by Burollet (1956) would introduce a much greater contemporaneous rate of subsidence, followed by an inexplicably fast rising of the basement (in the order of 500–1,000 m/Ma, for which no evidence in the form of a regional tectonic phase or anything of the kind is available.

Pont du Fahs, Tunisia (figs. 10, 11)

An extensive description of this section was given by Salaj (1974). The detailed field data of Salaj were redrawn as a columnar section (fig. 11). The succession of lithologies is essentially the same as that in the Kef area, but the total thickness is much less and the Maastrichtian is strongly reduced. The base of the section is in the *globotruncanoides* Zone, the top of the sampled interval in the "*tricarinata*" Zone.

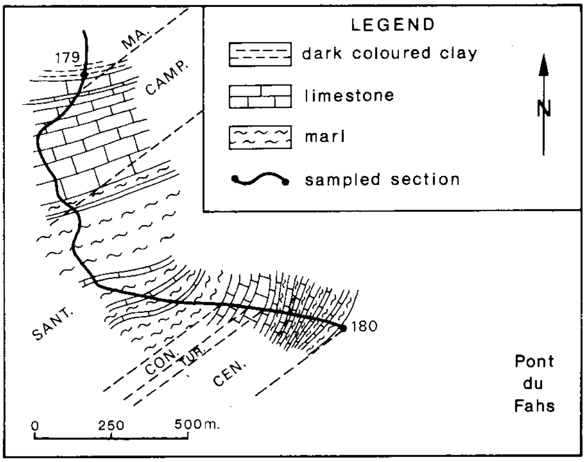


Fig. 10 Situation sketch of section Pont du Fahs. After Salaj (1974).

Sedimentary history

A sedimentary history diagram (fig. 12), constructed in the same way as that of the composite section of El Kef, shows approximately the same features as the latter. Although the Cenomanian of Pont du Fahs has approximately the same facies as that of El Kef, we chose a somewhat shallower in initial depth, because of the presence of more macrofossils and the

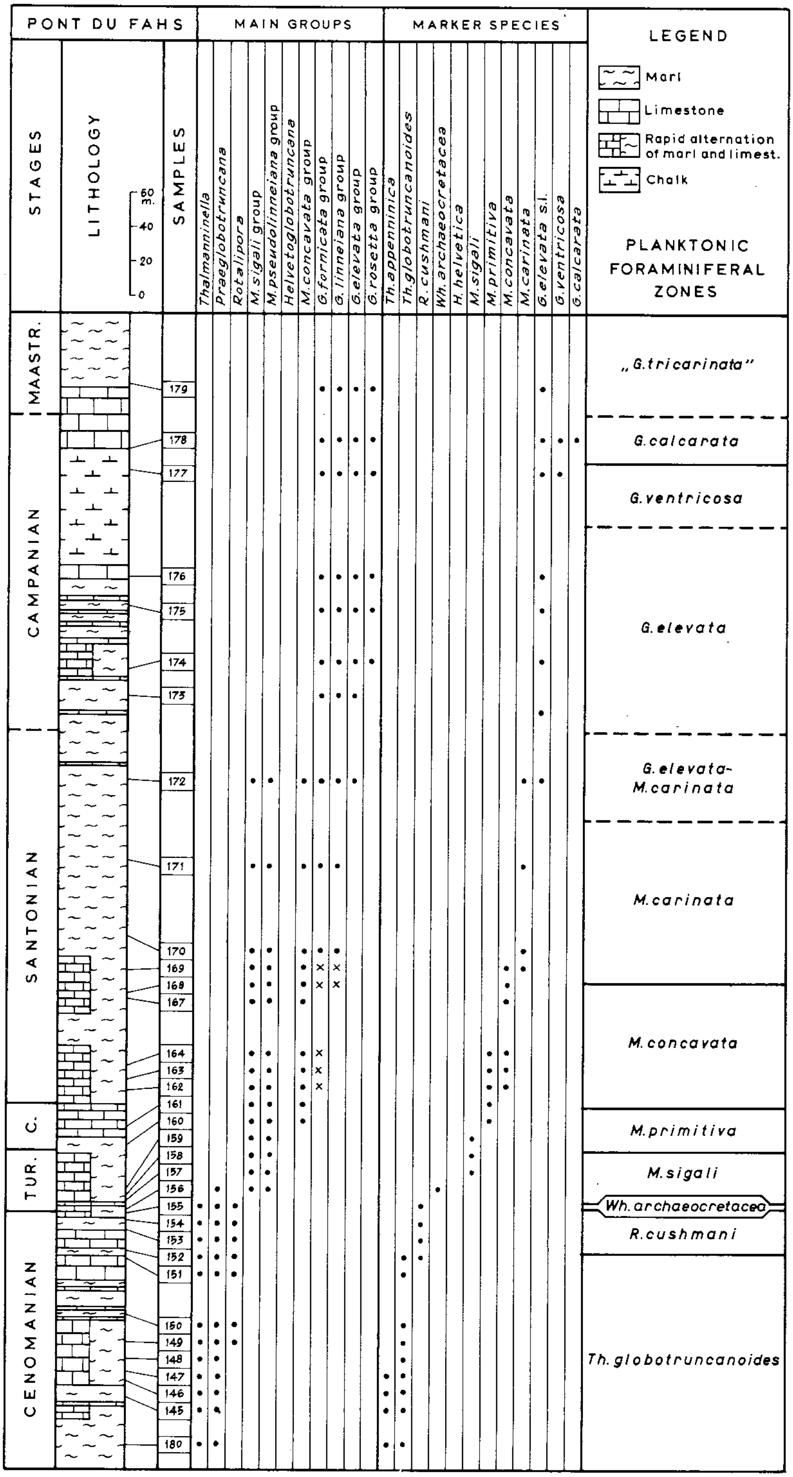


Fig. 11 Columnar section Pont du Fahs, with distribution of main groups and marker species, and zonation. Lithology redrawn after Salaj (1974). The zonation refers to the column "lithology", not to the column "samples".

paleogeographic position of Pont du Fahs further away from the axis of the "sillon tunisien" (Burollet, 1956; Salaj, 1974, 1979). The very shallow depositional depth of the Maastrichtian is suggested by the extremely low sedimentation rate and the probability of the presence of hiatuses (Salaj & Bellier, 1979). Starting from these presumptions, we calculated an average rate of subsidence of about 9 m/Ma, which is conspicuously less than that of section El Kef, and in accordance with the vicinity of the stable Saharan platform. Active subsidence of the basement appears to have been practically zero during the Late Cretaceous. The sedimentation rate is also lower: about 20 m/Ma. The more calcareous parts of the sediment column were deposited at rates of about 10 m/Ma, which approaches normal sedimentation rates of pelagic oozes. The Santonian and Lower Campanian marls, on the other hand, were deposited about ten times as fast. Again it seems more plausible to assume an infilling of the depositional basin by the rapid marl sedimentation during the Santonian and Early Campanian rather than to explain their thickness by more rapid foundering of the basement, which would make a drastic uplift phase in the Early Campanian necessary. For this, again, there is no evidence.

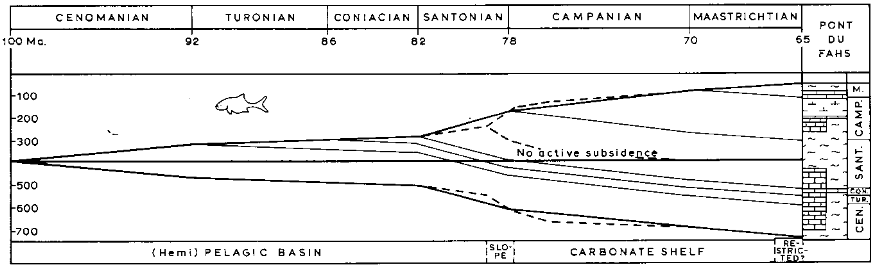


Fig. 12 Sedimentary history diagram of section Pont du Fahs. For basic assumptions see text. Full lines: basement subsidence and bathymetry history per stage. Dashed lines: same, corrected for lithology.

Cagli area, northern Italy (figs. 13, 14)

The Cretaceous of the Umbrian Sequence in the north central Apennines takes a unique place in the world's distribution of Cretaceous sedimentary rocks, because it is entirely developed in open marine, pelagic facies without any observable active terrigenous influence. The Marche-Umbria Apennines may be the only area in the world where the pelagic record is so continuous and well-exposed.

The Cretaceous in the Cagli area is about 600 metres thick, and evenly distributed over the Lower and Upper Cretaceous. The common rock type is micritic carbonate with minor quantities of clay minerals and iron sulfides, and with quite variable quantities of chert. At two levels, intercalations of varicoloured and black shales occur; these parts of the column are relatively condensed and rather bear witness of suppressed carbonate deposition than of increased clay influx.

The lithology of the carbonates is determined by the nature of the calcitic

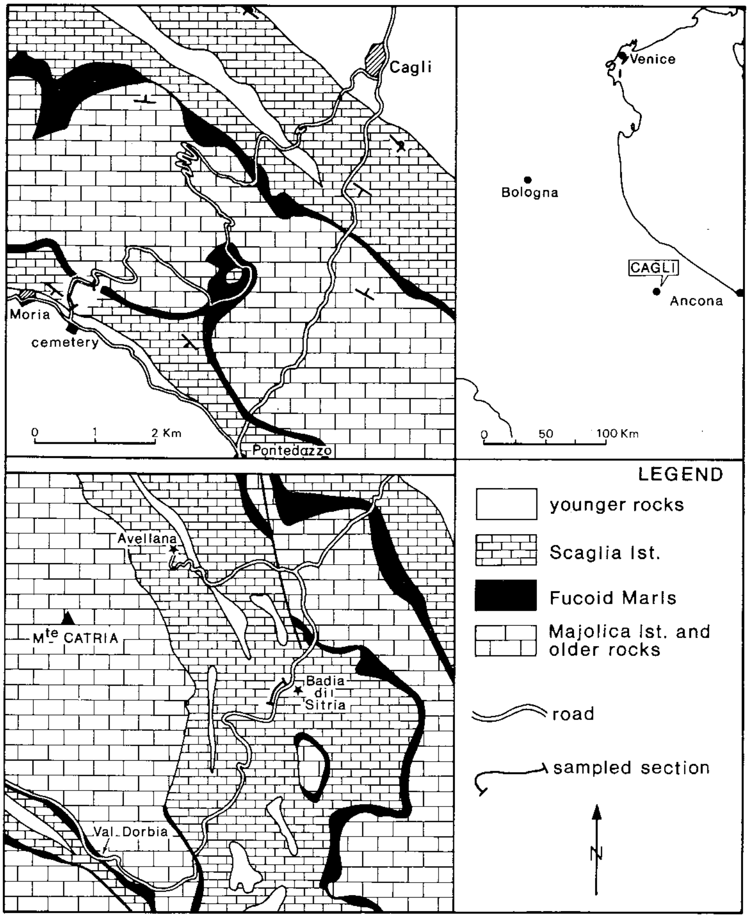


Fig. 13 Location of the Cagli area and geological sketch maps of the surroundings of Moria and Badia di Sitria. The apparent absence of the Fucoid Marls E of Monte Catria is due to tectonic reduction.

constituents of organic origin, the presence or absence of chert and the oxidation state of the sediment. The composition of the carbonates and the occasional shaly intercalations lead to a natural subdivision into three major units, the upper one (Upper Cretaceous) of which may be differentiated into three smaller entities (fig. 14):

A: *The Majolica Limestone* (the name refers to the very dense texture and the porcellaneous aspect of the rock): white to light grey well-bedded limestones with frequent chert lenses and nodules. The thickness of the Cretaceous part of the formation is about 250 metres;

B: *The Fucoid Marls* (named after the abundant horizontal burrows, often referred to as fucoids): varicoloured shales and marls, black shales, and minor intercalations of radiolarites and siliceous limestones. The colour of the marls and shales is predominantly red in the lower part, greenish-grey in the middle part and grey to black in the upper part, where white limestone beds become progressively more frequent. The thickness of the Fucoid Marls is about 50 metres.

C: *The Scaglia Limestones* (*scaglia* (It.) = scale; the name refers to the small angular fragments into which the rock tends to desintegrate upon weathering): white and pink well-bedded micritic limestones with chert lenses and nodules in the lower part. The individual beds are in the order of some centimetres to some decimetres thick – about half the thickness of the Majolica beds. The limestone beds are usually separated by very thin marly

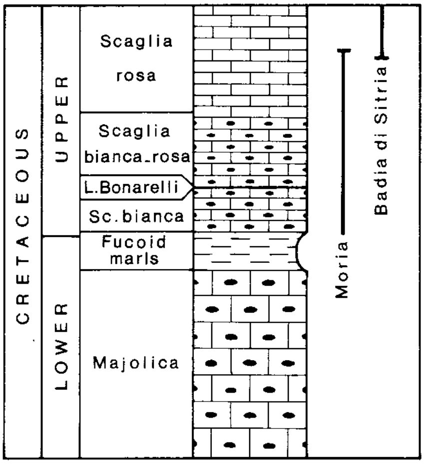


Fig. 14 Generalized lithology of the Cretaceous in the Cagli area, with indication of the parts which are covered by the sections.

interbeds. The total thickness is about 300 metres. A threefold subdivision is possible, based on colour and the presence or absence of chert:

1: *The Scaglia Bianca*: well-bedded, laminated, white and grey, sometimes pink micritic limestones with frequent chert lenses and nodules, which are mostly grey or black. Marly interbeds are more frequent and thicker in the lower part and dark coloured. The thickness is about 60 metres.

2: *The Scaglia Bianca-Rosa*: above a one metre thick bituminous black shale ("Livello Bonarelli"), topping the Scaglia Bianca, irregularly alternating white and pink, well-bedded micritic limestones with brick-red chert nodules are found. The thickness is about 100 metres.

3: *The Scaglia Rosa*: mostly pink Scaglia limestones without chert, 140 metres thick. The top of this unit is sharp and overlain by brick-red marly limestones of the Paleocene (Scaglia Rossa s. str.).

The Scaglia Bianca-Rosa and the Scaglia Rosa are often taken together with the Scaglia Rossa s. str. and referred to as Scaglia Rossa.

The sections (figs. 15, 16)

Two sections, which were the subject of a previous study (Wonders, 1979) are memorized here. One is near the village of *Moria,* 6.5 km SW of Cagli, at the southwestern flank of the main anticlinal structure which forms the backbone of the prominent calcareous chain in the area. Here, the top of the Fucoid Marls, the Scaglia Bianca, the Scaglia Bianca-Rosa and the lower part of the Scaglia Rosa are exposed in one continuous section from which 40 samples were taken. The base of the section is of Late Albian age (*subticinensis* Zone), the top is Middle Maastrichtian (*gansseri* Zone). The distribution of the main planktonic foraminiferal groups and zonal markers, as determined in thin sections, is given in fig. 16.

The other section is 15 km SE of Moria, in the northeastern flank of the calcareous chain, 4 km E of the summit of Monte Catria, along the road from Serra Santabbondio to Isola Fossara, in the vicinity of the medieval monastery *Badia di Sitria.* Here, the upper 70 metres of the Scaglia Rosa were sampled (8 samples), representing the Upper Maastrichtian. One additional sample from the very base of the Scaglia Rossa contains a typical *eugubina* fauna (Earliest Paleocene).

Sedimentary history (fig. 17)

The Marche-Umbria basin developed in Early Liassic times from the breaking-up of a very shallow marine carbonate platform. The carbonate platform sediments (Calcare Massiccio) are overlain by partly pelagic, partly clastic carbonates (Corniola), which are followed by marly limestones and

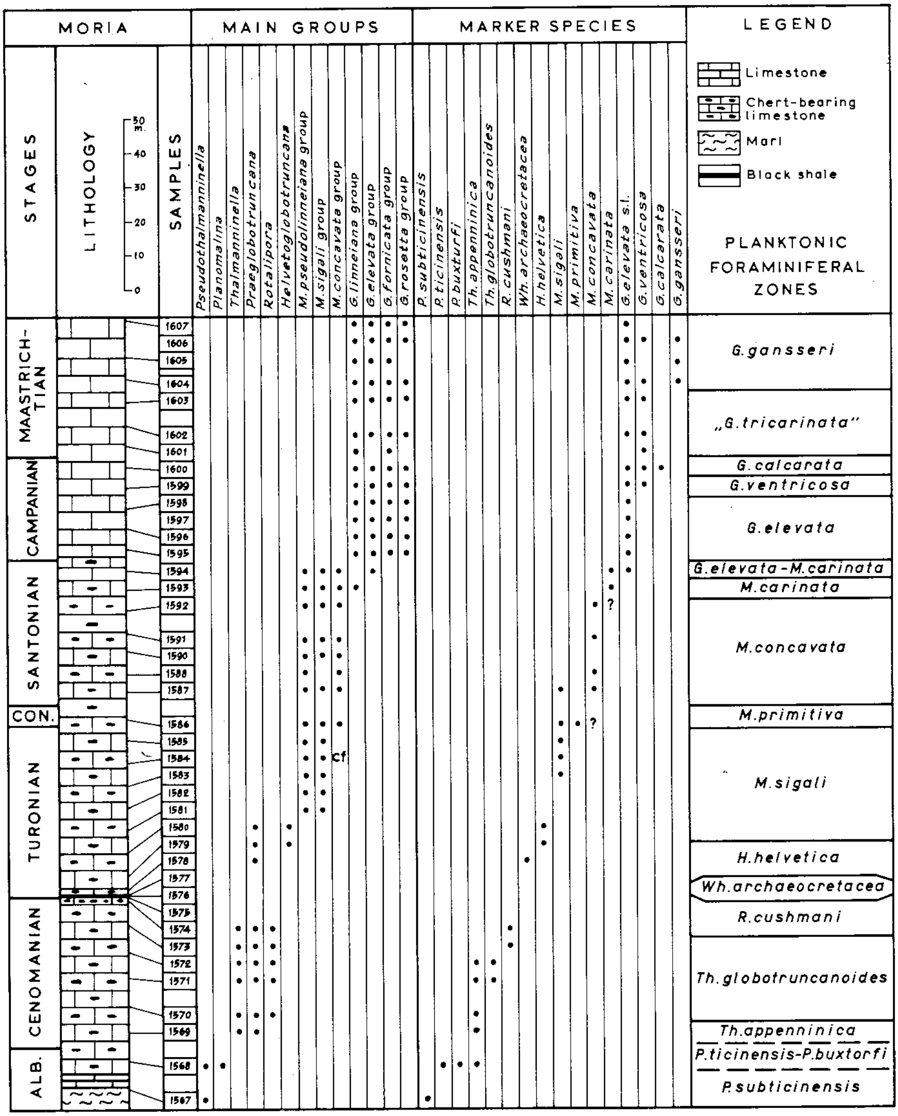


Fig. 15 Columnar section Moria, with distribution of main groups and marker species, and zonation. The column "zonation" refers to the column "lithology", not to the column "samples".

marls in Ammonitico Rosso facies. These, in turn, are covered by some tens of metres of cherts alternating with marly limestone (Diasprini), underlying the Majolica Limestone. An estimate of the depositional depth of the Lower Jurassic sequence is very important for estimates of the depth of the sea floor during the Cretaceous. There are two conflicting models in this respect: a deep water model and a relatively shallow water one. The deep water model is based on an explanation of the Ammonitico Rosso facies with the aid of various aragonite and calcite solution facies at oceanic depths (Garrison & Fischer, 1969; Bosellini & Winterer, 1975), and gives values of more than 3.000 metres for the base of the Majolica. In the shallow water model, the Ammonitico Rosso facies is interpreted as a result of early diagenetic processes in a shallow water (less than 1,000 metres) environment and the Diasprini as deposited in deeper water. On evidence from the Cretaceous, it is difficult to make a choice between these models because pelagic carbonates, in our opinion, may be deposited at any somewhat greater depth above the carbonate compensation depth. The deposition of the Fucoid Marls and the Bonarelli black shale does not necessarily plead for oceanic depths below the CCD, since it clearly occurred in relation to the two main oceanic anoxic events in the Mid-Cretaceous (Arthur & Schlanger, 1979).

A rough estimate is obtained by extrapolating the active subsidence rate

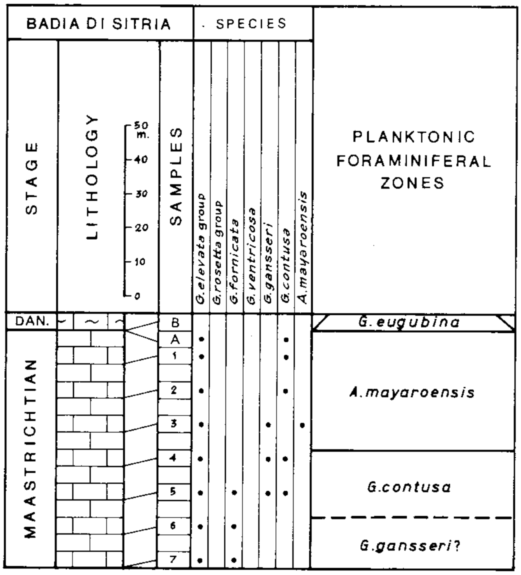


Fig. 16 Columnar section Badia di Sitria, with distribution of some important species, and zonation.

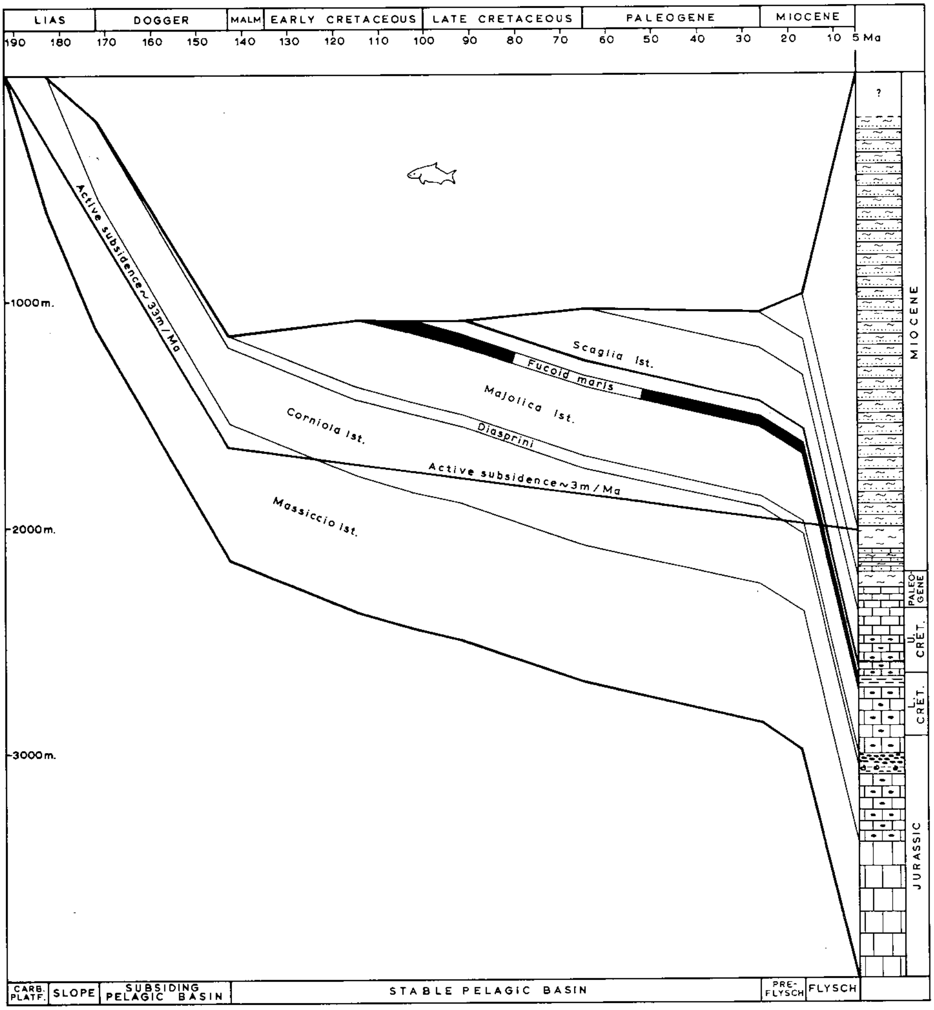


Fig. 17 Generalized sedimentary history diagram of the Mesozoic and Tertiary of the Cagli area until the end of the Miocene. For basic assumptions see text. Note that the Cretaceous sediments were deposited entirely within the long period of stable pelagic basin sedimentation.

during the deposition of the Calcare Massiccio, into the Jurassic until the beginning of the deposition of the Majolica, after which there is no indication of important vertical movements anymore and subsidence may have been very slow or absent. This leads to a depositional depth of about 1,000 metres during all of the Cretaceous and the Paleogene, after which increased terrigenous influx filled the basin with marls and turbidites (Marnoso-

Arenacea flysch). Whatever model is adhered to, the Cretaceous sediments constitute the middle part of a very long pelagic interval (Upper Jurassic to Lower Miocene), in which the development of pelagic faunas can be studied in great detail. In this respect, the Marche-Umbrian Cretaceous is a better example of fully marine pelagic sediments than the Cretaceous of Pont du Fahs, part of which was proposed as "faciostratotype" by Salaj (1977).

As was demonstrated before (Wonders, 1979), the lithological boundaries of the Cretaceous pelagic rocks in the Cagli area strikingly coincide with major changes in the faunal content, and approximately with chronostratigraphic boundaries. The development of planktonic foraminiferal faunas and the main other groups of pelagic life is visualized in the sedimentary history diagram of fig. 42. Apparently, anoxic conditions at the bottom, during deposition of the Fucoid Marls and the Bonarelli bed, were accompanied by circumstances which were unfavourable for keeled planktonic foraminifera in the upper water layers.

Bassano del Grappa area, northern Italy (figs. 18–20)

Two sections in the Southern Alps were studied in order to give further documentation on the correlation of the planktonic foraminiferal zonation with the geomagnetic reversal scale. Lithostratigraphically, the Cretaceous of the Southern Alps resembles the Umbrian Sequence of the Cagli area. Wherever the facies is pelagic, the Lower Cretaceous is represented by a monotonous series of mainly grey and white, but sometimes greenish and pink limestones with chert lenses and nodules: the "Biancone" (literally translated *Big White*) of authors, named "Calcare di Soccher" in the extensive stratigraphic and micropaleontologic study by Casati and Tomai (1969).

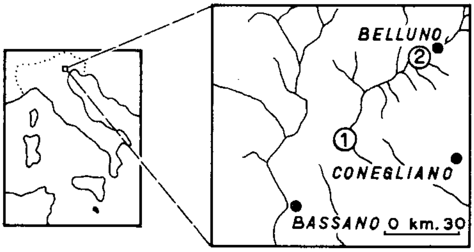


Fig. 18 Location of section Valle del Mis (1) and section Quero-Schievenin (2). Modified after VandenBerg & Wonders (1979).

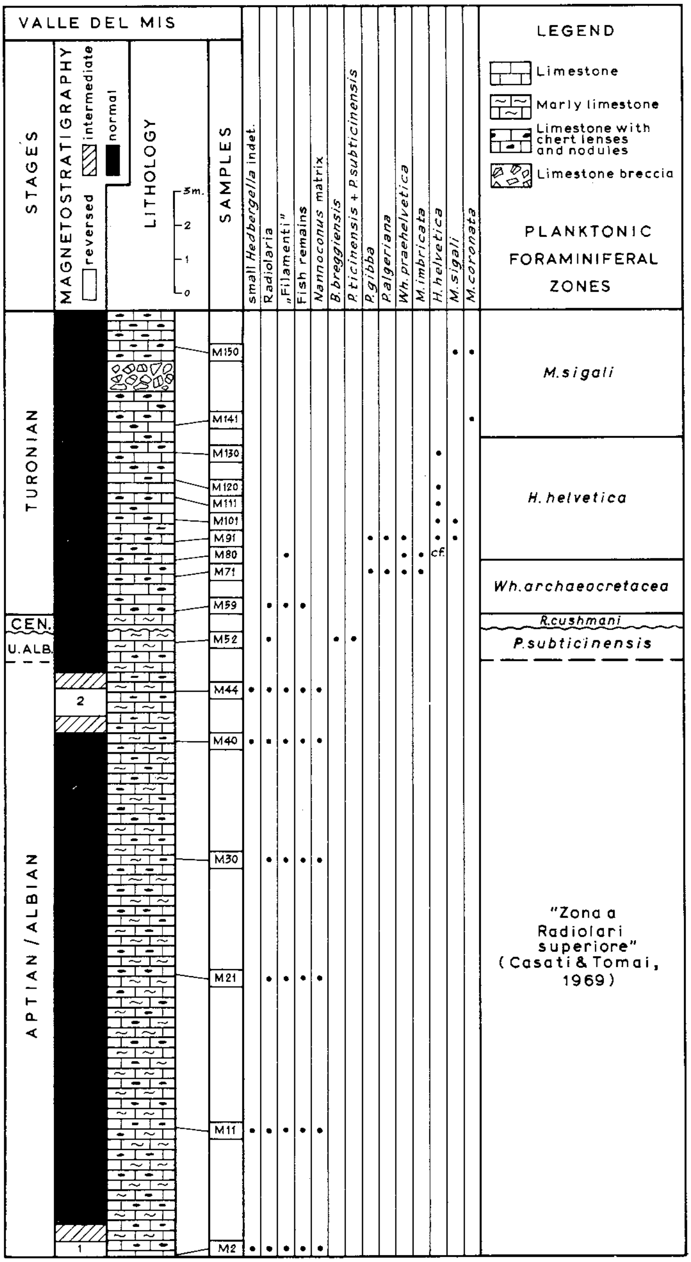


Fig. 19 Columnar section Valle del Mis, with distribution of species as determined in thin sections and zonation. Magnetostratigraphy after VandenBerg & Wonders (1979). M-samples are selected cores which were used for paleomagnetic measurements. Note that the absence of Cenomanian reversals may be due to the presence of a hiatus.

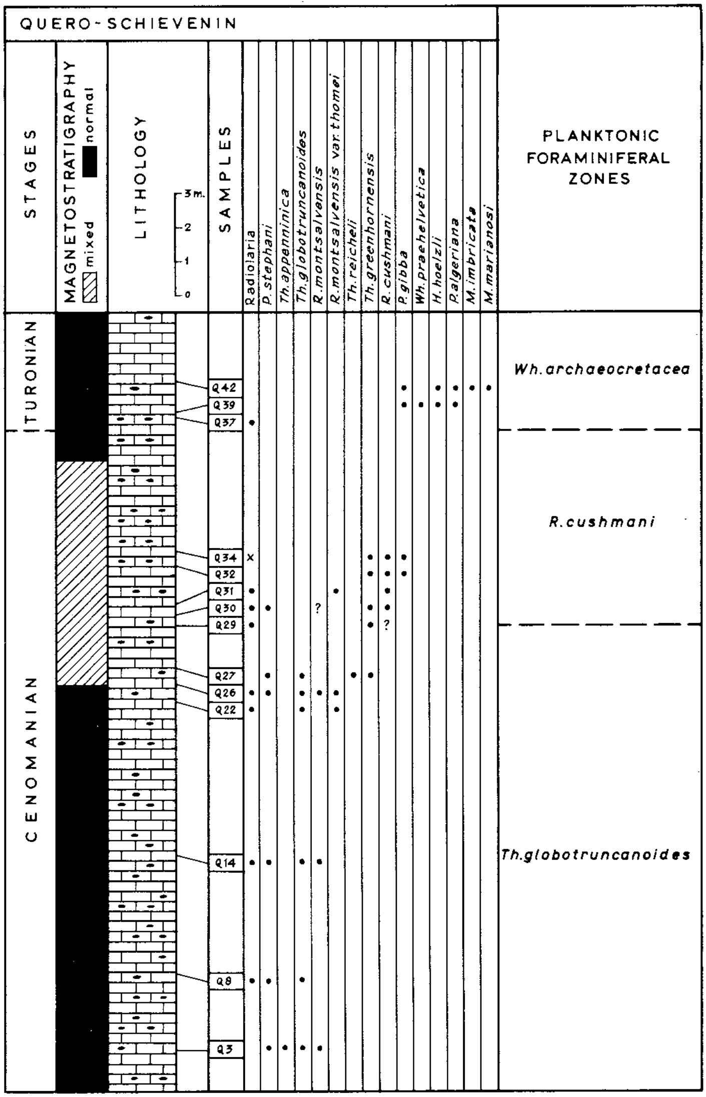


Fig. 20 Columnar section Quero-Schievenin, with distribution of species as determined in thin sections, and zonation. Magnetostratigraphy after VandenBerg & Wonders (1979). Q-samples are selected cores which were used for paleomagnetic measurements.

Although the lithology of the upper part of the Calcare di Soccher is somewhat different, i.e. more marly and with more frequent red and pink intercalations, the latter authors did not distinguish it as a separate lithologic unit and put the boundary with the overlying Scaglia Rossa at the level where the chert disappears. The marly upper part and the transition, still with chert, to the Scaglia Rossa evidently correspond to the Fucoid Marls, the Scaglia Bianca and the Scaglia Bianca e Rosa of the Umbrian Sequence.

The section *Valle del Mis* was extensively described by Casati & Tomai (1969) and its magnetostratigraphy was studied by VandenBerg & Wonders (1979). The section consists of 19 metres of Calcare di Soccher in its typical facies with thin marly intercalations between thin-bedded, siliceous limestones with chert nodules, lenses and beds. This part of the section was assigned to the Upper Albian by VandenBerg & Wonders (1979). In fact, the accurate age of most of this interval is not clear, as will be discussed in chapter IV. The top is certainly Late Albian (*subticinensis* Zone). It is overlain by 0.5 metres of pink marly limestone, which represent the reduced Cenomanian. Then follow ca. 10 metres of pink and red marly limestones with chert and siliceous beds, Turonian in age (*archaeocretacea* Zone).

The second section is the *Quero-Schievenin* section. 21 metres of white siliceous limestones, obviously belonging to the Calcare di Soccher, are overlain by 65 metres of pink and red micritic limestones with rare chert. The white lower part is Cenomanian (*globotruncanoides* Zone and *cushmani* Zone), the upper part Turonian to basal Campanian (*archaeocretacea* Zone to *elevata* Zone) in age.

Additional material

Recently, Marks (1977), Verbeek & Wonders (1977), Wonders & Verbeek (1977) and De Vries (1977) furnished data bearing to the Cenomanian-Turonian boundary problem. All the material mentioned in their papers was at my disposal: samples and picked material from the Turonian and Cenomanian stratotypes and De Vries' material from the Javernant section, which was also used by Verbeek (1977).

In several cases, topotypes of planktonic foraminiferal species were used, that came at my disposal while working on the figurations in the Atlas of Mid Cretaceous planktonic foraminifera (Robaszynski & Caron, 1979). These are mentioned in the text.

Chapter II

ZONATION

INTRODUCTION

Most of the zones which are recognized in this study have repeatedly been defined before. Still, their definition and some characteristics are given here again in order to show the author's concept of the zones. This is thought to be of importance, since these zones are used for correlation to nannofossil stratigraphy, to magnetostratigraphy, and for chronostratigraphical assignments.

For all zones, only two events, each being an extinction or appearance of a single species are used for definition (fig. 21). Definitions, based on extinctions or appearances of more than one species, as used for some zones by Premoli Silva and Boersma (1977), were avoided, because they may introduce ambiguity.

The concept of phylozones, as defined by Van Hinte (1969), could be applied in only a few cases of apparently gradual transition from one taxon to the other. Even then, the "gradual transition" may be an artefact created by the limits of human observation. Examples are the *P. praebuxtorfi* – *P. buxtorfi* lineage, the *Th. appenninica* – *Th. globotruncanoides* – *Th. greenhornensis* lineage, the *M. primitiva* – *M. concavata* – *M. carinata* lineage and the *G. fornicata* – *G. contusa* transition.

Only coiled planktonic foraminifera were used for the zonation (Globotruncanidae and Planomalinidae). When further subdivision seemed to be possible by involving Heterohelicidae, these subdivisions are given as subzones.

For each zone the corresponding nannofossil zone or zones are given; a justification for this correlation is given in chapter III.

A comparison with zonations of other authors is briefly discussed for each zone, since homonymous zones may cover intervals which are different from the ones which are defined here. We confined ourselves to the zonations as proposed or used by Bolli (1966), Moullade (1966), Pessagno (1967), Van Hinte (1976), Sigal (1977), Premoli Silva & Boersma (1977) and Linares Rodriguez (1977) (fig. 21A).

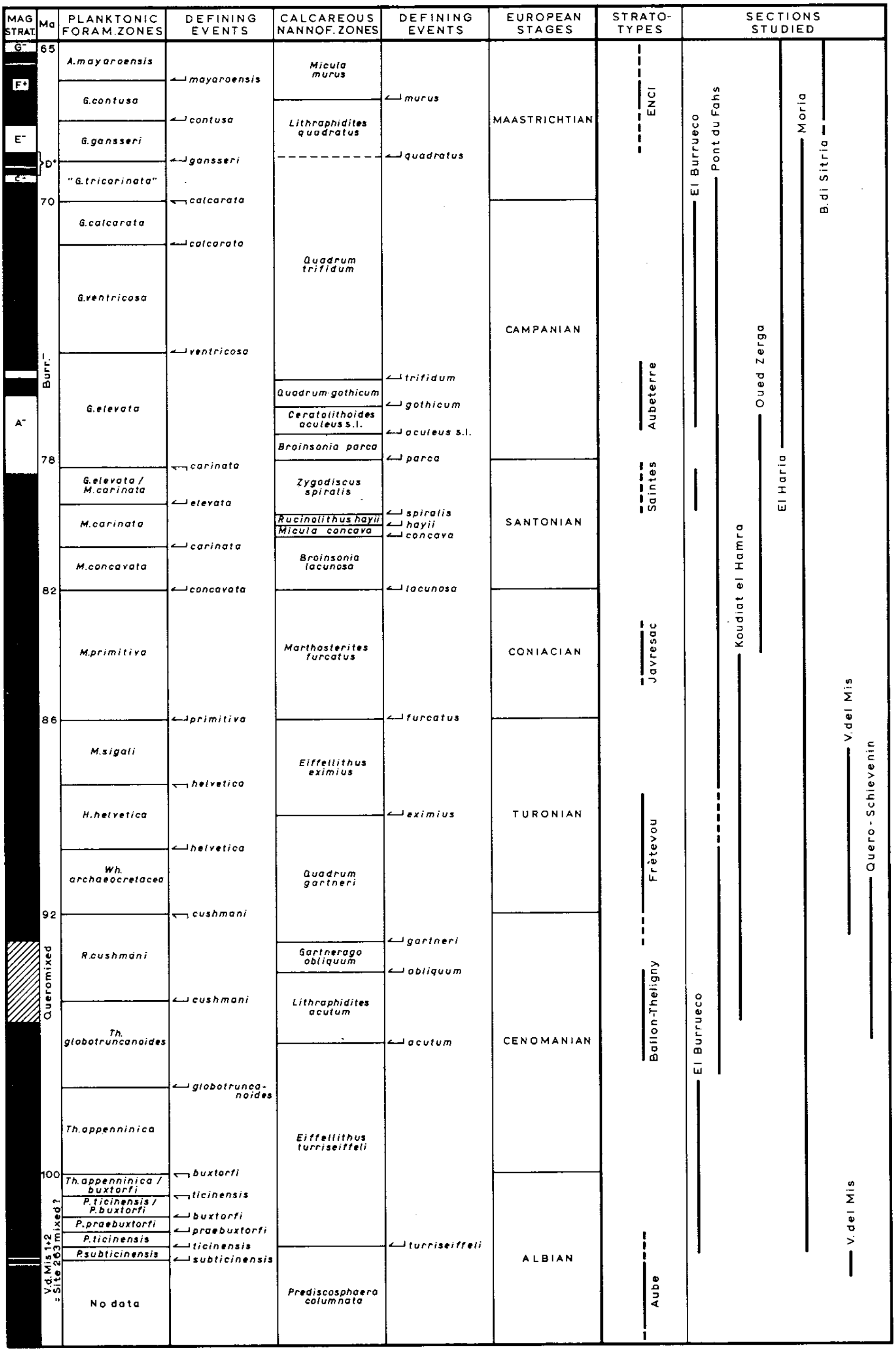


Fig. 21 Correlation chart of Albian to Maastrichtian bio-, magneto-, and chronostratigraphy, with position of stratotypes and studied sections. Numerical time scale after Van Hinte (1976).

Pseudothalmanninella subticinensis Zone

Definition: Interval between the first occurrence of *Pseudothalmanninella subticinensis* and the evolutionary appearance of *Pseudothalmanninella ticinensis.*

Remarks: The zonal marker is an intermediate stage between *Ticinella praeticinensis* and *Pseudothalmanninella ticinensis.* The transition between the latter two species was shown to be perfectly gradual in a previous paper (Wonders, 1978), in which the upper boundary of the zone was defined as the level where the average number of smooth final chambers counted on individuals between 250 and 500 microns reaches the number of 1. The typological appearance of *Pseudothalmanninella ticinensis* is somewhat earlier. The lower boundary of the zone was not found in our material. Therefore, its definition remains theoretical and provisional.

Faunas of the *Pseudothalmanninella subticinensis* Zone consist of several *Hedbergella* and *Ticinella* species (*H. infracretacea, H. planispira, H. delrioensis, T. raynaudi, T. primula*) and the very characteristic *Biticinella breggiensis.* Apart from the zonal marker, keeled forms are absent.

Calcareous nannofossils: The *Pseudothalmanninella subticinensis* Zone corresponds to the upper part of the *Prediscosphaera columnata* Zone (first order correlation based on El Burrueco section).

Comparison with other zonations: This zone corresponds to the upper part of the *Rotalipora roberti* Zone of Bolli (1966), and to the interval from the middle part of the *B. breggiensis* Zone of Moullade (1966) to just below the base of his *ticinensis-delrioensis* Subzone. This author was followed by Van Hinte (1976), Sigal (1977) and Premoli Silva & Boersma (1977).

Age: Late Albian.

Pseudothalmanninella ticinensis Zone

Definition: Interval with the zonal marker from its evolutionary appearance to the first occurrence of *Planomalina praebuxtorfi.*

Remarks: The faunas of the *Pseudothalmanninella ticinensis* Zone are almost the same as those from the underlying zone. A differentiation in the *Hedbergella* faunas takes place and the first forms assignable to *H. simplex* are found in the lower part. In the upper part of the zone partially keeled *Thalmanninella* (*Th. praebalernaensis*) appear.

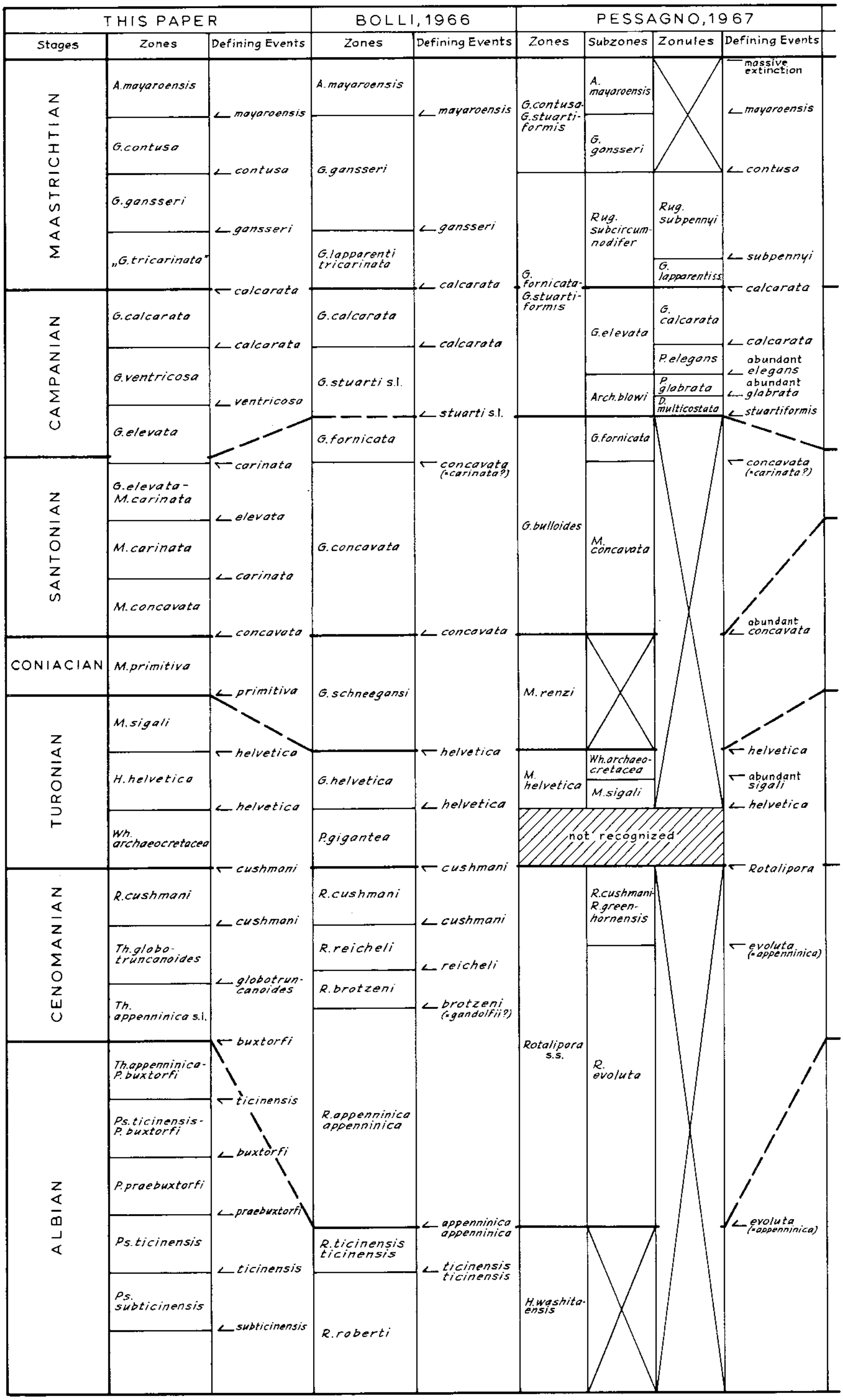
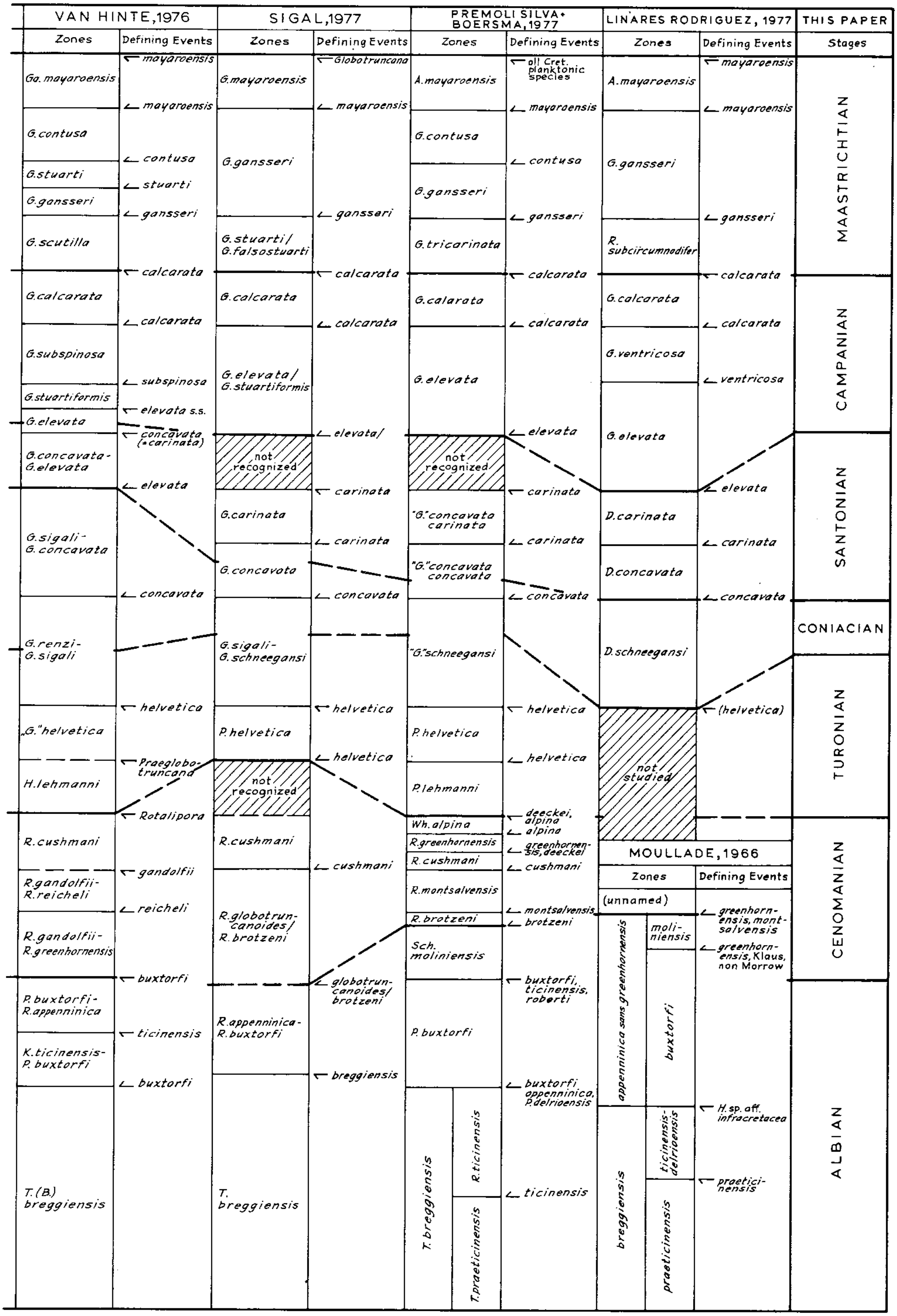


Fig. 21A Comparison of the proposed zonation and chronostratigraphic assignments with those of other authors.


VAN HINTE,1976
Zones
Defining Events
Ga. mayaroensis
G. contusa
G. stuarti
G. gansseri
G. scutilla
G. calcarata
G. subspinosa
G. stuartiformis
G. elevata
G. concavata - G. elevata
G. sigali - G. concavata
G. renzi - G. sigali
„G." helvetica
H. lehmanni
R. cushmani
R. gandolfii - R. reicheli
R. gandolfii - R. greenhornensis
P. buxtorfi - R. appenninica
K. ticinensis - P. buxtorfi
T. (B.) breggiensis
mayaroensis
mayaroensis
contusa
stuarti
gansseri
calcarata
calcarata
subspinosa
elevata s.s.
concavata (=carinata)
elevata
concavata
helvetica
Praeglobotruncana
Rotalipora
gandolfii
reicheli
buxtorfi
ticinensis
buxtorfi
SIGAL,1977
Zones
Defining Events
G. mayaroensis
G. gansseri
G. stuarti / G. falsostuarti
G. calcarata
G. elevata / G. stuartiformis
not recognized
G. carinata
G. concavata
G. sigali - G. schneegansi
P. helvetica
not recognized
R. cushmani
R. globotruncanoides / R. brotzeni
R. appenninica - R. buxtorfi
T. breggiensis
Globotruncana
mayaroensis
gansseri
calcarata
calcarata
elevata /
carinata
carinata
concavata
helvetica
helvetica
cushmani
globotruncanoides / brotzeni
breggiensis
PREMOLI SILVA + BOERSMA, 1977
Zones
Defining Events
A. mayaroensis
G. contusa
G. gansseri
G. tricarinata
G. calarata
G. elevata
not recognized
"G." concavata carinata
"G." concavata concavata
"G." schneegansi
P. helvetica
P. lehmanni
Wh. alpina
R. greenhornensis
R. cushmani
R. montsalvensis
R. brotzeni
Sch. moliniensis
P. buxtorfi
T. breggiensis
R. ticinensis
T. praeticinensis
all Cret. planktonic species
mayaroensis
contusa
gansseri
calcarata
calcarata
elevata
carinata
carinata
concavata
helvetica
helvetica
deeckei, alpina
alpina
greenhornensis, deeckei
cushmani
montsalvensis
brotzeni
buxtorfi, ticinensis, roberti
buxtorfi appenninica, P. delrioensis
ticinensis
LINARES RODRIGUEZ, 1977
Zones
Defining Events
A. mayaroensis
G. gansseri
R. subcircumnodifer
G. calcarata
G. ventricosa
G. elevata
D. carinata
D. concavata
D. schneegansi
not studied
mayaroensis
mayaroensis
gansseri
calcarata
calcarata
ventricosa
elevata
carinata
concavata
(helvetica)
MOULLADE, 1966
Zones
Defining Events
(unnamed)
appenninica sans greenhornensis
moliniensis
buxtorfi
ticinensis-delrioensis
breggiensis
praeticinensis
greenhornensis, montsalvensis
greenhornensis, Klaus, non Morrow
H. sp. aff. infracretacea
praeticinensis
THIS PAPER
Stages
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN

Calcareous nannofossils: The zone corresponds with the lower part of the *Eiffellithus turriseiffeli* Zone (first order correlation based on section El Burrueco).

Comparison with other zonations: This zone corresponds with the *Rotalipora ticinensis ticinensis* Zone of Bolli (1966), with possible exception of the very top, which may belong to Bolli's *Rotalipora appenninica* Zone already, since *Th. appenninica* seems to appear slightly earlier than *P. praebuxtorfi*. Also for this reason, the *Ps. ticinensis* Zone corresponds to the upper part of the *breggiensis* Zone and the basal part of the "*appenninica* sans *greenhornensis*" Zone of Moullade (1966). It is equivalent with the upper part of Van Hinte's (1976) *T.* (*B.*) *breggiensis* Zone, except for the topmost part. Van Hinte put the top of his zone at the last occurrence of *B. breggiensis*, which level is in the lower part of our *Ps. ticinensis* – *P. buxtorfi* Zone. The *Ps. ticinensis* Zone approximately corresponds to the *ticinensis* Zone of Boersma & Premoli Silva (1977), who defined the top of that zone with the simultaneous extinction of *B. breggiensis* and appearance of *P. buxtorfi*, which events do not coincide according to our observations.

Age: Late Albian.

Planomalina praebuxtorfi Zone

Definition: Interval with the total range of the zonal marker from its evolutionary appearance to its evolutionary transition to *Planomalina buxtorfi*.

Remarks: The range of *Planomalina praebuxtorfi* seems to be very short. The zonal marker was reported from a few places only, but in El Burrueco it is quite abundant. The zonal marker is a transitional evolutionary stage between *Globigerinelloides caseyi* and *Planomalina buxtorfi* (see the systematic part for a definition of the species).

This zone is in an interval where the faunas are rapidly changing in composition. *Thalmanninella appenninica* has its first occurrence at the base. *Ticinella* and *Biticinella* persist, but become less frequent. The characteristic non-keeled species are *Hedbergella simplex* and *Hedbergella delrioensis*. *Pseudothalmanninella ticinensis* is the most characteristic keeled form.

Calcareous nannofossils: The *Planomalina praebuxtorfi* Zone falls entirely within the lower part of the *Eiffellithus turriseiffeli* Zone (first order correlation based on section El Burrueco).

Comparison with other zonations: This zone has never been recognized by other authors. Moullade (1966) reported the nominal species informally from the very base of the range of *P. buxtorfi*.

Age: Late Albian.

Pseudothalmanninella ticinensis – Planomalina buxtorfi Zone

Definition: Interval from the evolutionary appearance of *Planomalina buxtorfi* to the exit of *Pseudothalmanninella ticinensis*.

Remarks: In this zone, the development from non-keeled to keeled faunas is completed by the appearance of partially keeled representatives of the genus *Praeglobotruncana*, apparently evolving from *Hedbergella simplex*. *Thalmanninella appenninica* is present throughout the zone. Just above the base *Ticinella* and *Biticinella* disappear.

Calcareous nannofossils: The zone falls entirely within the *Eiffellithus turriseiffeli* Zone (first order correlation based on section El Burrueco).

Comparison with other zonations: Although the zone has been recognized frequently, its definition as the interval occupied by the concurrent range of the nominal species was never used. It is the equivalent of:
– the lower part of the *R. appenninica appenninica* Zone of Bolli (1966);
– the lower part of the *buxtorfi* Subzone of the "*appenninica* sans *greenhornensis*" Zone of Moullade (1966);
– the lower part of the *R. appenninica*/*P. buxtorfi* Zone of Sigal (1977), except for the very base, which is somewhat older;
– the lower part of the *buxtorfi* Zone of Premoli Silva & Boersma (1977).

Van Hinte (1976) distinguished a *ticinensis – buxtorfi* Zone, of which the upper boundary was determined by the appearance of *Th. appenninica,* which he probably considered as direct descendant of *Ps. ticinensis.* In fact *Th. appenninica* appears earlier and is not related with *Ps. ticinensis.* It should be noted that application of Van Hinte's definition would reduce the zone to zero.

Age: Late Albian.

Thalmanninella appenninica – Planomalina buxtorfi Zone

Definition: Interval from the exit of *Pseudothalmanninella ticinensis* to the extinction of *Planomalina buxtorfi.*

Remarks: The total composition of the faunas in this zone is hardly different from that of the underlying zone, except for the absence of *Pseudothalmanninella ticinensis.* *Thalmanninella appenninica* is present in its most typical form.

Calcareous nannofossils: The *Thalmanninella appenninica – Planomalina buxtorfi* Zone falls entirely within the *Eiffellithus turriseiffeli* Zone (first order correlation based on section El Burrueco).

Comparison with other zonations: Similar discrepancies as in the definition of the subjacent zone exist for this one in the literature. The zone corresponds to:
- the middle part of the *R. appenninica appenninica* Zone of Bolli (1966);
- the middle part of the *buxtorfi* Subzone of the "*appenninica* sans *greenhornensis*" Zone of Moullade (1966). N.B.: *middle* part, because the base of the superjacent subzone was defined by the base of *Schackoïna moliniensis* rather than with the top of *P. buxtorfi*;
- the upper part of the *appenninica – buxtorfi* Zone of Van Hinte (1976); see remarks on the *P. ticinensis – P. buxtorfi* Zone;
- the *R. appenninica – P. buxtorfi* Zone of Sigal (1977);
- the upper part of the *buxtorfi* Zone of Premoli Silva & Boersma (1977).

Age: Late Albian.

Thalmanninella appenninica Zone

Definition: Interval with the zonal marker from the extinction of *Planomalina buxtorfi* to the entry of *Thalmanninella globotruncanoides*.

Remarks: After the disappearance of *Planomalina buxtorfi*, there is a gradual shift in morphology of the central group of *Thalmanninella* (see systematic part) from *Th. appenninica* to *Th. greenhornensis*. Faunas dominated by *Thalmanninella globotruncanoides* are typically intermediate. They may also contain the first representatives of *Rotalipora*, i.e. *R. montsalvensis*. In the *Thalmanninella appenninica* Zone, however, the latter is never found and *Thalmanninella* assemblages are dominated by typical *Th. appenninica*. The genus *Praeglobotruncana* is represented by flat forms (*P. delrioensis*) and moderately spiroconvex ones (*P. stephani*).

Calcareous nannofossils: The *Thalmanninella appenninica* Zone falls entirely within the *Eiffellithus turriseiffeli* Zone (see chapter III).

Comparison with other zonations: The gradual shift in morphology from typical *Th. appenninica* to *Th. greenhornensis* has been expressed in taxonomy in different ways, thus causing different names for the transitional interval. In our concept, the *Th. appenninica* Zone covers the interval with *Th. appenninica* above the disappearance of *P. buxtorfi*, but below the first *Th. globotruncanoides*. *Th. appenninica* includes forms which typologically

would belong to *Th. appenninica* tipica Gandolfi (= *Th. gandolfii* Luterbacher & Premoli Silva). This results in the correspondence of our zone to:
– the upper part of the *R. appenninica appenninica* Zone of Bolli (1966). Bolli defined the top of this zone at the first *R. brotzeni,* which in his concept probably was identical with *Th. gandolfii* of later authors, since Bolli (1957) changed the original definition of the top of the *appenninica appenninica* Zone of Dalbiez (1955) from the base of *R. appenninica* tipica (= *Th. gandolfii*) to the base of *R. brotzeni*;
– possibly the lower part of the *Rotalipora* s.s. Zone (upper part of the *R. evoluta* Subzone) of Pessagno (1967). Direct comparison is difficult because Pessagno did not report either *P. buxtorfi* or *Th. globotruncanoides*;
– the lower part of the *R. gandolfii – R. greenhornensis* Zone of Van Hinte (1976);
– probably the lower part of the *R. brotzeni – R. globotruncanoides* Zone of Sigal (1977). Sigal reports both nominal species from the top of the range of *P. buxtorfi* onwards, an observation which may be correct in a typological approach, but which is suspected to be the result of too much typological splitting;
– the *moliniensis* Zone of Premoli Silva & Boersma;
– the upper part of the "*appenninica* sans *greenhornensis*" Zone, including the top of the *buxtorfi* Subzone and the lower part of the *moliniensis* Subzone of Moullade (1966).

Age: Latest Albian to Earliest Cenomanian.

Thalmanninella globotruncanoides Zone

Definition: Interval from the evolutionary appearance of the zonal marker to the entry of *Rotalipora cushmani.*

Remarks: As stated above, this zone takes a typically intermediate position between the under- and overlying zones. In our material, we found the first *Thalmanninella* assemblages which were dominated by *Th. globotruncanoides* to be always accompanied by *R. montsalvensis,* and the first *Rotalipora cushmani* always together with a *Th. greenhornensis* assemblage.

Calcareous nannofossils: The *Thalmanninella globotruncanoides* Zone corresponds with an interval which probably includes the top of the *Eiffellithus turriseiffeli* Zone (see chapter III) and the lower part of the *Lithraphidites acutum* Zone. Only for the latter portion there is a first order correlation possible (section Koudiat el Hamra).

Comparison with other zonations: Although the species concepts of the various authors are not exactly clear, it is most likely that the *Thalmanninella globotruncanoides* Zone is equivalent with:

- the *R. brotzeni* Zone and the *R. reicheli* Zone of Bolli (1966);
- the major upper portion of the *moliniensis* Subzone of Moullade (1966);
- the upper part of the *Rotalipora evoluta* Subzone of Pessagno (1967);
- the upper part of the *R. gandolfii – R. greenhornensis* Zone and the *R. gandolfii – R. reicheli* Zone of Van Hinte (1976). Van Hinte defined the top of the latter zone rather vaguely with the last occurrence of *Th. gandolfii* and *Favusella washitensis* rather than the base of *R. cushmani*;
- the upper part of the *Th. globotruncanoides – R. brotzeni* Zone of Sigal (1977);
- the *brotzeni* Zone and the *montsalvensis* Zone of Premoli Silva & Boersma 1977).

Age: Early Cenomanian.

Rotalipora cushmani Zone

Definition: Interval of the total range of *R. cushmani.*

Remarks: Although transitional forms between *Rotalipora montsalvensis* and *Rotalipora cushmani* were found in section El Kef, we have too little material for illustrating a gradual transition between the species and for defining the lower boundary event as evolutionary.

Characteristic associated faunal elements in the *Rotalipora cushmani* Zone are *Thalmanninella greenhornensis, Praeglobotruncana stephani* and *Praeglobotruncana gibba.* In the upper part, primitive double-keeled representatives of *Praeglobotruncana* (*P. algeriana*) and extremely high ventroconvex *Thalmanninella* (*Th. deeckei*) may be present.

Calcareous nannofossils: The *Rotalipora cushmani* Zone corresponds to the *Lithraphidites acutum* Zone, the *Gartnerago obliquum* Zone and the lower part of the *Quadrum gartneri* Zone (first order correlation based on section Koudiat el Hamra).

Comparison with other zonations: Only Bolli (1966) defined the zone as a total range zone. Other authors give different definitions for the base. Consequently, the total range zone of *R. cushmani* corresponds with:

- the *R. cushmani – greenhornensis* Subzone of the *Rotalipora* s.s. Zone of Pessagno (1967);
- approximately the *R. cushmani* Zone of Van Hinte (1976), the base of which is rather ill-defined;

– the *R. cushmani* Zone of Sigal (1977). This author reported an overlap of *R. cushmani* and *H. helvetica,* but in a personal communication (4–2 1978) he gave a correction to this in the sense that the succession of events should be 1) exit of *R. cushmani,* 2) entry of *H. helvetica,* thus recognizing the existence of the *Wh. archaeocretacea* Zone (or equivalent);
– the *cushmani* Zone, *greenhornensis* Zone and *alpina* Zone of Premoli Silva & Boersma (1977). The upper boundary of the *alpina* Zone was defined by the simultaneous exits of *Wh. alpina* and *Th. deeckei.* The latter event probably coincides approximately with the last occurrence of *R. cushmani.*

Age: Late Cenomanian.

Whiteinella archaeocretacea Zone

Definition: Interval with the zonal marker from the extinction of *R. cushmani* to the first occurrence of *Helvetoglobotruncana helvetica.*

Remarks: An almost complete renewal of the fauna is observed in this zone. *Rotalipora* and *Thalmanninella* have disappeared, *Hedbergella* and *Whiteinella* become important, not only in numbers, but also in size, and the first representatives of *Marginotruncana* appear. Although the faunal assemblage is quite characteristic, the *Whiteinella archaeocretacea* Zone, by the same or any other name, has never become very popular, mainly because the associated planktonic foraminifera were considered non-diagnostic. Turning the argument around, one may say that the zone is characterized by non-diagnostic species. Several of them (*Praeglobotruncana turbinata, Hedbergella delrioensis, Hedbergella brittonensis, Praeglobotruncana algeriana*) were already present in the underlying zone, whereas others (*Whiteinella archaeocretacea, Marginotruncana* spp, *Whiteinella praehelvetica*) sometimes may be difficult to recognize because of their similarity to other forms. However, if encountered in a sequence of successive faunas, the zone is easily identified.

Calcareous nannofossils: The *Whiteinella archaeocretacea* Zone corresponds to part of the *Quadrum gartneri* Zone (first order correlation based on section Koudiat el Hamra). A questionable correlation to the *Gartnerago obliquum* Zone is discussed in chapter III.

Comparison with other zonations: As a result of the effects of the Cenomanian-Turonian boundary event (see chapter VI), the *Whiteinella archaeocretacea* Zone may not be recognizable in many areas. It was not reported by Pessagno (1967), Porthault (1974) or Sigal (1977). It seems to be widespread in North Africa (Sigal, 1952; Dalbiez, 1955; Schijfsma, 1955; Lehmann, 1963), where it was commonly referred to as "zone à grandes globigérines". It appears under different names in literature, as a consequence of the complex taxonomy of the marker species. Its definition almost invariably is the same, except in Van Hinte (1976), who defined the top with the exit of the genus *Praeglobotruncana* rather than with the base of *H. helvetica,* and in Premoli Silva & Boersma (1977), who gave a peculiar definition of the base, with the assumedly simultaneous exits of *Wh. alpina* and *Th. deeckei.*

Age: Earliest Turonian.

Helvetoglobotruncana helvetica Zone

Definition: Interval of the total range of the zonal marker.

Remarks: The evolutionary development of the zonal marker from a *Whiteinella* ancestor, as reported by Lamolda (1976) is not observable in our material, probably due to too wide spacing of the samples.

In the *Helvetoglobotruncana helvetica* Zone a rapid evolution within the genus *Marginotruncana* takes place. Both single-keeled (*M. sigali, M. marianosi*) and double-keeled forms (*M. canaliculata, M. imbricata, M. pseudolinneiana*) appear, as well as the group of *M. renzi*. Of the genus *Hedbergella, H. hoelzli* is a characteristic form.

Calcareous nannofossils: The *Helvetoglobotruncana helvetica* Zone corresponds to the upper part of the *Quadrum gartneri* Zone and the lower part of the *Eiffellithus eximius* Zone (first order correlation based on section Koudiat el Hamra and section Javernant, respectively).

Comparison with other zonations: This zone is commonly defined on the total range of the marker, except by Van Hinte (1976). His "*G.*" *helvetica* partial range Zone has the last occurrence of *Praeglobotruncana* as its base.

Age: Turonian.

Marginotruncana sigali Zone

Definition: Interval with the nominate species from the exit of *Helvetoglobotruncana helvetica* to the entry of *Marginotruncana primitiva.*

Remarks: This zone is the lowermost of four zones, in which a very slow development of planktonic foraminiferal faunas is observed, with sometimes very subtle and difficultly observable modifications in groups that already existed in the *Helvetoglobotruncana helvetica* Zone. All main groups of *Marginotruncana* are present in this zone, except for the group of *M. concavata.* In the upper part of the zone intermediate forms between *M. schneegansi* and *M. primitiva* are observed.

Calcareous nannofossils: The *Marginotruncana sigali* Zone corresponds to the upper part of the *Eiffellithus eximius* Zone. Probably due to too wide spacing between the samples in section Oued Zerga, the upper boundaries of both zones seem to be coinciding (first order correlation based on sections Koudiat el Hamra and Oued Zerga).

Comparison with other zonations: Most authors have not distinguished a *primitiva* Zone between the *H. helvetica* Zone and the *M. concavata* Zone. Consequently, their zone between the last occurrence of *H. helvetica* and the entry of *M. concavata,* which, dependent on the choice of the zonal marker, may bear different names (*schneegansi, renzi, sigali*) covers a longer interval. Linares Rodriguez (1977) reported *Dicarinella indica* (= *M. primitiva*) from the very base of the interval which was studied by her in southern Spain. Her *Dicarinella schneegansi* Zone therefore corresponds to our *M. primitiva* Zone and not to the *M. sigali* Zone.

Age: Late Turonian.

Marginotruncana primitiva Zone

Definition: Interval from the evolutionary appearance of *M. primitiva* to that of *M. concavata.*

Remarks: The zonal marker is an intermediate stage between *Marginotruncana schneegansi* and *Marginotruncana concavata.* As far as could be observed, the transitions to both species are gradual. The first types of *M. primitiva* are found as extreme forms in an assemblage dominated by *M. schneegansi.* Such forms may easily be overlooked and are not considered zonal markers of the *primitiva* Zone. Only when the total assemblage is dominated by *primitiva* types, it is assigned to the *primitiva* Zone.

Characteristic other species are rare in the zone; most species are long-ranging and persist up to the top of the *carinata* Zone (*M. coronata, M. pseudolinneiana,* and representatives of the *M. sigali* – *renzi* group).

Calcareous nannofossils: The *M. primitiva* Zone is correlated with the *Marthasterites furcatus* Zone (first order correlation based on sections Koudiat el Hamra and Oued Zerga).

Comparison with other zonations: See *M. sigali* Zone. The top of the zone is invariably defined by the first *M. concavata.*

Age: Coniacian.

Marginotruncana concavata Zone

Definition: Interval from the evolutionary appearance of the zonal marker to that of *M. carinata.*

Remarks: By gradual accentuation of the ventral convexity, *M. primitiva* evolved to *M. concavata,* which, in turn, led to *M. carinata* by acquisition of periumbilical ridges and a still more pronounced ventral convexity. The "assemblage concept" (Zachariasse 1975) was used for the definition of the zone.

Faunas are dominated by the various types of the *M. pseudolinneiana* group and the *M. sigali – renzi* group. Within the zone, the first true *Globotruncana* forms appear, at first as extreme forms of both groups, i.e. *G. linneiana* and *G. fornicata.*

Calcareous nannofossils: The *M. concavata* Zone corresponds to the lower part of the *Broinsonia lacunosa* Zone. In our material, the lower boundaries of both zones seem to coincide. It must be noted, however, that the two samples at either side of the common boundary are about 35 metres apart and that the assemblages of the *M. concavata* group in both samples are very similar. This means that there remains a certain interval of uncertainty, mainly by the vagueness of the "evolutionary appearance" of *M. concavata.* The correlation of the two zonal boundaries can only be improved by laborious statistical work on more abundant material.

Comparison with other zonations: The definition of the base of the *Marginotruncana concavata* Zone offers no problems. Some authors, however, included *M. carinata* in their species concept of the marker (Pessagno, 1967; Van Hinte, 1976). Therefore, assignments to the *M. concavata* Zone should be considered with care. Our biostratigraphic concept of the zone is the same as that of Sigal (1977), Premoli Silva & Boersma (1977) and Linares Rodriguez (1977).

Age: Early Santonian.

Marginotruncana carinata Zone

Definition: Interval from the evolutionary appearance of *M. carinata* to the entry of *G. elevata.*

Remarks: The zonal marker is only distinguished from *M. concavata* by the presence of periumbilical ridges. Assemblages dominated by forms with periumbilical ridges are assigned to the *M. carinata* Zone.

The lower part of the zone may be recognized by the presence of *M. concavata* types. The genus *Sigalia* appears just before the exit of the last *M. concavata* types, *S. decoratissima* was found to occur in the top of the zone. All *Marginotruncana* species of the *pseudolinneiana* group and the *sigali-renzi* group which were already present in the underlying zone persist. *G. fornicata* and *G. linneiana* also remain present.

Near the top of the zone, transitional forms between *M. sinuosa* and *G. elevata* are found.

Calcareous nannofossils: The *M. carinata* Zone is correlated with the top portion of the *Broinsonia lacunosa* Zone, the *Micula concava* Zone, the *Rucinolithus hayii* Zone and the lowermost part of the *Zygodiscus spiralis* Zone (first order correlation based on section Oued Zerga and section El Burrueco). The correlation with the *Zygodiscus spiralis* Zone is from El Burrueco only; this part of the column was probably missed in Tunisia by too wide spacing of the samples.

Comparison with other zonations: The *Marginotruncana carinata* Zone was used in the same sense by Linares Rodriguez (1977), Sigal (1977) and Premoli Silva & Boersma (1977). Bolli (1966) did not mention *M. carinata*; in his zonal scheme our zone may range up to the base of his *G. stuarti* s.l. Zone. Pessagno (1967) considered *M. carinata* to be synonymous with *M. concavata* but only figured a *M. concavata* specimen. Therefore, the correlation to the American zonations remains uncertain.

Age: Late Santonian.

Globotruncana elevata – Marginotruncana carinata Zone

Definition: Interval from the first appearance of *G. elevata* to the exit of *M. carinata.*

Remarks: The overlap in the ranges of the marker species is very short and probably it has therefore not often been recorded. The accompanying fauna is as that of the *M. carinata* Zone. Transitional forms between *Marginotruncana* and *Globotruncana* members of the same groups are frequent (*sinuosa-elevata, pseudolinneiana-linneiana, sinuosa-fornicata*). The genus *Sigalia* is represented by *S. decoratissima.*

Calcareous nannofossils: The zone falls entirely within the *Zygodiscus spiralis* Zone (first order correlation based on section Oued Zerga and section El Burrueco).

Comparison with other zonations: In zonations based on material from Middle and North America (Bolli, 1966; Pessagno, 1967) this zone was not recognized. A considerable gap between the ranges of representatives of the *concavata* group and the *elevata* group seems to be present there. In European and North African zonations both groups either succeed each other without a gap or overlap (Sigal, 1977; Premoli Silva & Boersma, 1977), or have a small overlap (Van Hinte, 1976; Linares Rodriguez, 1977). The overlap situation seems to be the most normal case. One might argue that the succession of species as reported by Pessagno (1967) may be the result of a more complete biostratigraphic record, and point to a hiatus in the European succession as given by Sigal (1977). This point of view is visualized in fig. 22. This way, however, an overlap of the ranges can only have been created by reworking, for which we have no indication whatsoever. Therefore, an alternative explanation is given: probably the American faunas lack

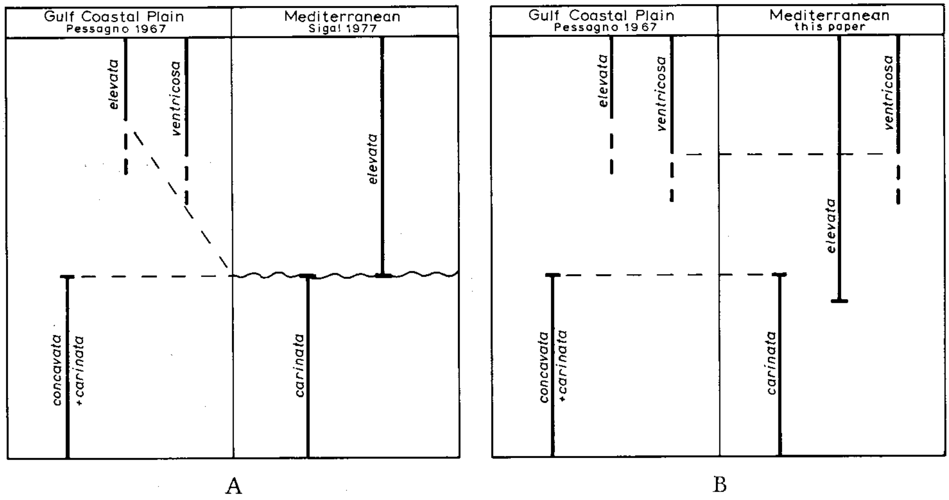


Fig. 22A Comparison of the ranges of the *M. concavata* group and Campanian markers as reported by Pessagno (1967) and by Sigal (1977), with possible explanation by means of a hiatus in the Western Mediterranean area.

Fig. 22B Comparison of the ranges of the *M. concavata* group and Campanian markers as reported by Pessagno (1967) and as found during this study, with probable explanation by absence of the *G. elevata* group in the Lower Campanian of the Western Gulf Coastal Plain.

representatives of the *elevata* group because of unfavourable ecological conditions (fig. 22).

Age: Late Santonian.

Globotruncana elevata Zone

Definition: Interval with the nominate species s.l. from the last occurrence of *G. carinata* to the entry of *G. ventricosa.*

Remarks: A lower and an upper part may be recognized in this zone. The lower part is characterized by rather primitive forms of the *G. elevata* group (*G. elevata* s. str.) and by the absence of *G. rosetta* and *G. esnehensis.* In the upper part, the *G. elevata* group is represented by *G. stuartiformis* and accompanied by the *G. rosetta* group.

In the *G. elevata* Zone, the genus *Marginotruncana* has disappeared and the main groups are only represented by *Globotruncana* species (*G. arca, G. linneiana, G. fornicata, G. rosetta,* etc.).

Calcareous nannofossils: The *G. elevata* Zone corresponds to the top of the *Zygodiscus spiralis* Zone, the *Broinsonia parca* Zone, the *Ceratolithoides aculeus* s.l. Zone, the *Quadrum gothicum* Zone and the lowermost part of the *Quadrum trifidum* Zone (first order correlations based on sections Oued Zerga, El Haria and El Burrueco).

Comparison with other zonations: Most authors do not use *G. ventricosa* as a zonal marker and define the top of their *G. elevata* Zone with the base of *G. calcarata.* Consequently, our *G. elevata* Zone is restricted to the lower part of theirs (Sigal, 1977; Premoli Silva & Boersma, 1977), except for the very base, if defined by the entry of *G. elevata.* Comparison with Pessagno's (1967) zonation learns that in the Western Gulf Coastal Plain *G. elevata* appears *after* the first *G. ventricosa.* Probably, our *G. elevata* Zone has to be correlated with part of Pessagno's *G. fornicata* Subzone of the *G. bulloides* Zone, although *G. elevata* was not reported from that part of the column.

Age: Early Campanian.

Globotruncana ventricosa Zone

Definition: Interval from the entry of *G. ventricosa* to the first occurrence of *G. calcarata.*

Remarks: Even in the closely sampled section of El Burrueco, the zonal marker appears suddenly, without morphological gradation to any other species. It may be regarded as an immigrant, which puts some doubt upon the value of the base of its range as a datum level in interregional correlations. As far as known, however, it never has been reported from the Lower Campanian and consequently may be regarded as an Upper Campanian form.

Planktonic faunas of the *G. ventricosa* Zone are very constant in their composition. Always present are *G. stuartiformis, G. arca, G. linneiana, G. rosetta,* and *G. falsostuarti, G. subspinosa* persists throughout the zone.

Calcareous nannofossils: The *G. ventricosa* Zone falls entirely in the *Quadrum trifidum* Zone.

Comparison with other zonations: See remarks on the *G. elevata* Zone. The *G. ventricosa* Zone is the same as that of Linares Rodriguez (1977) and corresponds to the upper part of the *elevata* Zone of Premoli Silva & Boersma (1977), and the *Archaeoglobigerina blowi* Subzone and lower part of the *G. elevata* Subzone (*Pseudotextularia elegans* Zonule) of Pessagno (1967). Note that Pessagno's *elevata* Subzone and our *G. elevata* Zone are not equivalent and even have no overlap. *G. ventricosa* appears just above the first forms assignable to *G. subspinosa,* and the zone corresponds with the entire *G. subspinosa* Zone of Van Hinte (1976).

Age: Late (not latest) Campanian.

Globotruncana calcarata Zone

Definition: Interval of the total range of the zonal marker.

Remarks: *G. calcarata* suddenly appears; its phylogenetic origin remains unclear. It probably also is an immigrant in the Western Mediterranean area, and therefore its first occurrence may not be an absolutely reliable datum plane. Still, it appears to be a wide-spread species, representing a short stratigraphic interval. All the species present in the *G. ventricosa* Zone persist throughout the *G. calcarata* Zone.

Calcareous nannofossils: The *G. calcarata* Zone falls entirely within the *Quadrum trifidum* Zone (first order correlation based on section El Burrueco).

Comparison with other zonations: The total range of *G. calcarata* is commonly used to define a *G. calcarata* Zone or Subzone.

Age: Latest Campanian.

"Globotruncana tricarinata" Zone

Definition: Interval from the last occurrence of *G. calcarata* to the entry of *G. gansseri*.

Remarks: The name of this zone, which invariably has been recognized in some form or other by authors has always been a problem. *G. tricarinata* was shown to be synonymous with *G. linneiana* by Pessagno (1967). The latter species, however, is not a characteristic element in the interval concerned. Linares Rodriguez (1977) dealt with the nomination problem quite extensively. She rejected *G. falsostuarti, G. stuartiformis, G. fornicata* and *G. arca* as zonal markers on various grounds and finally chose *Rugotruncana subcircumnodifer*. This species, however, was not found in our material. Therefore, the original name of the zone (*Globotruncana lapparenti tricarinata* Zone) of Bolli (1957) is partly retained, also to emphasize the fact that our definition of the zone is the same as that of Bolli. Moreover, by any other name, the zone would be as problematic.

Calcareous nannofossils: The "*G. tricarinata*" Zone falls entirely within the *Quadrum trifidum* Zone (first order correlation based on section El Haria).

Comparison with other zonations: In its present definition, the "*G. tricarinata*" Zone is identical with the *G. lapparenti tricarinata* Zone of Bolli (1966), the *Rugotruncana subcircumnodifer* Subzone of Pessagno (1967) and of Linares Rodriguez (1977), the *tricarinata* Zone of Premoli Silva & Boersma (1977), the *G. stuarti/G. falsostuarti* Zone of Sigal (1977) and the *G. scutilla* Zone of Van Hinte (1976).

Age: Early Maastrichtian.

Globotruncana gansseri Zone

Definition: Interval from the entry of the nominate species to the base of *G. contusa*.

Remarks: See remarks on the "*G. tricarinata*" Zone. *G. gansseri* apparently may be rare or absent in relatively shallow water deposits. The top of the zone is rather vague because of the gradual transition from *G. fornicata* to *G. contusa*.

Calcareous nannofossils: The *G. gansseri* Zone falls entirely within the *Lithraphidites quadratus* Zone.

Comparison with other zonations: The *G. gansseri* Zone has not generally been recognized. In our definition, it corresponds to the lower part of the *G. gansseri* Zone of Bolli (1966), Pessagno (1967) and Linares Rodriguez (1977) and to the entire *gansseri* Zone of Sigal (1977) and Premoli Silva & Boersma (1977).

Age: Early to Middle Maastrichtian.

Globotruncana contusa Zone

Definition: Interval from the entry of the zonal marker to the first occurrence of *A. mayaroensis.*

Remarks: See remarks on *G. gansseri* Zone. The upper part of the zone is characterized by the presence of *Racemiguembelina fructicosa* and may be distinguished as a subzone.

Calcareous nannofossils: The *G. contusa* Zone is equivalent with the upper part of the *Lithraphidites quadratus* Zone and the lower part of the *Micula murus* Zone. In section El Haria, *M. murus* and *R. fructicosa* appear in the same sample.

Comparison with other zonations: See *G. gansseri* Zone. The *G. contusa* Zone corresponds to the upper part of the *G. gansseri* Zone of authors who do not use *G. contusa* as a separate zonal marker.

Age: Middle to Late Maastrichtian.

Abathomphalus mayaroensis Zone

Definition: Interval from the entry of the zonal marker to the massive extinction of Cretaceous planktonic foraminifera.

Remarks: The marker is very rare in our material. It was found in three samples only: in sample 3 from section Moria and in samples AFN 200 and 202 in section El Haria.

Calcareous nannofossils: The *A. mayaroensis* Zone corresponds with the upper part of the *Micula murus* Zone (first order correlation based on section El Haria).

Comparison with other zonations: The *A. mayaroensis* Zone, either defined as total range zone or in the same way as here, has found world-wide recognition.

Age: Late Maastrichtian.

Chapter III

CORRELATION OF PLANKTONIC FORAMINIFERAL AND CALCAREOUS NANNOFOSSIL ZONATIONS

INTRODUCTION

As the samples used for this study are essentially the same as those of Verbeek (1977), a first order correlation of his calcareous nannofossil zonation and the planktonic foraminiferal zonation is possible. After Verbeek's (1977) publication a slightly modified zonal scheme for the interval from Upper Aptian to Coniacian was proposed by Manivit et al. (1977). Since Verbeek was co-author of this publication, the nannofossil events used therein were applied for correlation with the planktonic foraminiferal zones, with some minor modifications, which are discussed below.

CORRELATIONS

Base of Prediscosphaera columnata

This level apparently is older than any material used for this study. Manivit et al. (1977) placed it in the Lower Albian, in accordance with Thierstein (1973). The same authors stated that the base of *P. columnata* was observed at the base of the Middle Albian at Courcelles (Dept. Aube, France: type Albian) and in section El Burrueco. Verbeek (1977), however, found *P. columnata* also in the section Montiéramy (Lower Albian of the type area) and correctly noted that the sediments of El Burrueco were probably younger. The base of the range of *P. columnata* in El Burrueco is at the base of the section in the *Ps. subticinensis* Zone, which is certainly younger than Early Albian.

Base of Eiffellithus turriseiffeli

In El Burrueco, *E. turriseiffeli* was found to have its first occurrence at the very base of the *Ps. ticinensis* Zone. As *Ps. ticinensis* rapidly evolved from *Ps. subticinensis* (Wonders, 1978), the correlation of the base of *E. turriseiffeli* and that of *Ps. ticinensis* as defined here seems to be rather accurate.

Base of Lithraphidites acutum

If we only could depend on our own material, then the correlation of this datum with planktonic foraminifera is not sufficiently accurate. *L. acutum* was not found in section El Burrueco, but this does not mean that its base is higher than that of *Th. globotruncanoides,* because Verbeek (1977) did not study sample Bu 41, the only sample in which *Th. globotruncanoides* is present. At the base of section Koudiat el Hamra, *L. acutum* is already present in the *Th. globotruncanoides* Zone, below the entry of *R. cushmani.* With these data, we can only conclude that the base of the *L. acutum* Zone is in (the upper part of) the *Th. appenninica* Zone or in the *Th. globotruncanoides* Zone.

Manivit et al. (1977), however, put the base of *L. acutum* Zone in the *saxbyi* ammonite zone, allegedly within the range of *Th. reicheli.* This species is extremely rare in our material, but it is certainly younger than the first *Th. globotruncanoides.* Therefore, the base of *L. acutum* must be in the *Th. globotruncanoides* Zone.

Top of Cruciellipsis chiasta

Manivit et al. (1977) consider this rare species to have its last occurrence within the *L. acutum* Zone, thus defining a subzone in the lower part of it. Verbeek (1977) attributed a similar range to it in his composite range chart, but reported it also from sample Kef 10 of section Koudiat el Hamra, which is well above the base of *Q. gartneri,* marker of the next higher zone. Therefore, *C. chiasta* is not used in the correlation scheme here.

Base of Gartnerago obliquum

According to Manivit et al. (1977) the first occurrence of this species is not well established, but it would be in the Cenomanian. Verbeek (1977) reported it to be present in the lower part of the *R. cushmani* Zone in section Koudiat el Hamra.

Base of Quadrum gartneri

This datum level is approximately in the top part of the *R. cushmani* Zone in section Koudiat el Hamra (sample Kef 10). Manivit et al. (1977) placed this first occurrence in the "Lower Turonian", but still in the *R. cushmani* Zone.

Base of Eiffellithus eximius

Both in section Koudiat el Hamra and in section Javernant (De Vries, 1977; Verbeek, 1977) *E. eximius* was found to have its first occurrence in the *H. helvetica* Zone.

Base of Marthasterites furcatus

The first *M. furcatus* was found together with the first *M. primitiva* in sample Kef 19 in section Koudiat el Hamra. The gradual transition from *M. schneegansi* to *M. primitiva* makes the lower boundary of the *M. primitiva* Zone rather vague, and consequently the correlation of the bases of the *M. furcatus* and *M. primitiva* Zones cannot be considered as being very precise.

Base of Broinsonia lacunosa

As the transition from *M. primitiva* to *M. concavata* is gradual, the zonal boundary between the respective zones is correspondingly vague. The first *B. lacunosa* was found in the lowermost sample with a typical *M. concavata* assemblage in section Oued Zerga. Therefore, the base of the *B. lacunosa* Zone is provisionally considered to be coincident with that of the *M. concavata* Zone.

Bases of Micula concava, Rucinolithus hayii and Zygodiscus spiralis

These three successive zonal markers have their first occurrences in the *M. carinata* Zone. *Z. spiralis* appears just below the first *G. elevata* in section El Burrueco, where a hiatus is present below this first occurrence. In section Oued Zerga, it appears together with *G. elevata,* but there the wide sampling space leaves more than 50 metres open for a difference between the bottom of the ranges of *Z. spiralis* and *G. elevata.*

Base of Broinsonia parca

The base of *B. parca* is in the lower part of the *G. elevata* Zone in section Oued Zerga. The *B. parca* Zone was not found in section El Burrueco due to the presence of a hiatus.

Base of Ceratolithoides aculeus

In section Oued Zerga *C. aculeus* is found with the first *G. rosetta* in the *G. elevata* Zone. Also in section El Burrueco it has its first occurrence together with *G. rosetta,* but this joint entry is immediately above a hiatus and the base of the *C. aculeus* Zone may be younger there.

Bases of Quadrum gothicum and Quadrum trifidum

Both species appear in the upper part of the *G. elevata* Zone. *Q. trifidum* first occurs just below the first *G. ventricosa* both in section El Burrueco and in section El Haria.

Base of Lithraphidites quadratus

This species was found to appear together with *G. gansseri* in section El Haria. It is noted that in Verbeek's (1977) planktonic foraminiferal scheme the boundaries of the *G. gansseri* Zone and the *G. contusa* Zone differ considerably from those in ours. This is due to the rarity of *G. gansseri* in the lower part of its range in the section, in which it had not yet been found a few years ago.

Base of Micula murus

M. murus was found to have its first occurrence in the *G. contusa* Zone together with the first *R. fructicosa* in section El Haria. This joint entry is in a part of the section with rather closely-spaced samples, so that *R. fructicosa* and *M. murus* seem to be characteristic for the upper part of the *G. contusa* Zone and the *A. mayaroensis* Zone.

CONCLUDING REMARKS

A number of 22 planktonic foraminiferal zones are correlated with 17 calcareous nannofossil zones. From the correlation chart (fig. 21) it appears at first glance that rapid successions of zones in one group occur in intervals with long zones in the other.

Planktonic foraminiferal zones may be subdivided by means of calcareous nannofossil zones and vice versa. A simple exercise on the correlation chart in doing so increases the number of Albian and Upper Cretaceous planktonic zones to 33, covering a period of about 40 millions of years. This would imply an average duration of the zones of about 1.2 Ma, which figure approaches the limits of biostratigraphic accuracy as pointed out by Drooger (1974).

Chapter IV

CORRELATION WITH THE CRETACEOUS REVERSAL SCALE

INTRODUCTION

In recent years an enormous advance in Cretaceous and Tertiary magnetostratigraphy has been made, mainly triggered by the studies on pelagic limestone sequences (Alvarez et al., 1977; Napoleone, 1977; Roggenthen, 1977; Lowrie & Alvarez, 1977; VandenBerg & Wonders, 1979; Channell et al., 1979). The main tool for dating the reversal sequences is offered by planktonic foraminifera and a direct result has been a detailed calibration of the Cretaceous and Tertiary reversal sequence and planktonic foraminiferal zonation.

In this study, a compilation of the available data is given. Some Mid-Cretaceous reversals from the reputed Cretaceous Long Normal Zone, as reported by VandenBerg & Wonders (1979) are documented, as well as one from the Lower Campanian.

In several cases the correlation between calcareous nannofossil zonation and reversal sequence is also possible; a first order correlation based on section El Burrueco and several second order correlations via the planktonic foraminiferal zonation could be established.

THE GUBBIO SEQUENCE

The correlation between the Upper Cretaceous magnetic reversal sequence and planktonic foraminiferal zonation is mainly based on Alvarez et al. (1977), who compiled data offered by Lowrie & Alvarez (1977), Roggenthen & Napoleone (1977) and Premoli Silva (1977), and on the data from section Moria given by Alvarez & Lowrie (1978). Together, these records cover the whole Upper Cretaceous, with a small extension into the Upper Albian.

Unfortunately, Alvarez & Lowrie (1978) did not give a documentation of the biostratigraphy upon which they based their age assignments of the results from Moria. The present author, however, recently studied the planktonic foraminifera of the Moria section (Wonders, 1979) and the results can be directly compared. The base of the magnetic zone Gubbio A^- is just above the base of the *G. elevata* Zone in section Moria (in El Burrueco it is in the *elevata-carinata* Zone, which determination is more reliable because the foraminifera were determined from residues and not from thin sections). On top of magnetic zone Gubbio A^-, Alvarez & Lowrie found a transitional interval which had not been reported from Gubbio and which probably corresponds to the interval from which VandenBerg & Wonders (1979) reported a reversed site in section El Burrueco. This interval is indicated as $Burr.^-$ in fig. 21. Magnetic zone Gubbio C^- is just above the *G. calcarata* Zone and falls entirely in the *G. "tricarinata"* Zone, as does zone $D2^-$. The magnetic zone Gubbio E^- is within the *G. gansseri* Zone; zone Gubbio G^- has its base in the *A. mayaroensis* Zone and straddles the Cretaceous-Tertiary boundary.

THE CRETACEOUS LONG NORMAL ZONE

Most of the Cretaceous magnetic reversal scales show a considerable interval with only normal polarities, which ranges from some level in the Lower Cretaceous to fairly high up in the Upper Cretaceous and which corresponds to the well-known Cretaceous Quiet Zone in magnetic anomaly profiles of oceanographers. The duration of the timespan with strongly prevailing normal polarities is of particular interest, because it has direct bearings on estimates of spreading rates in the oceans and therefore on paleo-oceanographic and paleogeographic reconstructions.

From all the previous magnetostratigraphic work in Italy it has become clear that the base of magnetic Zone Gubbio A^- is the top of the Cretaceous Long Normal Zone. After identification of the top, finding the bottom should be easy by looking for the first reversal down-section. However, such reversed directions have not yet been reported from the Gubbio section and also in the Moria section they seem to be absent at least down to the Upper Albian (Alvarez & Lowrie, 1978).

The highest reversed direction reported so far from the Gubbio area is that of Site ISEA in the Sentino Gorge at Val Dorbia near Scheggia, some 15 km. N. of Gubbio (VandenBerg et al., 1978). Site ISEA is in a conspicuous red layer in the lower part of the Fucoid Marls, about 12 metres above the base. Thin sections of a measured core revealed well-preserved specimens of *H. trocoidea* and *Planomalina cheniourensis,* which are indicative for the uppermost Aptian. (pl. 9, figs. 2–7).

A magnetostratigraphic study in the Southern Alps (VandenBerg & Wonders, 1979) revealed more reversed directions: one set in pelagic carbonates which could be dated as Cenomanian (*Th. globotruncanoides* Zone and *R. cushmani* Zone) and two short reversals in what was dated as Upper Albian (*B. breggiensis* Zone), but in fact may be older. These results are documented and discussed here.

Cenomanian reversals: the Quero-Schievenin mixed Zone

Rapidly alternating normal, intermediate and reversed directions were reported from the Quero-Schievenin section by VandenBerg & Wonders (1979) from an interval straddling the boundary between the *Th. globotruncanoides* Zone and the *R. cushmani* Zone, and which, both at the bottom and at the top, is bordered by intervals with normal directions only. As the authors already noted, the number of small intervals with opposite magnetic directions that was found may have been dependent on the spacing of the samples. Anyway, the existence of an interval with rapidly changing polarities was clearly demonstrated. The assignment of the interval with mixed directions to the *Th. globotruncanoides* Zone and the *R. cushmani* Zone is documented here by figuring some relevant forms from both the base and the top of the interval concerned (pl. 10, figs. 1–4).

Cenomanian reversed or mixed intervals have not been adequately described before. Essentially, there are two sources of information pertaining to them. The oldest is that of Keating & Helsley (1978b) who mention a reversal near the Cenomanian – Turonian boundary with reference to Keating & Helsley (1978a). The latter, however, refer to Keating et al. (1975), in which publication no Mid-Cretaceous reversal is mentioned.

Behrens et al. (1978) reported a sequence of seven reversed intervals from the Cenomanian of southern Morocco, in the Cenomanian part of their section Zem-Zem. They do not indicate, however, the evidence upon which the age assignment was based. Although it may be possible that this sequence is the same as that of the section Quero-Schievenin, we have no positive evidence for such a correlation and therefore consider the mixed zone recorded from the latter as newly found by VandenBerg & Wonders (1979).

Late Albian reversals: Valle del Mis 1 and 2 (= site 263 mixed Zone?)

VandenBerg & Wonders (1979) also reported two short intervals with reversed polarity from section Valle del Mis in the Southern Alps. The dating of these results as being Late Albian (*B. breggiensis* Zone) cannot be clearly substantiated, as planktonic foraminifera of the *Ps. subticinensis* Zone were found only at a somewhat higher stratigraphic level, whereas below that level only indeterminable *Hedbergella* and Radiolaria were encountered (see fig. 19). Study of calcareous nannofossils failed because of the unsuitable facies; analysis of possibly present *Nannoconus* could not be performed before achievement of this paper.

Consequently, the age of the two Valle del Mis reversals remains uncertain. In view of the position in the section, they may correspond to the short reversals reported by Green & Brecher (1974), Green et al. (1974) and

Jarrard (1974) from DSDP site 263. The dating of these reversals was a problem: calcareous nannofossil, planktonic foraminiferal and benthic foraminiferal evidence was strongly conflicting, and Bukry's statement (1974) that the reversals were Aptian in age did not solve the problem.

Recently, Hailwood et al. (1979) reported a number of reversals from the northern margin of the Bay of Biscay. These cores could be dated by means of planktonic foraminifera and confirm the presence of reversals in the Upper Albian. Although there is no direct proof that these reversals are the same as those of Valle del Mis, it is provisionally assumed that they are.

Chapter V

CORRELATION WITH THE STRATOTYPES OF MIDDLE AND UPPER CRETACEOUS STAGES IN EUROPE

INTRODUCTION

Chronostratigraphic ages of Cretaceous rocks are generally given in terms of European stage names all over the world. This is more or less by tradition and not because the European stratotypes would be such a good standard or because of the enormous importance of correlating any Cretaceous piece of rock with those of Europe. We compiled a correlation between the European stratotypes and the integrated nannofossil and planktonic foraminiferal scheme based on the evidence which is now available. The correlation chart which is now currently used is that of Van Hinte (1976). The nannofossil evidence in that chart is poor and needs revision; some modifications were necessary in the planktonic foraminiferal scheme. This way we hope to contribute to the updating of the Cretaceous time scale.

Verbeek (1977) gave short historic reviews of each stage. These will not be repeated here. The reader may consult some of the recent literature on the subject as indicated in the following paragraphs. If not indicated otherwise, the concept of Verbeek is followed in the choice of sections and the extension of type sections.

ALBIAN

The foraminifera of the type Albian were studied recently by Magniez-Jannin (1974), who distinguished three main zones which were based on the differentiation of *H. delrioensis, H. planispira* and *Ticinella primula* from *H. infracretacea*. In the Lower Albian, only *H. infracretacea* is present with small individuals. In the Middle Albian, *H. infracretacea* has variants which already may belong to *H. planispira* and *H. delrioensis*. In the Upper Albian, *H. planispira* and *H. delrioensis* are present as separate species, with *T. primula* in addition.

In section El Burrueco, *H. delrioensis* appears at the base of the *Ps. ticinensis* Zone. If the appearances of *H. delrioensis* in El Burrueco and in the type area are isochronous, our *Ps. ticinensis* Zone would correspond to at least the lower part of the Upper Albian in the type region.

Verbeek (1977) assigned three sections (Montiéramy, Villemoyenne and

Courcelles, together representing most of the Lower and Middle Albian) to the *Prediscosphaera columnata* Zone. The top of that zone is at the base of the *ticinensis* Zone in El Burrueco, which may mean that the base of *H. delrioensis* is not isochronous in France and in Spain. As we in include the Vraconnian in the Albian, this diachronism does not alter the assignment of the base of the *E. turriseiffeli* Zone to the Upper Albian.

It is difficult to draw any precise boundary between the Upper Albian and the Cenomanian. In the Albian type area, the Cenomanian chalk overlies the Albian as the natural continuation of a transgressive series, and in the Cenomanian type area the Cretaceous transgression had already started in the Late Albian (Juignet, 1974). Therefore, it seems that the Albian – Cenomanian boundary cannot be recognized from an important geologic event. Provisionally, we follow Van Hinte (1976) and put the boundary at the top of the *Th. appenninica – P. buxtorfi* Zone.

CENOMANIAN

An extensive study of the Cenomanian in its type area was performed by Juignet (1974). This author proposed a great number of sections in as many as nine formations which he distinguished in what he considers the composite Cenomanian stratotype. Included in this series of sections are the Craie de Théligny and the Sables du Perche, which had been proposed by Marks (1967) as the type deposits. A schematic representation of the various units of Juignet's composite Cenomanian stratotype is given in fig. 23, with indication of the approximate position of the composite section of Marks (1967).

Planktonic foraminifera are present at some levels only. A well-preserved fauna was described by Marks (1967) from the upper part of the Craie de Théligny. It contained abundant *R. cushmani.* The same samples were studied by Verbeek (1977), who assigned the lower part of the Craie de Théligny to the *E. turriseiffeli* Zone and the upper part to the *L. acutum* Zone. At the same occasion, the Marnes de Ballon were assigned to the *E. turriseiffeli* Zone.

More planktonic foraminiferal evidence is found in Juignet (1974). He reported:

– no planktonic foraminifera from the "Argile glauconieuse à minerai de fer";

– *Hedbergella* aff. *H. delrioensis* from the "Marnes de Ballon";

– no planktonic foraminifera from the "Glauconie à *O. vesiculosa*" and the "Craie glauconieuse";

– no planktonic foraminifera from the "Sables et Grès de la Trugalle et de Lamnay";

– no planktonic foraminifera from the "Sables et Grès du Mans";

– *H. delrioensis, P. stephani* and *R. cushmani* from the "Craie de Théligny";

– *H. delrioensis* from the "Sables du Perche";

– *H. delrioensis*, "*H.* intermédiaire avec *Rotundina cretacea*" (?) and *H. portsdownensis* from the "Marnes à *O. biauriculata*";

– *R. cushmani, P. stephani, P. aumalensis, H. delrioensis, H. portsdownensis, Rotundina cretacea, Guembelitria cretacea* and *Heterohelix* cf. *H. globulosa* from the "Sables et Grès à *Catopygus obtusus*";

– *P. stephani, P. aumalensis, H. brittonensis* and *Rotundina cretacea* from the "Craie à *Terebratella carentonensis*".

The lower part of the Cenomanian type deposits obviously cannot be correlated directly to our zonation. The "Craie de Théligny" is assigned to the *R. cushmani* Zone. We do not have samples from the "Sables et Grès à

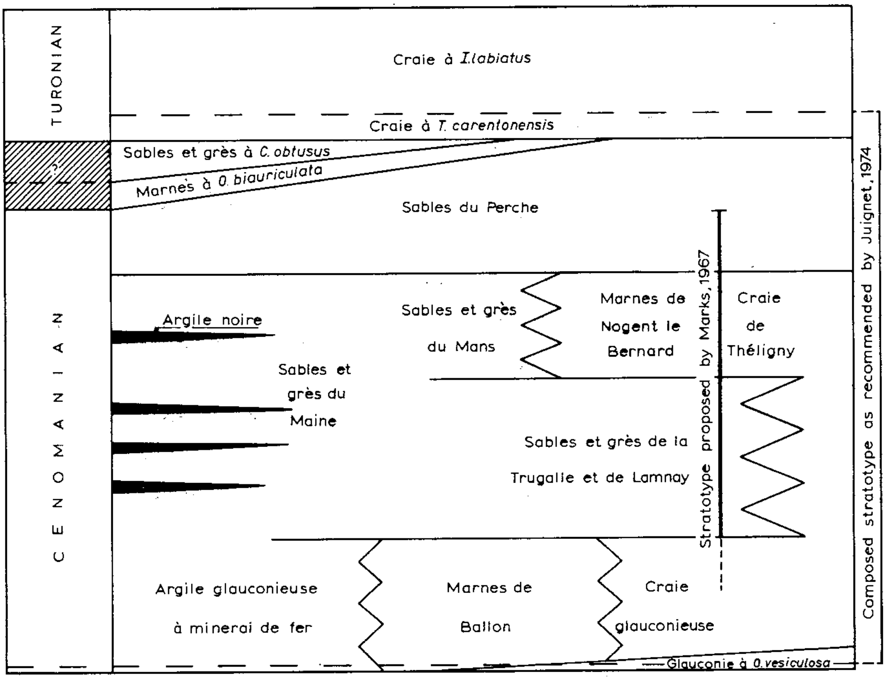


Fig. 23 Schematic representation of the horizontal and vertical distribution of lithologic units in the Cenomanian type area, slightly modified after Juignet (1974). Note that Juignet proposed a composite stratotype which extends into the uniform chalk facies overlying three different units.

C. obtusus". The fauna which accompanies *R. cushmani* here, however, is reminiscent of that of the *Wh. archaeocretacea* Zone. This, in combination with the fact that Juignet indicated a hiatus below the "Sables et Grès à *C. obtusus*" led us to consider this occurrence of *R. cushmani* rather suspect. It may be a reworked element found in the sandy base of a new transgressive sequence.

From the "Craie à *T. carentonensis*", Juignet reported *P. stephani, P. aumalensis, H. brittonensis,* and *Rotundina cretacea,* a fauna which may be indicative of the *Wh. archaeocretacea* Zone. From the overlying "Craie à *Inoceramus labiatus*", which by original designation by d'Orbigny (1842) belongs to the Turonian, Juignet (1974) reported the same fauna, in which *P. stephani* was substituted by *P. hagni.* Juignet correctly stated that this fauna is identical with that of the type Turonian, as it was described by Butt (1966) and Bellier (1971).

It is clear, that the planktonic foraminiferal fauna of the "Craie à *T. carentonensis*" postdates the disappearance of the keeled Rotaliporinae and represents one of the most primitive stages of the new radiation. Possibly, also the fauna of the "Craie à *G. obtusus*" already belongs to that stage of development.

Juignet drew the Cenomanian – Turonian boundary at the level of first appearance of *I. labiatus,* stating that this would be based both on historical and paleontological grounds. In our opinion, it would be more convenient to draw a boundary at a faunistic break, which in this case probably is at the base of the "Sables et Grès à *C. obtusus*". Anyway, in our scheme the end of the Cenomanian is marked by the extinction of *Rotalipora* as a witness of an important event rather than at the sudden appearance of new forms which had needed a certain time to evolve elsewhere.

For the time being, we should like to draw the Cenomanian boundary at the base of, within, or at the top of the "Sables et Grès à *C. obtusus*" or, alternatively, at the top of the "Marnes à *O. biauriculata*" or even at the top of the "Sables du Perche", until sedimentological investigations on the sequentional position of these formations will have confirmed or denied the "Sables et Grès à *C. obtusus*" as a basal formation of the Turonian transgressive sequence.

TURONIAN

The same section as discussed by Verbeek (1977), namely that of Frètevou, is accepted here as the type Turonian. However, Verbeek suggested that "the base of the Turonian Stage must be present somewhere in the

Frètevou section, but it is impossible to recognize the exact position of this boundary in the quarry". This statement was based on planktonic foraminiferal and calcareous nannofossil evidence (Verbeek & Wonders, 1977), which briefly is summarized here:

- *Quadrum gartneri* has its first appearance in the upper part of the *R. cushmani* Zone in section El Kef;
- *Quadrum gartneri* first appears in the middle part of section Frètevou;
- Consequently, the lower part of section Frètevou was assigned to the *G. obliquum* Zone, which corresponds to most of the *R. cushmani* Zone. Admittedly, *G. obliquum* was not found in the lower part of section Frètevou.

The present author does not adhere to this point of view any more. He felt already somewhat insecure when he wrote down the conclusion 2 in Verbeek & Wonders (1977): "Application of generally accepted biostratigraphical methods in planktonic biostratigraphy would lead to the conclusion, that the upper part of the *R. cushmani* Zone is of Turonian age, but only if the Frètevou chalk formation is accepted as Type Turonian."

In our present opinion, the only thing that has to be explained is the absence of *Q. gartneri* in the lower part of the Frètevou section. The planktonic foraminiferal faunas as described by Butt (1966) and Bellier (1971) may not be diagnostic but they are, in their composition, very different from those of the *R. cushmani* Zone and should better be compared with those of the *Wh. archaeocretacea* Zone. The absence of *H. helvetica* – a single-keeled form, see chapter VI – may be due to too old an age of the Frètevou chalk, but also to environmental conditions, in which case the sediments even would belong to the *H. helvetica* Zone.

Assignment to the *Wh. archaeocretacea* Zone or the *H. helvetica* Zone is not in contradiction with the regional stratigraphy of the interval concerned. In case of correlation with the *R. cushmani* Zone, one would expect at least some trace of a discontinuity to be present somewhere higher up in the section (hardgrounds, hiatus, marly interval?), as commonly found in the area (Juignet, 1974; Hart, pers. comm.).

CONIACIAN

Van Hinte (1979) discussed the validity of some sections near Cognac (Charente) and concluded that the sections Richemont and Javresac are the two type sections of the lower part (member A of Coquand, 1857) and the upper part (member B of Coquand, 1857) of the Coniacian. Verbeek (1977), however, considered the reference section of Parc François I in Cognac as the stratotype. We shall follow Van Hinte in this respect.

Planktonic foraminifera have not been reported so far from the type Coniacian. Calcareous nannofossil evidence is also scanty. Verbeek (1977) mentioned one sample from near Javresac (FR 1519) from rocks directly overlying beds which can be correlated with the park section and assigned it to the middle part of the *M. furcatus* Zone. Sissingh (1977) studied five samples from the lower part (member A of Coquand, 1857) of the section of Parc François I and also assigned these to the *M. furcatus* Zone, albeit with a question-mark. This is the only direct positive evidence: the type Coniacian corresponds with part of the *M. furcatus* Zone.

Provisionally, we shall adhere to Verbeek's (1977) conclusion that the Coniacian corresponds with the *M. furcatus* Zone and that its top is marked by the entry of *B. lacunosa*. The *M. furcatus* Zone was correlated with the *M. primitiva* Zone in sections Koudiat el Hamra and Oued Zerga in Tunisia (chapter III).

The resulting equivalence of the Coniacian stage, the *M. furcatus* Zone and the *M. primitiva* Zone may turn out to be not quite as accurate as is suggested in our scheme, when more data become available in the future.

SANTONIAN

There has been some uncertainty about the identity of the original stratotype of the Santonian as designated by Coquand. The latter only mentioned exposures along the road from Javresac to Saintes without further specification. From one of these outcrops, 4 km. from Cognac along road N 141, only one sample (FR 900) is available. It yielded the same, badly preserved nannoflora as five samples from a section near Saintes, which was mentioned by Coquand in 1858 and which has also been considered as the stratotype. All these samples were assigned to the *Zygodiscus spiralis* Zone by Verbeek (1977). The *Zygodiscus spiralis* Zone was correlated with the *M. carinata* Zone and the *M. carinata – G. elevata* Zone in section El Burrueco, and with the *M. carinata – G. elevata* Zone and the basal *G. elevata* Zone in section Oued Zerga. As the base of the Campanian type section is in the *C. aculeus* Zone, which is in the lower part of the *G. elevata* Zone, the Santonian – Campanian boundary may well be put at the base of the *G. elevata* Zone, as commonly presumed by workers on planktonic foraminifera. It is quite hazardous, however, to use this as a standard, because the type Santonian might turn out to be somewhat younger than that level. Therefore, we follow Verbeek (1977) and put the boundary at the base of *B. parca*, which, with certainty, is within the biostratigraphic gap existing between the type sections of both stages.

The assignment to the *Z. spiralis* Zone of the type Santonian shows that there is a considerable biostratigraphic gap between the type Santonian and the type Coniacian. As the Lower Santonian, in ammonite biostratigraphy, is characterized by *Texanites texanum,* the range of which goes as far down as the *Broinsonia lacunosa* Zone (Verbeek, 1977) and at least up into the *M. carinata* Zone, the Santonian corresponds to the *M. concavata* Zone, the *M. carinata* Zone, the *M. carinata – G. elevata* Zone and the basal *G. elevata* Zone in our scheme.

CAMPANIAN

The stratotype of the Campanian is the section of Aubeterre, designated by Coquand in 1853. Van Hinte (1965) described the planktonic foraminifera of this section, from Coquand's lithologic units B through G, unit A at the top having an erosional base and to be left out of the stratotype and the sample from unit A being unfossiliferous. Although the faunas are not truly Tethyan and mainly composed of double-keeled *Globotruncana,* they can be assigned to the *G. elevata* Zone, according to Van Hinte to the upper part, which was confirmed by Verbeek (1977), who recognized the *C. aculeus* Zone, the *Q. gothicum* Zone and the *Q. trifidum* Zone in Aubeterre. The *Q. trifidum* Zone corresponds with the entire interval from the upper part of the *G. elevata* Zone to the base of the *G. contusa* Zone. The top of the Campanian is usually drawn at the exit of *G. calcarata,* which does not interfere with the base of the type Maastrichtian. The biostratigraphic data collected from the type Campanian so far (Van Hinte, 1966; Verbeek, 1977) are represented in fig. 24.

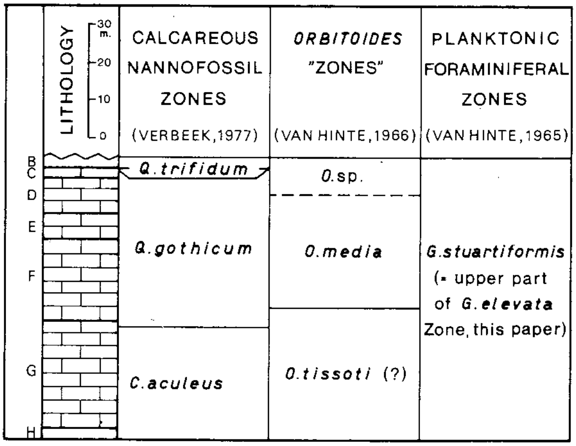


Fig. 24 Compilation of the micropaleontology of the Campanian stratotype.

MAASTRICHTIAN

Planktonic foraminifera from the type Maastrichtian (Lichtenberg section, E.N.C.I. quarry near Maastricht, Holland) have been described by Bellier & Villain (1975). The species which were encountered are little diagnostic, but the sporadic occurrence of *G. contusa* justifies an assignment to the *G. contusa* or *A. mayaroensis* Zone in our scheme. It is emphasized that the original type section has the so-called coprolite layer (Ma) at its base and that the white chalk below it may belong to the Maastrichtian s.l., but does not belong to the stratotype. Verbeek assigned the three next higher lithologic units to the *L. quadratus* Zone (Mb) and the *M. murus* Zone (Mc and Md). The *A. mayaroensis* Zone has its base in the *M. murus* Zone in Tunisia and the *G. contusa* Zone in the upper part of the *L. quadratus* Zone. This means that the type section of the Maastrichtian is to be correlated with at least part of the *G. contusa* Zone and possibly with part of the *A. mayaroensis* Zone.

In planktonic biostratigraphy, the top of the Cretaceous is marked by the simultaneous extinction of most species. It seems most logic to assume this drastic event as the end of the Maastrichtian stage, as is usually done.

CONCLUDING REMARKS

In fig. 21, the extension of the Albian and Upper Cretaceous stratotypes as discussed above is indicated. It is to be noted that there are no examples of overlapping stratotypes but that conspicuous biostratigraphic gaps exist between them. Some stage boundaries could be drawn at distinct levels representing no, or only minor hiatuses in the record (Cenomanian-Turonian; top Maastrichtian); the others, however, had to be chosen arbitrarily. In case of the Turonian, Coniacian and Santonian, the mutual "boundaries" seem to be of little geological significance and probably will always be the result of their very definition. The Santonian – Campanian boundary, however, may be different. In planktonic foraminiferal biostratigraphy, an almost complete renewal of foraminiferal faunas is observed just below the arbitrarily chosen boundary, as well as a relatively great number of new calcareous nannofossil species (Verbeek, 1977). As we have no positive evidence for the correlation of the lowest part of the range of *G. elevata* with the Santonian type section, we were forced to leave this possibility open and to include the lower part of the *G. elevata* Zone in the Santonian. If future research would show the top of the type Santonian to be older than the base of *G. elevata*, the boundary with the next stage preferably should be placed either at the base of, within, or at the top of the *M. carinata* – *G. elevata* Zone rather than higher.

The resulting scheme (fig. 25) shows a striking parallelism between the main chronostratigraphic and biostratigraphic units. The Albian typically has ticinellid faunas, from which the rotaliporid faunas of the Cenomanian rapidly evolved during the Late Albian (Vraconnian of authors). A sudden extinction of the keeled Rotaliporinae marks the top of the Cenomanian and a rapid radiation of keeled forms, i.e. *Helvetoglobotruncana* and *Marginotruncana* followed during the Early Turonian. The next two stages constitute an entity together with the Turonian. At the end of the Santonian, the marginotruncanid faunas were substituted by almost entirely new globotruncanid faunas, which persisted until the end of the Maastrichtian.

The development of the Mid Cretaceous faunas apparently took place in

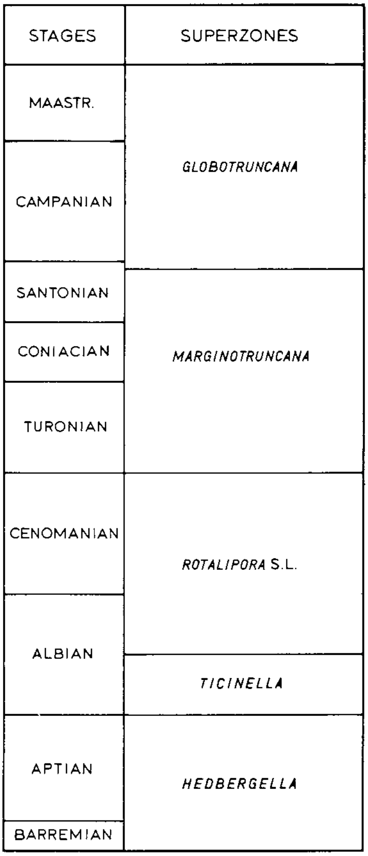


Fig. 25 The Middle and Late Cretaceous stages and their characteristic planktonic foraminiferal faunas.

close relation to what Arthur & Schlanger (1979) called "Oceanic Anoxic Events". Their oxygen depletion curve for great parts of the oceanic water masses is put along a schematic diversity curve of keeled planktonic foraminifera in fig. 26. A possible explanation of the correlation between anoxic events and minima in the diversity curve is given in chapter VI, where also the faunal turn-over near the Santonian – Campanian boundary and the extinction event at the end of the Maastrichtian are discussed.

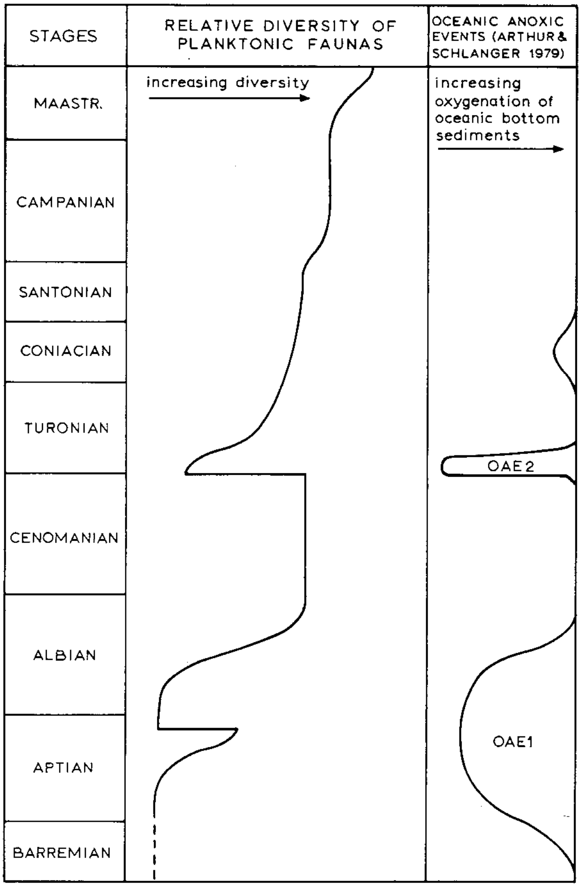


Fig. 26 Comparison of an estimated diversity curve of Middle and Late Cretaceous planktonic foraminiferal faunas and the oxygenation curve for oceanic bottom sediments according to Arthur & Schlanger (1979).

Chapter VI

EVOLUTION AND SYSTEMATICS

INTRODUCTION

A fundamental problem in the study of Cretaceous (and other) planktonic foraminifera is the interference between the subjective, artificial subdivision into taxa by application of some hierarchic system of diagnostic morphological features on the one hand, and the construction of alleged lineages by means of the names of these taxa. Two lineages may serve as examples: the "*Globigerinelloides* – *Planomalina* lineage" and the "*Marginotruncana* – *Globotruncana* lineage".

The genus *Planomalina* is generally considered to have developed from the non-keeled planispiral genus *Globigerinelloides.* This may be true, but not in the simple sense that *Globigerinelloides* is the one and only ancestral form of the one and only descendant *Planomalina*:

Globigerinelloides → *Planomalina*

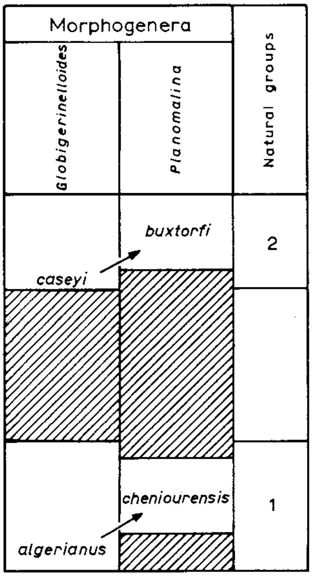


Fig. 27 The discrepancy between generic assignment and natural groups in *Globigerinelloides* and *Planomalina.*

In fact, *Planomalina*-like forms evolved twice, at distinctly different times, from very similar, non-keeled ancestors: in the Late Aptian (*G. algerianus* → *P. cheniourensis*) and in the Late Albian (*G. caseyi* → *P. buxtorfi*). The phylogenetic relation between the species *algerianus* and *caseyi*, if there is any, is completely obscure and the two *Planomalina* species are obviously not related within the genus. Clearly the two related couples of species from different "genera" constitute natural groups, more than the official (morpho-)genera do, and they would deserve common generic names to include both non-keeled and keeled species of one lineage rather than to be separated by a morphogeneric boundary. Alternatively, one might refer to the natural groups as to the "*cheniourensis* group" and the "*buxtorfi* group". Fig. 27 visualizes the morphology vs. evolution problem.

The genus *Marginotruncana* comprises species which led to several later forms which are assignable to *Globotruncana.* Ancestral forms of *G. fornicata* are found within the group of *M. sigali* as defined in chapter VII, whereas species of the *G. linneiana* group descend from the *M. pseudolinneiana* group. Also here, a simple

Marginotruncana → *Globotruncana*

series should be substituted by a more complex one comprising two species groups which each consist of a *Marginotruncana* and a *Globotruncana* species, as shown in fig. 28. Also here, the related species would deserve to be united into genera rather than to be separated from each other by artificial generic boundaries.

Van Hinte (1963) subdivided the species of *Globotruncana* (including *Marginotruncana* as used here) into four main groups (the *linneiana*-group with the *concavata*-group as a subgroup, the *stuartiformis, fornicata* and *rosetta* groups), each of which unites species which may be assigned to the three "genera" *Dicarinella, Marginotruncana* and *Globotruncana,* except for the *rosetta* group. In the present author's opinion, Van Hinte's subdivision with a few adjustments, is still valid. Each of his informal groups could be given a generic status, rather than to be kept subdivided into two or three morphogenera (fig. 28).

Also Linares Rodriguez (1977) noticed the discrepancy between the phylogenetic relations and the classical generic assignments. She proposed an informal and unnamed subdivision into eleven genera. However, to forma-

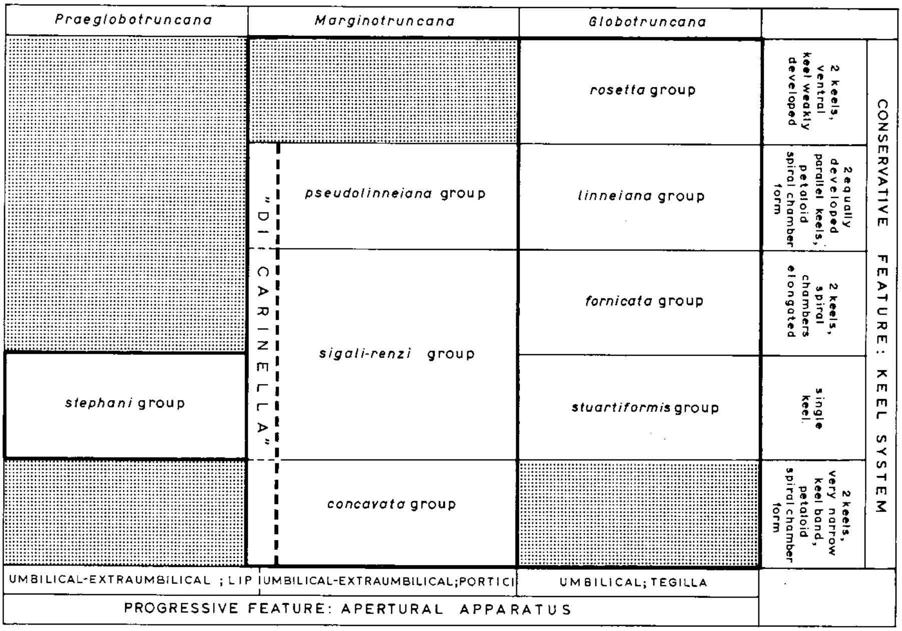


Fig. 28 Morphological structure of the central group of Globotruncanidae, showing the discrepancy between the subdivisions based on progressive and conservative features respectively. Note the ambiguous position of the genus *Dicarinella.*

lize all these groups by choosing new generic names would create more taxonomic problems than it would solve, and therefore the old generic names are retained here. The species groups, however, are dealt with separately. In this respect, we follow both Van Hinte and Linares Rodriguez, who wished to avoid taxonomic confusion, however correct the creation of new names would have been.

GENERAL EVOLUTIONARY TRENDS

It has now generally been accepted that, as a rule, the evolution of Cretaceous planktonic foraminifera shows trends from forms with globose chambers and a simple extraumbilical primary aperture towards forms with either ornamented or truncated chambers and a complex apertural apparatus. There are numerous variants to this rule. The features that change rapidly in time are different from group to group. This complicates, and all but impedes, the establishment of a fixed system of diagnostic features that can be used both in systematics and to distinguish evolutionary lineages.

Application of too rigid a hierarchic system of diagnostic features has led earlier authors to distinguish main morphological groups as a basis, in which erroneous evolutionary lineages were recognized afterwards. The important feature of the presence of a single keel thus led to the hypothetical lineage *Praeglobotruncana* → *Rotalipora* → *Globotruncana* which lineage has turned out to be imaginary and the result of underestimating the importance of the apertural apparatus.

In the following pages, the main evolutionary groups will be treated separately. As our attention has been focused mainly on keeled groups, lineages leading to keeled forms are treated more extensively, whereas groups as *Hedbergella, Whiteinella* and *Rugoglobigerina* and derived forms (*Trinitella, Plummerita*) are only mentioned briefly. The main trends in morphology are discussed in a paleoecological context.

THE MAIN EVOLUTIONARY LINEAGES

The origin of the keeled Rotaliporinae

In a previous paper, the phylogeny of *Pseudothalmanninella, Thalmanninella* and *Rotalipora* was extensively treated (Wonders, 1978). *Pseudothalmanninella* (i.e. the group of *Ps. ticinensis*) is the oldest keeled Albian form; it evolved from *Ticinella praeticinensis* by proterogenetic acquisition of a single keel and of raised dorsal and ventral sutures. *Thalmanninella* is the second offshoot of *Ticinella*: it evolved from *T. raynaudi* in an analogous way. *Th. praebalernaensis* is considered a partly keeled, intermediate form, analogous to the partly keeled *P. subticinensis.* The successive species of *Thalmanninella* constitute one evolutionary series with an over-all trend towards more angular and ornamented forms (*praebalernaensis – appenninica – globotruncanoides – greenhornensis*) and with two side-branches of extremely umbilicoconvex forms (*reicheli* and *deeckei*). The resulting phylogenetic scheme at the generic level is given in fig. 29. It should be noted that the position of *Anaticinella* in this scheme is not the result of observations on material from the western Mediterranean but on topotype material of *A. multiloculata* kindly put at our disposal by Don L. Eicher.

The position of *Rotalipora* s. str. (i.e., the *R. cushmani* group) is seen as a side-branch of *Thalmanninella.* As no obviously intermediate forms between the first *Rotalipora* and the contemporaneous *Thalmanninella* were observed, this phylogenetic relation remains hypothetical, although supported by the observation of an internal canal in the peripheral keel of both *Thalmanninella* and *Rotalipora* (Wonders, 1979).

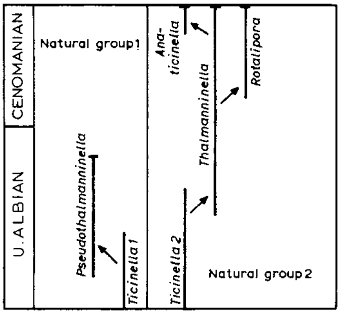


Fig. 29 Phylogeny of the keeled Rotaliporinae at the generic level.

In consequence, the Rotaliporinae do not pose any problem of the kind depicted in the introduction. Each lineage is translated into a generic name, and natural groups coincide with genera, as far as our observation goes.

The Planomalina buxtorfi lineage

The phylogeny of the *P. buxtorfi* group was described before (Wonders, 1975). Immediately after the development of keeled Rotaliporinae, partly keeled planispiral forms appear (*P. praebuxtorfi*) as predecessors of the entirely keeled *P. buxtorfi.* It must be noted that the ancestral form (*Globigerinelloides caseyi*) persists throughout the Cenomanian, unlike the ticinellid ancestors of *Thalmanninella* and *Pseudothalmanninella.*

The origin of Praeglobotruncana

In the *ticinensis – buxtorfi* Zone, numerous intermediate forms between *H. simplex* and *P. delrioensis* are found. Typical *Praeglobotruncana* representatives only appear in the *ticinensis – buxtorfi* Zone. They remain remarkably constant in morphology during the Cenomanian and only show a gradual increase in relative spiral convexity, thus constituting the lineage *delrioensis – stephani – gibba.* In the uppermost Cenomanian, primitive double-keeled forms appear, which differ from the *P. stephani* group only in the presence of a distinctly double row of pustules in the older part of the last whorl. These forms are assigned to *P. algeriana,* which species is one of the very few keeled forms to cross the Cenomanian – Turonian boundary. It is the ancestral form of all later representatives of the genus *Marginotruncana.*

The *Hedbergella – Praeglobotruncana* lineage is the modest start of the

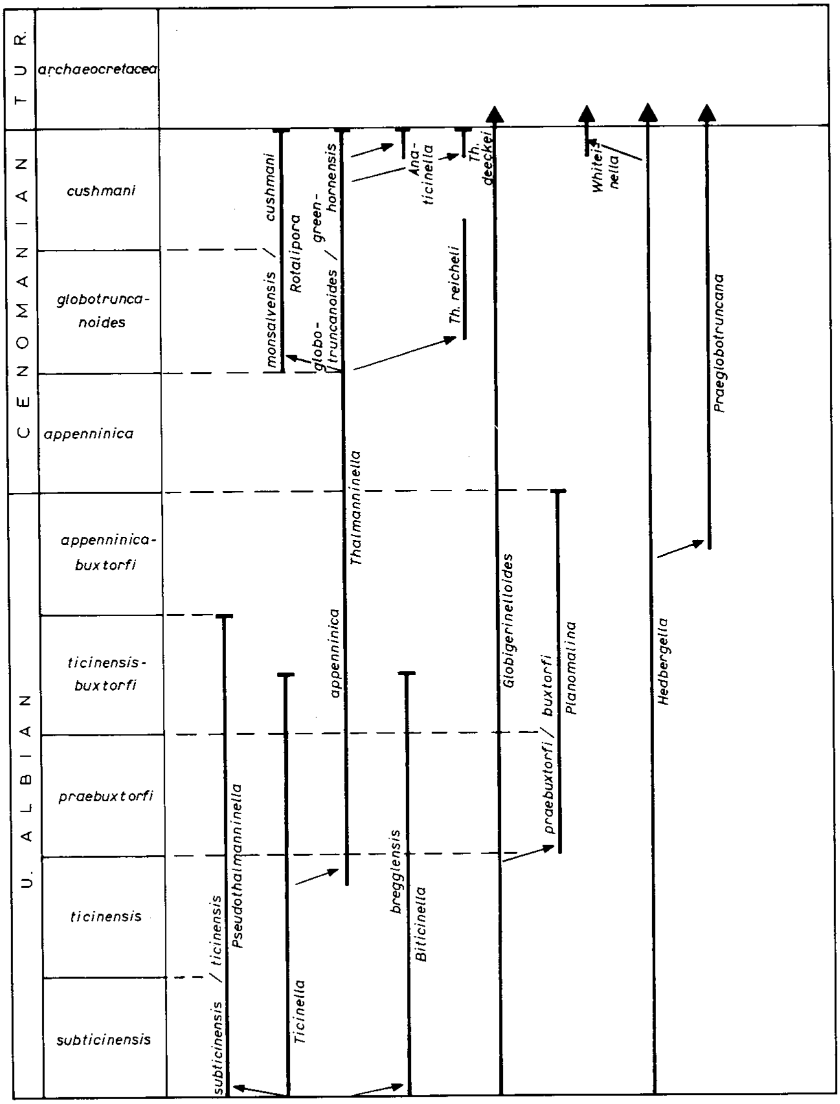


Fig. 30 Phylogeny of Late Albian and Cenomanian planktonic foraminifera, with indication of the evolutionary and extinction events which define zonal boundaries.

phylogeny of all the younger, post-Cenomanian keeled forms. Apparently, the ecological niche for distinctly single-keeled, angular forms was occupied by the keeled Rotaliporinae during the Late Albian and the Cenomanian. It was only after the extinction of these competitors that a new radiation of keeled planktonic foraminifera could take place.

The phylogenetic relations between most of the Albian and Cenomanian species are shown in fig. 30.

The phylogeny of the central group of Globotruncana s.l.

What is called here the central group of *Globotruncana* s.l. consists of all single- and double-keeled post-Cenomanian forms which commonly are referred to as *Dicarinella, Marginotruncana* and *Globotruncana.* The group does not contain *Helvetoglobotruncana, Whiteinella, Archaeoglobigerina, Rugoglobigerina* and derived genera (e.g. *Trinitella* and *Plummerita*) and *Abathomphalus.* As defined this way, *Globotruncana* s.l. constitutes a morphological and phylogenetical entity with only one ancestral form: *Praeglobotruncana algeriana.* This species developed from *P. stephani.* It gave rise to a diversified *Marginotruncana* fauna in the Turonian. In the *helvetica* Zone, within an otherwise distinctly intergrading population three main groups of morphological types are recognized:

a) double-keeled types (*M. imbricata, M. canaliculata*),
b) single-keeled types with depressed ventral sutures (*M. marianosi*), and
c) single- and double-keeled types with raised ventral sutures (*M. sigali, M. renzi*).

M. marianosi became soon extinct. It was only found in sample Kef 13, in the middle part of the *helvetica* Zone. The other two groups from the base of three main groups, two of which persist throughout the Late Cretaceous. The *M. concavata* group disappears close to the Santonian-Campanian boundary. The other two are the *G. linneiana* lineage group with the *G. rosetta* group as a side-branch, and the *G. fornicata* lineage group with the *G. stuartiformis* group as a side-branch.

The features of the keel system appear to be very *conservative,* whereas other features evolve more or less rapidly: portici, tegilla, convexity, number of chambers in the last whorl, etc. It is on these *progressive* features that the historically grown threefold subdivision into genera c.q. subgenera has been established:

– *Dicarinella* Porthault, 1970, for forms with two closely spaced keels, an umbilical to extraumbilical primary aperture, umbilical portici and depressed ventral sutures;

– *Marginotruncana* Hofker, 1956, sensu Pessagno, 1967, for single- or double-keeled forms with umbilical to extraumbilical primary aperture, portici and raised ventral sutures;

– *Globotruncana* Cushman, 1927, for single- or double-keeled forms with umbilical primary aperture, tegilla and either raised or depressed ventral sutures.

The individual lineage groups within *Globotruncana* s.l. consist of successive stages which may be assigned to these morphogenera. They are summarized below with the application of the historical generic names *Marginotruncana* and *Globotruncana*; *Dicarinella* is considered to be a synonym of *Marginotruncana* for reasons which are discussed in chapter VII.

The G. linneiana lineage group (figs. 31, 32)

The history of this group starts with three morphologically very similar species which already occur in the Lower Turonian: *M. imbricata, M. canaliculata* and *M. marginata.* All three are of the *Dicarinella*-type. They differ from each other in conservative morphological features which remain present throughout the development of the group into other *Marginotruncana* and *Globotruncana* representatives:

– *M. imbricata*: imbricated keel band pattern; chambers succeed each other obliquely; truncated chambers;

– *M. canaliculata*: parallel keel band; truncated chambers;

– *M. marginata*: parallel keel band; inflated chambers.

The group as a whole evolved from this *Dicarinella* stage into a *Globotruncana* stage via a *Marginotruncana* stage. The *Marginotruncana* representatives are (in the same morphological order as above): *M. imbricata, M. pseudolinneiana* and *M. marginata*; the *Globotruncana* stage is composed of *G. linneiana obliqua, G. linneiana* (and derivates) and *G. bulloides.*

After having reached the *Globotruncana* stage, the group diverges into a number of species, mainly by modifications in the relative convexity of dorsal and ventral sides. *G. arca* (biconvex) already is present in the Lower Campanian, and gave rise to a form with elongated spiral chamber outline in the Maastrichtian: *G. trinidadensis.* In the Late Campanian, the strongly ventroconvex *G. ventricosa* suddenly appears. The morphological structure of the *G. linneiana* group is visualized in fig. 31, the phylogeny in fig. 32.

The G. fornicata lineage group

From the Late Cenomanian – Early Turonian *Praeglobotruncana algeriana, Marginotruncana*-type forms with elongated crescentic spiral chamber outline developed during the Turonian. They have a number of conservative

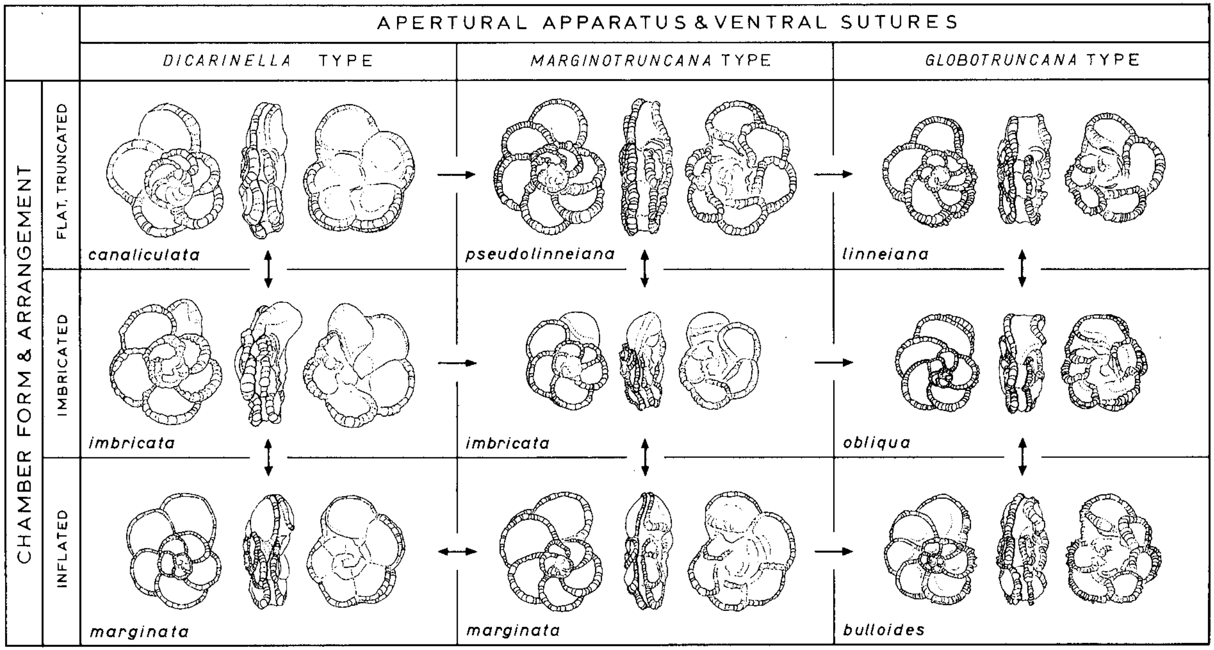


Fig. 31 Morphological structure of the *G. linneiana* lineage group.

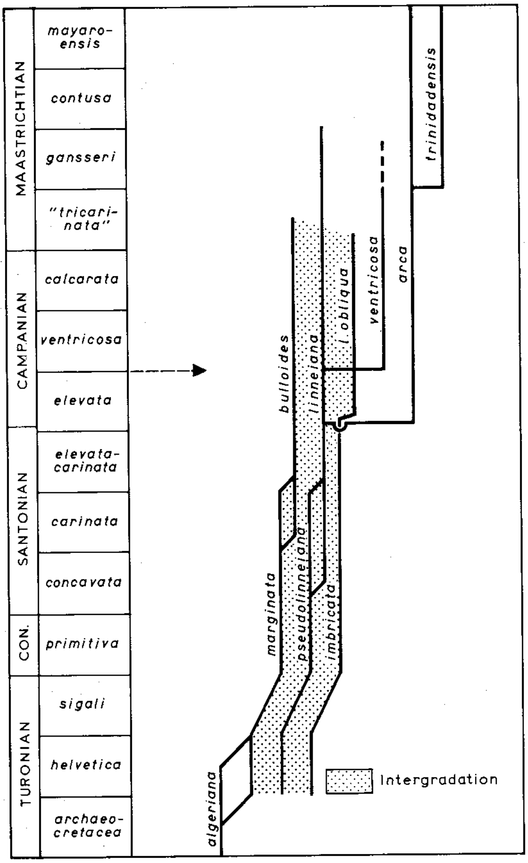


Fig. 32 Phylogeny of the *G. linneiana* lineage group.

features which unite them in one morphologically homogeneous group, in which the narrow double keel band characteristically diverges in the direction of growth. The *Marginotruncana* representatives of the group have a tendency to include forms with single-keeled final chambers; this part of the highly variable Turonian to Santonian associations is thought to lead to the single-keeled *Globotruncana* in the Latest Santonian. The group always comprises forms with undulating (plicate) chamber surfaces on the spiral side.

In the present author's opinion, these "plicate forms" are variants of a central group which can be assigned to *M. renzi* s.l., which persists up to the top of the *carinata-elevata* Zone (fig. 33). Accentuation of the spiral convexity and of the length of the crescentic chambers led to *M. sinuosa*, a group which soon includes *Globotruncana* type forms assignable to *G. fornicata* (figs. 33, 35). This species always contains forms with either un-

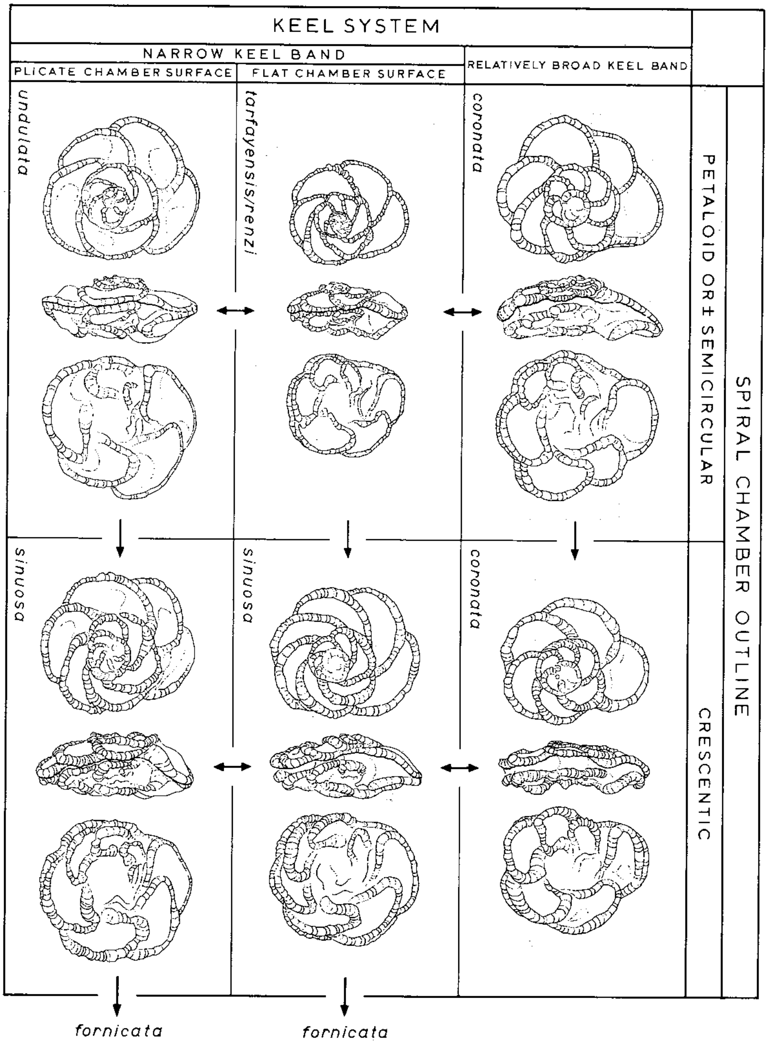


Fig. 33 Morphological structure of the *M. renzi* s.l. group, *M. coronata* included.

dulated or inflated chambers (*plummerae*), as does its descendant, *G. contusa.* The *G. fornicata* group only evolves towards more spiroconvex forms (*contusa, walfischensis, navarroensis*; fig. 35).

Many species have been erected to include all sorts of morphological variants in the *fornicata* group, depending on relative convexity, inflation of chambers, number of chambers in the last whorl and over-all peripheral outline. As the complex of conservative features remains the same within the group, it is believed that these species are the result of an artificial subdivision by means of two essentially different criteria: in a horizontal sense by separating forms with regular, undulated chambers and inflated chambers at the spiral side; and in a vertical (evolutionary) sense by taking into account the relative spiral convexity. The resulting interrelations within the *fornicata* group as a whole are represented in fig. 35, which also may serve as a determination key.

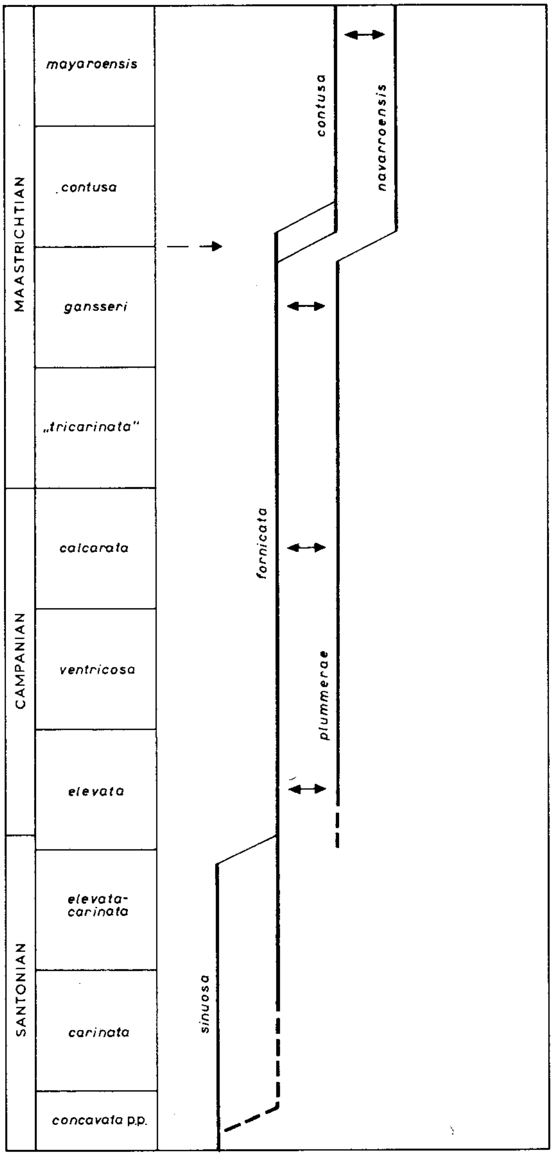


Fig. 34 Phylogeny of the *G. fornicata* group.

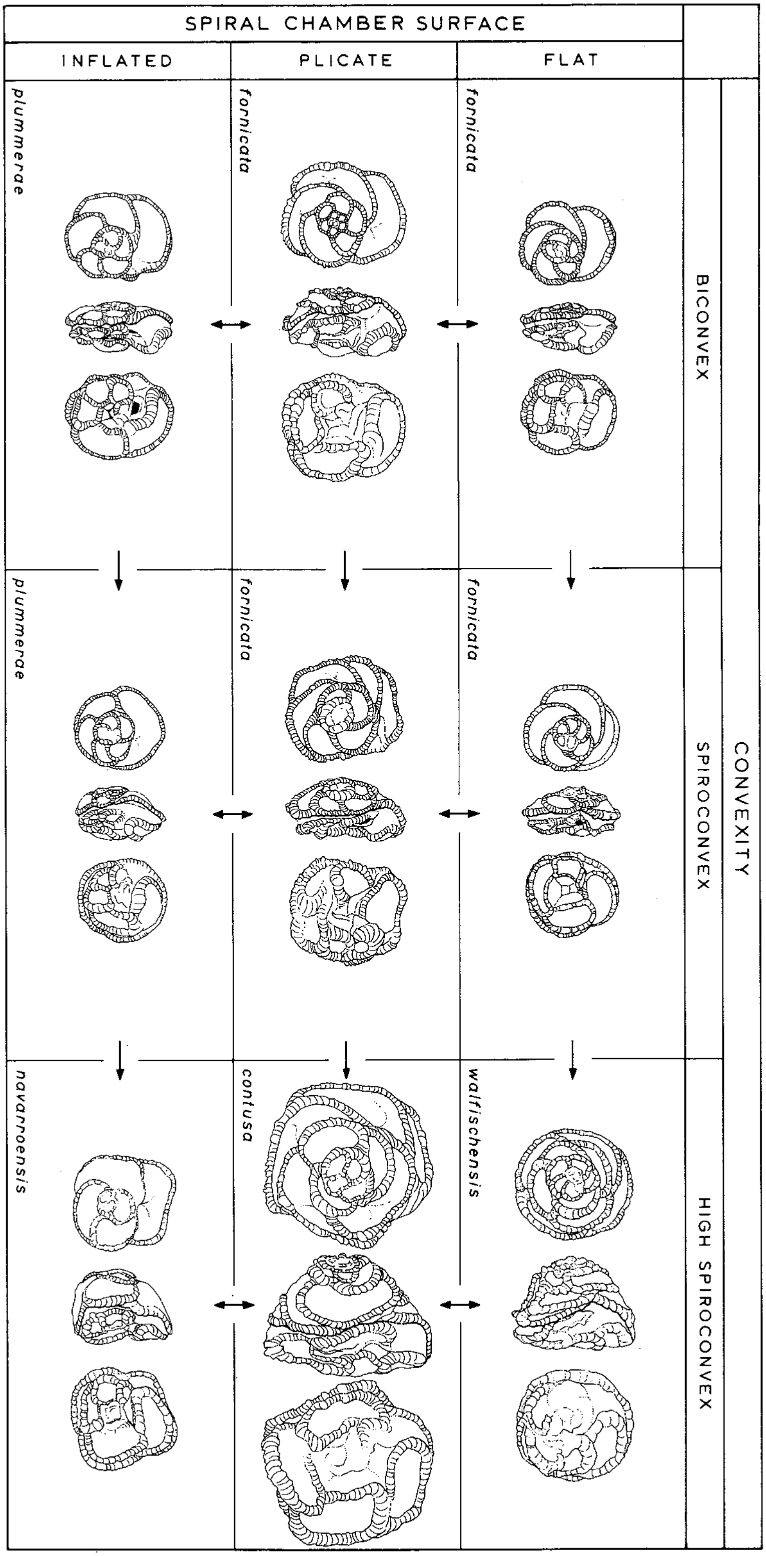


Fig. 35 Morphological structure of the *G. fornicata* group.

The M. concavata lineage group

The first "*Dicarinella*" type precursors of this group are found in the Upper Turonian. They possess a single keel which consists of a double row of pustules. These forms are assigned to *M. schneegansi*. Accentuation of the double keel and the accompanying acquisition of a typically semicircular spiral chamber outline gradually led to *M. primitiva*. This species already has all the conservative features of the group: very narrow keel band, ventrally inflated initial chambers and the typical chamber form at the spiral side.

Progressive features distinguish the successive members of the group, as already pointed out by Dalbiez (1955): increase of the ventral convexity and acquisition of periumbilical ridges.

All transitions between the typical forms (pls. 5, 6) may be found. As the members of the group (*M. primitiva, M. concavata* and *M. carinata*) are markers of three successive zones, the zonal boundaries are not clear-cut; their position depends on a clear definition of both the species themselves and on that of the zonal boundaries (fig. 36). As already stated in chapter II, the assemblage concept (Zachariasse, 1975) was used for definition of the zonal boundaries. In this concept, a whole assemblage of forms belonging to one group without discontinuities in the morphological variation is assigned to the "species" which dominates the assemblage. The definition of the species is according to Dalbiez (1955) (see chapter VII).

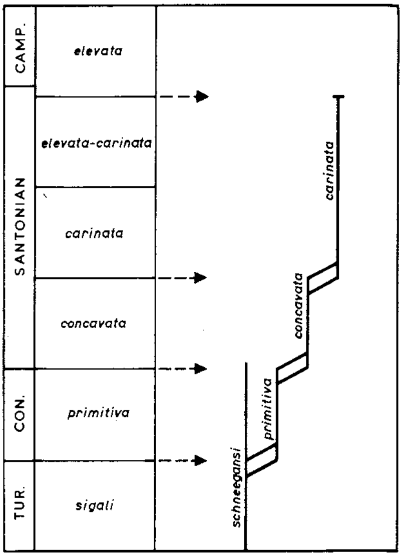


Fig. 36 Phylogeny of the *M. concavata* group.

The G. stuartiformis lineage group

The first distinctly single-keeled member of this group is *G. elevata*. It

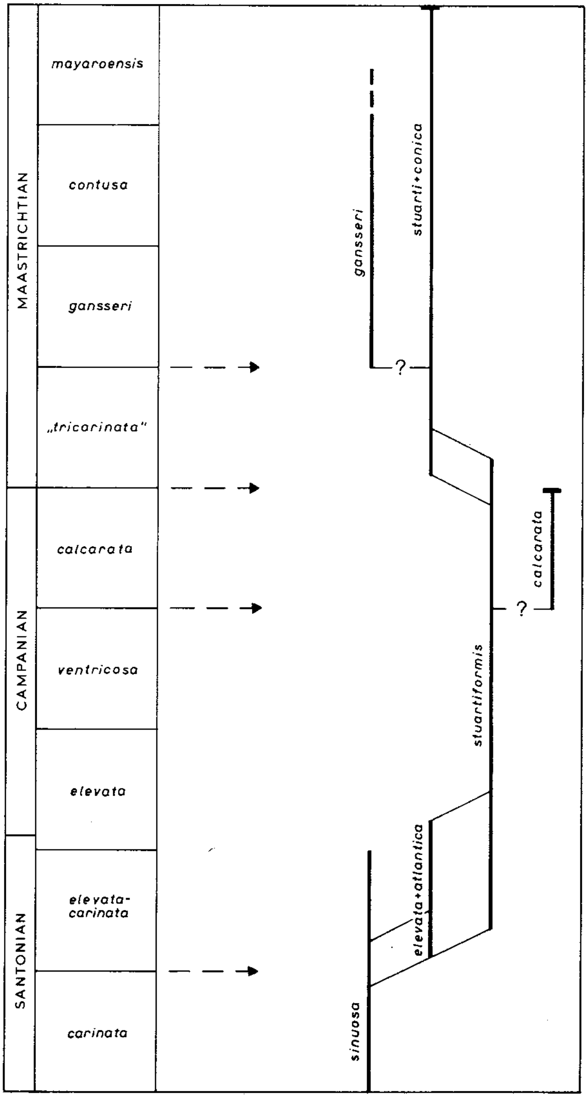


Fig. 37 Phylogeny of the *G. stuartiformis* group.

originated from the *M. sigali* group, but not from *M. sigali* s. str. as supposed earlier by Van Hinte (1969, 1976). The initial part of typical *G. elevata* is rather similar to *M. sinuosa* (figs. 33, 38) and transitional forms are frequently found in the *elevata-carinata* Zone. It should be noted that the lectotype (Kuhry, 1970) was taken from that zone.

The *conservative* features of the *G. elevata* group are the single keel, the typical tegillar structure with large infralaminal accessory apertures, and to some extent, the convexity. The main progressive feature is the chamber form at the spiral side. The general tendency is towards more isometric chambers, i.e. from elongated crescentic (*G. elevata* and *G. atlantica*) via triangular (*G. stuartiformis*) towards either trapezoid (*G. stuarti* and *G. conica*) or petaloid (*G. gansseri*). A hypothetical offshoot from *G. stuartiformis* (including *G. subspinosa* in our concept) is *G. calcarata,* with hollow peripheral tubulospines. As we did not find transitional forms at the base of the range of *G. calcarata* in the closely sampled section El Burrueco, it remains possible that *G. calcarata* has a different origin.

The G. rosetta lineage group

A group of *Globotruncana* with two parallel, but unequally developed keels, a very high tegillar structure and rather isometric chamber form at the spiral side appears in the Early Campanian. The ventral keel typically is much weaker than the dorsal keel or substituted by a faint row of small pustules. The keel band always is inclined to the umbilical side. All forms belonging to this group have rather pronounced, sigmoid periumbilical ridges, with small openings between them that probably had a function in connection with the infralaminal accessory apertures of the tegilla.

The group contains four species, which can be grouped into two pairs which appear to be closely related: *G. rosetta* and *G. aegyptiaca* on one hand and *G. esnehensis* and *G. falsostuarti* on the other. *G. esnehensis* and *G. rosetta* are hard to separate at the base of their range. Both species are similar to *G. arca,* from which the group probably evolved.

The only feature which shows considerable variation is the number of chambers in the last whorl, the two couples of species mentioned above already being separated by a distinct difference in convexity: *G. rosetta* and *G. aegyptiaca* are asymmetrically biconvex, much more convex ventrally than dorsally, whereas the other two species in their typical form are about equally biconvex, although ventroconvex variants of *G. esnehensis* are quite frequent in the Maastrichtian.

G. aegyptiaca has a variant with inflated chambers, which often is referred to as *G. gagnebini,* but which is considered as a synonym here.

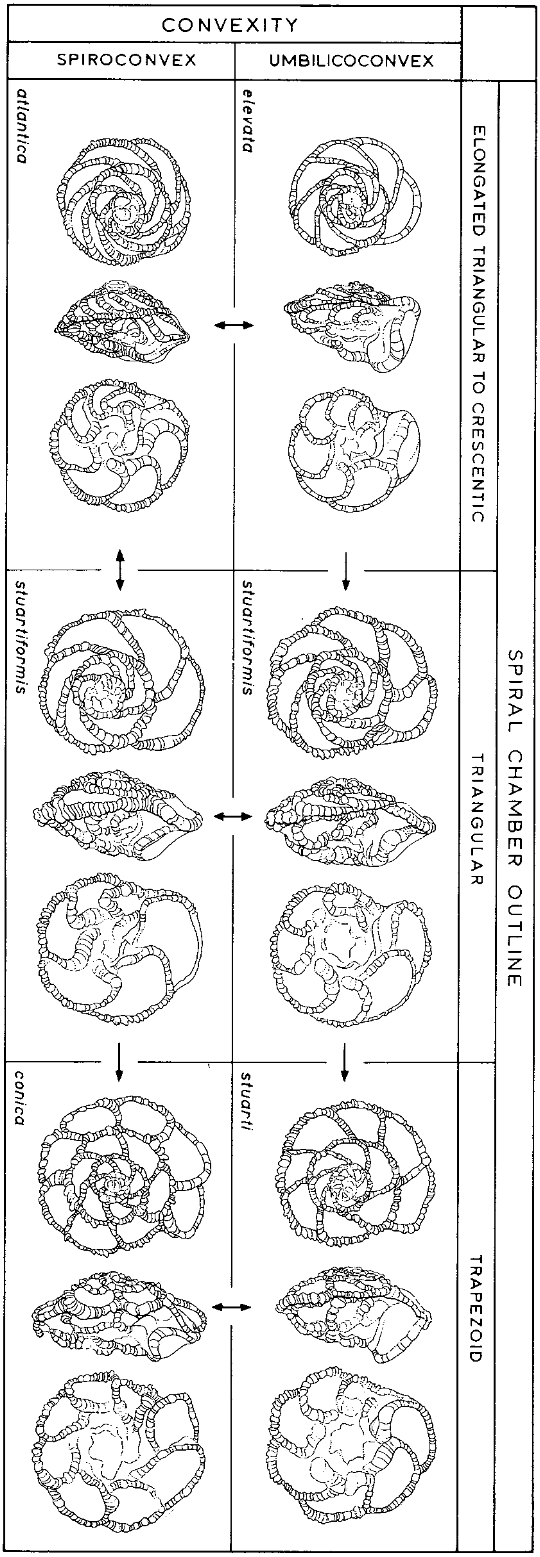


Fig. 38 Morphological structure of the *G. elevata* group, without *G. calcarata* and *G. gansseri.*

The supposed phylogenetic relations within the group are presented in fig. 39. As no detailed observations were made on this group, we refrain from figuring the species.

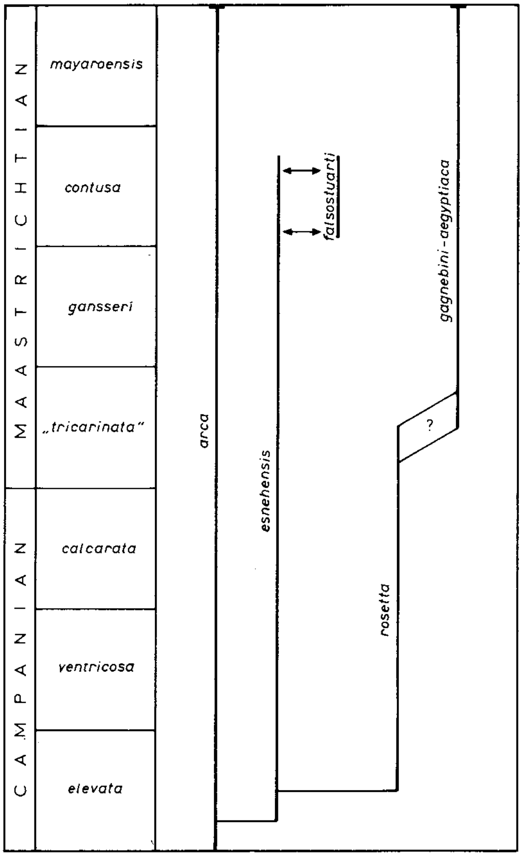


Fig. 39 Phylogeny of the *G. rosetta* group.

Other lineages

At least four other lineage groups in the coiled Cretaceous planktonic foraminifera are present; these were not studied in detail. Each group deserves detailed study separately; the eventual results of these studies probably will reveal the phylogenetic relations to be much more complicated than is suggested below:

Hedbergella – Whiteinella – Helvetoglobotruncana

According to Lamolda (1976), *Helvetoglobotruncana* evolved from a *Whiteinella* ancestor. Intermediate forms have been described and figured as the species *praehelvetica* under different generic names. As *H. helvetica* morphologically is a *Whiteinella* with a single keel and intermediate forms do exist, this lineage seems to be realistic.

Hedbergella – Globotruncanella – Abathomphalus

Very few *Hedbergella* species are present in rocks which are younger than Turonian. The best known are relatively large, somewhat compressed forms. The oldest of them is *H. hoelzli,* a species with numerous pustules all over the test. It was found in the Turonian to Coniacian part of the column. A very similar form, but without pustules, is known as *H. flandrini.* It has a smooth chamber surface and laterally compressed chambers; the periphery is somewhat pinched in a *Praeglobotruncana*-like fashion, but there is no trace of a keel. In the Campanian, the first representatives of *Globotruncanella* are found, with a small, but rather thick and strong tegillum. Otherwise, these forms are very similar to *H. flandrini,* also in the extraumbilical position of the primary aperture.

At the end of the Maastrichtian, *Globotruncanella havanensis* rapidly evolved to *Abathomphalus* by acquisition of two keels. An intermediate form was described as *A. intermedius* (Bolli).

Hedbergella – Whiteinella – Rugoglobigerina and derivates

The first *Whiteinella* have been reported from the Uppermost Cenomanian (*Wh. alpina* Porthault 1969). Probably polyphyletically, various species of *Whiteinella* originated during the Turonian. They are characteristic elements in Turonian and Coniacian faunas. In the Santonian the first forms with meridionally arranged pustules appear, at first without, but later with tegilla. A true radiation of *Rugoglobigerina* takes place in the Maastrichtian, leading to forms with an angular periphery at the last chambers (*Trinitella*) or with tubulospines at the periphery (*Plummerita*).

Hedbergella – Globigerinelloides

The morphogenus *Globigerinelloides* probably evolved several times during the Cretaceous from trochospiral *Hedbergella* ancestors. In one case, *Globigerinelloides* developed a thick wall with a rugose surface. Other species tend to develop a more complicated primary aperture by dividing it into two parts, from which a double series of planispirally arranged chambers starts (morphogenus *Biglobigerinella* Lalicker).

All the evolutionary lineages which are summarized above consist of series of species which, in one way or another, become successively more complex in their apertural apparatus, more ornamented by keels or surface ornamentation (pustules, costellae), and more angular by truncation of the chambers. There is only one example in opposite direction, from *Th. greenhornensis* to *Anaticinella multiloculata*.

The evolutionary history of Cretaceous planktonic foraminifera from an ecological point of view

The generalized evolutionary lineages of Cretaceous planktonic foraminifera as depicted above put along each other produce a total picture in which the discontinuity of their development strikes the eye (fig. 40). There are three main types of faunas:

1. faunas composed of simple, mainly non-keeled forms;
2. faunas composed of forms in various stages of development of keel(s) and other ornamental features;
3. faunas composed of all morphological types from simple, non-ornamented tests with globular chambers to complicated tests with keel(s) and raised sutures, secondary ridges etc.; these faunas persist over longer periods.

Faunas of type 1 are present in the early Late Albian (*subticinensis* Zone) and in the Early Turonian (*archaeocretacea* Zone). They are also typical for the Latest Aptian to Middle Albian. In both cases, they are followed by associations of type 2: the radiating, incipiently keeled faunas of the Late Albian, and those of the Early Turonian. These give rise to the rather stable associations of type 3, which characterize the Latest Albian and the Cenomanian on the one hand and the Late Turonian to Latest Maastrichtian on the other. The latter interval is divided into two parts by the transition from diversified *Marginotruncana* faunas to *Globotruncana* faunas at the base of the *elevata* s.l. Zone.

There must be some reason for faunas to develop in this fashion. Instead of going into the functional morphology of planktonic foraminifera, little of which is really known, we shall rather use the evidence about their horizontal and vertical distribution, for which the studies of Bé & Tolderlund (1971; zoogeography of recent planktonic foraminifera) and of Douglas & Savin (1978; vertical distribution in the water column of recent to Late Cretaceous planktonic foraminifera based on oxygen isotope data) may serve as guide lines.

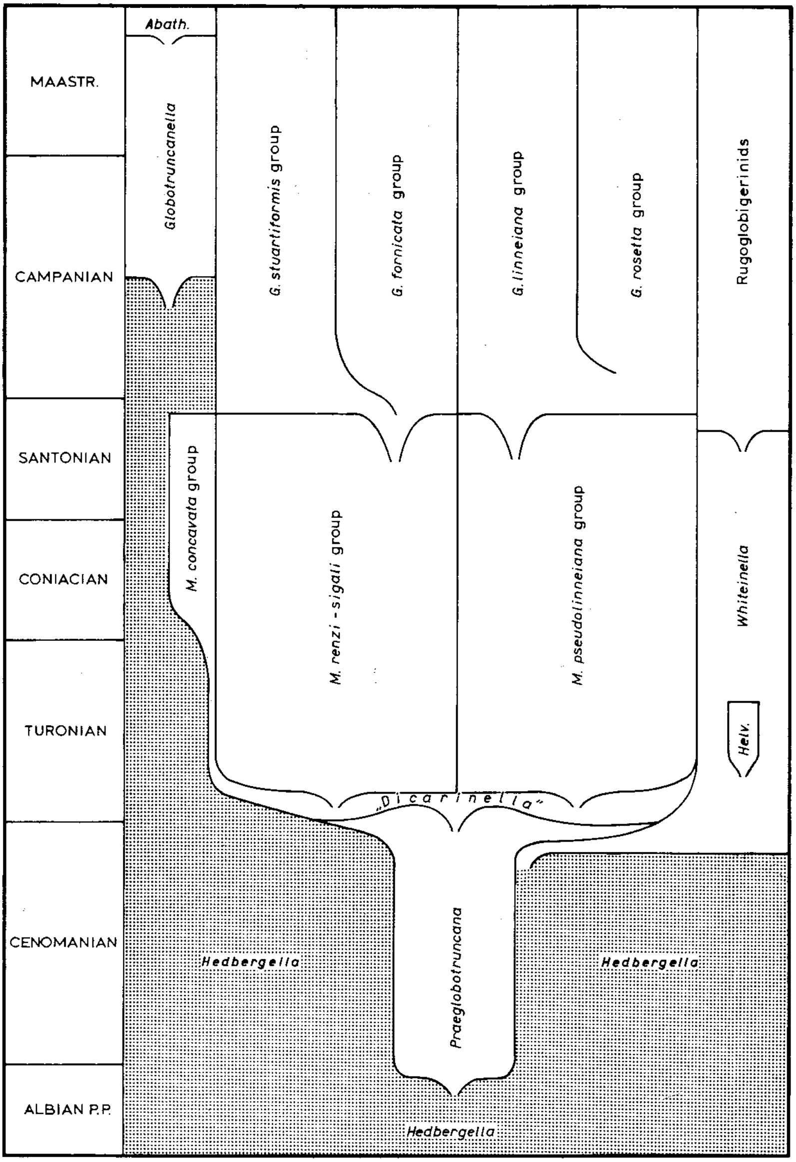


Fig. 40 Tentative phylogenetic scheme, with position of the main natural groups, of Late Cretaceous planktonic foraminifera. Vertical scale according to the numerical scale in fig. 21.

Recent faunas composed of small, mainly non-keeled forms are present in the uppermost few metres of the water column of the World's oceans, in the seas surrounding the arctic and antarctic regions, in marginal, shallow seas and in the Gulf of Aqaba, the only example of a warm, relatively deep basin without a thermal gradient (Reiss, 1977). Although the latter author stresses the importance of nutrients for the life habitat of planktonic foraminifera, it must be noted that all these recent environments share the absence of a thermocline in the water column during most of the year.

Diversified faunas including keeled forms are found in the tropics and subtropics, where the difference in temperature between surface waters and deep waters is greatest, i.e. where the thermocline is most pronounced.

Oxygen isotope studies have revealed that simple forms with globular chambers form their calcite chamber walls at higher temperatures than those with angular, keeled chambers, and that they already did so during the Latest Cretaceous. It even was concluded that a certain stratification of the water column in the oceans must have been present from the Latest Cretaceous onward (Douglas & Savin, 1978). Data from the older part of the Late Cretaceous were less conclusive, but it seems justified to extrapolate these ecological interpretations into the older part of the record, from an extended actualistic point of view.

Therefore, it is assumed that our Tethyan faunas lived in warm waters of normal salinities, with potential ecological niches for epi-, meso- and bathypelagic species. The depths at which these species lived cannot be accurately defined for several reasons. Absolute depths are not very important, since it can be argued that every planktonic foraminiferal species must have stages in its life cycle in which it inhabits water at different depths. Otherwise, no planktonic foraminifera would be able to be present in areas with consistently diverging surface current patterns, unless they would be able to develop considerable velocities in a horizontal up-stream sense. An interesting result of Douglas & Savin's study in this respect was, that smaller individuals of the same keeled (meso- to bathypelagic) species give higher oxygen isotope temperatures than larger ones. This may indicate that bathypelagic species spend part of their life-time in shallow waters and that they descend to deeper waters later, which enables them to return to places to which no surface current leads, by making use of deep countercurrents.

This model offers an attractive explanation for the diversity of tropical and subtropical faunas. Each individual species may spend part of its lifetime in the same waters as other species do, but its migration pattern may be essentially different. Thus, an ecological isolation of species, reputedly required for the origin of species, becomes possible within what looks as one and the same biotope. Planktonic foraminiferal faunas at high latitudes and in isolated warm basins lack the opportunity of making use of vertical gradients to compose a complicated life cycle; they are bound to their homogeneous water mass, in which it does not make much difference whether one is deep or shallow, and where the depth of the photic zone may be the main parameter. Tropical and subtropical faunas, on the other hand, can use vertical gradients in the water column, each species in its own way. It seems plausible to accept the idea that each species has its own characteristic behaviour in this respect and that species evolve together with their environment, which is mainly defined by the vertical gradients in the water mass and the horizontal and vertical circulation patterns in the oceans.

Following this line of reasoning, one may assume that the ecological niches for bathypelagic planktonic foraminifera, as schematically outlined in figs. 41–43, did not exist during the Latest Aptian to the Late Albian, and during a short interval straddling the Cenomanian – Turonian boundary. Both time spans are characterized, in the pelagic record, by various kinds of apparently aberrant sedimentary processes. In pelagic sequences, e.g. the Marche-Umbrian Cretaceous, the continuous sedimentation of well-oxygenated pelagic limestones was interrupted and substituted by the deposition of varicoloured and black shales, often bituminous, with conspicuous and very fine laminations, which are only slightly disturbed by bioturbation (fucoids). As was pointed out by Arthur & Schlanger (1979), these two episodes of aberrant bottom conditions are the reflection of wide-spread anoxic conditions in large parts of the World's ocean waters, which these authors refer to as Oceanic Anoxic Events (OAE).

The oxygenation curve (fig. 26) runs strikingly parallel with the evolutionary history of Tethyan planktonic foraminiferal faunas, which could be followed in detail by studying thin sections of the indurated sediments of the Marche-Umbrian basin (Wonders, 1979), and it is plausible to suppose a common environmental factor of both features.

There are two different ways in which the ecological niche for deep-living planktonic foraminifera may disappear: either by hostile conditions in the deeper waters (e.g. anoxic conditions), or by the absence of a thermocline, i.e. a conspicuous thickening of the uppermost mixed water layer, which seems to coincide with the ecological niche for epipelagic forms. These two possibilities are visualized in figs. 41 and 42.

Fig. 41 shows the sedimentary history of the Marche-Umbrian basin during the Cretaceous with occasional obliteration of the deep ecological niches by oxygen deficiency in the water column (some kind of dead layer). Anoxic bottom conditions were present as well. Combination of the data strongly suggests that after anoxic water masses came in touch with the bottom, the anoxic front rose to depths where bathypelagic foraminifera had to spend at least part of their life cycle. In the Late Aptian this led to the extinction of *Planomalina cheniourensis*, immediately followed by *Globigerinelloides algerianus,* a species which, according to Douglas & Savin's (1978) relation between test morphology and depth habitat, would have occupied a mesopelagic niche. The deeper water layers remained anoxic until the Late Albian, when partly keeled predecessors of entirely keeled species appeared one after another, indicating more and more bathypelagic ecological niches to become available. Only shortly after a diversified fauna including *Pseudothalmanninella, Thalmanninella, Planomalina* and *Praeglobotruncana* had come into existence, the circumstances at the bottom became oxygenized again, as witnessed by the deposition of the Scaglia Bianca. The circumstances from then on remained normal, i.e. characterized by a good water stratification, and circulation systems without frequently occurring stagnant anoxic water masses on a large scale.

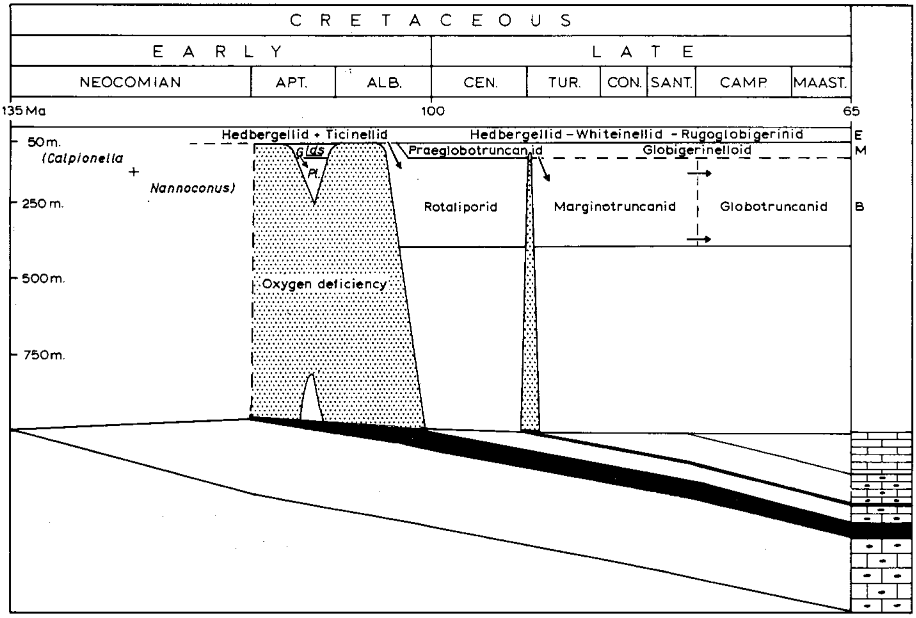


Fig. 41 Sedimentary history diagram for the Umbrian Cretaceous, with indication of the supposed ecological niches of main groups. Disturbance of ecological niches explained by oxygen deficient water masses.

Approximately the same thing happened at the end of the Cenomanian: bottom conditions deteriorated, as indicated by a siliceous limestone bed with fish remains in which *Rotalipora cushmani* is still present; somewhat later the anoxic water mass reached the ecological niche of the keeled Rotaliporinae, until then the characteristic bathypelagic forms. In this respect, it is interesting to see that *Th. greenhornensis,* just before its extinction, gave rise to the practically non-keeled *Anaticinella multiloculata*; it looks as if *Th. greenhornensis* tried to escape its doomed bathypelagic niche by assuming a shallower habitat. The imperfectly keeled group of *Praeglobotruncana stephani* survived the Cenomanian – Turonian boundary anoxic event, which suggests that at least part of the mesopelagic niche was not affected. Bituminous black shales were deposited at the bottom until partly keeled representatives of *Helvetoglobotruncana* (*H. praehelvetica*) and the first *Marginotruncana* species had already occupied a new ecological niche, which came available when the anoxic front was lowering.

Fig. 42 shows the alternative model. The same sequence of evolutionary and extinction events may have been caused by thickening of the epipelagic ecological niches, i.e. absence of a thermocline. This can only happen in

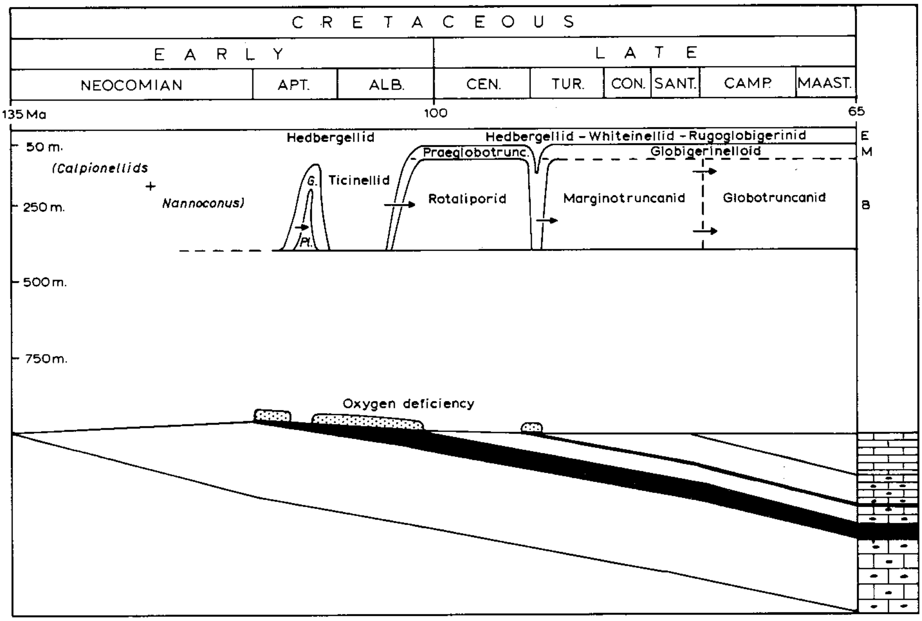


Fig. 42 | As fig. 41, but disturbance of ecological niches of bathypelagic foraminifera explained by thickening of the epipelagic niches, and anoxic conditions at the bottom by oxygen deficient stagnant bottom waters.

oceanic basins with either strongly restricted circulation or such a strong circulation that intensive mixing of the upper water layers took place. In the latter case, one would not expect accompanying anoxic circumstances at the bottom over large areas. The first possibility, however, would rapidly enhance the creation of anoxic water masses which attack the bathypelagic ecological niches from below. Whether the model of fig. 41 or that of fig. 42 can be applied to the Mid Cretaceous anoxic oceanic events, or that a combination of the two (fig. 43) is what really happened, all possibilities have in common that the oceanic circulation was strongly slowed down or stagnant.

Quite another phenomenon is the gradual, but fundamental faunal turnover at the end of the Santonian or at the Santonian-Campanian boundary, from *Marginotruncana* to *Globotruncana* faunas. There is no trace of a world-wide anoxic event or anything of that kind, nor is there a major extinction event preceding the radiation of new, globotruncanid species. It seems that the extant ecological niches for meso- and bathypelagic forms became occupied by new forms directly evolving from the former inhabitants. In this respect, the Santonian-Campanian boundary interval is a short period of rapid evolution rather than an extinction-radiation interval, as the Cenomanian-Turonian boundary. One may assume that existing ecological

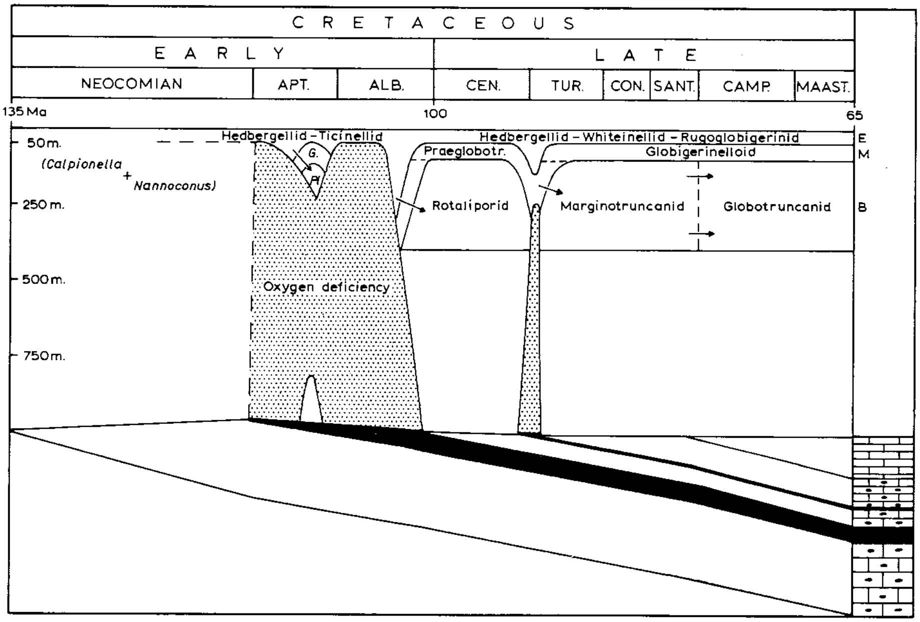


Fig. 43 Combination of the models of figs. 41 and 42.

niches for planktonic foraminifera changed within themselves, without giving rise to hostile circumstances but enhancing the development of new groups.

In the preceding pages we have explained the radiation of new groups by the restauration of a normal oceanic circulation after anoxic events. As the faunas remain normal and diversified during all post-Early Turonian times, it has to be assumed, that the water stratification and circulation remained normal till the end of the Cretaceous. How to find an explanation for a fundamental change in the ecological niches of most planktonic foraminifera, with maintenance of favourable conditions?

The answer probably lies in the changing configuration of oceans and continents in the Late Cretaceous. During that time, the still narrow Atlantic Ocean was continuously widening, its connection with both northern and southern high-latitude seas became more and more effective. An island arc came into existence between the two American continents (Schmidt-Effing, 1979), possibly obstructing a deep E-W connection between the Central Atlantic and the Pacific. All this together may have enhanced a rather independent circulation system in the growing Atlantic Ocean, in which new species could find new ecological niches. The broadest part of the basin was in subtropical regions: an overall divergent surface current pattern under persistent subtropical high atmospheric pressure conditions is most likely to have been present there. This in contrast to the previous situation, in which the Tethys Sea, including the relatively small Atlantic basin, constituted a continuous, roughly E-W trending connection between both sides of the Indo-Pacific.

The independent Atlantic circulation system may have served as a new, rather small evolutionary play-ground for new forms. Some of these probably were successful and could substitute their Santonian homeomorphic predecessors.

Conclusions

The development of Middle and Late Cretaceous planktonic foraminiferal faunas was related to three major events, each of which has its own characteristics and is different from the others:

1) a prolonged period of prevailing anoxic conditions in the World's Oceans during most of the Aptian and the Early and Middle Albian;

2) a short, but intense anoxic event near the Cenomanian-Turonian boundary;

3) an important change in the oceanic circulation pattern at the Santonian-Campanian boundary.

The evolution of faunas is intrinsically related to these events; the oceanographic events are biostratigraphically characterized by important extinction and/or radiation events.

This seems to be the most simple and satisfying answer to the urgent request directed to micropaleontologists by other geoscientists during the Uppsala meeting (1975) of I.G.C.P. project nr. 58 "Mid Cretaceous Events" to provide a standard zonal scheme for dating the events.

Oceanographers, sedimentologists, micropaleontologists and marine-geochemists will have long years of work to do before acceptable scientific models will have been developed to explain the mechanics of the Cretaceous events. The present author hopes to have contributed to the formulation of the problem by pointing to the relation between anoxic conditions, circulation patterns and planktonic life in the oceans.

THE CRETACEOUS-TERTIARY BOUNDARY

Until here, nothing has been said about the massive extinction of Cretaceous planktonic foraminiferal faunas at the Cretaceous-Tertiary boundary. Recently, a symposium was held on this problem (Copenhagen, 1979), which resulted in two volumes of specialist's papers on the subject, which, nevertheless, did hardly come closer to a solution. In planktonic biostratigraphy, the characteristics of the boundary are:

1) Its sudden and (quasi?) catastrophic nature. The peculiar sediments adjoining to the Cretaceous-Tertiary boundary are seldom more than a few centimetres thick. They reflect totally aberrant sedimentation conditions with respect to the under- and overlying deposits. In complete sedimentary sequences as the Gubbio section, no important hiatus in the magnetostratigraphic record turns out to be present with respect to oceanic magnetic profiles (Larson, 1977). An estimate of the duration of the event was made by Kent (1977) at about 10,000 years or less;
2) The survival of very small, globose forms only;
3) An analogous event in the calcareous nannofossil record;
4) The presence of hiatuses in the sedimentary record, also in pelagic realms, straddling the boundary (Luterbacher & Premoli Silva, 1964);
5) A rapid, but gradual development of entirely new planktonic faunas afterwards, both in planktonic foraminifera and in calcareous nannofossils.

All this evidence together points to a rather sudden and drastic obliteration of nearly all ecological niches of planktonic life, followed by a rapid restauration of normal conditions. The event is different from the two anoxic events in the Middle Cretaceous in its shorter duration and by its much greater effectivity. Planktonic faunas and floras did exist during the Mid Cretaceous anoxic episodes, whereas at the end of the Maastrichtian practically all planktonic foraminifera disappeared (it still is unknown from what kind of forms the earliest Danian species originated).

Therefore, other explanations for the Cretaceous-Tertiary extinction event have to be looked for. Minutious study of the small interval concerned is the only way to eliminate at least some of the wild speculations that show up in literature.

The first, spectacular results of such a study were obtained by Alvarez et al. (1980) and Smit & Hertogen (1980). There authors independently discovered anomalously high Iridium contents of the Cretaceous-Tertiary boundary clay layer at Gubbio (Italy), Caravaca (Spain) and Stevns Klint (Denmark). They convincingly pleaded for an extraterrestrial origin of this anomaly and built slightly different models for the catastrophic effects on the Earth's ecological systems of the impact of a huge meteorite.

Chapter VII

TAXONOMY

SPECIES CONCEPT

In the representation of the distribution of important taxa, a purely typological species concept was applied. Therefore, the first occurrences of individual taxa in the charts should be interpreted as the entries of individual specimens that conform to the type description, with disregard of their position in the morphological variation of the fossil assemblages. Occurrences of "species" which rather should be regarded as extreme variants of an assemblage labelled under a different name (e.g. *G. fornicata* as extreme of a *M. sinuosa* assemblage) are indicated as such by a different signature.

Since, in such cases, the typological taxon probably was biologically conspecific with another species, its occurrence should be suspected to be strongly dependent on evironmental factors wich influence the morphological variation of that species. Therefore, occurrences of taxa as extreme variants of other species were not used as zonal markers. It is obvious, that where the phylogenetic origin of a species is not clear, the first occurrence of types has to be used (e.g. *G. ventricosa, G. calcarata, G. gansseri*). Also where the available material does not allow for the recognition of gradations from one species to another, the entry of types of the marker species was used to define the lower limit of the range of such a marker, even if the origin of the species has been described to be gradual elsewhere (e.g. *H. helvetica, A. mayaroensis*).

All taxa which were mentioned in the previous chapters are dealt with. The purpose of this taxonomical chapter is twofold. Primarily the author's concept of the width of the variation of the species is illustrated with a number of subjective synonyms where necessary, and, secondarily, the validity of the names of taxa is justified by adding some taxonomic notes.

As to the generic assignments, the reader is referred to the general considerations in chapter VI which led to them. For each genus, the diagnostic features are briefly summarized and the taxonomic validity is discussed.

Genus **Abathomphalus** Bolli, Loeblich & Tappan, 1957

Type species: *Globotruncana mayaroensis* Bolli
Remarks: The diagnosis of Bolli, Loeblich & Tappan is followed herein. The

apertural apparatus (primary aperture umbilical-extraumbilical; umbilicus covered by a thick and strong tegillar structure which seems to be the continuation of the last chamber rather than an extended apertural lip) is analogous to that of *Globotruncanella,* transitional forms to which genus have been described as *Abathomphalus intermedius* (Bolli).

Abathomphalus mayaroensis (Bolli)
(pl. 8, fig. 1a-c)

Globotruncana mayaroensis Bolli, 1951, J. Pal., vol. 25, p. 198, pl. 35, figs. 10—12 (holotype).
Abathomphalus mayaroensis (Bolli), Bolli, Loeblich & Tappan, 1957, U.S. Nat. Mus. Bull. 215, p. 43, pl. 11, fig. 1a-c.

Genus **Biticinella** Sigal, 1956

Type species: *Anomalina breggiensis* Gandolfi, 1942

Biticinella breggiensis (Gandolfi)
(pl. 1, fig. 4a-c)

Anomalina breggiensis, Gandolfi, 1942, Riv. Ital. Paleont. vol. 68, Mem. 4, p. 102, pl. 3, fig. 6 (holotype); pl. 5, fig. 3; pl. 9, fig. 1; pl. 13, figs. 7, 8.
Biticinella breggiensis (Gandolfi), Sigal, 1956, C. R. Somm. Soc. géol. France, no. 3, p. 35.

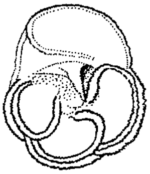
Genus **Globotruncana** Cushman, 1927

Type species: *Pulvinulina arca* Cushman
Remarks: *Globotruncana* is a polyphyletic genus, as pointed out in chapter VI. Four main groups are distinguished here, three of which evolved independently from *Marginotruncana* ancestors (the *G. linneiana-, G. fornicata-,* and *G. stuartiformis* groups), the *G. rosetta* group being an offshoot of the *G. linneiana* group.

As the type species belongs to the *G. linneiana* group, the latter and the *G. rosetta* group most logically should be included in *Globotruncana.* As both the *G. stuartiformis* group and the *G. fornicata* group have their origin in *M. sinuosa,* it seems plausible to include both groups in the same genus. The only genus name available is *Globotruncanita* Reiss (1957). This genus was meant to include only single-keeled species and a rigorous emendation of it in order to include also the *G. fornicata* group would probably find little response. Therefore, all four groups are included in *Globotruncana,* with emphasis on the existence of four natural groups, which will be treated separately.

The *Globotruncana fornicata* group

This group is distinguished from all other groups by its elongated chambers, and the two divergent keels. The tegillar structure is like that of the *G. stuartiformis* group and consists of large apertural flaps which leave large infralaminal, seldom intralaminal openings.



The group may be subdivided into two subgroups by means of the degree of spiral convexity: the biconvex to moderately spiroconvex group of *G. fornicata* and the high spiroconvex group of *G. contusa.* Each group has variants with regular, plicate and inflated chamber surfaces, which have been described under different names, but may as well be regarded as being conspecific. They are dealt with separately here.

Globotruncana contusa (Cushman)
(pl. 8, figs. 2a-c)

Pulvinulina arca Cushman var. *contusa* Cushman, 1926, Contr. Cushm. Lab. Foram. Res., vol. 2, p. 23.
Globotruncana linnei d'Orbigny *caliciformis* Vogler, 1941, Palaeontographica Suppl. 4, p. 288, pl. 24, fig. 23.
Globotruncana arca (Cushman) var. *contusa* Cushman, Cushman, 1946, U.S. Geol. Surv. Prof. Pap. 206, p. 150, pl. 62, fig. 6a-c (holotype).

Remarks: The validation of the species by Cushman (1946) by figuring the holotype came too late. The thin section, which is the holotype of Vogler's taxon, most obviously belongs to the same species. The name *contusa* is retained here as a non-official *nomen conservandum,* because the name *caliciformis* has been used in different ways. Moreover, recognition of *G. caliciformis* would mean a new name for the *G. contusa* Zone, which would add undesirable confusion in biostratigraphy.

Globotruncana fornicata Plummer

Globotruncana fornicata Plummer, 1931, Univ. Texas Bull. 2644, p. 198, pl. 13, fig. 4a-c (holotype).
Globotruncana (*Globotruncana*) *fornicata* Plummer subsp. *cesarensis* Gandolfi, 1955, Bull. Am. Pal., vol. 36 (155), p. 45, pl. 2, fig. 10a-c.
Globotruncana contusa (Cushman) subsp. *scutilla* Gandolfi, 1955, ibid., p. 54, pl. 4, fig. 1a-c.
Globotruncana contusa (Cushman) subsp. *withwickae* El Naggar, 1966, Brit. Mus. nat. Hist. Bull., geol. Suppl. no. 2, p. 95, pl. 7, fig. 1a-c.

Remarks: A well-defined concept of the width of variation of *G. fornicata* is difficult to give. The holotype is biconvex and less convex spirally than the average specimen of the accompanying assemblage. Irrespective of the dorsal convexity, the number of chambers in the last whorl shows considerable variation. In topotype material, we found it ranging from 3 to 6, thus extending into the extreme variants of *G. scutilla* Gandolfi (3 to 4 according to Linares Rodriguez, 1977) and *G. menaurensis* Gandolfi (more than 5 according to Linares Rodriguez, 1977).

El Naggar reported intermediate forms (*G. withwickae*) between *G. fornicata* and *G. contusa* from the Lower Maastrichtian, but figured a moderately spiroconvex specimen which in our concept falls within the variation of *G. fornicata*.

Forms with inflated chambers are included in *G. plummerae* Gandolfi.

Globotruncana navarroensis Smith & Pessagno

Globotruncana navarroensis Smith & Pessagno, 1973, Cushm. Found. Foram. Res. Spec. Publ. 12, p. 49, pl. 22, figs. 1–3 (holotype).

Remark: This form intergrades with *G. contusa,* with which it co-occurs, and from which it differs by the strongly inflated chambers and the tendency to be single-keeled in some of the last chambers.

Globotruncana plummerae Gandolfi

Globotruncana (Globotruncana) fornicata Plummer subsp. *plummerae* Gandolfi, 1955, Bull. Am. Pal., vol. 36 (155), p. 42, pl. 2, fig. 3a-c (holotype).

Remark: This form may be conspecific with *G. fornicata,* with which it cooccurs. It only differs by the inflated chambers.

Globotruncana walfischensis Todd

(pl. 8, fig. 3a-c)

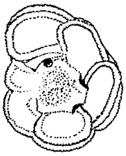
Globotruncana walfischensis Todd, 1970, Rev. Esp. Micropal., vol. 2, p. 153, pl. 5, fig. 8a, b (holotype).

Remark: This form may be conspecific with *G. contusa.* Todd (1970) mentioned the globular initial chambers as a difference with the latter. However, nearly all representatives of the *G. fornicata* group have such initial chambers. In our opinion, the non-plicate chamber surface of the later chambers is more characteristic.

The *Globotruncana linneiana* group

This group contains forms with two widely-spaced parallel keels and a tegillar structure which consists of a system of tegilla with both infra- and intralaminal accessory apertures. Each tegillum covers the entire umbilical area or a large part of it.

The central form is *G. linneiana.* This species gave rise to *G. bulloides* (inflated chambers), *G. arca* (spiroconvex), *G. ventricosa* (ventroconvex) and *G. trinidadensis* (elongated chambers).



A variant of *G. linneiana* with an imbricated keel pattern, which is analogous to that of *M. imbricata,* may be distinguished as *G. linneiana obliqua.*

Globotruncana arca (Cushman)

Pulvinulina arca Cushman, 1926, Contr. Cushm. Lab. Foram. Res., vol. 2, p. 23, pl. 3, fig. 1a-c (holotype).

Globotruncana lapparenti Brotzen, 1936, Sver. Geol. Unders. Ser. C, Årsb. 30, p. 175, pl. 2, fig. n (designated lectotype by Pessagno, 1967).

non Globotruncana lapparenti lapparenti Brotzen, Bolli, 1945, Ecl. Geol. Helv., vol. 37, p. 230, text-fig. 1; figs. 15, 16; pl. 9, fig. 11.

Globotruncana arca (Cushman), Cushman, 1946, U.S. Geol. Surv. Prof. Pap. 206, p. 150, pl. 62, fig. 4a-c, not fig. 5a-c.

Globotruncana arca (Cushman) Pessagno, 1967, Palaeontographica Americana, vol. 5 (37), p. 321, pl. 79, figs. 5–8; pl. 90, figs. 6–8; pl. 96, figs. 7, 8, 17.

Globotruncana lapparenti Brotzen, Pessagno, 1967, ibid., p. 314, pl. 71, figs. 6–13; pl. 97, fig. 9, not fig. 8.

Remarks: From the published figures there appears to be no significant difference between the types of *G. arca* and *G. lapparenti.* Pessagno (1967) already noted the similarity of the two species, but distinguished them on the basis of the supposed existence of two "basic" types of keel structure. The similarity and close identity of these two types were clearly illustrated by text-fig. 40 of Pessagno. It shows that this feature creates no means of discrimination.

Another difference mentioned by Pessagno is in the relative convexity of the spiral side. Pessagno gives mean T'X/TX values of *G. lapparenti* and *G. arca* of 0.72 and 0.45 respectively, which means that *G. arca* is more spiroconvex than G. *lapparenti* (measurements after separation of species).

Measuring T′X/TX values of both type figures gives

T′X/TX of *G. arca* = 0.70
T′X/TX of *G. lapparenti* = 0.58

which shows that the types of both species are not that much different.

Pessagno's figures of *G. lapparenti* (pl. 71, figs. 6–13) all clearly show the distinct tilt of the keel band towards the ventral side and the typical chamber outline at the spiral side, which outline is petaloid with a slight tendency to become rounded triangular, a feature which is also observed on *G. arca*. Consequently, both species are considered synonyms here.

Globotruncana bulloides Vogler

Globotruncana linnei (d'Orbigny) subsp. *bulloides* Vogler, 1941, Palaeontographica Suppl. 4, p. 287, pl. 23, fig. 33 (lectotype designated by Pessagno, 1967).
Globotruncana bulloides Vogler, Pessagno, 1967, Palaeontographica Americana, vol. 5 (37), p. 324, pl. 64, figs. 15–17; pl. 67, figs. 1–3; pl. 73, figs. 9, 10; pl. 75, figs. 4–8; pl. 97, figs. 14, 15.

Remarks: Although the width of the keel band is generally less than in *G. linneiana* (analogous to that of *M. marginata*, which is less than that of *M. pseudolinneiana*), *G. bulloides* may be seen as a *G. linneiana* with inflated chambers.

The species is rare in our material from Spain and Tunisia, whereas it seems to be very common in the Gulf Coast area.

Globotruncana linneiana (d'Orbigny)

Rosalina linneiana d'Orbigny, 1839, *in* de La Sagra: Hist. Phys. Nat. Cuba 8, p. 110, pl. 5, figs. 10–12 (holotype).
Pulvinulina tricarinata Quereau, 1893, Beitr. Geol. Karte Schweiz 33, p. 89, pl. 5, fig. 3a-c (designated lectotype of *P. tricarinata* by Pessagno, 1967).
Globotruncana lapparenti lapparenti Brotzen, Bolli, 1945, Ecl. Geol. Helv., vol. 37, p. 230, text-fig. 1, fig. 15.
Globotruncana linneiana (d'Orbigny), Brönnimann & Brown, 1956, Ecl. Geol. Helv., vol. 48, p. 540, pl. 20, figs. 13–15 (neotype).

Globotruncana linneiana obliqua Herm

Globotruncana linneiana obliqua Herm, 1965, Zeitschr. Deutsch. Geol. Ges., vol. 115, p. 336, pl. 8, figs. 1–4; text-fig. 14 (holotype).
Globotruncana linneiana obliqua Herm, Linares Rodriguez, 1977, Publ. Dep. Geol. Univ. Malaga 1, p. 263, pl. 30, fig. 3a-c; pl. 31, fig. 1a-c.

Remarks: In all its characters, this form is very similar to *G. linneiana*, except for the imbricate chamber arrangement.

Globotruncana trinidadensis Gandolfi

Globotruncana caliciformis trinidadensis Gandolfi, 1955, Bull. Am. Pal., vol. 36 (155), p. 47, pl. 3, fig. 2a-c (holotype).

Globotruncana trinidadensis Gandolfi, Pessagno, 1967, Palaeontographica Americana, vol. 5 (37), p. 359, text-fig. 57 (refiguration of holotype); pl. 84, figs. 4—12; pl. 90, figs. 9, 10; pl. 96, figs. 1, 2.

Remarks: *G. trinidadensis* is very similar to *G. arca,* from which it differs by its more elongated chambers both ventrally and dorsally, which feature makes it reminiscent of *G. fornicata.* Co-occurring representatives of the *G. fornicata* group, however, have a much higher trochospire and a narrower keel band.

Globotruncana ventricosa White
(pl. 7, fig. 3a-c)

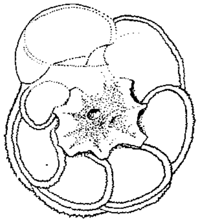
Globotruncana canaliculata var. *ventricosa* White, 1928, J. Pal., vol. 2, p. 284, pl. 38, fig. 3a-c (holotype).

Globotruncana ventricosa White, Pessagno, 1967, Palaeontographica Americana, vol. 5 (37), p. 362, pl. 79, figs. 9—12 (topotypes).

Remarks: According to Pessagno (1967), *G. ventricosa* is linked with *G. linneiana,* from which it evolved, by transitional forms. In the closely sampled section of El Burrueco, this could not be substantiated. *G. ventricosa* was found to appear suddenly. Only juvenile forms may be confused with *G. linneiana.*

The *Globotruncana rosetta* group

This group is characterized by the presence of two parallel keels, the ventral one of which is less developed and sometimes absent on the last-formed chambers, and by a complex and typically high tegillar structure with both intra- and infralaminal accessory apertures.



Four species were recognized in our material. They seem to constitute two lineages: one, with *G. arca* as ancestor, leads to large, multichambered forms with a tendency to loose the ventral keel, the other, probably starting from *G. esnehensis,* includes *G. rosetta* and the group of *G. aegyptiaca* and evolves to forms with less chambers in the last whorl and a higher ventral convexity.

Globotruncana aegyptiaca Nakkady

Globotruncana aegyptiaca Nakkady, 1950, J. Pal., vol. 24, p. 690, pl. 90, figs. 20–22 (holotype).
Globotruncana aegyptiaca Nakkady var. *duwi* Nakkady, ibid., p. 690, pl. 90, figs. 17–19.
Globotruncana gagnebini Tilev, 1951, Univ. Lausanne Lab. Géol. Min. Géophys., Bull. 103, p. 50, pl. 3, fig. 2a-c.

Globotruncana esnehensis Nakkady

Globotruncana arca (Cushman) var. *esnehensis* Nakkady, 1950, J. Pal., vol. 24, p. 690, fig. 23 (holotype; only dorsal side).
Globotruncana stephensoni Pessagno, 1967, Palaeontographica Americana, vol. 5 (37), p. 354, pl. 69, figs. 4–6.
Globotruncana esnehensis Nakkady, Linares Rodriguez, 1977, Publ. Dep. Geol. Univ. Málaga 1, p. 246, pl. 27, figs. 1, 2.

Remarks: Although the type figure is insufficient for determination, Nakkady's description leaves little doubt about the identity of this species. In this respect, we follow Linares Rodriguez, who considered *G. stephensoni* as a junior synonym.

G. esnehensis differs from *G. falsostuarti* in possessing a somewhat less developed ventral keel, which, moreover, is parallel to the peripheral one in *G. esnehensis* and typically convergent towards the middle of the periphery of each chamber in *G. falsostuarti.*

Globotruncana falsostuarti Sigal

Globotruncana falsostuarti Sigal, 1952, 19e Congr. Géol. Int. Alger, 1952, Monogr. Rég. Ser. 1 (26), p. 43, fig. 46 (holotype?).
Globotruncana falsostuarti Sigal, Postuma, 1971, Manual of Plankt. Foram., p. 36, figs. on p. 37.

Globotruncana rosetta (Carsey)

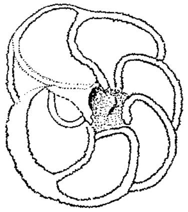
Globigerina rosetta Carsey, 1926, Univ. Texas Bull. 2612, p. 44, pl. 5, fig. 3a-c (holotype).
Globotruncana arca (Cushman), Plummer, 1931, Univ. Texas Bull. 3101, p. 195, pl. 13, fig. 11a-c (refiguration of holotype of *G. rosetta*).
Globotruncana cretacea Cushman, 1938, U.S. Geol. Surv. Prof. Pap. 206, p. 151, pl. 62, figs. 6a-c.
Globotruncana mariei Banner & Blow, 1960, Contr. Cushm. Found. Foram. Res., vol. 11, p. 8 (new name for *G. cretacea* Cushman).
Globotruncana rosetta (Carsey), Pessagno, 1967, Palaeontographica Americana, vol. 5 (37), p. 352, pl. 70, figs. 9–12; pl. 73, figs. 5–8 (refiguration of holotype of *G. cretacea*).
Globotruncana rosetta (Carsey), Esker, 1968, Contr. Cushm. Found Foram. Res., vol. 19, p. 170, text-figs. 1–3 (lectotype).

Remarks: Our species concept of *G. rosetta* is based on the figurations of the holotype, not on the lectotype. The latter is rather bad; the axial view is strongly oblique and does not show the apertural side.

G. rosetta in its typical form has a rather strong ventroconvexity, the periumbilical ridges are sigmoid and leave openings which lead to the infralaminal accessory apertures of the tegillar structure. The latter is very high, and protrudes over the umbilical cavity.

The *Globotruncana stuartiformis* group

This group corresponds with the genus *Globotruncanita* Reiss. It includes all single-keeled *Globotruncana* species. They seem to constitute a natural group. There is a central group of relatively large, angular forms which show approximately the same variation in relative convexity of the test throughout the Campanian and Maastrichtian. This group gradually evolved from forms with elongated crescentic chamber outlines at the spiral side to forms with trapezoidal chambers. There are two side-branches: one with tubulospines developing at the periphery, near or at the sutures, and one with extreme ventral convexity and inflation and rugosities at the ventral side.



In well-preserved specimens, the peculiar tegillar structure can be observed. It does not, as in other *Globotruncana* species consist of a number of superposed tegilla each covering the entire umbilical cavity or a large part of it, but rather of large flaps, each of which leaves a large infralaminal accessory aperture near the last suture. The successive infralaminal accessory apertures form a characteristic turbine structure, which is quite unlike other globotruncanid apertural apparatuses, except for that of the *G. fornicata* group.

Some specimens of species belonging to the *G. stuartiformis* group, especially juvenile forms, display an umbilical to extraumbilical position of the primary aperture (see pl. 7, fig. 2c).

All this together makes the *G. stuartiformis* group rather *Marginotruncana*-like.

Globotruncana elevata (Brotzen)
(pl. 6, fig. 2a-c)

Rotalia elevata Brotzen, 1934, Z. Deut. Ver. Palästina, vol. 57, p. 66, pl. 3, fig. C.
Globotruncana elevata (Brotzen), Kuhry, 1970, Rev. Esp. Micropal., vol. 2, p. 292, pl. 1, figs. 1–3 (lectotype).
Globotruncanita elevata (Brotzen) "formas primitivas" Linares Rodriguez, 1977, Publ. Dep. Geol. Univ. Málaga 1, p. 335, pl. 39, figs. 1, 2.

Remarks: Brotzen (1934) did not designate a holotype, an omission which was corrected by Kuhry (1970) by selecting a lectotype from the type sample. This sample also contained *M. carinata.* Therefore, the strongly ventroconvex forms from the *elevata – carinata* Zone with occasionally two keels in the older part of the last whorl should not be considered "primitive" forms, but they are typical. Typical *G. elevata* are only found in the *elevata – carinata* Zone and in the lower part of the *elevata* Zone.

Globotruncana atlantica Caron

Globotruncana atlantica Caron, 1972, Init. Rep. D.S.D.P. 11, p. 553, text-fig. 1a-c (holotype).

Globotruncana calcarata Cushman
(pl. 7, fig. 2a-c)

Globotruncana calcarata Cushman, 1927, Contr. Cushm. Lab. Foram. Res., vol. 3, p. 115, pl. 23, fig. 10a, b (holotype).

Globotruncana conica White

Globotruncana conica White, 1928, J. Pal., vol. 2, p. 285, pl. 38, fig. 7a-c (holotype).

Remarks: This species may be regarded as a spiroconvex variant of *G. stuarti.* As already stated by Pessagno (1967), it is easily confused with *G. esnehensis,* from which it mainly differs by the tegillar structure (see remarks on *G. esnehensis*), and the absence of a weakly developed second keel.

Globotruncana gansseri Bolli
(pl. 7, fig. 1a-c)

Globotruncana gansseri Bolli, 1951, J. Pal., vol. 25, p. 196, pl. 35, figs. 1–3 (holotype).
Globotruncana lugeoni Tilev, 1951, Univ. Lausanne Bull. Lab. Geol. Min. Géophys., Bull. 103, p. 41, pl. 1, fig. 5a-c; text-fig. 10.
Globotruncana arabica El-Naggar, 1966, Bull. Brit. Mus. nat. Hist., Geol., Suppl. 2, p. 81, pl. 6, fig. 3a-d.
Globotruncana youssefi El-Naggar, 1966, ibid., p. 144, pl. 6, fig. 4a-d.

Remarks: The subjective synonymy list illustrates our wide concept of *G. gansseri*. The types of all the species mentioned above have in common that they are strongly ventroconvex and flat or nearly so dorsally, that they possess a rugose surface at the ventral side, and somewhat elongated crescentic chambers at the spiral side, where the surface of the chambers is much smoother than at the ventral side. In the order *G. lugeoni* – *G. gansseri* – *G. arabica* the ventral convexity increases progressively; *G. arabica* even has a concave spiral side. In this respect, *G. youssefi* is like *G. gansseri* and differs only from it by a peculiarly shaped last chamber.

Morphologically, the *G. arabica*-type representatives of *G. gansseri* resemble *Rugoglobigerina*, especially in their rugose ventral side. The tegillar structure, however, is different and is composed of relatively simple, large and imbricating tegilla with, according to our observations, only infralaminal accessory apertures, rather than of tegilla which cover the whole umbilicus. In this respect, *G. gansseri* rather belongs to the *G. elevata* group.

Globotruncana stuarti (De Lapparent)

Rosalina stuarti De Lapparent, 1918, Serv. Carte Géol. France Mém., p. 11, pl. 4, lower 3 figs. (lectotype designated by Pessagno, 1967).

Globotruncana stuartiformis Dalbiez

Globotruncana (*Globotruncana*) *stuartiformis* Dalbiez, 1955, Micropaleontology, vol. 1, p. 168, text-fig. 10a-c (holotype).

Genus **Globotruncanella** Reiss, 1957

Type species: *Globotruncana citae* Bolli

Globotruncanella havanensis (Voorwijk)

Globotruncana havanensis Voorwijk, 1937, Proc. Kon. Ned. Akad. Wet., vol. 40, p. 195, pl. 1, figs. 25, 26, 29 (holotype).

Globotruncana citae Bolli, 1951, J. Pal., vol. 25, p. 197, pl. 35, figs. 4–6.

Globotruncanella havanensis (Voorwijk), Van Hinte, 1963, Jb. Geol. B. A. Wien, Sonderband 8, p. 94, pl. 12, fig. 1a-c (refiguration of holotype).

Genus **Globigerinelloides** Cushman & Ten Dam, 1948

Type species: *Globigerinelloides algeriana* Cushman & Ten Dam

Globigerinelloides caseyi (Bolli, Loeblich & Tappan)

Planomalina caseyi Bolli, Loeblich & Tappan, 1957, U.S. Nat. Mus. Bull. 215, p. 24, pl. 1, fig. 4a, b (holotype).

Globigerinelloides algerianus Cushman & Ten Dam

Globigerinelloides algeriana Cushman & Ten Dam, 1948, Contr. Cushm. Lab. Foram. Res., vol. 24, p. 43, pl. 8, figs. 4–6 (holotype).

Genus **Hedbergella** Brönnimann & Brown, 1958

Type species: *Anomalina lorneiana* d'Orbigny var. *trocoidea* Gandolfi
Remarks: Brönnimann & Brown (1958) proposed this name as a substitute for *Hedbergina* Brönnimann & Brown, 1956, in order to avoid confusion which might result from the obscure identity of the type species of the latter genus. The genus includes all non-keeled Cretaceous planktonic foraminifera with a trochoid chamber arrangement, a primary aperture which is distinctly umbilical-extraumbilical and extends to the periphery, and a simple apertural lip.

Hedbergella costellata Saint-Marc

Hedbergella costellata Saint-Marc, 1973, J. Foram. Res., vol. 3, p. 11, pl. 1, fig. 1a-c (holotype).

Remarks: This species has only been found in sediments which may be assigned to the *ticinensis – buxtorfi* Zone or the *appenninica – buxtorfi* Zone, i.e. the uppermost Albian. The presence of costellae generally is considered a generic character, but it seems quite useless to create a new genus for a single species.

Hedbergella brittonensis Loeblich & Tappan

Hedbergella brittonensis Loeblich & Tappan, 1961, Micropaleontology, vol. 7, p. 274, pl. 4, fig. 1a-c (holotype).

Remarks: Our specimens from the lower part of section El Burrueco are considerably older than the type material, but are not notably different.

Hedbergella delrioensis (Carsey)

Globigerina cretacea d'Orbigny var. *delrioensis* Carsey, 1926, Univ. Texas Bull. 2612, p. 43.
Hedbergella delrioensis (Carsey), Longoria, 1974, Rev. Esp. Micropal., No. extr. Diciembre 1974, pl. 10, figs. 1–3 (neotype).

Hedbergella flandrini Porthault

Hedbergella flandrini Porthault, 1970, Geobios, vol. 3, p. 64, fig. 1a, b (holotype).

Remarks: This species is the only *Hedbergella* representative in rocks which are younger than Coniacian. It is very close to *Globotruncanella havanensis*, which probably evolved from it, but lacks tegilla.

Hedbergella hoelzli (Hagn & Zeil)

Globigerina hoelzli Hagn & Zeil, 1954, Ecl. Geol. Helv., vol. 47, p. 50, 32, pl. 2, fig. 8a-c (holotype).
Hedbergella hoelzli (Hagn & Zeil), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–1, p. 135, pl. 26, fig. 1a-c (lectotype).

Remarks: This species was found in the Turonian and Coniacian of Pont du Fahs and section Koudiat el Hamra. It differs from *H. flandrini* in having 5 to 6 instead of 4 to 5 chambers in the last whorl and by the presence of numerous pustules all over the test.

The designation of the lectotype became necessary after the present author observed the holotype to be entirely crushed.

Hedbergella planispira (Tappan)

Globigerina planispira Tappan, 1940, J. Pal., vol. 14, p. 12, pl. 19, fig. 12.

Hedbergella simplex (Morrow)

Hastigerinella simplex Morrow, 1934, J. Pal., vol. 8, p. 198, pl. 30, fig. 6 (holotype).
Hedbergella amabilis Loeblich & Tappan, 1961, Micropaleontology, vol. 7, p. 274, pl. 3, fig. 1a, b.
Clavihedbergella simplex (Morrow), Loeblich & Tappan, ibid., p. 279, pl. 3, figs. 11–14.

Genus **Helvetoglobotruncana** Reiss, 1957

Type species: *Globotruncana helvetica* Bolli
Remarks: Reiss erected the genus because of the independent development of *H. helvetica* from a non-keeled ancestor, as already suggested by Schijfsma (1955) and Sigal (1955), and again confirmed by Lamolda (1976). The partly keeled intermediate form between a *Whiteinella* ancestor (*Wh. archaeocretacea*?) and *H. helvetica*, i.e. the species *praehelvetica* Trujillo, is included in the genus here, for the same reason why we included other partially keeled species in genera defined to include keeled forms (*Planomalina, Praeglobotruncana, Pseudothalmanninella, Thalmanninella*).

Helvetoglobotruncana helvetica (Bolli)
(pl. 3, fig. 2a-c)

Globotruncana helvetica Bolli, 1945, Ecl. Geol. Helv., vol. 37, p. 226, pl. 9, fig. 6.
Helvetoglobotruncana helvetica (Bolli), Reiss, 1957, Contr. Cushm. Found. Foram. Res., vol. 8, p. 137.

Helvetoglobotruncana praehelvetica (Trujillo)

Rugoglobigerina praehelvetica Trujillo, 1960, J. Pal., vol. 34, p. 340, pl. 49, fig. 6a-c.

Genus **Marginotruncana** Hofker, 1956, sensu Pessagno, 1967

Type species: *Rosalina marginata* Reuss
Remarks: The concept of *Marginotruncana* has considerably changed since the original description. The genus was erected by Hofker (1956) to include several globotruncanids sharing certain apertural features which distinguished them from *Globotruncana* s.s. Hofker's distinction between protoforamen and deuteroforamen is very confusing and essentially not correct, since it is based on the alleged evolution of globotruncanids from *Conorbina* and *Conorboides*. Pessagno emended the genus, using a more adequate terminology in the description of the apertures. In his concept, *Marginotruncana* includes globotruncanids with 1) an extraumbilical to umbilical primary aperture, 2) large portici with only infralaminal accessory apertures and, 3) an angular periphery. We adhere to this concept with exception for the group of *H. helvetica* (see remarks on *Helvetoglobotruncana*).

Porthault (1970) created the subgenus *Dicarinella* for double-keeled forms with radial, depressed ventral sutures, with *Globotruncana indica* Jacob & Sastry as type species. Later on, several species have been assigned to this subgenus, e.g. *Praeglobotruncana algeriana* Caron, *Globotruncana imbricata* Mornod, *Rosalina canaliculata* Reuss, *Globotruncana schneegansi* Sigal and the representatives of the *concavata* group. In all these taxa, however, there is a great variability in the ventral sutures, and it was found that a strict discrimination of *Dicarinella* and *Marginotruncana* based on depressed ventral sutures would cut through morphologically homogeneous groups, i.e. through species. Even *M. marginata* often has depressed ventral sutures.

Moreover, the identity of the type species *G. indica* is obscure. The holotype is not available for examination and topotype material could not be obtained from the authors. The stratigraphic position of the type locality is not clear. If, as the authors claim, *G. indica* was found together with *Th. appenninica,* there is no European form which may be labelled as *G. indica,* certainly not the species *primitiva,* which was put in synonymy with *G. indica* by Linares Rodriguez (1977), but which must be much younger. All this led us to include forms which possibly would be assigned to *Dicarinella* in *Marginotruncana* when portici are present, and in *Praeglobotruncana* when not (e.g. *P. algeriana*).

The *Marginotruncana pseudolinneiana* group

This group unites forms with two rather widely spaced keels. Its earliest representatives can hardly be separated from primitive forms of the *M. sigali – renzi* group, which illustrates their common origin from *P. algeriana.* In our material, the representatives of this group play a subordinate role in the composition of the faunas. In boreal faunas, however, they often are the only representatives of *Marginotruncana* to be found.

Marginotruncana canaliculata (Reuss)

Rosalina canaliculata Reuss, 1844, Denkschr. d. K. Akad. Wiss. Wien, Math.-Naturw. Kl., vol. 7, p. 70, pl. 26, fig. 4a, b (holotype).

Marginotruncana canaliculata (Reuss), Pessagno, 1967, Palaeontographica Americana, vol. 5 (37), p. 302, pl. 74, figs. 5–8 (neotype).

Remark: This species is the most primitive typical representative of the *M. pseudolinneiana* group. It differs from all other *Marginotruncana* species in the combination of a parallel keel band, petaloid chamber outline at the spiral side and radial, depressed ventral sutures. In axial view, it is typically biplanar in outline.

Marginotruncana imbricata (Mornod)

Globotruncana imbricata Mornod, 1949, Ecl. Geol. Helv., vol. 42, p. 581, fig. 5-III (holotype).

Dicarinella imbricata (Mornod), Caron, 1976, Ecl. Geol. Helv., vol. 69, p. 332, fig. 3a-c (neotype).

Remarks: Mornod's type material being lost, Caron (1976) designated a neotype from the type locality.

M. imbricata differs from *M. canaliculata* by its imbricated pattern of the parallel double keel at the periphery and by the frequently present aberrant last chamber. From *P. algeriana* it differs in the somewhat better development of the portici and the imbricated keel pattern. Otherwise, it is very close to *P. algeriana.*

Marginotruncana marginata (Reuss)

Rosalina marginata Reuss, 1845, Verst. Böhm. Kreideform., p. 36, pl. 8, figs. 54a, b; 74a, b; pl. 13, fig. 68a, b (designated lectotype by Pessagno, 1967, *after* the designation of a neotype by Jírová, 1956).

Globotruncana marginata (Reuss), Jírová, 1956, Univ. Carol. Geol., vol. 2, p. 239, pl. 1, fig. 1a-c (neotype).

Remarks: This species is very rare in our material. It occurs abundantly in boreal faunas, where it may display a great variability.

Marginotruncana pseudolinneiana Pessagno

Marginotruncana pseudolinneiana Pessagno, 1967, Palaeontographica Americana, vol. 5 (37), p. 310, pl. 65, figs. 24–27 (holotype).

Remarks: In our concept, all biplanar forms with angular rhomboid chambers and petaloid spiral chamber outline belong to this species. From the *M. concavata* Zone onward, the assemblages of the species may contain extreme forms with a practically umbilical primary aperture and true tegilla. These forms may be assigned to *Globotruncana linneiana.*

The *Marginotruncana sigali – renzi* group

The group is characterized by angular rhomboid chambers, a narrow, often diverging keel band or by a single keel, and by large portici which leave one large infralaminal aperture each. The group contains a great variety of forms, which may be separated into a central subgroup (*M. renzi* s.l.), with two extreme forms as end members in the variation (*M. sigali* and *M. coronata*) and two distinct species which are almost homeomorphic (*M. marianosi* and *M. schneegansi*).

For detailed descriptions and figures of the various types within the group the reader is referred to Robaszynski & Caron (1979).

Marginotruncana renzi (Gandolfi) s.l.

This subgroup is characterized by two closely spaced keels, which either diverge in the direction of growth or run parallel at the periphery, but are so close to each other then, that they leave no imperforate peripheral band. The ventral sutures are always raised and V-shaped. The last chamber(s) may be single-keeled. The following "species" have been recognized within the large and variable group:

Marginotruncana angusticarinata (Gandolfi)
(pl. 4, fig. 3a-c)

Globotruncana linnei (d'Orbigny) var. *angusticarenata Gandolfi*, 1942, Riv. Ital. Pal. Mem. 4, p. 126, fig. 3a-c.

Marginotruncana sinuosa Porthault, Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–2, p. 147, pl. 75, fig. 2a-c (topotype of *G. linnei* var. *angusticarenata*).

Marginotruncana renzi (Gandolfi)

Globotruncana renzi Gandolfi, 1942, Riv. Ital. Pal. Mem. 4, p. 124, pl. 3, fig. 1 (designated holotype by Caron, 1966).

Globotruncana renzi Gandolfi, Caron, 1966, Rev. Micropal., vol. 9, p. 78, fig. 5a-c (refiguration of holotype).

Marginotruncana renzi (Gandolfi), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979-2, p. 129, pl. 69, figs. 1a-c, 2a-c (topotypes).

Marginotruncana sinuosa Porthault

Marginotruncana sinuosa Porthault, 1970, Geobios, vol. 3, p. 81, pl. 11, figs. 11—13 (holotype).

Marginotruncana sinuosa Porthault, Robaszynski & Caron, 1979, Cahiers de Micropal. 1979—2, p. 147, pl. 74, fig. 1a-c (topotype).

Marginotruncana tarfayensis (Lehmann)

Globotruncana tarfayensis Lehmann, 1963, Notes Mém. Serv. Géol. Maroc 21 (156), p. 146, pl. 5, fig. 4a-c (holotype).

Marginotruncana tarfayensis (Lehmann), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979—2, p. 155, pl. 76, figs. 1a-c, 2a-c (topotypes).

Marginotruncana undulata (Lehmann)

Globotruncana undulata Lehmann, 1963, Notes Mém. Serv. Géol. Maroc 21 (156), p. 148, pl. 9, fig. 3a-c (holotype).

Marginotruncana undulata (Lehmann), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979—2, p. 159, pl. 77, figs. 1a-c, 2a-c (topotypes).

Marginotruncana coronata (Bolli)
(pl. 4, fig. 2a-c)

Globotruncana lapparenti Brotzen subsp. *coronata* Bolli, 1945, Ecl. Geol. Helv., vol. 37, p. 233, pl. 9, fig. 15 (designated lectotype by Pessagno, 1967).

Marginotruncana marianosi (Douglas)

Globotruncana marianosi Douglas, 1969, Micropaleontology, vol. 16, p. 183, text-fig. 5a-c (holotype).

Marginotruncana marianosi (Douglas), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979—2, p. 115, pl. 65, fig. 1a-c (topotype).

Marginotruncana schneegansi (Sigal)

Globotruncana schneegansi Sigal, 1952, 19e Congr. Géol. Int. Alger, Monogr. Rég. Ser. 1 (26), p. 33, fig. 34.

Globotruncana schneegansi Sigal, Caron, 1977, Actes 6e Coll. Afr. Micropal. Tunis 1974, vol. 1, p. 330, text-fig. 1a-c (neotype); pl. 1, figs. 1-9 (neoparatypes).

Marginotruncana schneegansi (Sigal), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979—2, p. 135, pl. 70, fig. 1a-c (refiguration of neotype), fig. 2a-e (topotype).

Marginotruncana sigali (Reichel)
(pl. 4, fig. 1a-c)

Globotruncana sigali Reichel, 1950, Ecl. Geol. Helv., vol. 42, p. 610, text-fig. 5a-c (holotype).
Globotruncana sigali Reichel, Caron, 1977, Actes 6e Coll. Afr. Micropal. Tunis 1974, vol. 1, p. 333, text-fig. 2a-c (refiguration of holotype).
Marginotruncana sigali (Reichel), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979-2, p. 141, pl. 72, figs. 1a-c, 2a, b (topotypes).

The *Marginotruncana concavata* group sensu Dalbiez, 1955

Dalbiez (1955) described the representatives of this group as subspecies of *G. ventricosa*, with the remark that they possibly should be assigned to the species *concavata* because his concept of *G. ventricosa* might be erroneous. Most later authors have done so, and the group now commonly is known as the *concavata* group. It contains *M. primitiva, M. concavata* and *M. carinata,* which three species succeed each other in time and are markers of three successive zones.

Unfortunately, this clear picture is blurred by some taxonomic complications:

1. The holotype of *Rotalia concavata* Brotzen, 1934, being lost, Kuhry (1970) designated a lectotype. This specimen, however, seems to be a juvenile form of what Dalbiez certainly would have assigned to his subspecies *carinata.* This is not surprising, since examination of topotype material of *G. concavata* revealed it to be a *carinata* assemblage.
2. *Globotruncana asymetrica* Sigal appears to be a senior synonym of *M. carinata.* After the refiguration of the specimen figured by Sigal (1952) with a full description and the explicite statement that this specimen is the holotype (Robaszynski & Caron, 1979), Sigal's species is doubtlessly valid relative to *M. carinata* (Dalbiez).

This taken into account, *M. carinata* should be called *M. concavata* and a new name should be chosen for *M. ventricosa ventricosa* Dalbiez, non White. This also would change the names of the corresponding zones. As the zones have found wide recognition under the names suggested by Dalbiez, we think that such a procedure would mean an undesirable complication of the matter. Therefore, the group is dealt with according to Dalbiez's concept, with reference to his figurations.

Marginotruncana carinata (Dalbiez)
(pl. 6, fig. 1a-c)

Globotruncana (Globotruncana) ventricosa carinata Dalbiez, 1955, Micropaleontology, vol. 1, p. 168, text-fig. 8a-d (holotype).

Dicarinella asymetrica (Sigal), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–2, p. 61, pl. 51, fig. 1a-c (holotype of *G. asymetrica* Sigal).

Marginotruncana concavata (Brotzen) "sensu Dalbiez, 1955"
(pl. 5, fig. 2a-c)

Globotruncana (Globotruncana) ventricosa ventricosa White, Dalbiez, 1955, Micropaleontology, vol. 1, p. 168, text-fig. 7a-d.

Marginotruncana primitiva (Dalbiez)
(pl. 5, fig. 1a-c)

Globotruncana (Globotruncana) ventricosa primitiva Dalbiez, 1955, Micropaleontology, vol. 1, p. 168, text. fig. 6.

Dicarinella primitiva (Dalbiez), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–2, p. 93, pl. 60, fig. 1a-c (lectotype), fig. 2a-c (topotype).

Genus **Planomalina** Loeblich & Tappan, 1946

Type species: *Planomalina apsidostroba* Loeblich & Tappan

Planomalina buxtorfi (Gandolfi)
(pl. 2, fig. 3a-c)

Planulina buxtorfi Gandolfi, 1942, Riv. Ital. Pal. Mem. 4, p. 103, pl. 3, fig. 7a-c (holotype).

Planomalina apsidostroba Loeblich & Tappan, 1946, J. Pal., vol. 20, p. 258, pl. 37, figs. 22, 23.

Planomalina buxtorfi (Gandolfi), Caron & Luterbacher, 1969, Contr. Cushm. Found. Foram. Res., vol. 20, p. 25, pl. 8, fig. 5a-c (refiguration of holotype).

Planomalina cheniourensis (Sigal)

Planulina cheniourensis Sigal, 1952, 19e Congr. Géol. Intern. Alger, Monogr. Rég. Ser. 1 (26), p. 21, fig. 17.

Planomalina praebuxtorfi Wonders
(pl. 1, fig. 1a-c)

Planomalina praebuxtorfi Wonders, 1975, Proc. Kon. Ned. Akad. Wet. Ser. B, vol. 78, p. 90, pl. 1, fig. 1a-c (holotype).

Planomalina praebuxtorfi Wonders, Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–1, p. 47, pl. 1, fig. 1a-c (refiguration of holotype).

Genus **Praeglobotruncana** Bermudez, 1952

Type species: *Globotoralia delrioensis* Plummer

Remark: For an extensive discussion of the taxonomic position of the genus the reader is referred to Robaszynski & Caron (1979).

Praeglobotruncana delrioensis (Plummer)

Globorotalia delrioensis Plummer, 1931, Univ. Texas Bull. 3101, p. 199, pl. 13, fig. 2a-c (holotype).

Praeglobotruncana gibba Klaus

Praeglobotruncana gibba Klaus, 1960, Ecl. Geol. Helv., vol. 53, p. 694, fig. 1.

Praeglobotruncana stephani (Gandolfi)

Globotruncana stephani Gandolfi, 1942, Riv. Ital. Pal. Mem. 4, p. 130, pl. 3, fig. 4 (holotype).

Genus **Pseudothalmanninella** Wonders, 1978

Type species: *Globotruncana ticinensis* Gandolfi
Remarks: The genus was erected because of the phyletic origin of the *Ps. ticinensis* group, which is different from that of all other keeled Rotaliporinae. Morphologically, *Pseudothalmanninella* can hardly be separated from *Thalmanninella.* Characteristic are the trapezoid outline of the chambers at the spiral side and the very small accessory apertures, which never enter the ventral sutures, but always remain umbilical in position.

Pseudothalmanninella subticinensis (Gandolfi)
(pl. 1, fig. 3a-c)

Globotruncana ticinensis var. α Gandolfi, 1942, Riv. Ital. Pal. Mem. 4, p. 114, pl. 2, fig. 4a-c (holotype).
Globotruncana (*Thalmanninella*) *ticinensis subticinensis* Gandolfi, 1957, Contr. Cushm. Found. Foram. Res., vol. 8, p. 59, fig. 1a-c (= pl. 2, fig. 4a-c, Gandolfi, 1942).
Pseudothalmanninella subticinensis (Gandolfi), Wonders, 1978, Proc. Kon. Ned. Akad. Wet. Ser. B, vol. 81, p. 125, pl. 1, fig. 2a-c.
Rotalipora subticinensis (Gandolfi), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979—1, p. 107, pl. 19, figs. 1a-c, 2a-d (topotypes).

Pseudothalmanninella ticinensis (Gandolfi)
(pl. 1, fig. 2a-c)

Globotruncana ticinensis Gandolfi, 1942, Riv. Ital. Pal. Mem. 4, p. 113, pl. 2, fig. 3a-c (holotype).
Rotalipora ticinensis (Gandolfi), Caron & Luterbacher, 1969, Contr. Cushm. Found. Foram. Res., vol. 20, p. 25, pl. 8, fig. 6a-c (refiguration of holotype).
Pseudothalmanninella ticinensis (Gandolfi), Wonders, 1978, Proc. Kon. Ned. Akad. Wet. Ser. B, vol. 81, p. 128, pl. 1, figs. 3a-c, 4a-c.
Rotalipora ticinensis (Gandolfi), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979—1, p. 111, pl. 20, fig. 1a-d (topotype).

Genus **Rotalipora** Brotzen, 1942

Type species: *Rotalipora turonica* Brotzen

Remarks: Recognition of *Thalmanninella* restricts the genus *Rotalipora* to the species belonging to the group of *R. cushmani,* a subjective senior synonym of the type species. Wonders (1978) emphasized the importance of the sutural position of the accessory apertures in combination with the both dorsally and ventrally inflated chambers, which two features define the genus.

Rotalipora has the same peculiar *internal peripheral fossula* (Wonders, 1978) as *Thalmanninella* and most probably evolved from a *Thalmanninella* ancestor rather than from *Praeglobotruncana,* as defended by Maslakova (1963).

Rotalipora cushmani (Morrow)
(pl. 3, fig. 3a-c)

Globorotalia cushmani Morrow, 1934, J. Pal., vol. 8, p. 199, pl. 31, figs. 2—4 (holotype).

Rotalipora turonica Brotzen, 1942, Sver. Geol. Unders. Ser. C, vol. 36, p. 32, text-figs. 10, 11.

Rotalipora cushmani (Morrow), Brönnimann & Brown, 1956, Ecl. Geol. Helv., vol. 48, p. 537, pl. 20, figs. 10—12 (refiguration of holotype).

Rotalipora cushmani (Morrow), Longoria, 1973, Acta Pal. Polonica, vol. 18, p. 457, pl. 33, fig. 1a-d, pl. 34, figs. 1a-c, 3a.

Rotalipora turonica Brotzen, Longoria, 1973, ibid., p. 457, pl. 34, figs. 2, 3c (lectotype of *R. turonica*).

Remarks: The synonymy of *R. turonica* and *R. cushmani* is subjective and not generally accepted. Brotzen (1942) figured two specimens, without explicitely designating a holotype. His fig. 10, however, should be regarded as the type figure, since it was included in the description, whereas fig. 11—4 was meant as an illustration in Brotzen's review of the Globotruncaninae.

Longoria (1974) designated Brotzen's specimen of fig. 11—4 as lectotype of *R. turonica,* and assigned Brotzen's fig. 10 to *R. cushmani.* Although this procedure is legal, it is rather artificial and apparently not in agreement with the intention of Brotzen, who only failed to designate his fig. 10 as the holotype.

The lectotype of *R. turonica* has seven chambers and a very slow increase of the chamber size in the last whorl. According to Longoria *R. turonica* generally would have a higher trochospire than *R. cushmani,* a statement which is in contradiction with the type figures. In our material, both features show a great variability, and all forms with umbilical shoulders and ridges on the spiral side are assigned to *R. cushmani.*

Rotalipora montsalvensis Mornod

Globotruncana (*Rotalipora*) *montsalvensis* Mornod, 1949, Ecl. Geol. Helv., vol. 42, p. 584, fig. 4, Ia-c (holotype).

Rotalipora montsalvensis Mornod, Caron, 1976, Ecl. Geol. Helv., vol. 69, p. 329, fig. 1a-c (neotype), pl. 1, figs. 1–6 (topotypes).

Rotalipora montsalvensis Mornod, Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–1, p. 95, pl. 15, fig. 1a-c (topotype).

Globotruncana (*Rotalipora*) *montsalvensis* var. *minor* Mornod, 1949, Ecl. Geol. Helv., vol. 42, p. 586, fig. 4, IIa-c (holotype of var. *minor*).

Rotalipora montsalvensis Mornod var. **thomei** Hagn & Zeil

Rotalipora turonica Brotzen *thomei* Hagn & Zeil, 1954, Ecl. Geol. Helv., vol. 47, p. 28, pl. 1, fig. 6 (holotype).

Remarks: This high-spired variety of *R. montsalvensis* was found in thin sections from section Quero-Schievenin, just below the entry of *R. cushmani.* According to Robaszynski & Caron (and all the members of the European Working Group on Planktonic Foraminifera, 1979) this variety is a "phylogenetically terminal form". If this holds true, it may indicate that the zonation of section Quero-Schievenin, although based on thin sections only, is rather accurate.

Genus **Thalmanninella** Sigal, 1948

Type species: *Thalmanninella brotzeni* Sigal

Remarks: As the type species is considered to be a junior synonym of *Th. greenhornensis*, the latter species is thought to display all the characteristic features of the genus.

The genus was erected to include keeled Rotaliporinae with accessory apertures in umbilical rather than sutural position. The latter were assigned to *Rotalipora.* The type species of both genera show a marked difference in this respect and offer no problems. There are, however, certain variants of the *appenninica* group, which show a tendency towards a more sutural position of the accessory apertures, e.g. *Th. globotruncanoides.* Therefore the characteristically inflated chambers of *R. cushmani* are considered to be the discriminating feature between *Rotalipora* and *Thalmanninella.*

The species of *Thalmanninella* were dealt with extensively by the present author in a previous paper. Some additional taxonomic notes are made here.

Thalmanninella appenninica (Renz)
(pl. 2, fig. 2a-c)

Globotruncana appenninica Renz, 1936, Ecl. Geol. Helv., vol. 29, p. 14, fig. 2 (left specimen, holotype).

Globotruncana appenninica Renz var. α Gandolfi, 1942, Riv. Ital. Pal. Mem. 4, p. 117, text-fig. 40a-c, pl. 4, fig. 12.

Globotruncana (Rotalipora) appenninica balernaensis Gandolfi, 1957, Contr. Cushm. Found. Foram. Res., vol. 8, p. 60, pl. 8, fig. 3a-c.

Rotalipora appenninica appenninica (Renz), Luterbacher & Premoli Silva, 1962, Riv. Ital. Pal., vol. 68, p. 266, pl. 19, figs. 1a-c, 2a-c; pl. 20, figs. 1a-c, 4a-c; pl. 21, figs. 1a-c, 4a-c (topotypes).

Rotalipora appenninica (Renz), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–1, p. 59, pl. 4, figs. 1a-c, 2a-c (topotypes), fig. 3a-c (topotype of *G. appenninica* var. α Gandolfi and of *G. (R.) appenninica balernaensis*).

Remarks: The taxonomic problems concerning this species are not extensively dealt with here. It is emphasized again that the species is defined by its type material from Gubbio, Italy, and not by the material of *G. (R.) appenninica appenninica* Gandolfi from Breggia.

A new name had to be chosen for the latter subspecies, since the topotype material of *G. appenninica* turned out to correspond with Gandolfi's subspecies *balernaensis*. Luterbacher & Premoli Silva (1962) renamed the subspecies *appenninica* into *gandolfii*. On purely subjective grounds, *Th. gandolfii* (Luterbacher & Premoli Silva) is considered a synonym of *Th. appenninica* here (Wonders, 1978).

Thalmanninella deeckei (Franke)

Rotalia deeckei Franke, 1925, Abh. Geol.-Pal. Inst. Univ. Greifswald, vol. 6, p. 90, pl. 8, fig. 7a-c (holotype).

Thalmanninella deeckei (Franke), Dalbiez, 1957, Micropaleontology, vol. 3, p. 187, figs. 1–4 (topotype?), fig. 5a-c (original figure of Franke).

Rotalipora deeckei (Franke), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–1, p. 75, pl. 9, figs. 1a-c, 2a-c; pl. 10, figs. 1a-c, 2a-c.

Remarks: Dalbiez (1957) figured a second specimen which was assigned to *Rotalia deeckei* by Franke, because the holotype was damaged. Dalbiez did not designate this specimen as the neo- or lectotype.

See remarks on *Th. reicheli.*

Thalmanninella globotruncanoides (Sigal)
(pl. 2, fig. 1a-c)

Rotalipora globotruncanoides Sigal, 1948, Rev. Inst. Fr. Pétr., vol. 3, p. 100, pl. 1, fig. 4a-c; 1952, 19e Congr. Géol. Intern. Alger, Monogr. Rég. Ser. 1, (26), p. 26, fig. 24 (figures of holotype).

Thalmanninella globotruncanoides (Sigal), Wonders, 1978, Proc. Kon. Ned. Akad. Wet. Ser. B, vol. 81, p. 132, pl. 2, figs. 1a-c, 2a-c.

Remarks: This species is considered to be an intermediate evolutionary stage between *Th. appenninica* and *Th. greenhornensis.* It differs from *Th. appenninica* in possessing periumbilical ridges throughout the last whorl and more elongated crescentic, rather strongly overlapping chambers at the spiral side, and from *Th. greenhornensis* by the more sutural position of the accessory apertures, a more lobulate peripheral outline and more or less depressed sutures between the last chambers at the ventral side.

Thalmanninella greenhornensis (Morrow)

Globorotalia greenhornensis Morrow, 1934, J. Pal., vol. 8, p. 199, pl. 31, fig. 2a-c (holotype).
Thalmanninella brotzeni Sigal, 1948, Rev. Inst. Fr. Pétr., vol. 3, p. 102, pl. 1, fig. 5a-c.
Thalmanninella greenhornensis (Morrow), Brönnimann & Brown, 1956, Ecl. Geol. Helv., vol. 48, p. 535, pl. 20, figs. 7–9 (refiguration of holotype).
Rotalipora greenhornensis (Morrow), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–1, p. 85, pl. 12, figs. 1a-c, 2a-c (topotypes).

Remarks: See remarks on *Th. globotruncanoides.*

Thalmanninella praebalernaensis (Sigal)

Rotalipora praebalernaensis Sigal, 1969, Proc. First Int. Conf. Plankt. Micr. Geneva 1967, vol. 2, p. 635, pl. 1, figs. 1–12; pl. 2, figs. 1, 3.
Rotalipora praebalernaensis Sigal, Collignon, Sigal & Grékoff, 1979, Ecl. Geol. Helv., vol. 72, p. 224, pl. 2, figs. 1, 2 (from core which provided paratypes).
Thalmanninella praebalernaensis (Sigal), Wonders, 1978, Proc. Kon. Ned. Akad. Wet. Ser. B, vol. 81, p. 129, pl. 1, fig. 1a-c.

Thalmanninella reicheli (Mornod)

Globotruncana (*Rotalipora*) *reicheli* Mornod, 1950, Ecl. Geol. Helv., vol. 42, p. 583, text-fig. 5, IVa-c (holotype).
Rotalipora reicheli (Mornod), Caron, 1976, Ecl. Geol. Helv., vol. 69, p. 330, text-fig. 2a-c (neotype).
Rotalipora reicheli (Mornod), Robaszynski & Caron, 1979, Cahiers de Micropal. 1979–1, p. 99, pl. 16, fig. 1a-c (topotype).

Remarks: This species can easily be confused with *Th. deeckei,* of wich it is an almost perfect homeomorph. The slight differences are in the chamber form at the spiral side, where *Th. reicheli* has more curved sutures in the older part of the whorl, in the depressed sutures between most of the chambers of the last whorl ventrally, and in the absence of a relatively high-spired initial stage in *Th. reicheli.*

Genus **Whiteinella** Pessagno, 1967

Type species: *Whiteinella archaeocretacea* Pessagno

Remarks: *Whiteinella* was erected to include forms with a hedbergellid chamber arrangement and an umbilical primary aperture provided with protici. It may have an imperforate peripheral band, but it has no keel(s). As such, the genus offers no taxonomic problems.

Whiteinella archaeocretacea Pessagno
(pl. 3, fig. 1a-c)

Whiteinella archaeocretacea Pessagno, 1967, Palaeontographica Americana, vol. 5 (37), p. 298, pl. 54, figs. 22–24.

Praeglobotruncana (?) *gigantea* Lehmann, 1962, Notes Mém. Serv. géol. Maroc, vol. 21 (156), p. 140, pl. 2, fig. 4a-c.

Praeglobotruncana lehmanni Porthault, 1969, Proc. First Int. Conf. Plankt. Microfoss. Geneva 1967, p. 538.

Remarks: The taxonomy of this species is somewhat confused. Pessagno properly described *Wh. archaeocretacea* as a new species. Topotypes of *P. gigantea* turned out to be nearly identical to *Wh. archaeocretacea* (cf. Robaszynski & Caron, 1979). *P. gigantea* was a junior homonym of *Praeglobotruncana biconvexa gigantea* (Samuel & Salaj, 1962). Consequently, Porthault (1969) chose the new name *P. lehmanni* with reference to Lehmann's type specimen. However, Porthault's figures of specimens from SE France do not correspond to the type material of Lehmann's species, as they are partially keeled. This does not change the taxonomic position of the new name.

Wh. archaeocretacea is very close to *H. praehelvetica,* from which it mainly differs in the absence of a flattening of chambers at the spiral side.

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Plate 1

Fig. 1 *Planomalina praebuxtorfi* Wonders, SP 323 (topotype), Utr. Micropal. Coll. CH 6161–4; a, c: umbilical views, b: apertural view.

Fig. 2 *Pseudothalmanninella ticinensis* (Gandolfi), SP 416, Utr. Micropal. Coll. CH 6161–3; a: dorsal view, b: lateral view, c: ventral view.

Fig. 3 *Pseudothalmanninella subticinensis* (Gandolfi), SP 412, Utr. Micropal. Coll. CH 6161–2; a: ventral view, b: lateral view, c: dorsal view.

Fig. 4 *Biticinella breggiensis* (Gandolfi), SP 411, Utr. Micropal. Coll. CH 6161–1; a, c: umbilical views, b: apertural view.

All magnifications X 90.

Plate 1

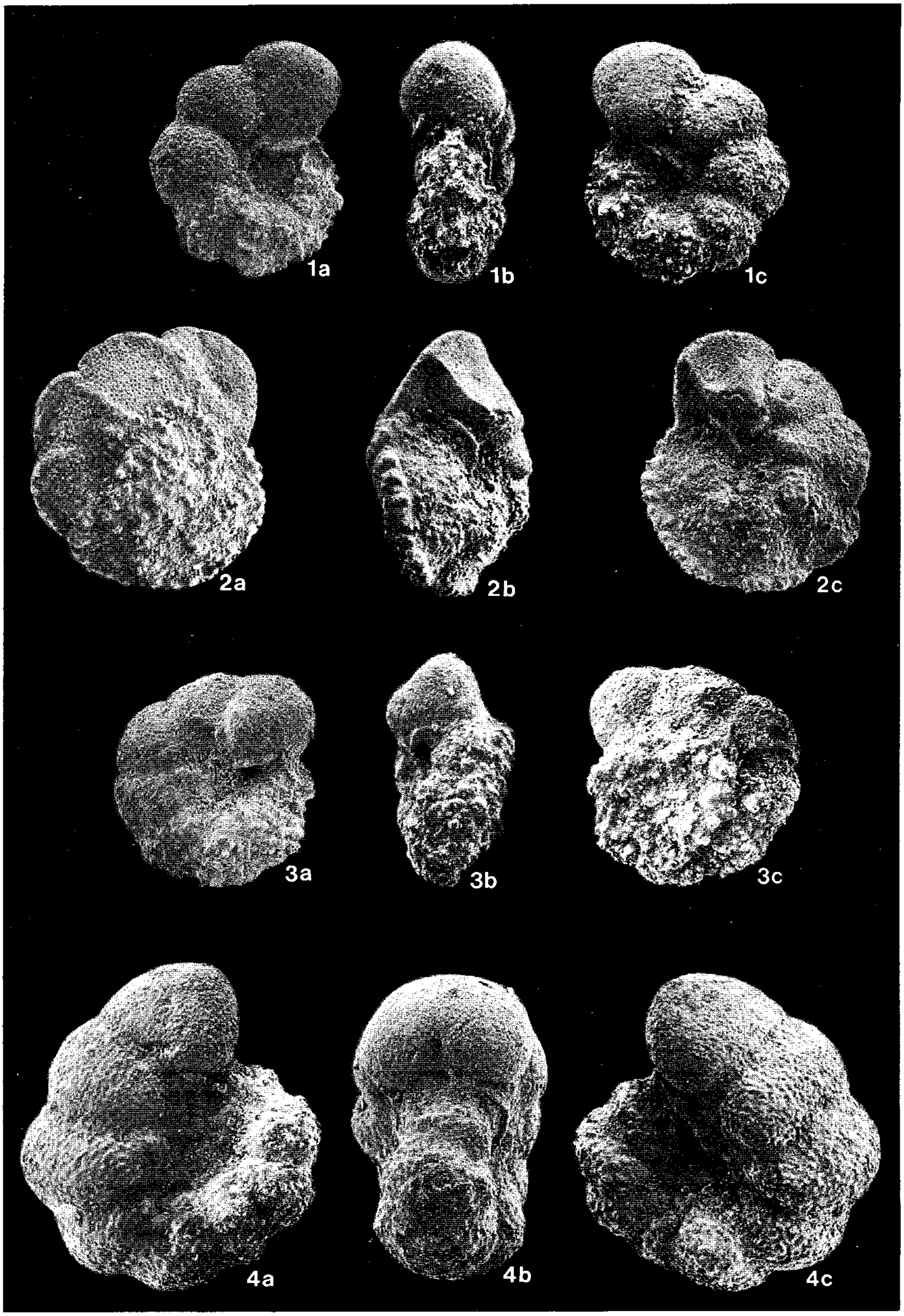


Plate 2

Fig. 1 *Thalmanninella globotruncanoides* Sigal, Bu 41, Utr. Micropal. Coll. CH 6161–7; a: dorsal view, b: lateral view, c: ventral view.

Fig. 2 *Thalmanninella appenninica* (Renz), SP 317, Utr. Micropal. Coll. CH 6161–6; a: dorsal view, b: lateral view, c: ventral view.

Fig. 3 *Planomalina buxtorfi* (Gandolfi), SP 319, Utr. Micropal. Coll. CH 6161–5; a, c: umbilical views, b: apertural view.

All magnifications X 90.

Plate 2

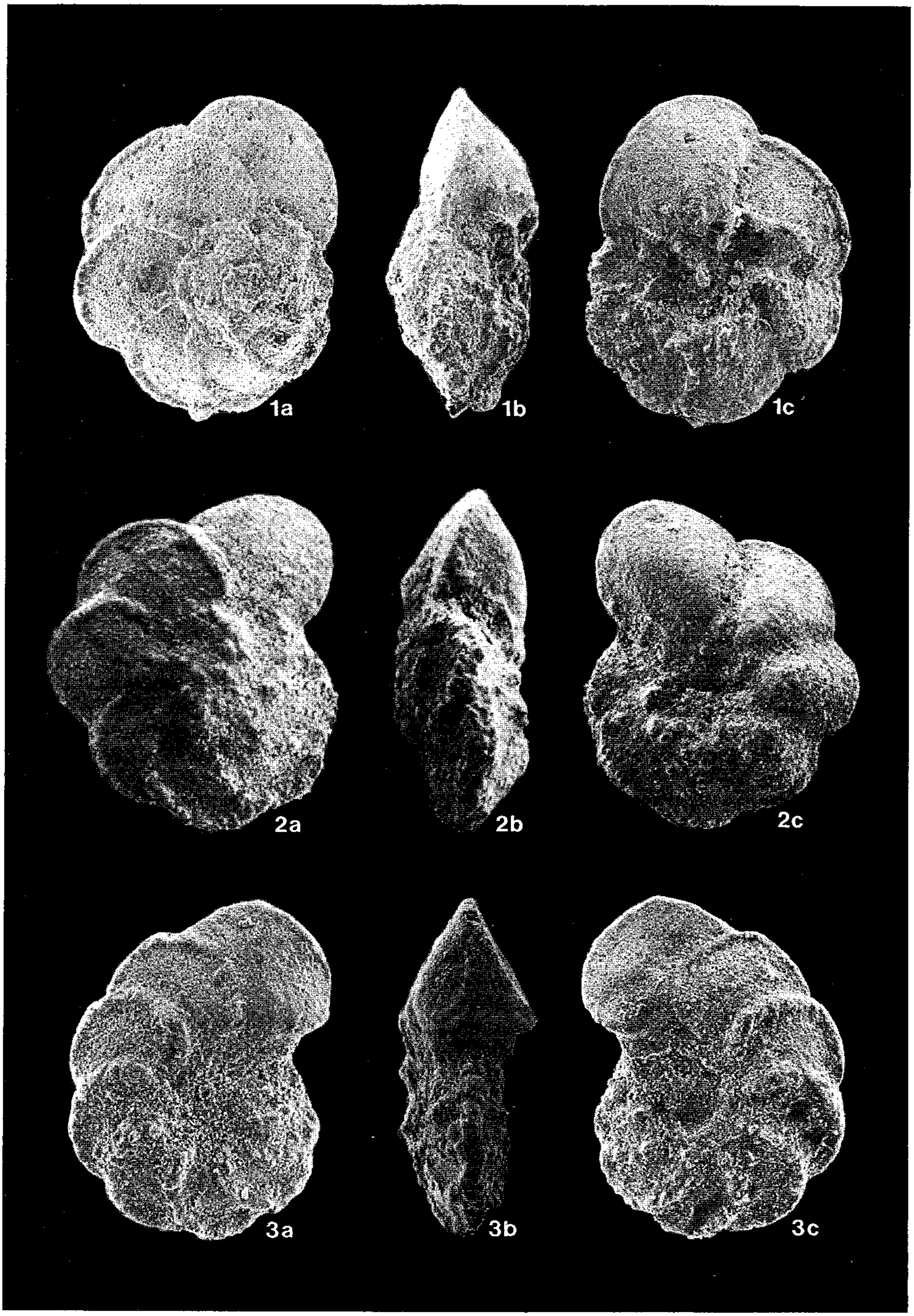


Plate 3

Fig. 1 *Whiteinella archaeocretacea* Pessagno, Kef 11, Utr. Micropal. Coll. CH 6161–10; a: dorsal view, b: lateral view, c: ventral view.

Fig. 2 *Helvetoglobotruncana helvetica* (Bolli), Kef 14, Utr. Micropal. Coll. CH 6161–9; a: dorsal view, b: lateral view, c: ventral view.

Fig. 3 *Rotalipora cushmani* (Morrow), Kef 9, Utr. Micropal. Coll. CH 6161–8; a: dorsal view, b: lateral view, c: ventral view.

All magnifications X 90, except fig. 2a: X 100.

Plate 3

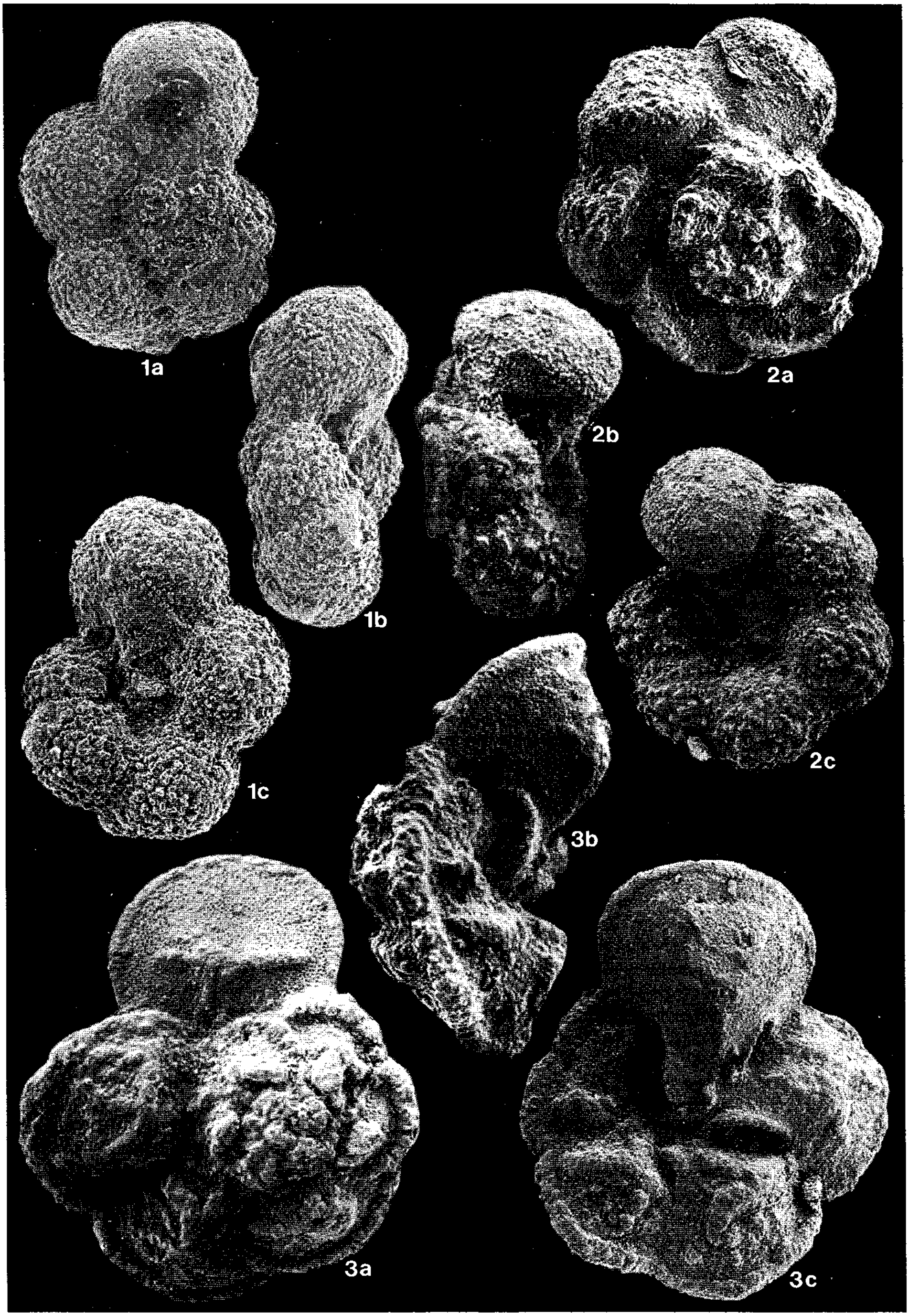


Plate 4

Fig. 1 *Marginotruncana sigali* (Reichel), AFN 158, Utr. Micropal. Coll. CH 6161–13; a: dorsal view, b: lateral view, c: ventral view.

Fig. 2 *Marginotruncana coronata* (Bolli), AFN 158, Utr. Micropal. Coll. CH 6161–12; a: dorsal view, b: lateral view, c: ventral view.

Fig. 3 *Marginotruncana angusticarinata* (Gandolfi), AFN 158, Utr. Micropal. Coll. CH 6161–11; a: spiral view, b: dorsal view, c: ventral view.

All magnifications X 90.

Plate 4

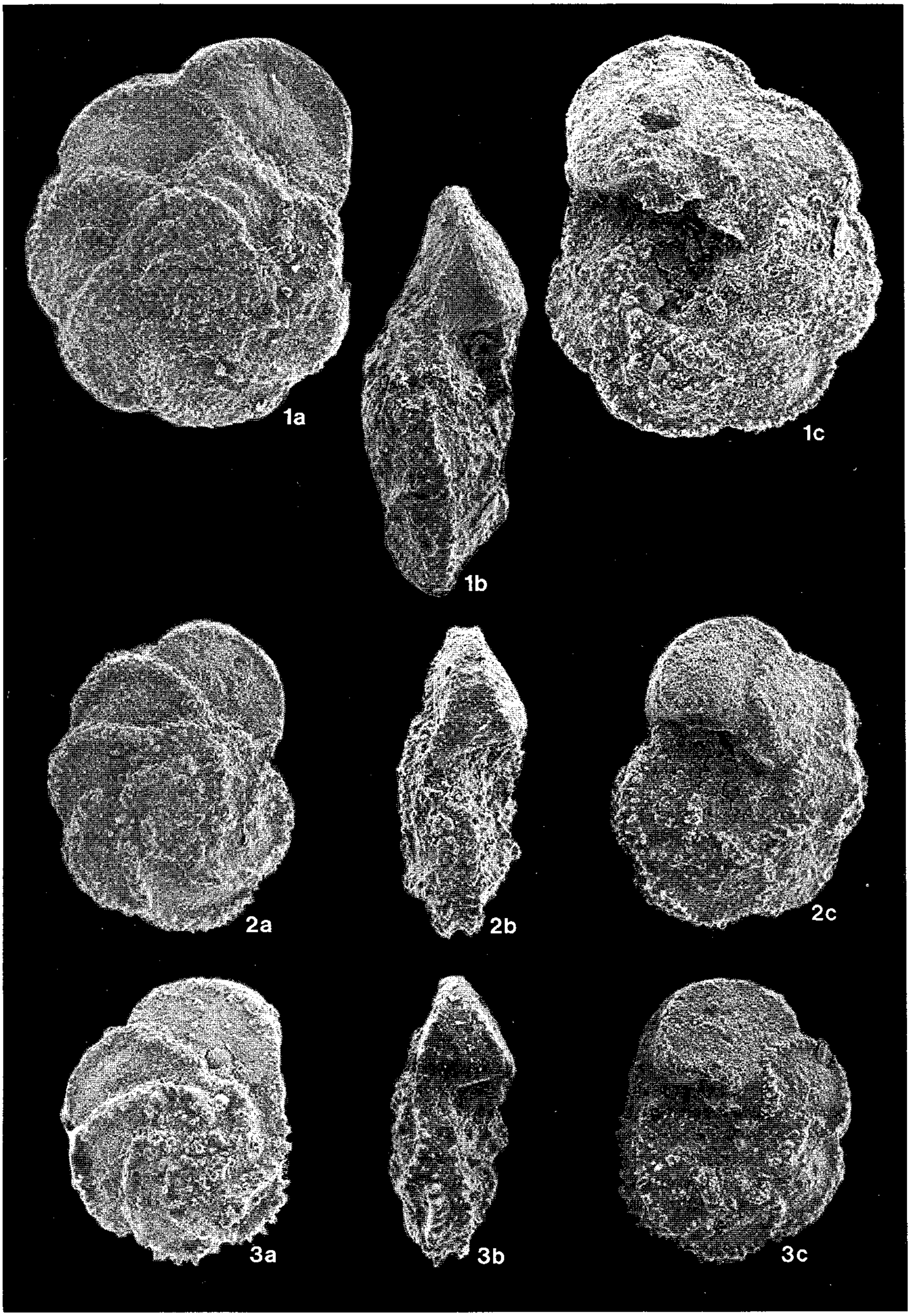


Plate 5

Fig. 1	*Marginotruncana primitiva* (Dalbiez), Kef 23, Utr. Micropal. Coll. CH 6161–15; a: dorsal view, b: lateral view, c: ventral view.
Fig. 2	*Marginotruncana concavata* (Brotzen), sensu Dalbiez, 1955, Kef 26, Utr. Micropal. Coll. CH 6161–14; a: dorsal view, b: lateral view, c: ventral view.

All magnifications X 90.

Plate 5

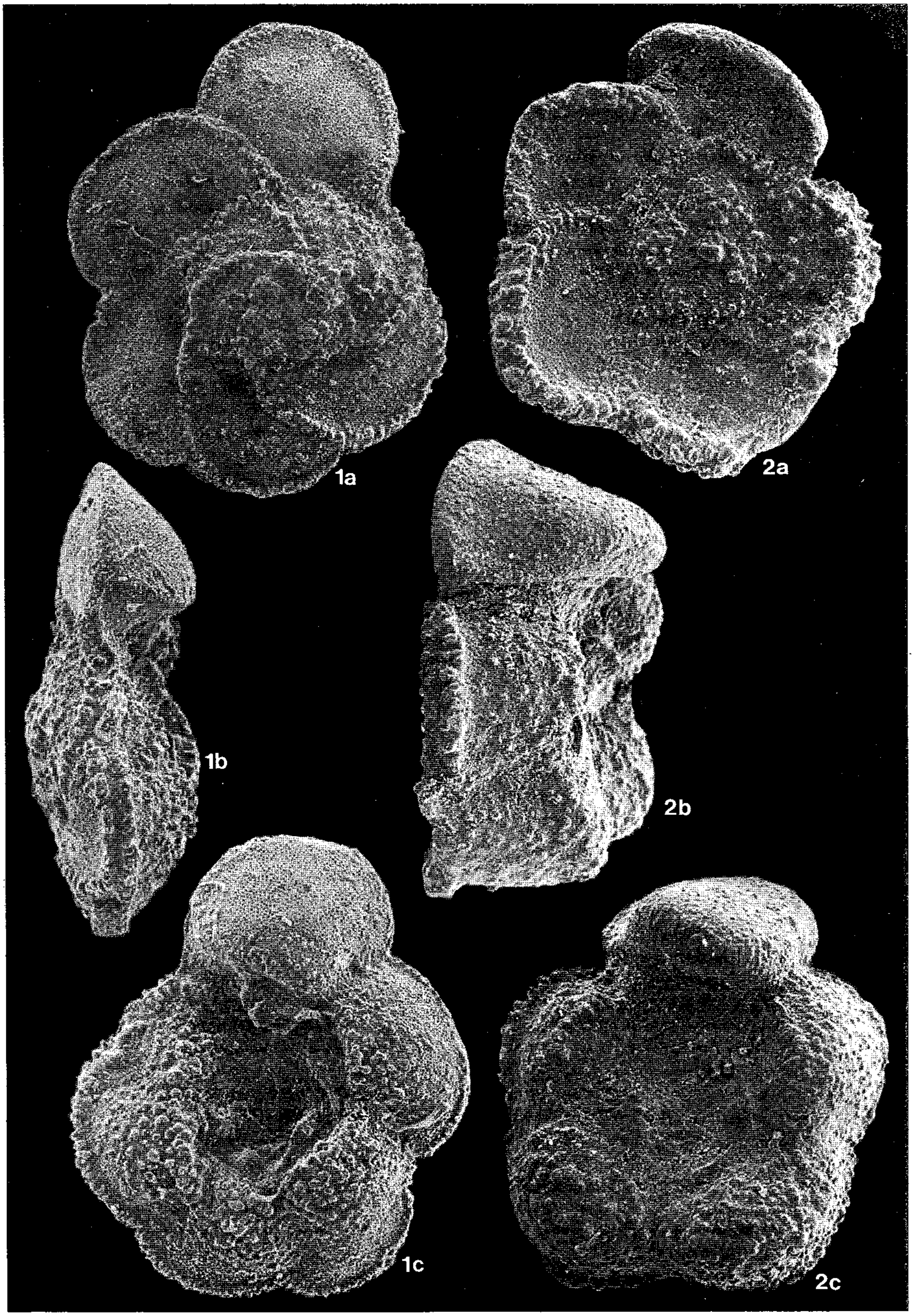
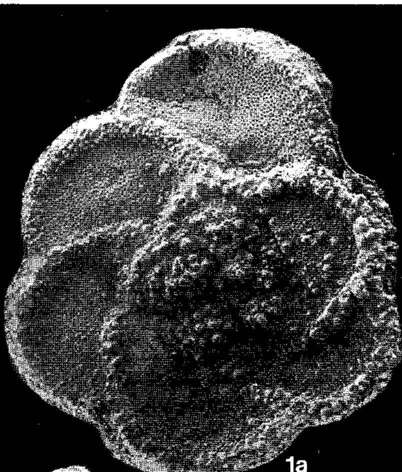


Plate 6

Fig. 1	*Marginotruncana carinata* (Dalbiez), Kef 34, Utr. Micropal. Coll. CH 6161–17; a: dorsal view, b: lateral view, c: ventral view.
Fig. 2	*Globotruncana elevata* (Brotzen), Kef 44, Utr. Micropal. Coll. CH 6161–16; a: dorsal view, b: lateral view, c: ventral view.

All magnifications X 90.

Plate 6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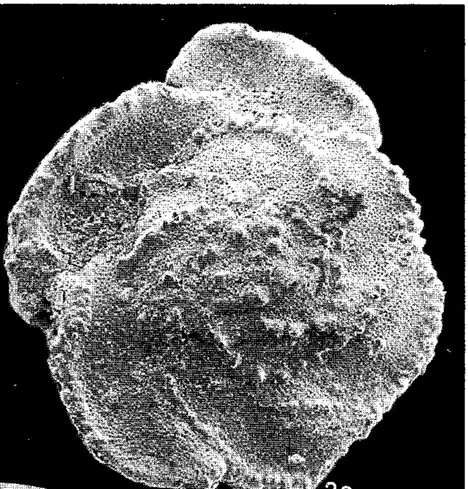
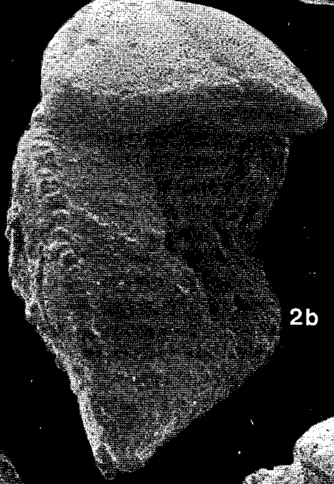
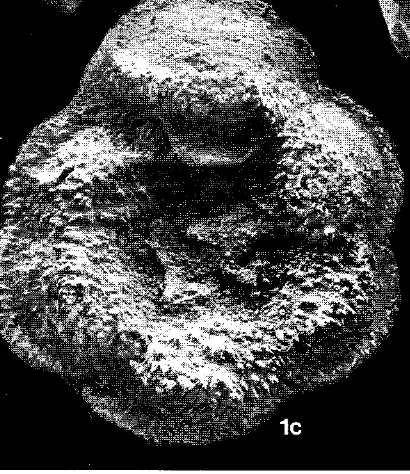

2a


1b


2b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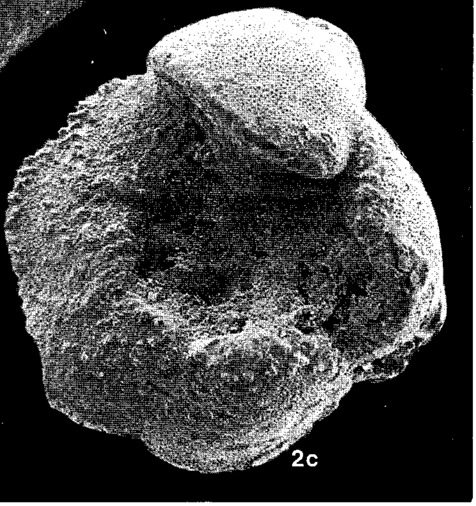

2c

Plate 7

Fig. 1	*Globotruncana gansseri* Bolli, AFN 191, Utr. Micropal. Coll. CH 6161–20; a: dorsal view, b: lateral view, c: ventral view.
Fig. 2	*Globotruncana calcarata* Cushman, SP 124, Utr. Micropal. Coll. CH 6161–19; a: dorsal view, b: lateral view, c: ventral view.
Fig. 3	*Globotruncana ventricosa* White, SP 194, Utr. Micropal. Coll. CH 6161–18; a: dorsal view, b: lateral view, c: ventral view.

All magnifications X 90.

Plate 7

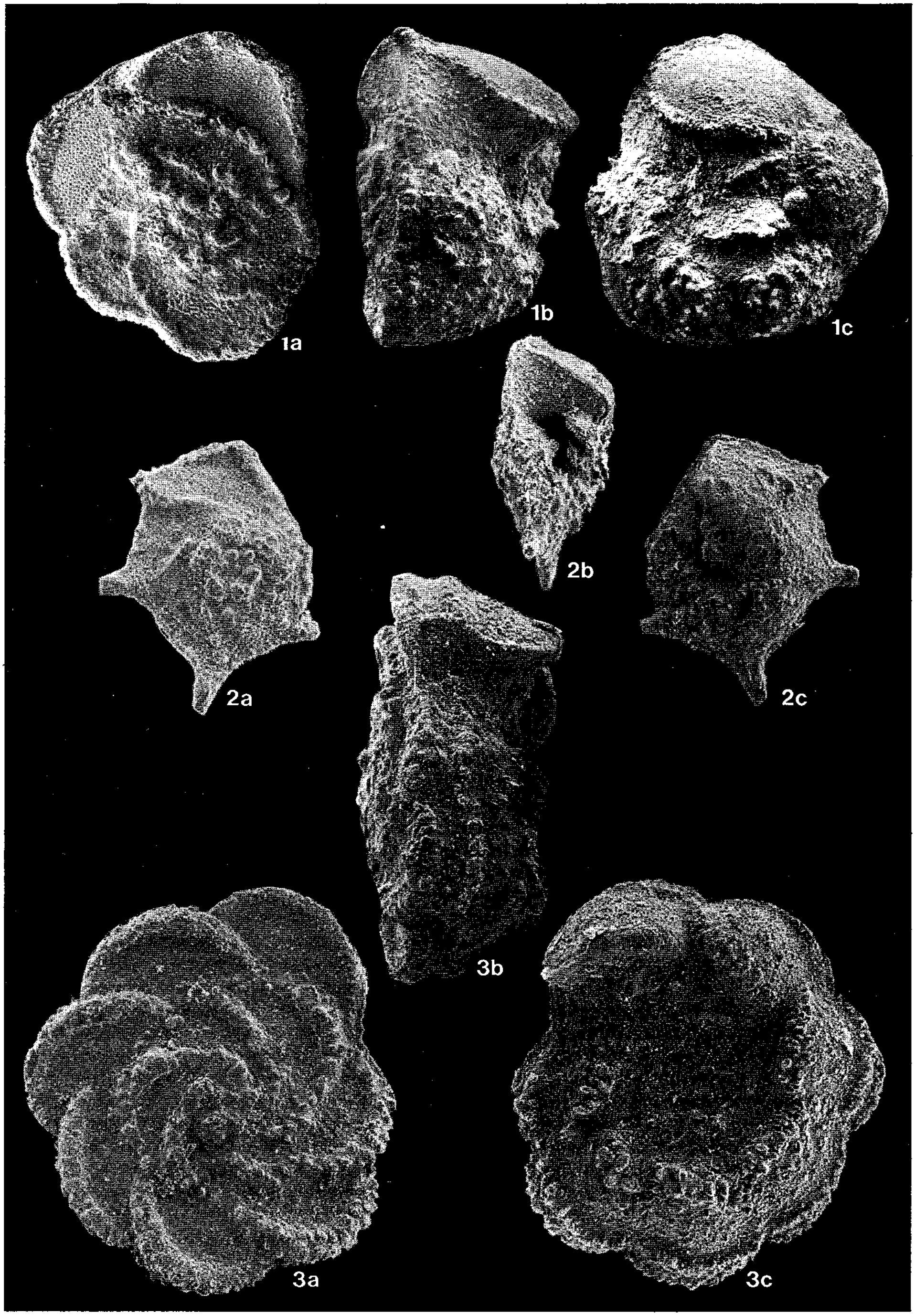


Plate 8

Fig. 1 *Abathomphalus mayaroensis* (Bolli), AFN 200, Utr. Micropal. Coll. CH 6161–23; a: dorsal view, b: lateral view, c: ventral view.

Fig. 2 *Globotruncana contusa* (Cushman), AFN 195, Utr. Micropal. Coll. CH 6161–22; a: dorsal view, b: lateral view, c: ventral view.

Fig. 3 *Globotruncana walfischensis Todd*, AFN 195, Utr. Micropal. Coll. CH 6161–21; a: dorsal view, b: lateral view, c: ventral view.

All magnifications X 90.

Plate 8

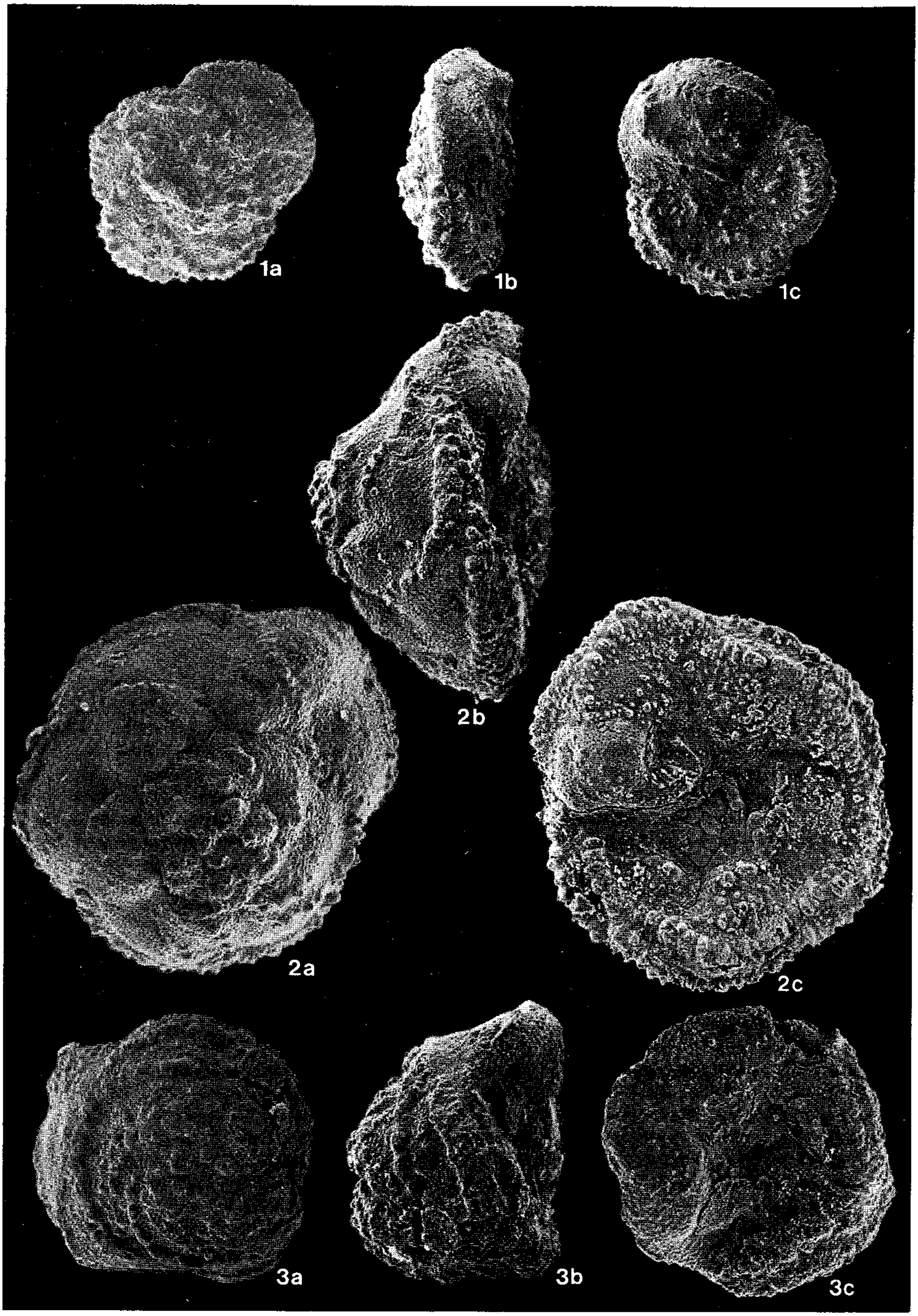
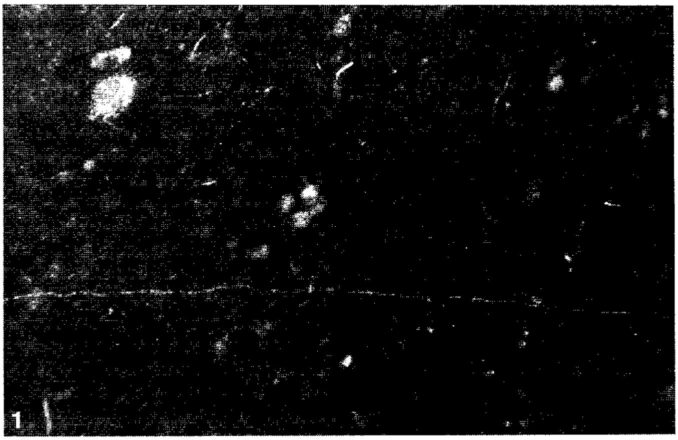


Plate 9

Fig. 1	Microfacies of the reversed core M 2, Valle del Mis, X 62.5, Utr. Micropal. Coll. CH 6167. The matrix is microsparitic and consists almost entirely of *Nannoconus.* Small *Hedbergella* (centre) are rare. This facies persists up to sample M 44, which is also reversed.
Figs. 2–7	Planktonic foraminifera from the reversed core ISEA, Valdorbia, Utr. Micropal. Coll. 6168, X 100.
Figs. 2, 4, 6, 7	*Planomalina cheniourensis* Sigal.
Fig. 3	*Hedbergella trochoidea* (Gandolfi).
Fig. 5	*Globigerinelloides algerianus* Cushman & Ten Dam.

Plate 9



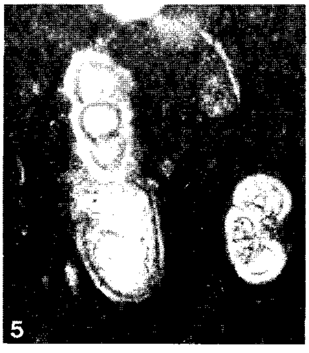


Plate 10

Fig. 1 *Praeglobotruncana* sp. and *Whiteinella archaeocretacea,* Q 42, Utr. Micropal. Coll. CH 6162; *Wh. archaeocretacea* Zone, X 62.5.

Fig. 2 Radiolaria, Q 37, Utr. Micropal. Coll. CH 6163; *Wh. archaeocretacea* Zone, X 62.5.

Fig. 3 *Thalmanninella reicheli,* Q 27, Utr. Micropal. Coll. CH 6164, *Th. globotruncanoides* Zone, X 62.5.

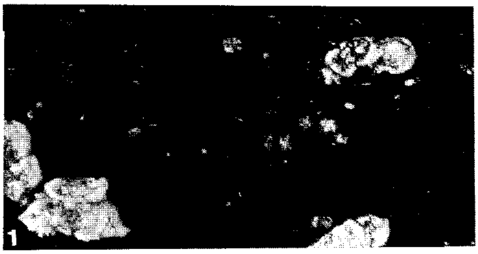
Fig. 4 *Rotalipora cushmani*, Q 34, Utr. Micropal. Coll. CH 6165, *R. cushmani* Zone, X 62.5.

Fig. 5 *Pseudothalmanninella ticinensis,* M 52, Utr. Micropal. Coll. CH 6166, *P. subticinensis* Zone, X 100.

Fig. 6 *Pseudothalmanninella subticinensis,* M 52, Utr. Micropal. Coll. CH 6166, *P. subticinensis* Zone, X 100.

Q samples are from Quero-Schievenin, M samples from Valle del Mis.

Plate 10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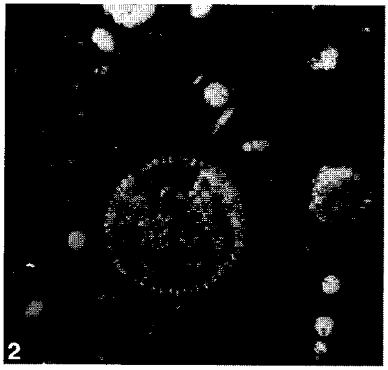
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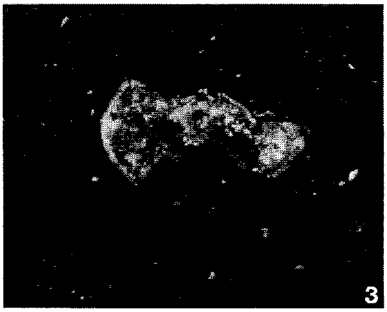
3


4


5


6

Bull. 15. Z. REISS, S. LEUTENEGGER, L. HOTTINGER, W. J. J. FERMONT, J. E. MEULENKAMP, E. THOMAS, H. J. HANSEN, B. BUCHARDT, A. R. LARSEN and C. W. DROOGER – Depth-relations of Recent larger foraminifera in the Gulf of Aqaba-Elat. 244 p., 3 pl., 117 figs. (1977) ƒ 53,–

Bull. 16. J. W. VERBEEK – Calcareous nannoplankton biostratigraphy of Middle and Upper Cretaceous deposits in Tunisia, Southern Spain and France. 157 p., 12 pl., 22 figs. (1977) ƒ 51,–

Bull. 17. W. J. ZACHARIASSE, W. R. RIEDEL, A. SANFILIPPO, R. R. SCHMIDT, M. J. BROLSMA, H. J. SCHRADER, R. GERSONDE, M. M. DROOGER and J. A. BROEKMAN – Micropaleontological counting methods and techniques – an exercise on an eight metres section of the Lower Pliocene of Capo Rossello, Sicily. 265 p., 23 pl., 95 figs. (1978) ƒ 59,–

Bull. 18. M. J. BROLSMA – Quantitative foraminiferal analysis and environmental interpretation of the Pliocene and topmost Miocene on the south coast of Sicily. 159 p., 8 pl., 50 figs. (1978) ƒ 49,–

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