Early Cretaceous *Nannoconus* (Calcareous nannofossil, *Incertae sedis*) in NW Europe.

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For my mother

Non Sibi Sed Omnibus

Abstract

Early Cretaceous nannofossil assemblages were studied, with particular emphasis on the calcareous nannolith genus *Nannoconus*. A total of 409 samples were observed from 16 Lower Cretaceous sections from NW Europe, consisting of 221 sidewall cores, 113 core chips and 75 ditch cutting samples. Coverage was from the Danish Central Graben to the Porcupine Basin, and from the Viking Graben to the Central Netherlands Basin.

The problematic morphology of the genus *Nannoconus* was initially considered as a simple composite cone structure built from a spiral arrangement of plates surrounding an axial canal or cavity. New observations on the fine structure of *Nannoconus* have been made with the Scanning Electron Microscope. Two distinct cycles and corresponding crystal plate orientations are recognised in longitudinal sections of the nannoconid body. These characteristics can be correlated to the morphological interpretations on the ultrastructure by earlier workers as seen in the Light Microscope. These new interpretations allowed recognition of a total of 5 distinct morphogroups to which the 33 taxa recognised in this study could be assigned.

A discussion of the early phylogeny of this genus in the Tethyan Realm is used as an introduction to a new evolutionary model. This model considers the evolution of the taxa within the morphogroup assignments proposed in this study.

Samples from the Munk Marl showed interesting associations of nannoconid individuals in the form of double structures. A total of 3 species: *N. abundans*, *N. circularis* and *N. truitti* were observed to show double associations in perfect crystallographic continuity. The occurrence of this phenomena is discussed in relation to ecological controls.

The nannoconid biostratigraphical distribution was correlated to the nannofossil zonation scheme, which provided a time-framework for the distribution of *Nannoconus* in the sections. A compendium of the worldwide occurrence of *Nannoconus* from published literature and results obtained in this study was used as a data base to determine controls on the occurrence patterns of this genus in NW Europe.

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Chapter 1.
Introduction

1.1 Research Objectives

The primary objectives of the project were twofold, with several secondary aims, set out below. It subsequently emerged that a better understanding of the morphological nature and ultrastructure (and hence taxonomic identification) of nannoconids was needed before a clear understanding of their spatial and temporal distribution could be determined.

OBJECTIVE 1.
Morphological and taxonomical investigation:

i) To review the nature of the nannoconid body and interpret the systematic position of this genus.

ii) To clarify the detailed ultrastructure observed in the light microscope proposed by Kamptner (1931), and later modified by Brönnimann (1955), using detailed scanning electron micrographs.

iii) To define the taxa recognised in NW Europe using the new observations.

iv) To revise the species evolution model for nannoconids put forward by Deres and Achériteguy (1980).

OBJECTIVE 2.
Temporal and spatial occurrence of *Nannoconus* in NW Europe:

i) To determine the palaeoenvironmental controls on this genus and correlate these to the seasonal blooms interpreted by Thomsen (1987, 1989a & b) and Lambert (1987).

ii) To recognise nannoconid species influxes into the Boreal realm and relate this to periodic marine connections between the Tethyan and Boreal realms.

iii) To interpret the data and recognise endemic evolution as opposed to species appearance by migration.

* The total nannofossil assemblage was studied during the project to obtain a stratigraphic framework for the distribution of *Nannoconus* in NW Europe.

At the beginning of the project it was considered that due to time constraints correlation of the well sections would be through published nannofossil data from the following sources:

LAND SECTIONS.
Speeton: Taylor (1982), Crux (1989).
NW Germany: Mutterlose (1984, 1987a & b, 1988, 1991), Mutterlose and Harding (1987).

WELL SECTIONS.
Skinnabanken Core 7B: Aarhus *et al.* (1986), Crux (1989).
Danish Central Trough: Thomsen (1987, 1989a & b).
Moray Firth: Jakubowski (1987).

Correlation of the sections with magnetostratigraphy was not possible due to the lack of available data.

1.2 Literature Review

Most North Sea wells are industrial and as a result only a handful of papers on Lower Cretaceous nannofossil biostratigraphy and distribution patterns have been published, consequently available literature on the occurence of *Nannoconus* in NW Europe is limited.

The first exemplars of *Nannoconus* were recorded from the Berriasian of Gigondas, Haute Province and from the Barremian of Majorca by Lapparent in 1925. Subsequently, the oldest species were recognised in the Western Tethys and the high abundance of this genus in this realm indicates the ideal environment for the majority of species (warm water). For this reason I will begin by giving the key reference to this genus in Tethyan regions and subsequently consider the handful of NW European references which discuss *Nannoconus*.

The most recent study to solely consider the genus *Nannoconus* was published in 1980 by Deres and Achériteguy as a successor to their observations in 1972. This paper was the culmination of 10 years research and incorporates a general worldwide occurrence map for the Early Cretaceous distribution of this genus. A new biostratigraphical

scheme was proposed based upon nannoconid assemblage zones. An attempt was made to analyse the evolutionary development of this genus and several new taxa were described.

The following papers include reference to nannoconids in NW Europe:

BIOSTRATIGRAPHY.
Taylor (1982), Jakubowski (1987), Crux (1989, 1992), Mutterlose (1991).

NEW SPECIES.
Perch-Nielsen (1988).

OCCURRENCE.
Mutterlose (1984, 1987a & b), Mutterlose & Harding (1987), Thomsen (1987), Aarhus *et al.* (1986).

An historical review of literature for other disciplines is given at the beginning of each chapter. This was considered a more practical method of introducing previous authors concepts and results.

1.3 Acknowledgements

It would be impracticable to name all those who have given generously of their time and experience throughout the duration of the project. The thanks are collectively theirs but in addition I would like to mention the following who warrant extra credit.

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Finally the receipt of a N.E.R.C research studentship is gratefully acknowledged.

Chapter 2.
NW Europe During the Early Cretaceous

2.1 Tectonic Setting

The Cretaceous period represents a period of 70 million years during which changes in the sedimentary history of the area resulted in the deposition of an extensive coccolith ooze (chalk) in the Late Cretaceous. The beginning of this sedimentary change took place during the Albian/Cenomanian interval and is closely linked to decreasing tectonism during this time.

In NW Europe the Early Cretaceous is represented by a continuation in the tectonic template established during the Late Jurassic. A tensional regime was responsible for rift and block faulting in the region, influenced by the crustal extension of the Arctic-North Atlantic megarifts (Ziegler 1988). Two main events are recognised: 1) Late Cimmerian movements during the Late Jurassic/Early Cretaceous boundary interval, and 2) Austrian phase in the mid Aptian. This tectonic activity decreased during the Albian with only minor rifting occurring into the Late Cretaceous (Hancock & Rawson in press).

Depositional areas established in the Late Jurassic continued into the Early Cretaceous. However, the marked sea level drop at the Tithonian/Ryazanian boundary isolated some of the southerly basins which show non-marine sedimentation until marine conditions became established in the Early Aptian (Hancock & Rawson in press). The extent and emergence of tectonic highs in the North Sea is difficult to determine and is still a matter of debate, some thought to show signs of periodic submergence. Central England was land with a few regions susceptible to flooding, e.g. Wessex Basin. To the NW of Ireland in the Donegal Basin marine conditions are not recognised until the Barremian (Ziegler 1988). In Scotland only two centres of marine deposition are found in the Solan and West Shetland Basin (Meadows *et al.* 1987). Figure 2.1 shows some of the active tectonic units of the Early Cretaceous.

A brief overview of the main tectonic history of NW Europe is subdivided into the Ryazanian, Mid-Hauterivian, Aptian and Albian.

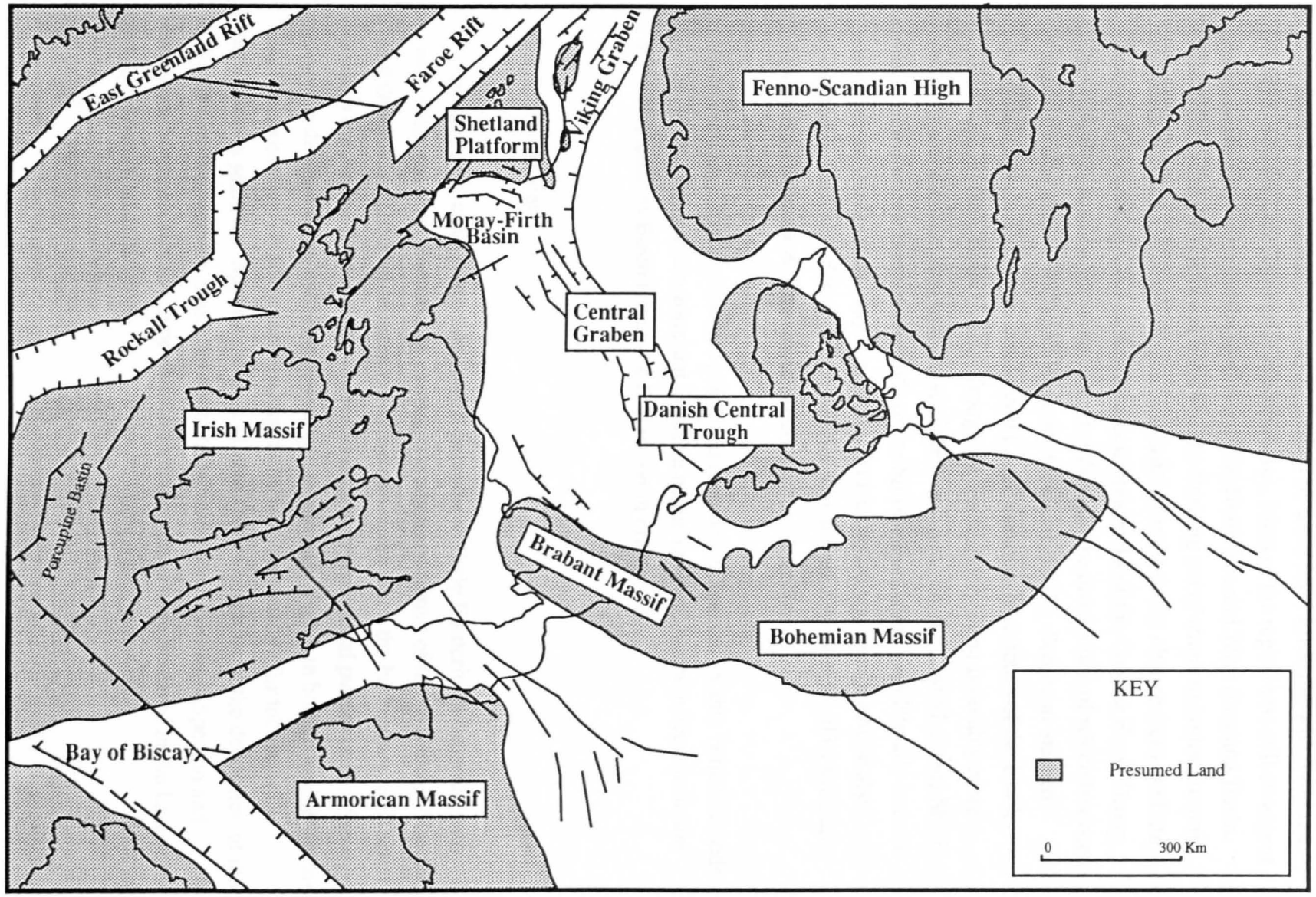


Figure 2.1. Tectonic framework of NW Europe During the Early Cretaceous (Ziegler 1990).

2.1.1 Ryazanian

The Jurassic/Cretaceous boundary is marked by a sea level lowstand which did not change until the Late Ryazanian transgression. Most of the region was still emergent with marine conditions established across the North Sea and West Shetland Basin. Associated with the rise in sea level was the flushing out of stagnant bottom waters (Rawson & Riley 1982) which was responsible for the facies change from the Late Jurassic Kimmeridge Clay to the calcareous mudrocks of the Cromer Knoll Group. The Valhall Formation forms an extensive deposit, the distribution of which has been studied by Day *et al.* (1981) and Hesjedel & Hamar (1983). Sediment-starved topographic highs show very condensed Late Ryazanian limestones of the Utvik Formation. In the Danish Central Trough the Valhall Formation is notably more calcareous at the base than in the rest of the North Sea. On the East Midlands Shelf shallow marine sands and silty sands of the Spilsby Formation pass laterally into the mudrocks of the Speeton Clay Formation. Fluviatile-Deltaic sedimentation also characterise the Celtic Sea and Dutch Sector which were not submerged by the Late Ryazanian (Hancock & Rawson in press).

Some contemporaneous volcanic activity is recorded at Speeton by thin bentonite beds in the *albidium* ammonite zone and intrusive nephelinite and basanite deposits in the West Netherlands Basin (Hancock & Rawson in press)

2.1.2 Hauterivian

No fundamental change from the Late Ryazanian to Early Hauterivian occurred with only minor sea level fluctuations causing a gradational retreat of the shorelines (Rawson & Riley 1982). The Mid Hauterivian saw a rise in sea level, the highest sea level stand prior to the Albian (Hancock & Rawson in press). Depositional patterns followed those established in the Late Ryazanian with an increase in clay in both marine and non-marine sediments. Waning surrounding highs were responsible for increasing argillaceous sediment input on the East Midland Shelf, resulting in the deposition of the Weald Clay Formation. Some bentonite beds have been recorded at Speeton and offshore boreholes but no major volcanism is thought to have occurred in the Late Hauterivian (Lott *et al.* 1986).

2.1.3 Aptian

The Late Hauterivian-Late Barremian interval shows a general pattern of decreasing sea level until the Early Aptian when marine conditions became established to the south of Britain, the first since the Late Jurassic. The Austrian tectonic phase peaked in the Mid Aptian, causing local tectonic uplift and a decline in sea level culminating in a rise in sea level in the Late Aptian. Mudrocks continued to be deposited across the North Sea but these have been placed in the Sola Formation due to a change in facies from the calcareous mudrocks of the Valhall Formation to the non-calcareous, darker mudrocks with a higher organic carbon content of the Sola Formation. The East Midlands Shelf and Speeton show evidence of marl deposition from the Speeton Clay Formation. In the Celtic Sea the collapse of highs bordering the Rockall Rift caused the establishment of marine conditions in the Celtic and Fastnet Basins during the Mid-Late Barremian.

Volcanicity was widespread in the *nutfieldensis* ammonite zone and is well-documented in southern England with the deposition of secondary bentonite facies in the form of 'Fullers Earth' until the Late Albian (Jeans *et al.* 1982). The initiation of sea floor spreading in the nearby Bay of Biscay caused the intrusion of basalts into the Western Approaches Basin.

2.1.4 Albian

The sea level rose rapidly in the Early Albian with only minor localised regressions in the Celtic Sea and Western Approaches Basin. The distribution of these facies has been recorded by Day *et al.* (1981); Fyfe *et al.* (1981); Jensen *et al.* (1986) and Hesjedel & Hamar (1983). The sediments consist of red-coloured mudrocks and marls with impure limestone in some localities. Due to the lack of borehole control the 'true' homogenous nature of this facies across the North Sea is not known, e.g. areas such as the Inner Moray Firth. In the North Sea and Danish Central Trough this facies is known as the Rødby Formation. Across the Wessex Basin the Albian deposits belong to the Gault Clay Formation, the Upper Greensand Formation persisting in southern England with the deposition of glauconitic sands.

2.2. Early Cretaceous Climate

The Late Jurassic saw the onset of a semi-arid climate in NW Europe (Hallam 1984, 1986; Wignall & Ruffell 1990). This persisted into the Ryazanian when changes in humidity became apparent in many areas (Allen 1975; Hallam 1984). Due to the complex transgressive and regressive phases present in the Barremian-Aptian interval it is difficult to demonstrate a suspected period of aridity (Ruffell & Batten 1990). Parker (1974) suggests that the kaolinite depletion of the Hauterivian-Barremian interval sediments at Speeton may imply a climatic influence. The Barremian of the Danish Central Trough also shows a low clastic component which has been interpreted by Jensen *et al.* (1986) as a period of aridity in the hinterland.

Palaeontological evidence (Kemper 1987) in the Barremian sediments of NW Germany is also thought to infer a Barremian climatic change in the North German and Southern North Sea areas. An excellent summary of an integrated model of climatic changes in NW Europe is given by (Ruffell & Batten 1990).

2.3. Sea Level Fluctuations

Tectonoeustatic sea level fluctuations overprint minor patterns of localised sedimentation (Vail 1977, Hallam 1978, Haq *et al.* 1987). The beginning of the Cretaceous was a period of relatively low sea level, with the majority of NW Europe being a vast expanse of land. The overall trend, for the Lower Cretaceous is transgressive phase, with a series of minor regressions. Vail *et al.* (1977) suggest that during the Aptian/Albian interval the sea level was comparable to that today. The lithofacies is therefore controlled by the clastic input into these grabens coupled with sea level fluctuations. Refer to figure 2.2 for a correlation panel of the lithostratigraphic units across NW Europe and figure 2.3 for a summary of the sea level curve and tectonic events during the Early Cretaceous.

2.4. Palaeogeography

The end of the Jurassic was marked by a restricted marine environment, with the majority of basins, e.g. the Wealden Basin, accumulating non-marine sediments. A land mass stretching from Ireland through Wales and central England, via the London

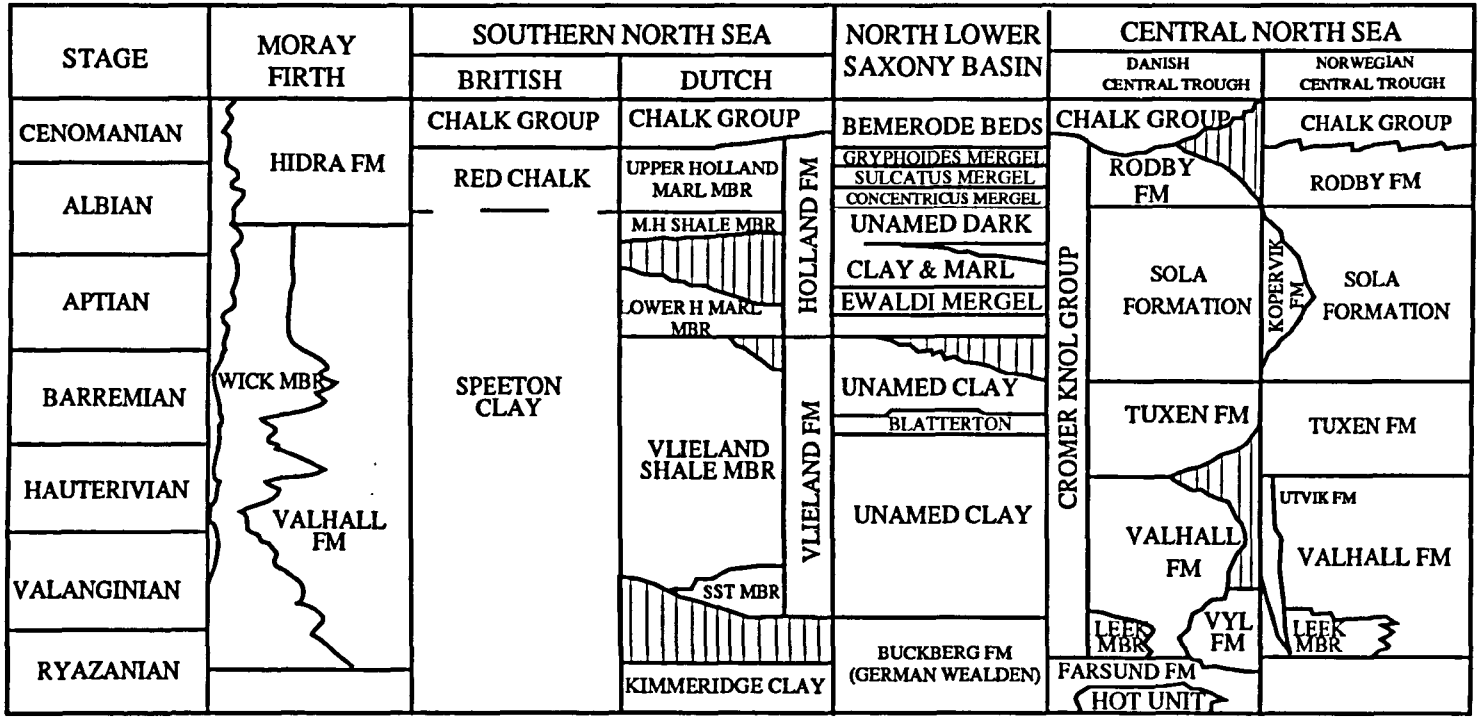


Figure 2.2. Lower Cretaceous Lithostratigraphic Correlation Chart of NW Europe. (After Frandsen et al. 1987).

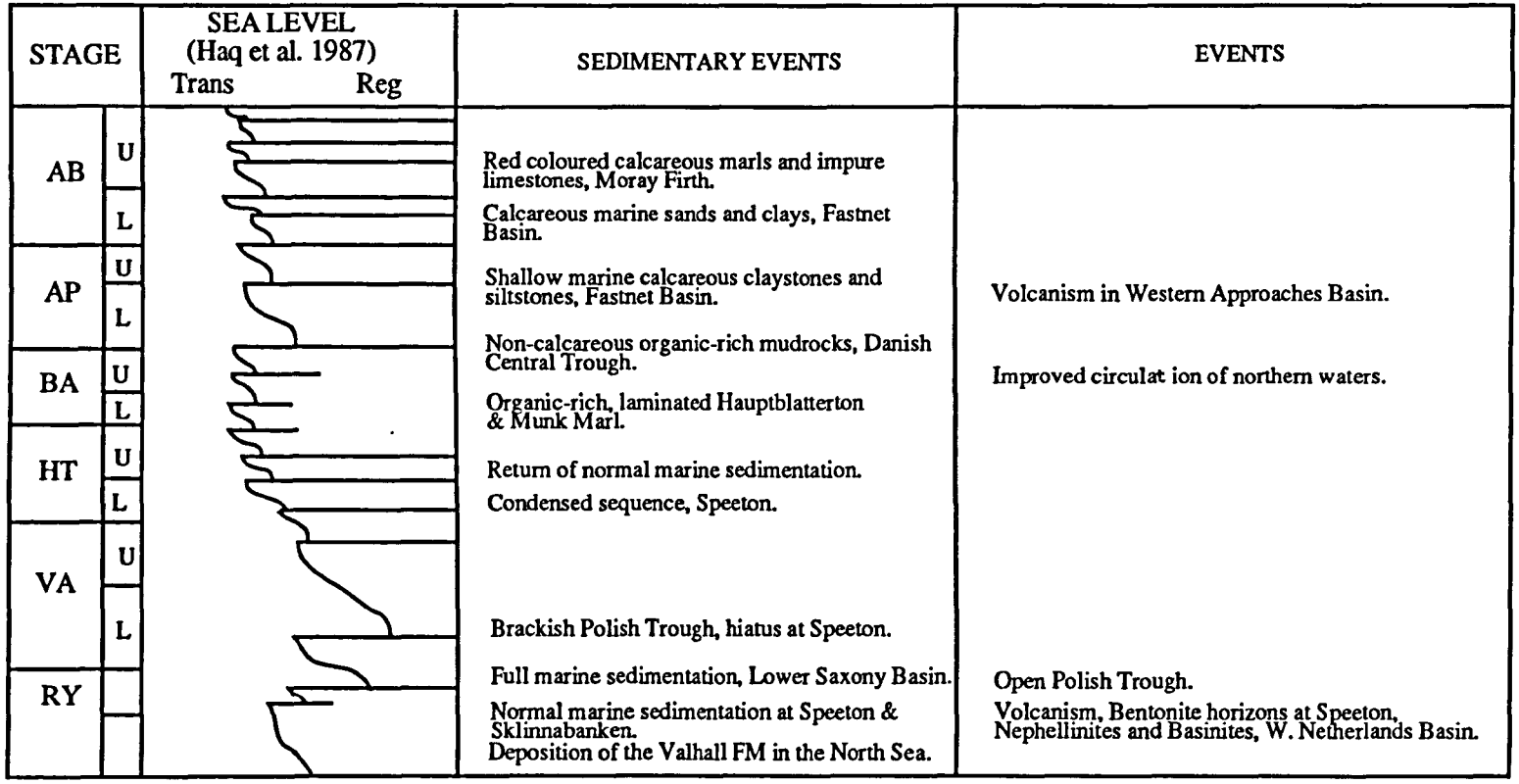


Figure 2.3. Summary of Tectonic events in NW Europe during the Early Cretaceous.

Brabant Platform across the Rhenish Massif to Bohemia created a barrier between the Boreal and Tethyan Realms (Hancock 1984). Marine connections existed eastwards through Germany and northwards via the Viking Graben. The major transgressive phase during the Aptian/Albian interval more than doubled the submerged area of the North Sea. Faunas and Flora in NW Europe are northern in character with the opening of marine connections recognised by the influx of predominantly Tethyan species. Detailed stage-by-stage palaeogeography and floral distribution patterns are discussed in Chapter 11.2.

2.4.1 Viking Graben

The Early Cretaceous deposits in the Viking Graben are sharply defined by bounding faults (Hancock 1984). Basin subsidence during the Cimmerian movements was accompanied to the east and west by downfaulting towards the centre, accompanied by basin subsidence. Throughout the Early Cretaceous, sandstones and mudstones (with thin limestones and coals) accumulated, reaching over 1100 m in thickness to the West Shetland Basin (Hancock & Rawson *in* press). Pre-Barremian sediments are poorly preserved, capped by thin Aptian/Albian marls or limestones.

2.4.2 Moray Firth Basin

This a collective term for a series of structurally complex basins and horsts to the east of the northern Scottish Highlands. The Lower Cretaceous thickens rapidly offshore in an arenaceous sequence of shales and sandstones.

2.4.3 Witch Ground Graben

This structure forms the primary connection between the Moray Firth Basin and the Viking Graben and Central Graben. Figure 3.3 shows in detail the structural components of the Witch Ground Graben. During the latest Ryazanian-Barremian there was downwarping of the Claymore structure to the north, associated with uplift and erosion of the Halibut Horst to the south. This sequence is dominated by a high argillaceous component, with localised marl deposition. The Barremian marls and marly limestones, a phase of waning tectonism, blanket these deposits (Hancock 1984). Minor sand pulses in the Aptian/Albian occurred associated with increased detrital input. Eastwards, pale tuffs dated as Aptian/Albian are found.

2.4.4 Central Graben

The Lower Cretaceous sequence is approximately 500-700 m thick. The dominant lithology is grey shales but marls are also important in the succession.

2.4.5 Central Netherlands Basin

Non-marine facies is dominant in the Central Netherlands Basin with marine sedimentation only taking place at the base of the Aptian transgression over most of the area. The Aptian/Albian marine facies are represented by the Holland$_{A}^{FM}$ shales and marls, which are micaceous, slightly silty and glauconitic.

2.4.6 Danish Central Trough

This major basin extends south into the German and Dutch sectors and northwards into the Norwegian and the U.K. sectors Figure 3.4. shows the structural elements of the Danish Central Trough. The latest Ryazanian is characterised by the Valhall Formation deposited in a well-oxygenated environment with the base containing a higher calcareous component than in the Central North Sea. Minor periods of regression can be recognised (Rawson and Riley 1982). The Hauterivian is marked by an increase in carbonate productivity associated with a reduction in detrital input. The Barremian is a marked regressive phase with extensive marl deposition continuing into the Aptian/Albian.

2.4.7 Fastnet Basin

The Fastnet Basin is a small elongate basin trending NE-SW, approximately 150 km off the SW coast of Ireland. The base of the Lower Cretaceous is marked by an unconformity which represents the Cimmerian tectonic event (Ainsworth *et al.* 1985). The lowermost unit is arenaceous, being succeeded by clays. This is interpreted as a restricted marine-littoral and neritic littoral facies (Ainsworth *et al.* 1985). The earliest Aptian reflects a marine incursion.

2.4.8 Porcupine Basin

Ziegler (1990) suggests that the deep water which was established in this area in the Jurassic was maintained in the Early Cretaceous with the deposition of shales with

occasional carbonate streaks. The Barremian marked a period of subsidence followed by a minor clastic transgression, with well-aerated waters. To the north of the basin a deltaic sequence became evident in the Aptian/Albian interval reflecting shallowing.

Chapter 3.
Locality/Section Information

The material for this project was kindly made available primarily by Shell Petroleum U.K and also Eric Thomsen, Maersk Olie & Gas, British Petroleum and the Irish Government. A total of sixteen Lower Cretaceous well sections from NW Europe were studied, a total of 409 samples (221 sidewall core, 113 core and 75 ditch cuttings).

The well logs (where available) and nannofossil distribution charts referred to in the text as enclosures (Enc.) are contained in a pocket at the rear of the thesis. Figure 3.1 shows the location of the studied sections in NW Europe. A summary of the stratigraphic interval of each of the studied sections is given in Figure 3.2.

3.1. Viking Graben

A total of four well sections were collected to provide the basis for a local study of the sequences.

210/20-1 (Enc. 1.): 6721-6890 ft, 14 sidewall core samples; interval from 6721-6890 ft is the Alwyn Marl Formation and from 6800-6890 ft is the Kimmeridge Clay Formation. The top of the section is characterised by an impoverished Aptian/Albian flora. The section contains a condensed Barremian sequence and no Hauterivian nannofossil assemblages are recognised. The Valanginian rests unconformably on the Kimmeridgian.

211/13-7 (Enc. 2.): 11246-11635 ft, 2 ditch cutting samples and 26 sidewall core samples (2 barren samples). Stratigraphic range from late Cenomanian-Albian to Upper Ryazanian. Hiatus during the Hauterivian-Late Valanginian interval.

211/21-2 (Enc. 3.): 8710-8840 ft, 15 ditch cutting samples and 6 sidewall core samples (2 barren samples and 4 non-diagnostic/barren samples). Argillaceous limestones and claystones dominate the section. The top of the studied well interval is Late Barremian, which lies unconformably on Valanginian sediments which in turn rest on the Kimmeridgian.

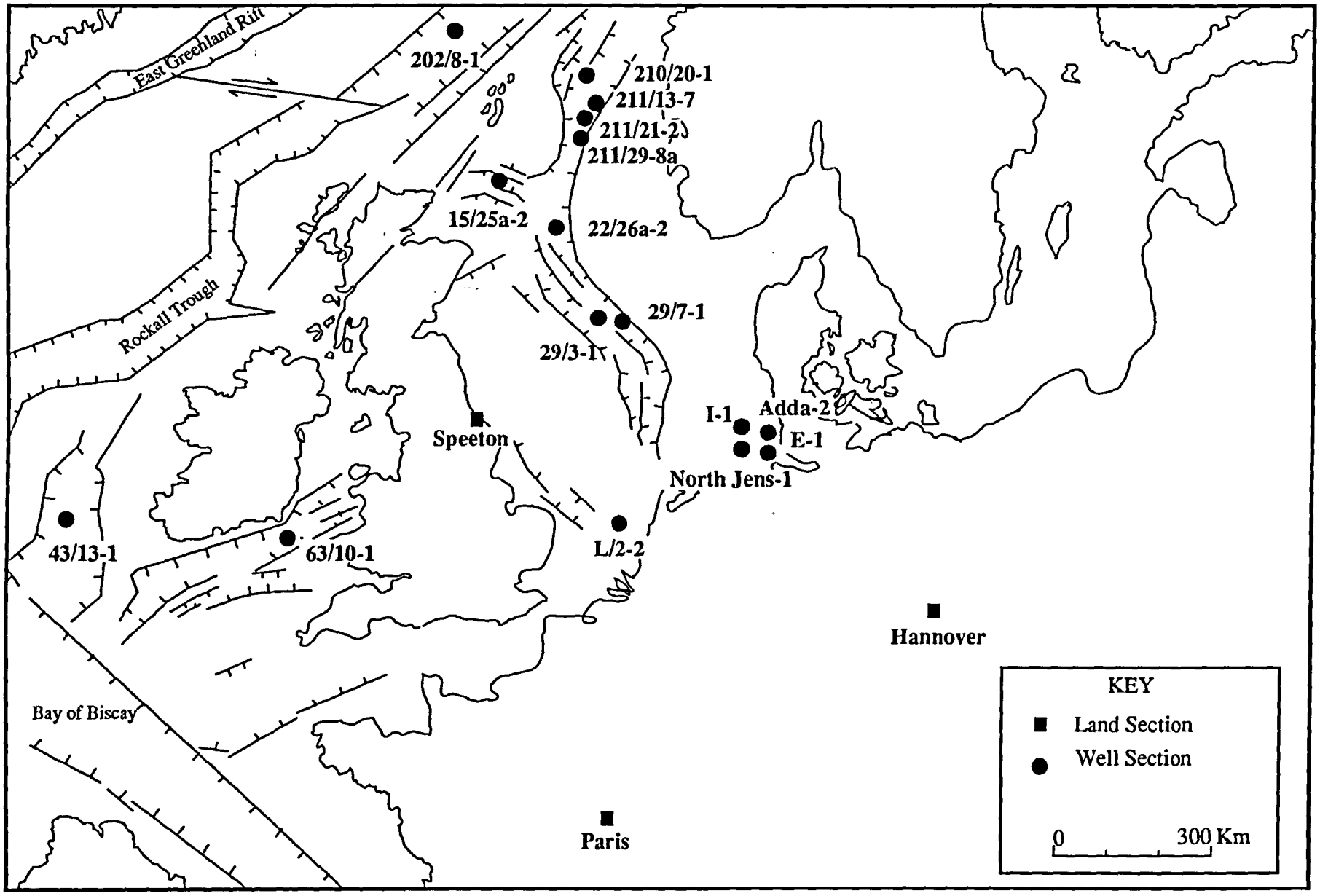


Figure 3.1 Location of sections studied.

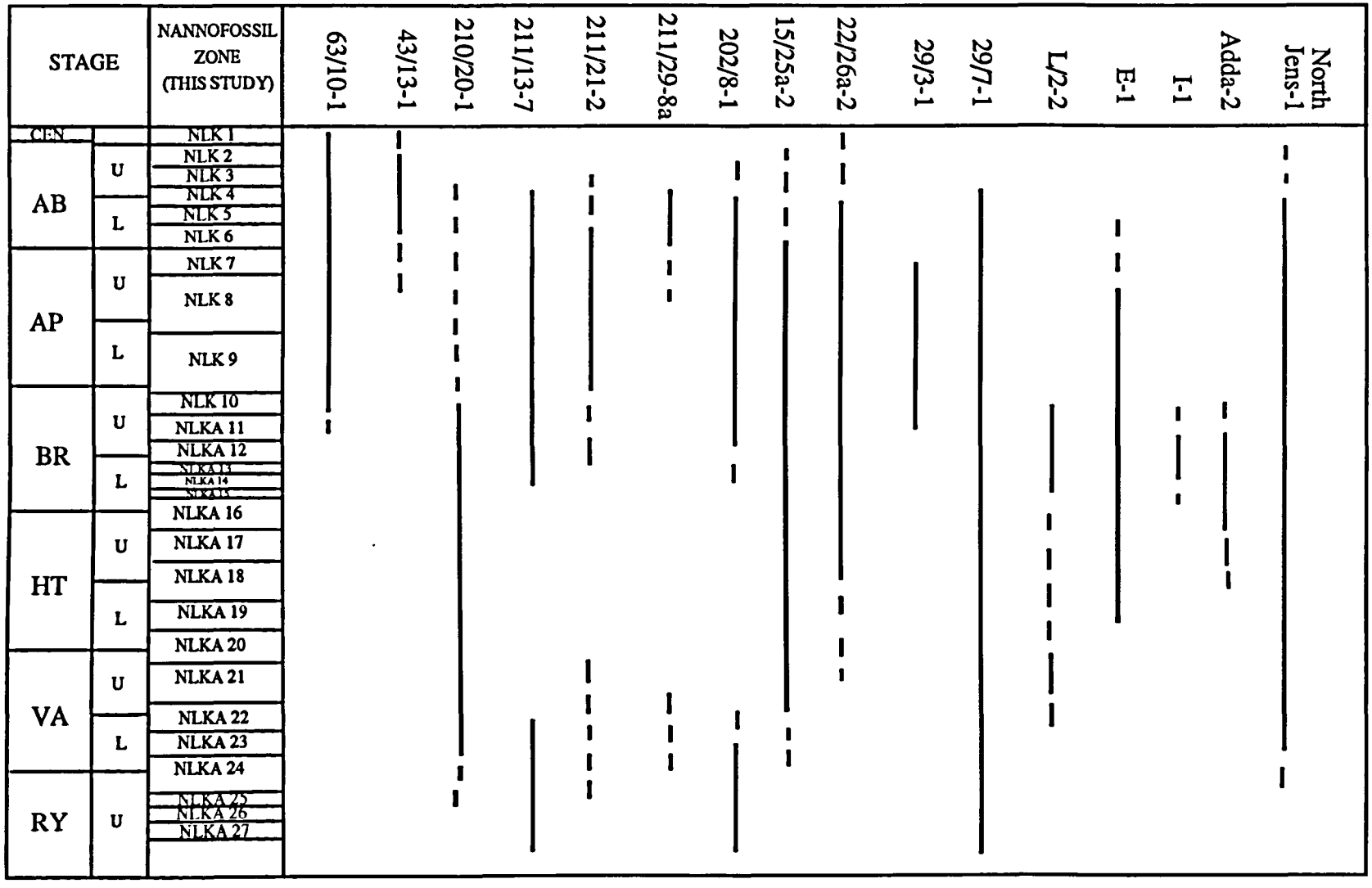


Figure 3.2. Summary of the stratigraphic distribution of studied sections.

211/29-8a (Enc. 4.): interval of 10279-10912 ft, 10 ditch cutting samples, 19 sidewall core samples from the Cromer Knoll Group (10 barren samples). The lithology is dominantly shales and limestones. The youngest sediments studied in the section are Late Aptian, the Barremian and Hauterivian are absent and the base of the section is marked by Valanginian which rests unconformably on the Kimmeridgian.

3.2. Moray Firth Basin

202/8-1 (Enc. 5.): interval from 4725-5140 ft, comprising of 14 ditch cutting samples and 9 sidewall core samples. Stratigraphic interval is from Upper Albian-Upper Barremian with a hiatus during the Hauterivian-Upper Valanginian. The lower section was dated as Lower Valanginian-Upper Ryazanian.

3.3. Witch Ground Graben

15/25a-2 (Enc. 6.): interval from 12601-13549 ft, a total of 39 sidewall samples, 9 core samples were investigated. The section is dominantly composed of marls with an occasional argillaceous component, characteristic of the Cromer Knoll group. The section is dated as Aptian/Albian-Valanginian. The exact location of the section in the basin is shown in figure 3.3.

3.4. Central Graben

22/26a-2 (Enc. 7.): interval from 10040-11643 ft, a total of 8 ditch cutting samples, 36 sidewall core samples, 14 core samples. The section was dated as Early Albian to Early Hauterivian.

29/3-1 (Enc. 8.): interval from 10628-11386 ft, a total of 7 sidewall core samples (1 barren sample). The section was dated as Late Aptian-Late Barremian.

29/7-1 (Enc. 9.): interval from 9900-19819 ft, a total of 39 sidewall core samples were studied. The section is part of the Cromer Knoll Group with the Kimmeridge Clay boundary recognised at 10819 m by a dramatic change in lithology marked as a gamma peak on the log and impoverished nannofossil assemblages. The section was dated as

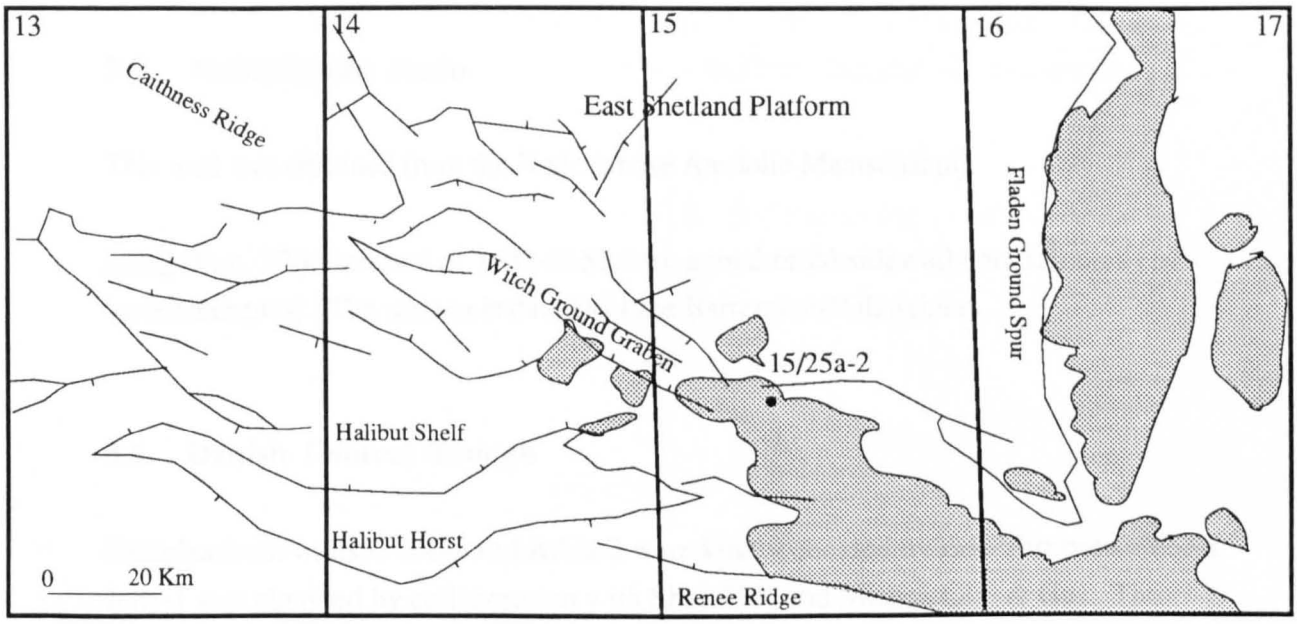


Figure 3.3 Location of 15/25a-2 in the Witch Ground Graben. Map from Harker et al. (1986).

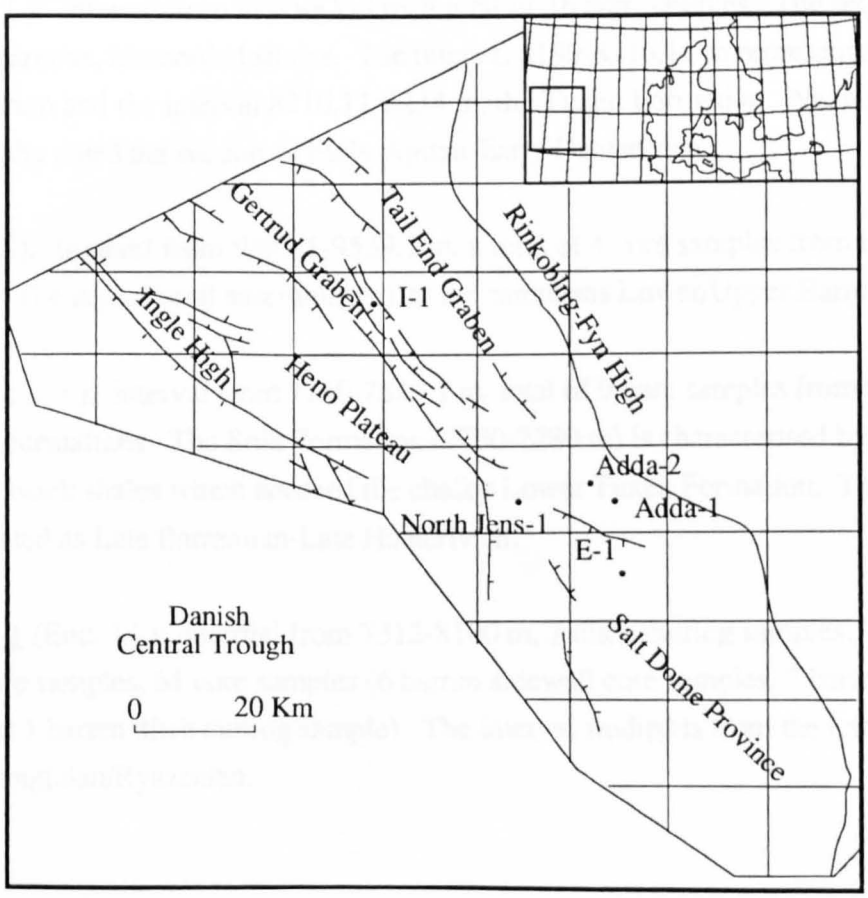


Figure 3.4 Location of the Danish Sector Wells (Thomsen 1987).

Upper Albian-Upper Ryazanian, containing a thick Valanginian sequence.

3.5. Netherlands Basin

This well was obtained from the Nederlandse Aardolie Maatschaapij.

L/2-2 (Enc. 10.): interval of 1633-2153.5 m, a total of 24 sidewall core samples (14 barren samples). The section is dated as Late Barremian-Valanginian.

3.6. Danish Central Trough

Samples from wells E-1, I-1 and Adda-2 were kindly donated by Eric Thomsen. North Jens-1 was obtained by collaboration with Shell U.K and Maersk Olie & Gas. The exact geographic location of the wells is given in figure 3.4.

E-1 (Enc. 11.): interval from 8190-8234 m, a total of 16 core samples. The sequence is dark, calcareous, biomottled shales. The interval 8190-8210.11 m represents the Sola Formation and the interval 8210.11-8234 m, the Tuxen Formation. Nannofossil biostratigraphy dated the section as Early Aptian-Early Hauterivian.

I-1 (Enc. 12.): Interval from 9493.1-9539.1 m, a total of 4 core samples from the Sola Formation. The nannofossil assemblage date the samplesas Lower/Upper Barremian.

Adda-2 (Enc. 13.): interval from 7750-7849.1 m, total of 9 core samples from the Sola and Tuxen Formations. The Sola Formation (7750-7780 m) is characterised by calcareous, black shales which succeed the chalky Lower Tuxen Formation. The section is dated as Late Barremian-Late Hauterivian.

North Jens-1 (Enc. 14.): interval from 7312-8100 m, 7 ditch cutting samples, 21 sidewall core samples, 61 core samples (6 barren sidewall core samples, 7 barren core samples and 1 barren ditch cutting sample). The interval studied is from the Late Albian-Valanginian/Ryazanian.

3.7. Irish Celtic Sea

Well kindly recommended by N. Ainsworth (*pers. comm.*), not previously analysed for nannofossils. The sample material was obtained from the Irish Department of Energy.

63/10-1 (Enc. 15.): interval from 1149-1350 ft, 13 ditch cutting samples.
The samples are of an argillaceous nature and nannofossil preservation is poor. The stratigraphic range of the section is Cenomanian-Barremian.

3.8. Porcupine Basin

British Petroleum well, located on the south western limb of the Porcupine Basin.

43/13-1 (Enc. 16.): interval from 2720-2830 ft, a total of 6 ditch cutting samples. The samples contain abundant Tertiary cavings and poorly preserved nannofossil assemblages. The stratigraphic range of the section is from the Cenomanian to Aptian/Albian.

Chapter 4.
Methodology

4.1 Preparatory Techniques

Prior to sample preparation the ensuing factors were taken into consideration:

1) Lithology. Optimum extraction and preservation of nannofossils is from marls. During the selection of wells for this project this factor was one of high priority, however, a variety of techniques suited to extraction from different lithologies are available (refer to Taylor and Hamilton, 1982).

2) Contamination. Prior to preparation the sample is cleaned by removing the outermost layer with a clean knife. Paper towelling is used to cover the work-surface before each sample is processed. Disposable pipettes prevent inter-sample contamination, but due to the cost it is more economical to re-use glassware (beakers' etc.). These are washed with tap water to remove previous sediment and soaked in 10 % HCl overnight. Before commencing, the glassware is thoroughly washed with tap water and rinsed in distilled water (to prevent possible contamination from tap-water).

Three methods are used in the study of *Nannoconus*, closely controlled by the lithology of the sample: a) thin sections; b) fractured rock surfaces, and
c) dispersed sediment. Selection of suitable lithologies during sampling meant that only the latter two techniques were used in this study:

4.1.1 Thin Sections

This technique is used when the sediment is well-indurated, since dispersion techniques require the physical breakdown of the sediment, destroying the specimens. The Maiolica Formation (Cretaceous, Appenines), which contains numerous nannoconid limestone beds, is usually studied by this method. The size fraction in which nannoconids occur requires extremely thin sections to be made to observe their massive structure.

1) The individual nannoconids are frequently orientated obliquely to the section, which is not conducive to ease of species identification.

2) Due to the indurated nature of the host sediment, specimens may have undergone recrystallization of the wall and canal/cavity (essential criteria for nannoconid species level determination).

3) Beds containing abundant nannoconid assemblages in the Maiolica Formation contain only very sparse nannofossil assemblages or are barren of non-nannoconid nannofossils; datum levels are therefore difficult to determine.

Spherical associations (Nannosphaeroidina) have been recognised by Trejo (1960) in thin sections from the Tampico region of Mexico although these are very scarce. Noël (1991) used slightly etched thin sections to enhance the outline of individual specimens for study in the Scanning Electron Microscope.

4.1.2 Fractured Rock Surfaces

This technique uses the scanning electron microscope to observe the surface of a split sample section. Harding (1987) and Thomsen (*pers. com.*) have recognised monospecific assemblages of *N. bucheri* in faecal pellets using this technique. Lambert figures a lamina of *N. fragilis* (1987, pl. 16, fig. 3).

This method of study is only feasible if the sample has the following characteristics:

1) Very diverse and abundant nannofossil/nannoconid assemblages in routine smear slides

2) Laminations at a microscopic level.

In NW Europe the only Early Cretaceous facies suitable for detailed study of nannofossil abundance is from the Barremian and Aptian (Munk Marl, Haüptblätterton and Fischschiefer).

Preparation: Careful cleaning and preparation of the sample prior to gold coating ensures optimum clarity of these nannofossil-rich laminae in the scanning electron microscope. The sample is carefully split along a lamina or across several laminae using a clean, sharp scalpel. See figure 4.1.

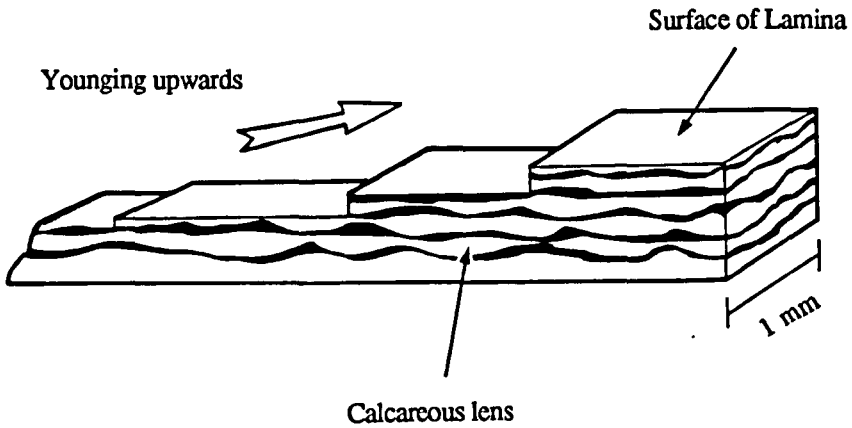


Figure 4.1. Preparation of a lamina for fracture surface study in the S.E.M.

The use of a magnifying glass or microscope with a x10 objective is recommended for accuracy. A 0.1 Rötring pen can be used to mark the way-up orientation of the sample.

Requirements for this technique to be effective are:

1) Nannoconids need to be very abundant in the routine smear slides. Solitary laminae of monospecific nannoconid assemblages, from sample material studied in this project, are very scarce and were only observed in North Jens-1, in the Munk Marl layer.

2) In boreholes core material is needed due to the minute quantity of sediment available in sidewall core study; cuttings are not suitable.

3) Preservation needs to be perfect.

4.1.3 Dispersed Sediment

The numerous techniques for the recovery of nannofossils from dispersed raw sediment are excellently reviewed by Taylor and Hamilton (1982). The following techniques were used routinely during the course of the project:

Routine Biostratigraphical/Analytical Study

Preparation: This preparation technique is a time-effective, whole rock study which is thought to yield a representative thanatocoenose assemblage. All preliminary observation of the nannofossils used smear slides.

1) The sample is cleaned as outlined above.

2) A small quantity of sample is scraped or crushed onto a glass slide, which has been cleaned with methylated spirit to prevent cohesion of the water droplet when added and facilitate a more even distribution of the smear.

3) A single drop of distilled water is placed on the sample and left for 1 minute.

4) Another solitary drop of distilled water is added and a flat toothpick is used to smear a thin coating over the slide. It is advantageous to make this smear slightly thicker towards one margin of the slide, to enable the recognition of rare species in the sample.

If the sediment is sandy or silty then the coarse fraction is removed by retaining all the dispersed sediment at one end of the slide trapped by the flat toothpick, gently tilting the slide and lifting the toothpick to allow the suspension containing the finest fraction underneath the toothpick. A less satisfactory method is to gently scrape the coarse sediment from the surface of the smear.

5) Dry the slide gently on a hotplate, and check that the smear is not too thick, which will hinder effective observation of the contents. Leave to cool prior to permanent or semi-permanent mounting (to allow the specimens to be teased into a suitable orientation for study, especially for short bodied species e.g. *N. concavus*).

6) Add a drop of Norland Optical Adhesive and gently lower the coverslip into place to avoid trapping air bubbles. Cure under UV light, if excess Norland Optical Adhesive needs to be cleaned off use methylated spirits and a scalpel after 3 minutes.

A total of 10-20 slides can be prepared in 1 hour and the method is clean, cheap and time-efficient.

The mounting medium needs to have refractive index which falls below that of calcite

(1.658ηe - 1.486 ηw). This is necessary for a good resolution to be obtained in transmitted light and to avoid the effect of inverted relief (Edwards, 1963). The medium must be permanent and non-corrosive if the slides are to be stored for re-observation at a later date. Norland Optical Adhesive is actively used on board scientific cruises due to its negligible toxicity levels and ease of use, with curing of the slide under a ultra violet lamp. No visible etching of specimens was recorded during the project.

Observational tools: For observation of these slides an Olympus BH-2 optical microscope, fitted with x40 and x100 oil immersion objectives was used (refer to section 4.2 for types of light microscopy used). The eyepiece contained a scale which was calibrated with a graduated microscope slide, each mark on the eyepiece scale was found to correlate to 1 μm.

Centrifuge Technique for Detailed Study - for concentrating nannofossils and especially cleaning out clay minerals for Scanning Electron Microscopy. This technique originates from the short-centrifuge technique outlined by Edwards (1963), later modified by Pienaar (1966).

Preparation: A small quantity of cleaned crushed sample is placed in a labelled beaker and a sufficient amount of distilled water added to cover the sample. This is left to soak overnight. Smear slides can also be made from the resulting suspension but it was found to be time-inefficient, only a few indurated samples needing soaking to disperse the sediment.

1) The suspension is agitated and more distilled water added to give a turbid suspension. This is left for approximately 1 minute to allow coarser particles to settle, e.g. small aggregates of sediment.

2) A centrifuge tube (labelled) is filled up to 1 cm from the rim of the tube. A small plug of paper towelling is placed in the mouth of the tube to prevent possible contamination.

3) The samples were symmetrically distributed in the centrifuge to balance the tubes.

4) The samples are spun at 1,000 rpm for 30 seconds and allowed to stop slowly

(usually about another 30 seconds).

5) decant the supernatent (containing micrite) and resuspend the pellet at the bottom of the tube in distilled water. Repeat the process until the supernatent appears almost clear. The pellet is then re-suspended and the diluted suspension can be used to make slides (control) and/or coverslips for LM/SEM study.

No pre-spin at 350 rpm was found to be necessary, so that the fraction observed included the larger, denser nannoconids. The scarcity in comparison with the other nannofossils, of nannoconids and the diverse size variation within the nannoconids precluded splitting of the sample into size fractions suitable for optimum nannoconid recovery.

Other techniques, previously used in particle-size analysis of clay minerals, were experimented with but proved either to require large amounts of sample material, expensive equipment/chemicals (or hazardous) or were time-inefficient.

Control slide preparation: Comparison of the control slide and the centrifuged slides ensured that there was a representative assemblage in the centrifuged slides, with no major loss of nannofossil species during preparation.

Final preparation involves the following steps:

1) Flood a labelled slide with the diluted suspension, and leave to dry on a hotplate (lowest setting to prevent vigorous bubbling).

2) cool and mount as for smear slides.

Same Specimen Observation in the LM and SEM

This technique was described in detail by Gallagher (1988) and is extremely useful to determine the species identification of nannoconids in the Light Microscope and also to enhance the detail of the wall structure, of the same specimen, in the Scanning Electron Microscope. It provides one of the most complete methods for specimen identification and detailed study.

1) The round, 13 mm diameter, coverslips are soaked in methylated spirit and are left to

dry between two sheets of paper towelling. This provides a more cohesive surface for the ink grid.

2) A fine grid pattern is drawn onto each coverslip using a 0.1 Rötring pen filled with waterproof ink. Figure 4.2

3) The coverslips are baked in a moderate oven between two sheets of paper for 1 hr and then left to cool. Several can be prepared at one time and can be used as necessary if stored in a clean box.

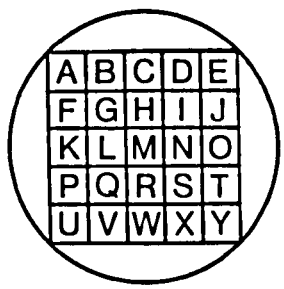


Figure 4.2 A grid pattern used for the relocation of nannofossils in the S.E.M.

4) An upturned petri dish, with labelled sectors, is used to hold the coverslips (printed side upwards).

5) Using a pipette a small drop of the diluted suspension is placed on the coverslip. This is left to dry overnight in a dust free environment. Several coverslips of one sample are made with varying numbers of drops of solution.

Observation/photography in the light microscope: The coverslip is carefully lowered onto a small drop of immersion oil placed on a standard glass slide (preventing the coverslip from moving). Another small drop of immersion oil is placed on the coverslip and a square coverslip placed over the surface. Observation with a x40 or x100 oil immersion objective can then take place, the square coverslip preventing contamination of the immersion oil needed for the x100 objectives. Upon photographing the specimen its position in relation to the coverslip grid is recorded using a low power objective. After completion of the photographic study the coverslip is soaked in

methylated spirit for 2 minutes, gently swirling the meths over the coverslip. This removes the immersion oil little/no loss of the nannofossil film.

Observation in the Scanning Electron Microscope: An aluminium stub is labelled on the undersurface and placed in a holder, e.g. small foam-filled coverslip box. A thin film of colloidal silver is used as an adhesive for the coverslip and improves the conductivity in the SEM. The stub, complete with coverslip, is left overnight to allow the solvents in the colloidal silver to completely evaporate.

The stub is coated using a sputter coater in an argon atmosphere with a 10-20 nm- (100-200Ã-) coating of gold. The SEM used during the course of this study was a JEOL T200. The specimens can be relocated using the coverslip grid system, the ink showing up as fine ridges.

This technique is excellent theoretically but can be very time consuming. However, same-specimen LM and SEM photographs are ideal for taxonomic reference. Some of the problems are outlined below:

1) Orientation of nannoconids frequently found to be oblique on coverslip surface and therefore could not be photographed in the light microscope;

2) Scarcity of nannoconid species means that several coverslips need to be made from one sample;

3) Overcoating, or remnant immersion oil on the coverslip means this light microscopy needs to be needs to be repeated with a new coverslip, due to loss of detail by the unwanted coating;

4) Re-location of the specimen may rely on good preservation, nannoconids can appear as clumps of sediment ! Centrifuging was found to cause the nannoconid tests to attract (presumably by static forces) micrite in the sample.

Photographic Materials

Standard Pan F 50 ASA speed film was used. To enhance the clarity of the light microscope images, a green filter was used for cross-polarized micrographs.

All the negatives are curated by the Postgraduate Unit of Micropalaeontology, University College London. The reference number, e.g. 2883/10 is made up as follows:

2883 refers to the film number, 10 to the frame number.

The magnification of the micrographs illustrated in the plates were determined using the following calculations:

From LM Photographs:

$$\text{magnification} = \text{objective} \times \frac{3.2 \times a}{b}$$

From SEM Photographs:

$$\text{magnification} = \frac{\text{SEM magnification}}{4} \times \frac{a}{b}$$

Where:

a = the enlarged dimension (mm) and;

b = the contact print dimension (mm).

The absolute dimensions of the contact prints were calculated using the following equation:

$$\text{dimension } (\mu m) = \frac{\text{dimension on photograph} \times 4 \times 1000}{\text{SEM magnification}}$$

Counting Techniques

Due to the time constraints it was not feasible to adopt a quantitative approach, this method would have concentrated the results on the relative abundance of the nannofossil assemblage (available from published and Shell in-house sources) without improving knowledge of the genus *Nannoconus*. A semi-quantitative approach was therefore adopted and all the abundance values given on the distribution charts are relative to each other, representative of a taphonomic assemblage study. The symbols used in the distribution charts are explained in the key notes on the individual charts.

4.2 Optical Techniques Used to study *Nannoconus*

An outline of the various optical methods used to study *Nannoconus* are discussed below:

4.2.1. Light Microscope

Nannoconus is known to be constructed of a complex array of calcitic plates which have an organic origin. The structural base-unit or plate is here considered to be built of a single crystal (or crystals of calcite in a similar crystallographic orientation.) Plate. 1, fig. 8 & 10. illustrates the application of the C axis to individual plates in an oblique view of *N. abundans*. These individual crystal units of calcite are usually rhomboidal to sub-triangular.

To understand observations in the light microscope it is necessary to discuss the optical properties of calcite. Figure 4.3 shows a single rhombohedral calcite crystal, a uniaxial (-) mineral with 3 axes at 120° in a plane at 90° to the c-axis. There are 4 optical techniques which are used to identify nannofossils: plane-polarised, cross-polarised light, phase contrast and using a sensitive tint e.g. gypsum plate. A modification of cross-polarized light in addition to the other techniques is described to aid the identification of nannoconids.

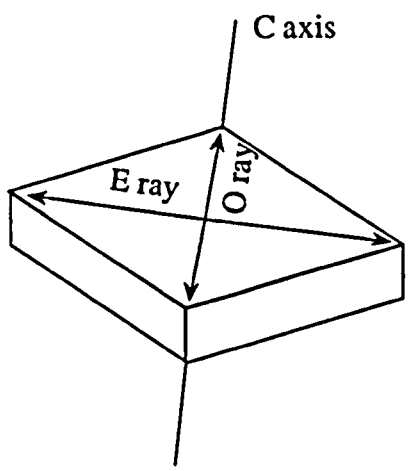


Figure 4.3. A calcite rhomb. O is the short diagonal, E is the long diagonal, C axis corresponds to the crystal symmetry.

Observation in Polarized Light

This is the most common method employed to observe very subtle changes in the crystallographic orientation of the plates and it is essential for the taxonomic identification of nannoconids. A trained eye can discern the wall structure in addition to the more easily recognisable features such as the central canal/cavity.

Polarization trains a light beam to vibrate in a known direction. This light beam is then diffracted upon passing through the crystal, in a manner characteristic to the unique crystal structure.



Figure 4.4. a) ordinary light, b) polarized light.

There are three different types of polarised light study; plane-polarized light; cross-polarized light and a modified technique, partially-polarized light.

Plane-Polarized Light: The light vibrates in one direction only as illustrated in figure 4.4 b) which can be used to distinguish different mineral compositions. This is not used to recognise the different structures in nannofossils which are all essentially of a calcitic nature.

Cross-Polarized Light: The substage polarizer is inserted in addition to a fixed analyzer on the Olympus BH-2 microscopes. This causes the light to be polarized before and after entering the specimen. The two polarizing sheets are orientated to transmit light vibrating at right angles to each other (E-W and N-S). This results in no light reaching the eye. However, if a crystal (anisotropic, e.g. calcite) is placed between the two sheets of polaroid then the light directions are altered and it becomes visible to the naked eye.

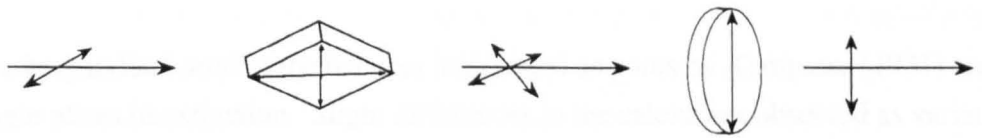


Figure 4.5. The change in direction of a light beam when observing calcite in cross-polarized light.

If the stage is rotated through 360° then there will be 4 positions when the two vibration directions are parallel to the polarizer and analyzer; these are known as points of extinction. When we observe a top view of a nannoconid, extinction lines can be seen at 90° to each other, indicative of several plates orientated in a manner as mentioned.

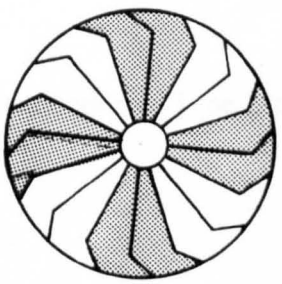


Figure 4.6. A schematic sketch of a top view of *Nannoconus* with four distinct sectors of extinction.

These sectors are not symmetrical in width from the exterior to the centre of the horizontal section (top view/disc), this is related to:

a) Degree of overlap of each rhomboidal plate and consequently orientation of the plate to the vibration directions of the polarizer and analyzer.

b) Uneven orientation of the plate due to the plate flexibility and slight imperfections in the plate nature due to their biological origin. This can cause plates to have a greater

degree of curvature towards the central canal/cavity in relation to the external wall. This is more evident in species which are constructed of thin plates, e.g. *N. abundans.*

In a longitudinal section the features interpreted as pores by Kamptner (1931) are in fact single plates in extinction. Slight differences in the calcite are observed as variations in the first order interference colours (greys and yellows). This is most marked when etching has occurred, the elements being distinctly grey in colouration and therefore loss of structural detail is evident.

The reader is refered to Chapter 6 for the new terms introduced in this chapter to describe the optical properties of nannoconids.

A problem when observing and photographing a longitudinal section of *Nannoconus* in cross-polarised light is that a uniform extinction of the elements in Cycle A occurs when the longitudinal axis is parallel to the Z crosswire. See figure 4.7. Maximum observational benefits are obtained when rotating the stage up to 45° from the Z or Y crosswire. This angle re-orientates the element orientation, maximum detail is usually obtained by rotating the stage to the approximate amount of degrees of the elements in Cycle B.

The angle corresponds to the extinction of Type B plates when the C axis of the plates are vertical to the microscope.

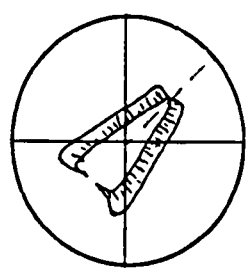


Figure 4.7. A view looking through the eyepiece at a specimen of *N. kamptneri.*

Observing a top view or disc in a similar manner does not aid taxonomic identification, the plates becoming extinct in a radial pattern upon rotation of the stage.
A point to note at this stage is that taxonomic identification requires the canal/cavity to

be studied at midpoint in a longitudinal section, a feature not always illustrated by some authors. Figure 4.8 shows the change in dimensions of the central cavity by focusing through a longitudinal section of *N. kamptneri.* Plate 1, figure 1-3 ilustrates this feature in *N. circularis.*

Due to the extinction of plates, detail can often be difficult to observe, especially when etching and/or overgrowth has occurred. A modification of polarized light observation was found to aid identification.

Partially-Polarized Light: This technique clearly illustrates the external outline and ultrastructure of *Nannoconus* and it is used by several nannofossil specialists (Prins *pers. comm.*) when observing large structures made of numerous calcitic plates.

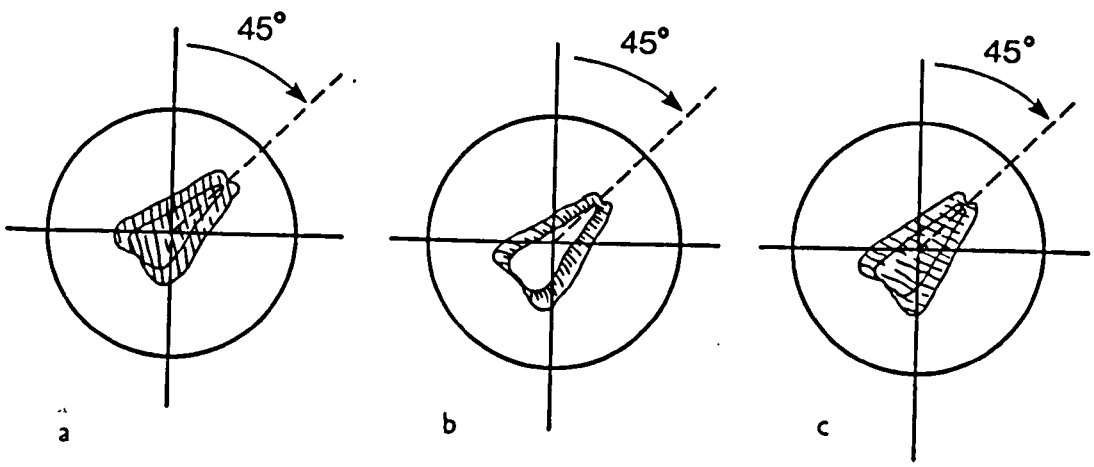


Figure 4.8. *N. kamptneri*: a) nearside wall; b) midpoint, the pointed ends of the plates are visible in a crossing pattern; c) far side wall.

The substage polarizer is rotated by up to 45° from the E-W orientation used in cross polarized observation. Instead of the two sheets of polaroid arranged at right angles giving a dark field of view, the basal polaroid is at an angle corresponding to the markings on the stage which can rotate up to 45°. The background in this instance is pale cream with the nannoconids showing a high optical relief.

Plate 1., figure 2 & 3 illustrates the detail which can be seen using partially polarized

light and cross-polarized light.

Nannoconid discs/top views can be studied in this manner, the direction of spiralling and the approximate size of the plates are clearly visible, e.g. plate 1, figure 4-6. The total nannoconid assemblage needs to be observed before taxonomic identification can take place.

Gypsum Plate

The Olympus BH-2 microscopes have no fitting for the use of tinted plates, this hindered the use of this technique during routine observation. Some study of nannoconids with a gypsum red plate was done.

When observing a top view of a nannoconid the C axis runs parallel to the direction of the fast ray of the gypsum plate. In a SW-NE direction the sectors are blue and in a NW-SE the sectors are yellow, C-axis of the plate is parallel to the slow ray of the gypsum plate (Moshkovitz and Varol 1989, pl. 4.4, fig. 19, pg. 95). The authors suggest that this may be useful when distinguishing between nannoconids in side and top view. The use of the gypsum plate was found to enhance the crystallographic features visible in polarized light observation. The high cost of colour plate production, in relation to the results obtained, did not make this a feasible means of presenting published results, however, the method is very useful during routine taxonomic work. Perch-Nielsen (1988) illustrates 3 new nannoconid species from the North Sea using the gypsum plate and colour photographs, as do Moshkovitz and Osmond(1989) who illustrate a *N. colomii* (senior syn. *N. steinmanni*).

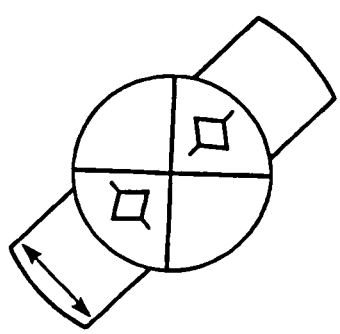


Figure 4.9. Uniaxial crystal of calcite with a gypsum plate.

Phase Contrast

This technique was not used during this study, partially polarized light was found to show more optical detail of the nannoconids.

4.2.2 Scanning Electron Microscope

This is extremely useful for a detailed study of the external structural characteristics of the wall but cannot be used solely for taxonomic identification at species level. Stereo pairs were taken at 5° to aid the three dimensional interpretation of the plate arrangement. For detailed investigations of the wall structure refer to Chapter 6.3.

4.3 Preservation and Taphonomy

Understanding the geological biocoenose and the ecological factors which control the correlation of the living community and the thanatocoenose assemblage are essential when considering their palaeobiogeographical distribution. Nannofossil preservation is a sensitive indicator of carbonate dissolution and recrystallisation, closely controlled by the fine structure. In fragile nannofossil species, e.g. *Corollithion geometricum*, the central bars particularly show a tendency towards etching and breakage. In contrast, *Watznaueria barnesae* is one of the most dissolution resistant species of the Early Cretaceous, due to the robust construction of the plates.

The process of re-calcification i.e. redeposition of $CaCO_3$ from pore waters is controlled by the lithology (i.e. $CaCO_3$ content and clay composition) and the surrounding environmental stresses.

Semi-quantitative estimates of preservation (Roth & Thierstein, 1972; Roth, 1983) enable us to give a uniform estimate of nannofossil preservational state. However, this was only found to be useful when observing the other nannofossil groups, since nannoconids which appear well-preserved in the L.M were usually found to have overgrowths when studied in the S.E.M. The following terminology is taken from Roth & Thierstein (1972, pg. 432-434):

Etching Ranking:

E-1 - Slightly serrate outline

E-2 - Moderate etching (more delicate species preferentially dissolved)

E-3 - Strong dissolution (only dissolution resistent taxa are present)

Overgrowth Ranking:

O-1 - Irregular secondary overgrowth of crystallites

0-2 - Delicate central structures frequently overgrown, taxonomic identifications may be hindered

0-3 - Identfiable delicate species overgrown to an extent that they are not identifiable.

Several authors (Roth & Thierstein, 1972; Roth, 1973; Roth & Berger, 1975; Roth & Krumbach, 1986) have used semi-quantitative methods (factor analysis) for analyzing nannofossil preservation. A dissolution ranking of mid Cretaceous nannofossils (Roth & Krumbach, 1986) lists approximately 18 species in order of their susceptibilty to dissolution. Nannoconids are not included in this list, but observation of the project material suggests that *Nannoconus* is a very dissolution-resistant genus comparable to *Watznaueria.* Recalcification is dependent upon two criteria, the lithological composition of the sediment, i.e. the availability of calcium carbonate, and the physical stresses within the sediment. These factors control the degree of overgrowth of the dissolution-resistant species.

The lack of reliable nannofossil depth indicators in the Early Cretaceous does not allow us to study the effects of nannoconid settling through the water column after death. However, the classic work of Honjo (1976) calculates the transportation, settling and dissolution rates for coccoliths in the open, deep ocean. His work also discusses the preservation of coccoliths below the CCD within faecal pellets. Zooplankton are responsible for grazing in the euphotic zone, the monospecific nature of the faecal pellets may imply that certain species grazed on a specific species or genus. Faecal pellets and bioturbation are recognised in core material from the Munk Marl, Danish Central Trough (Plates 4 & 5). These occur on the surface of laminae and are distinguished from burrows by their elliptical, slightly irregular outline. The pellets frequently contain intact monospecific assemblages, e.g. Plate 4, figure 1 & 2 *Pseudolithraphidites* sp. The preservation of these pellets is related to cool water preventing the biodegradation of the pellicles (an outer organic membrane coating the pellet) according to Honjo (1976).

Spherical associations of nannoconids (Nannosphaeroids) are extremely rare, which implies that the living nannoconid individuals were linked by thin connections of organic matter.

Overgrowth and dissolution play an important role in diagenesis. This is evident in the indurated nannoconid limestones from the Tethyan region. Overgrowth between the calcite plates causes the wall to become a structureless mass of calcite. Identification is therefore hindered by the loss of wall structure detail, with taxonomic interpretations relying on the overall shape and canal/cavity outline.

The progressive effects of alteration of the nannoconid ultrastructure, as far as observation is concerned, can be summarised as follows:

1) minor etching and overgrowth;
2) secondary overgrowth and etching;
3) massive overgrowth.

Experimentation with a pristine control sample left to stand in water over a period of time was not found to give a satisfactory projection of progressive dissolution/overgrowth. Adelseck *et al.* (1973) attempted to simulate the effects of diagenesis on a Pliocene ooze. Temperatures and pressures were estimated and reconstructed in a hydrothermal bomb, using sea water as a surrounding medium. The nannofossils showed interesting progressive etching and overgrowth. Some of the observational results can be correlated with dissolution/recrystallisation features evident on nannoconids.

Bain (1940, p. 7) demonstrates that different crystal faces of calcite have varying solubilities. Faces orientated perpendicular to the c-axis were found to be most resistant to solution while those crystal faces parallel to the c-axis were least resistant to solution. This feature has been used by Bukry (1972, p. 304) to determine the dissolution resistance of nannofossils.

Due to the relatively large and robust nature of the crystal elements in the nannoconid wall, these have a tendency to attract overgrowths. This is related to " larger crystals have a lower free energy" (Berner 1971 , p. 28) which causes crystals smaller than 1μm to preferentially dissolve, whereas larger crystals act as nuclei for secondary recrystallisation.

Preferential carbonate deposition occurred between the plates in Cycle A, the degree of overlap of the elements acting as an attractive force for carbonate precipitation. The more imbricate nature of the Cycle B plates may imply a susceptibility to dissolution, which is often visible in the light microscope as the spiral angle becomes more pronounced, combined with a loss of detail in Cycle A (only visible in species with a wide Cycle A). A loss of the characteristic high birefringence of a specimen is an indication of re-orientation of the crystal axis within the elements, with progressive recrystallisation and dissolution.

No preference for overgrowth towards the distal or proximal poles was found, although remnants of organic matter are thought to attract overgrowths. The initial stages of overgrowth are recognised in the SEM as thin, thread-like connections between the plates, in conjunction with a massive surface overgrowth observed in the SEM. The former minor overgrowth preserves the ultrastructure of the specimen (Plate 3, fig. 5-6). Massive overgrowth on the surface of the specimens obliterates detail, which can hinder recognition in the S.E.M, the observer having to rely only on the external outline for species identifications (Plate 3. fig. 7-9).

Etching and overgrowth are closely linked processes. Due to the relatively large nature of the individual calcite crystals within nannoconids, overgrowth takes preference to dissolution although some of the serrate nature of the individual plates may be due to minor etching.

4.4 Material

All photographic negatives and slides prepared by the author are deposited in UCL. Some slides loaned by Shell U.K are housed in the company collection in London.

Chapter 5.
The Systematic Position of *Nannoconus*

The ambiguous biological nature of *Nannoconus* has been the topic of relatively little discussion, with the zonal and palaeobiogeographical nature of this genus being the main topic of study. The lack of substantial evidence for the biological roots of nannoconids allows only for logical reasoning and assumptions to be made as to their affinities. I have outlined below previous authors concepts (summarised in Table 5.1 and Table 5.2), followed by a brief resumé of the postulated life cycle of a nannoconid organism.

PROTOZOA		INCERTAE SEDIS
Foraminifera	Thecamoeba	
Joukowsky & Favre (1913) De Lapparent (1925, 1931) Lombard (1938, 1945) Colom (1945, 1952) Trejo (1960) Aubry (1974)	Kaiser-Weidich (pers. comm.)	Baldi-Beke (1962)

Table 5.1 Summary of the systematic position of *Nannoconus* in the Protozoa.

UNICELLULAR ALGAE			
Pyrophyta	Chlorophyta	Charophyta	Haptophyta
Noël (1991)	Cadisch (1934)	Peck (1934) Brönnimann (1955)	Colom (1956) Deflandre (1959) Noël (1965)

Table 5.2 Summary of the systematic position of *Nannoconus* in the Unicellular Algae.

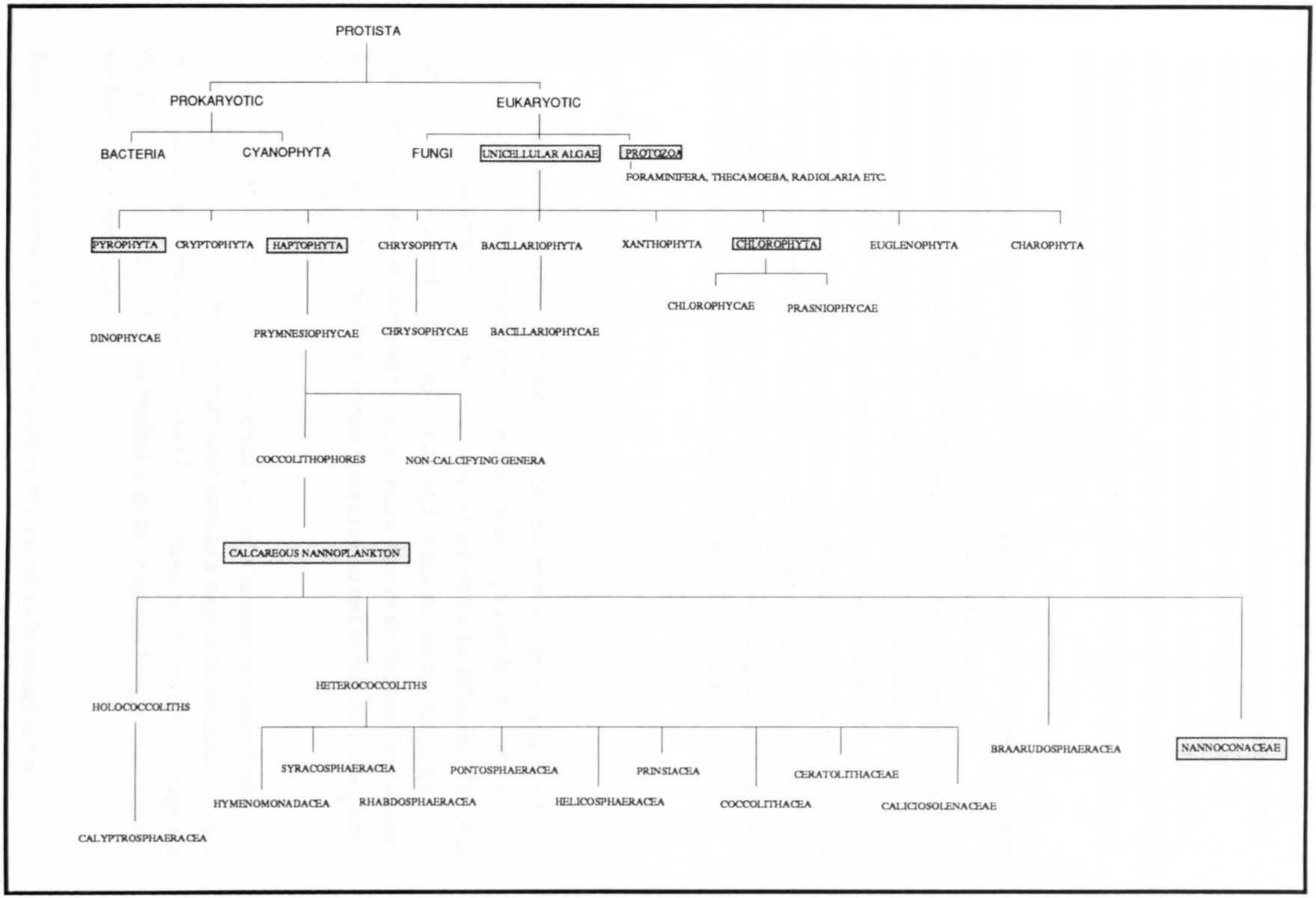


Figure 5.3 Informal Classification to highlight the groups and their relationships to which authors have assigned *Nannoconus* After Jeremy Young (1987).

There are two distinct divisions in the biological classification: plant and animal kingdoms, which, at a unicellular level can be difficult to determine. The lack of modern representatives of the genus *Nannoconus* does not allow us to confirm our observations. Previous authors, in a bid to determine the biological origin, and subsequently use of the correct code of nomenclature, have assigned this genus to either the Protozoa or Unicellular algae. Table 5.3 represents an informal classification, highlighting the groups to which the genus has been assigned (the groups being discussed in the following text).

Some early authors, e.g. Peck (1934) initially regarded specimens of *Nannoconus* to be of inorganic affinity. These structures were interpreted to have arisen by crystallizations of $CaCO_3$ in a lime-rich environment. Eventual acceptance of the defined structure of these organisms and systematic distribution patterns led authors to speculate on a biological classification of this genus. Classification of modern biota into the divisions outlined above are based upon certain soft-body features, but in the fossil record we can only deal with an incomplete record of the organism. This fact must always be considered when we discuss a possible biological affinity to a group and until modern representatives are found it will always be a matter of debate.

5.1 Protozoa

Joukowsky and Favre (1913) initially found organisms in samples associated with foraminifera and differentiated them by calling them "organism B". Due to the assemblage characteristics they were assumed to have protozoan affinities. This idea persisted with Lapparent (1925, 1931), who implied that the minute size of the specimens signified a relationship to an embryonic stage of the foraminifera *Lagena*. Lombard (1938, 1945) considered nannoconids to be related to the taxa *Globochaete alpina* and *Eothrix alpina*.

In 1960 Trejo found the first, rare, spherical masses of nannoconid individuals. Uncertain of their significance, he interpreted them as a stage in the evolutionary cycle of the foraminiferan genus *Trypanosoma (Schicotypanum)*. Aubry (1974) suggested that the fission of multilocular tests resulted in globular species being formed similar to the life cycle of protozoans.

Kaiser-Weidich (*pers. com.*, 1991) believes nannoconids to be related to the

Thecamoeba, in particular *Euglypha.* She recognises a similarity between the spherical mass of *Euglypha rotunda* and the spheres found by Trejo (1960). The former contain a group of bulbous individuals linked into a colony by cytoplasmic connections, resulting in a narrow central area similar to that found in Nannosphaeroids.

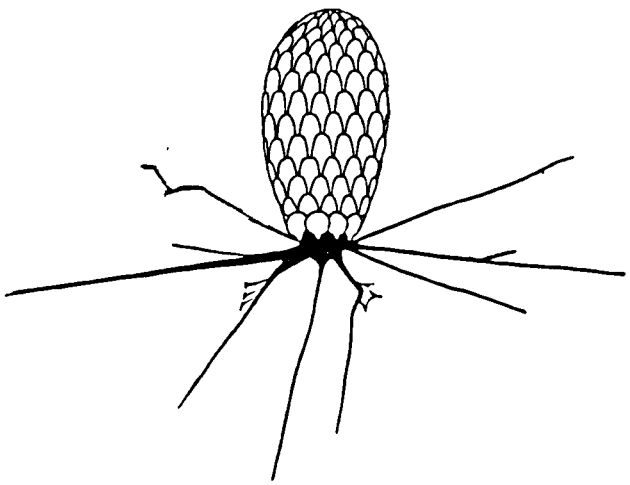


Figure 5.1 *Euglypha rotunda.*

An inferred similar pattern of connections would explain the extreme scarcity of Nannosphaeroids, the decay of organic connections after death allowing the colony to disaggregate. However, fundamental morphological differences in the wall structures of *Euglypha* and *Nannoconus* do not make this a reasonable relationship. In *Euglpha rotunda* the wall is constructed of a fish-scale pattern of siliceous plates (rarely calcareous) opening only at one polar end of the body. In contrast, nannoconids are characterised by a wall composed of a complex array of interlocking calcareous plates, with two apertures opening at polar ends of the test.

5.2 "Unicellular Algae"

Charophyta

The spiral surface impression and globular outline of the gyrogonite in the Order Charophyta (stoneworts) first inspired Peck (1934) to relate the nannoconids to this group; later Brönnimann (1955) also noted similarities between the groups.
The gyrogonite (used in the palaeontological manner to designate a fossilised

oosporangium) obtains its sinistral spiralling surface pattern when the oospores matures within the spiralling tubular cells of the sporophydium (figure 5.2). These can calcify at various stages of oogonia development.

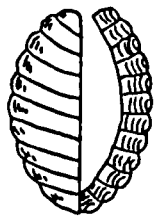


Figure 5.2 A mature charophyte gyrogonite.

Modern charophyte taxa are dominantly freshwater, only a few genera being able to cope with higher salinity levels, found in estuarine conditions. The size of the gyrogonites ranges from 275-300 μm, considerably larger than the longest nannoconid. The surface spiral is not constructed of plates but was formed by an impression on the surface.

Chlorophyta

In 1934 Cadisch linked nannoconids to another, morphologically different algal group, the Chlorophyta. This group contains a wide range of diversity of morphology, habit and habitat. Two stages usually occur during the life cycle; a motile and a vegetative phase, and some calcify to produce vegetative, aragonite cysts.

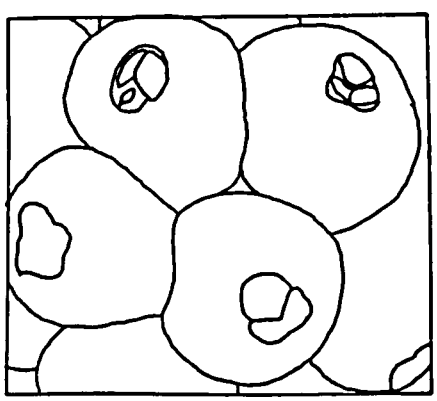


Figure 5.3 Section of a colony of Chlorococcacea (Chlorophyta).

A vegetative resting phase is characterised by a reproductive colony in some taxa. Change from the resting phase to the motile phase begins with an opening in the cyst wall. If an affinity to this group is to be inferred it would be necessary for nannoconid individuals to show a similar opening. The wall structure of calcified cysts also show no resemblance to that in the nannoconid body. Cysts of this order are also significantly larger than the longest species of *Nannoconus*.

Prymnesiophyta (Haptophyta)

The discovery of nannosphaeroids in material from Mexico by Trejo (1960) confirmed Colom's (1956) theoretical sketch of a spherical array of nannoconid individuals (although there was a discrepancy in the orientation of the specimens). Deflandre (1959) was convinced of the coccolithophorid affinities of *Nannoconus*, erecting a new family, the Nannoconidae. These similarities with coccolithophores have been discussed by Steinmann (1925), Deflandre (1959) and Noël (1965).



Figure 5.4 Generalised diagram of a coccolithophorid motile cell.

Coccolithophores (calcite secreting prymnesiophyta) consist structurally of a spherical array of organic scales and/or calcitic plates around a cell which are present during the motile, non-motile or even both stages. The change in morphological habit of the

different stages in the life cycle can be different adding to the complications of recognising fossil species. In living cells the cell membrane is flexible and the coccoliths arranged loosely on the surface, and local movement of the individual coccoliths, by unhooking their rim structures can take place (not all species have interlocking rims).

In 1973, Stradner & Grün compared the structure of *N. abundans* to the pattern of overgrowth evident in *Watznaueria*. A similar pattern of crystal growth in a centrifugal (clockwise) direction is evident in specimens of *W. barnesae*, and subsequent overgrowth follows this pattern. The early ideas of a simple spiralling arrangement of plates in nannoconids would correspond to this genus being of Prymnesiophyte affinities.

Pyrophyta

A recent hypothesis proposed by Busson & Noël (1991) compared nannoconids present in lithified limestones to calcareous dinoflagellates (Pryrophyta). They imply that the life cycle and ecological behaviour of dinoflagellates explain the unusual characteristics of the accumulations of nannoconids which have been found. The following characteristics were used in their argument:

1) The inhibition of coccolithophore development coincides with high percentages of nannoconids in the Maiolica Limestone and a decrease in detritus.

2) These high abundances of nannoconids may have inhibited the development of planktonic foraminifera by poisoning the surface waters. Benthic foraminifera are sparse and less diversified in the limestones than the marls.

3) Nannoconids are associated with radiolaria which also show changes in species diversity associated with changing lithology.

Busson & Noël (1991) argue that nannoconid blooms show similarities to the 'red tides' of modern dinoflagellates. Poisoning of the surface marine waters would effect other organisms in the surface waters and eventually impact upon benthic food chains. The formation of cysts in dinoflagellates also represents a reproductive system which greately helps the diffusion and migration of species. This model would be more feasable if a closer comparison of the structural characteristics of *Nannoconus* and

Dinoflagellates were made. If the nannoconid body is a cyst then we need to consider an opening for the motile phase of the life cycle, similar to the cysts found in the Chlorophyta. Similar blooms of coccoliths could also produce a poisoning effect of the surface waters, however, absence of other organisms during a nannoconid bloom could relate to depletion of the water by $CaCO_3$ or a particular element. This would explain the fluctuations in diversity of Radiolaria with facies changes, siliceous forms blooming in $CaCO_3$ depleted waters.

Incertae Sedis

Kamptner (1931) recognised the complex structure of *Nannoconus* and suggested that they should be regarded as planktonic organisms of uncertain origins. The dissimilarity of nannoconids to existing groups was mentioned by Baldi-Beke (1962) who also suggested they should be classified as incertae sedis. Theoretically the nannoconids should be classified as incertae sedis due to the lack of a modern representative to verify a biological classification. Only an inference to similarities with extant groups can be made from the palaeontological record.

Summary

The following observations on the characteristics and occurrence of the genus *Nannoconus* are here argued to indicate an algal origin, of uncertain affinities:

1) The double refractive nature of $CaCO_3$ and the closely interlocking nature of the calcite crystals may infer some use of the heavily calcified nannoconid body for photosynthesis. This is a feature which is readily accepted in unicellular algae, however a direct correlation with modern species of similar construction cannot be made.

2) The minute nature of the central cavity in Nannosphaeroids, in addition to the heavily calcified nature of the individuals would imply a physical impossibility for the organism to float in the uppermost sector of the water column. At a greater depth in the water column (within the photic zone) the calcitic plates, acting as an enhanced photosynthetic receptor, would have maximum efficiency. Water clarity would therefore also be essential, nannoconids are found in areas of low clastic input which may imply a link. However this group may have adapted a floatation mechanism such as some foraminifera

where they are surrounded by frothy cytoplasm.

3) The nannoconid body may be a calcified cyst or vegetative phase of an unknown organic cell which appears in response to adverse environmental conditions. However, no evidence exists for the presence of a motile phase, and the occurrence and distribution patterns are therefore reliant upon water mass circulation patterns, as with other Prymnesiophyta.

4) The recognition of rare spherical masses of nannoconid individuals may be compared in structure to the Coccolithophoridae. However, a hypothetical sphere of *N. steinmanni* which would have a minute central cell in comparison to coccolithophorids, the individual nannoconids not containing a sufficiently large enough cavity to house a cell, only cytoplasmic connections.

5) The high abundances of nannoconids in the Maiolica Formation and in the laminae of Haüptblatterton and Munk Marl are here interpreted as blooms of this genus. In NW Europe these blooms occur sporadically in a sequence of monospecific calcareous nannoplankton assemblages, no other organisms have been identified in the material studied. The sporadic occurrence of these laminae is argued to represent an optimum environment for the development of a single taxa.~~due to slight depletion in surface waters of an element essential to their growth~~. The taxa which is commonly found to have monospecific lamina is *N. abundans*. This species is small with thin, delicate plates and is endemic to the Boreal realm. It may represent depletion in a particular element and decreasing $CaCO_3$ levels. The latter, however, would seem contradictory due to the high abundance of the taxa in the sample, a more feasible hypothesis would be cool surface waters, i.e in winter.

An interesting feature is the double structures of *N. abundans*, which are perfectly attached by the flange (Plate 2. figs. 1-9 & 12), visible in numerous specimens within a lamina, which could suggest a reproductive mechanism (refer to Chapter 11.2).

To summarise, the nannoconids are thought in this study to be closely associated with the Prymnesiophycae (this study) due to their association with other plankton and similarities in structure and distribution.

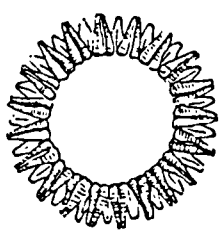
Chapter 6.
Morphology of *Nannoconus*

6.1 Groups of Nannoconid Individuals

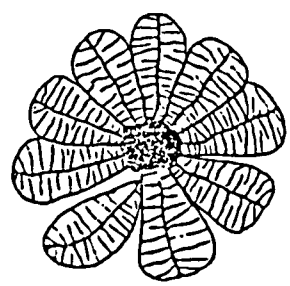
6.1.1 Nannosphaeroidina Colom (1968)

Nannosphaeroidina is a term which was initially used by Colom (1968) to describe spherical associations of *Nannoconus*.

Lapparent (1925) was the first to illustrate nannoconid individuals but associations were not discussed until Colom in 1956. He recognised similarities between rosette groupings of individuals and the coccolithophorids, attempting to reconstruct a theoretical sphere of *Nannoconus* (figure 6.1a). However, in his model he did not consider the orientation of the individual nannoconids and his sketch shows a sphere of *N. steinmanni* with the bases of the individual nannoconid cones directed towards the centre of the cell. Spherical arrangements of individual monospecific nannoconids were first observed by Trejo (1960, see figure 6.1b, which is an interpretative sketch from a photograph of an *N. steinmanni* sphere; Hauterivian, Tamaulipas, Mexico).



a)



b)

Figure 6.1a) Hypothetical model of nannoconids arrangement in a sphere (Colom 1956, fig. 28). Figure 6.1b) *N. steinmanni* sphere (Trejo 1960, fig. 1).

Trejo remarked (p. 275) that "en various ocasiones, de ejemplares de *N steinmanni* dispuestos en roseta formada por unas 12 testas". All the specimens illustrated appear to be arrangements of approximately 12 individuals in a circle, not a sphere. It is considered unlikely that such a perfect section of a sphere could be obtained through

thin-sectioning. These rosettes have been illustrated, from thin sections, at the following localities in Mexico (Trejo, 1960 p. 274): Pozo San Vicente 1 (1099.2-1100.2 m) Edo. de Tamaulipas, Pozo Martinica 1 (2092.9-2094.6 m) Edo. de Hidalgo, Pozo San Miguel del Rincn 1 (3026.8-3029.8 m) Edo. de Veracruz.

After personal communication with Brönnimann, Trejo suggests that these associations are related to a colonial protozoan, individual nannoconids being found in the assemblage due to disaggregation of the cytoplasmic connections. Original description (Trejo, 1960 p. 275):

> "ha sido vista también por él, sugiere la que presentan ciertos fitoflagelados coloniales tales como *Synura o Syncrypta*; si esta analogia tuviera algún valor, cada testa representar a el esquelto individual de un protozoario colonial y la prescencia normal de ejemplares aislados, puede explicarse por la decomposición de la substancia gelatinosa que en vivo mantiene unidos los individuos de la misma colonia."

He goes on to state that the rosettes represent an evolutionary cycle which can be found in the colonial protozoan species *Trypanosoma*. Original description (Trejo, 1960 p. 275):

> "las formas en roseta representen una etapa del ciclo evolutivo, tal como ocurre en algunas especies de *Trypanosoma (Schizotrypanum)*.

Colom (1965 p. 323) remarks on the scarcity of these rosettes, following study of nannoconid beds from the Mediterranean region, and implies that they are endemic to the Tampico region of Mexico in his statement.

> "ces formes sphériques semblentse localiser jusqu' présent exclusivement dans la région de Tampico (Mexique)"

Colom (1968) also records rosettes of nannoconids in sample material from Tampico, Mexico. He assigns a generic name, *Nannosphaeroidina*, to these rosettes of *N. colomi* (syn. *N. steinmanni*) and states that they are globular in outline with the narrowest part of the cone-shaped body directed towards the interior of the cell. The axial canals of the individuals are radial which, during life, would have been filled with cytoplasm connecting the central cell with the exterior. Original description (Colom 1968, p. 4):

> "Una coccolitoforinea de forma esferoidal, formada por una apretada reunión de sus *Nannoconus*, con la porci n aguzada da estos dirigida hacia el centro de la esfera y su lado abombado al exterior, dando lugar a una masa globulosa, de contornos algo irregulares, seg n los ejemplares. Los canales axiales de los *Nannoconus* se abren todos al exterior de manera radial a semajanza de la

colocai n de los mismos, dejando pasar los finos pseudopodos de lacúlula interior alojada en una diminuta cavidad central."

Lambert (1987) observed the presence of Barremian nannosphaeroids in smear slides from well B1, southern Cameroon. He assigns the individual, isolated specimens of *Nannoconus* to *Nannoconus* aff. *fragilis* Deres & Achériteguy 1980 (syn. *N. quadriangulus apertus*). In the description he notes the presence of a small conical element at the base of the individual, serving as a fixation point on the sphere. Lambert (1987, p. 58) states:

"A l'extrémité proximale, le <<couvercle>> est très nettement conique"

and then notes in the plate description:

" in clastic (not euxinic) normal sediments, this part is usually broken"

From the figured specimen (Lambert 1987, Plate 15, fig. 4) it appears that he has based his observation on an oblique view of an isolated specimen, giving a distorted view of the exterior outline. In the paper he has illustrated the spheres with light micrographs (Plate 15, fig. 5 and Plate 16, fig. 2) and scanning electron micrographs (Plate 15, fig. 3) and Plate 16, fig. 1).

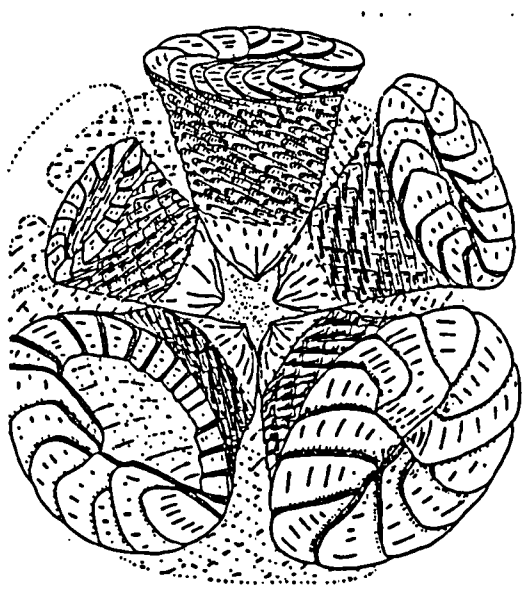


Figure 6.2. Drawing made from observations in the light microscope. (Lambert Pl. 16, fig. 2, published in Busson & Noël 1991).

Busson & Noël (1991) were the first to publish a sketch of Lambert's interpretation of the arrangement of nannoconids in a sphere. The drawing also illustrates Lambert's

(1987) interpretation of the dissociation of a sphere, and subsequent morphology of the individuals found in the sediment. A remarkable feature of this rosette arrangement of nannoconid individuals is that there is almost no central cavity. The sphere of *N. fragilis* (syn. *N. quadriangulus apertus*) is measured as 15 to 20 μm in diameter by Lambert (1987, p. 58), the only range of dimensions of the spheres recorded in literature.

No similar associations of nannoconids have been observed in the material studied from NW Europe, even in monospecific laminae from the Munk Marl. These laminae have been deposited under a very low energy regime so as to allow the preservation of details of each bloom (a few microns in thickness). Double structures of *N. abundans* have been observed in a lamina consisting entirely of this species (Plate 2, figs 5, 6 & 9). The specimens are in perfect crystallographic continuity with the flanges perfectly matched; this is discussed below.

6.1.2 Double Structures

Observation of the individual nannoconids in the laminae from the Munk Marl of North Jens-1 showed an interesting phenomenon, the presence of double structures of *N. abundans*. These specimens were common in the monospecific assemblages and consisted of two individuals attached at the flange. The line of contact between the specimens was perfectly matched and the plates in both specimens were in crystallographic continuity, the external ridges and grooves spiralling symmetrically around both specimens. This double structure of *N. abundans* was only recognised in whole rock SEM analysis of the Munk Marl in North Jens-1, where they were abundant in monospecific laminae but occasionally present in other assemblage laminae. Smear slides did not tend to show these structures due to the harsh nature of the preparation technique which would cause disaggregation of the sediment and of specimens.

The ideal preservation of the assemblages in the Munk Marl and the above observations may provide an insight into the life cycle of *N. abundans*. In the following notes I will discuss some hypotheses for the presence of these double structures in the Munk Marl.

Hypothesis 1. Depositional Collapse Structure

If we assume the nannoconids to have been assembled in spherical life associations, then, in relation to the orientation of the individuals towards the cell interior we can postulate two methods by which these structures may have formed.

A: Internal Collapse Structures

This would be applicable if the individual specimens were orientated in such a manner that the flange was adjacent to the cell membrane, with no overlap of the flanges. Please refer to figure 6.3.

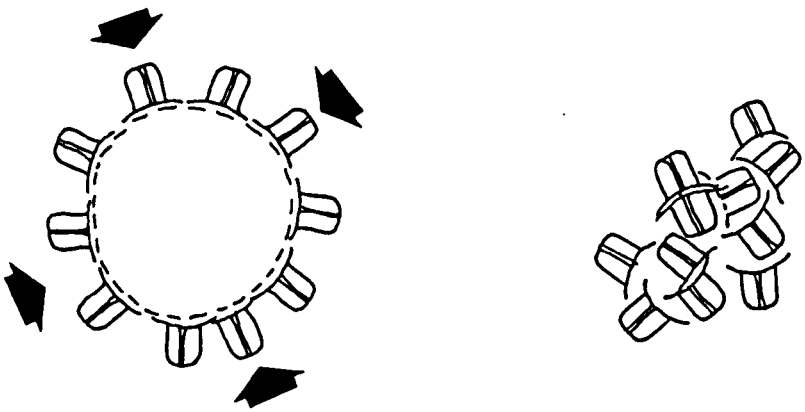


Figure 6.3. Hypothetical internal collapse of a sphere of *N. abundans*.

The orientation of the individuals to the cell membrane could be comparable with spheres found by Trejo (1960), the proximal aperture having a narrow central opening. However, the probability that the collapse of a sphere would produce double structures in exact crystallographic continuity seems unlikely. If the flanges of the individuals overlapped this would further decrease the probability of coupling through compaction.

B: External Collapse Structures

If we assume that the individuals were arranged with the flange directed towards the exterior of the cell then the deposition and then the compaction of a lamina composed of several spheres could cause the adhesion of two individuals in the manner shown below.

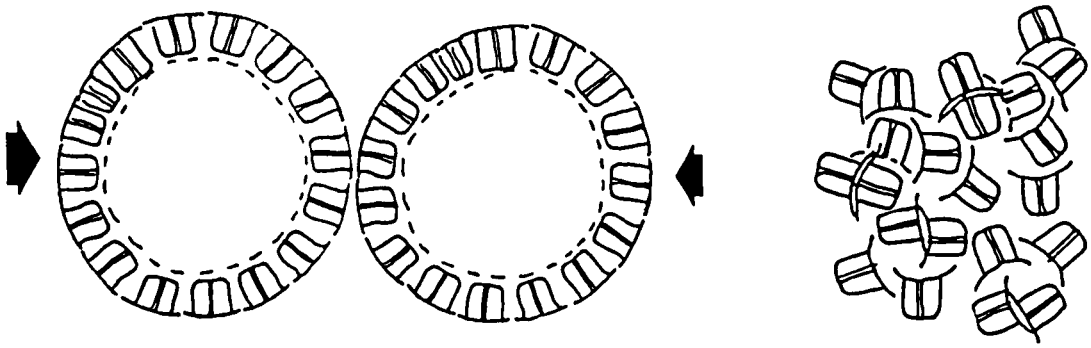


Figure 6.4. Hypothetical external collapse of a sphere of *N. abundans*.

Both the above compaction hypotheses would account for the lack of cohesive forces between the individuals which would allow them to be observed in the light microscope. However, the probability of the individuals being aligned in crystallographic continuity seems unlikely.

Hypothesis 2. Double Rim Construction

The nature of the structures may infer that *N. abundans* formed a protective exterior to harsh environmental conditions by creating a double rim structure. Please refer to figure 6.5.

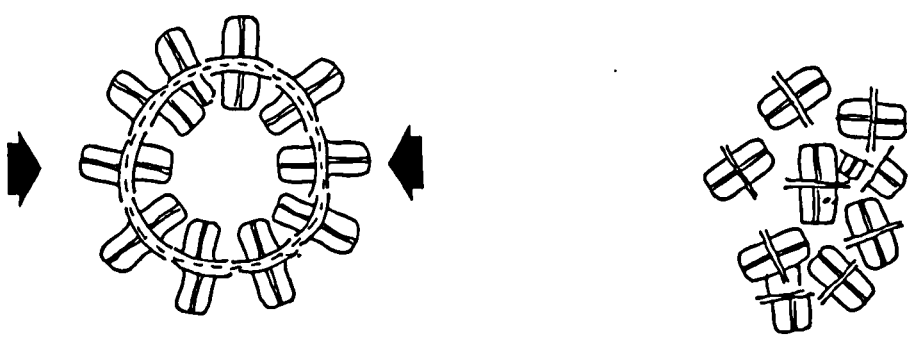


Figure 6.5. A hypothetical reconstruction of a double rim sphere of *N. abundans*.

N. abundans has been assigned to Morphogroup 1.1 (this study) which contains some of the smallest nannoconids. The individual platelets are the smallest found in the genus (this study) which could imply a lack of available of calcium carbonate. In addition to this, species of this morphogroup frequently dominate the nannoconid assemblage at particular time intervals. It would thus appear to be a contradiction to have a double rim of nannoconid individuals surrounding a sphere, i.e. an increased usage of the available $CaCO_3$.

Hypothesis 3. Decrease in the Number of Individuals on a Cell

The palaeontological and modern record has shown that there can be a great deal of variation in the number of individuals surrounding the cell in the Coccolithophoridae. It may be possible that a *N. abundans* sphere consisted of only two individuals, which could suggest a transitional phase in plate development. This might be possible, but it is unlikely that the two individuals would join up during sediment compaction. Refer to figure 6.6.

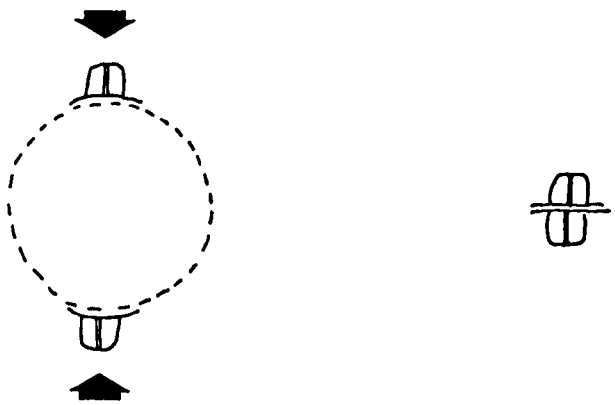


Figure 6.6. A hypothetical sphere of *N. abundans* with two individuals at opposite poles surrounding a cell.

Hypothesis 4. Reproductive Stage

The individual coccolith plates in a coccosphere are produced by the golgi body and are gradually positioned on the exterior of the cell, covering it partially or completely. In modern assemblages juvenile specimens are found associated with adult forms, however, juvenile nannoconids have not yet been recognised. A reproductive phase of unknown mechanism might explain the apparent crystallographic continuity of the individual specimens within the structure. Why these twin structures exist is still an

enigma and further research is needed on monospecific nannoconid laminae to give us a better understanding of the life cycle.

After observation of paired *N. abundans* during SEM analysis similar structures were recognised in smear slides from the Munk Marl. In the light microscope distinct plates could be seen to cut across the midpoint of large individuals of *N. circularis* and *N. truitti.* The nannoconid assemblages also contained apparent 'broken' individuals which showed a similar morphostructure to the paired specimens but differed only in length of the central body. The scarcity of these paired individuals has made it difficult to form a sound basis for interpretation but the most feasible explanation is thought to be a product of reproduction that is not yet fully understood, perhaps associated with an early stage of calcification.

6.2 Morphology of an individual specimen of *Nannoconus.*

From observation of a specimen of *N. colomi* (syn. *Lagena colomi*), Lapparent described the test as comparable to the shape of a bottle, constructed of intercrossing calcitic plates, which enclose pores and are arranged obliquely to the axis of the test. Lapparent (1925, p. 105) states:

> "L'organisme, de calcite hyaline, est fait de lames entrecroisees, obliques par rapport son axe, et dont les intervalles constituent des pores."

In 1931 (p. 223) he added:

> "La coquille, de calcite hyaline, est faite de lames entercroisees qui isolent des pores ; et qui donnent en section mince l'impression d'une structure fibreuse."

In the same year Kamptner (1931) provided a more detailed account of the structure and erected a new genus, *Nannoconus*, based upon his new species *N. steinmanni.* He observed the elements to be shaped like wedges, the pointed ends of which are orientated inwards into the canal. Kamptner (1931, p. 291) writes:

> "Elemente stozen mit ihren spitzen enden gegen innen zu an einen engeren oder breitereren, entlang der achse verlaufenden kanal."

These elements have a breadth of 1 μm.

> "Die höhe eines elementes, d. h. seine in der längsrichtung des zapfens gemessene dimension betragt etwa 1 μm."

He implies that the elements are arranged spirally around and perpendicular to the axis of the cone-shaped test, which is represented by a narrow canal, opening at either end of the test. He states (pp. 290-291):

"Während die längsschnitte das bild zweizeiliger fiederung bieten. Dies ist der ausdruck einer eigentümlichen feinstruktur der zapfen; denn der anblick rührt davon her, daz das individuum aus einer ansehnlichen zahl winziger, keilförmiger, rings um die zapfenachse radiär angeordneter teilchen aufgebaut ist." and "bei einer grozen zahl von zapfen ist dieser axial canal bis zum verschwinden verengt. Der längsschnitt eines zapfens läzt erkennen, daz die bausteine ann hernd senkrecht zur achse orientiert sind und nur an den beiden zapfenden sich derart in ihren radialebenen scief stellen, da das mikroskopische bild den eindruck gibt, als wolle ihre reihe von der einen längsseite des längsschnittes fächerförmig zur gegen überliegenden. Bei genauerer betrachtung zeigt sich aberdaselbst je eine terminale lücke ausgepart durch die der kanal an seinen beiden enden nach au en mündet."

In the text Kamptner (1931, p. 291) gives a schematic sketch through a longitudinal and horizontal section of *N. steinmanni* (figure 6.7).



Figure 6.7 Schematic sketch of *N. steinmanni* (Kamptner 1931).

A more comprehensive outline was given by Brönnimann (1955) during his investigation of globular and U-shaped species. The morphology of the test is summarized by an excellent, although outdated, schematic drawing through an axial section of *N. steinmanni* (see fig 6.8).

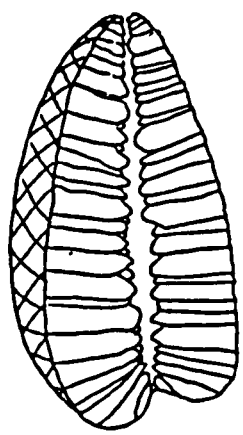


Figure 6.8 A schematic sketch of *N. steinmanni* (Brönnimann 1955).

He observed that the:

> "internal structure of the test is the same, both in the cone-shaped forms with thin axial canal and in the bulbous, U-shaped and barrel-like to globular forms with relatively large cavity." (Brönnimann 1955, p. 29).

This can only be regarded as a true statement if it is used to refer to the characteristics of the genus *Nannoconus*, since different morphogroup wall ultrastructures have been recognised in this study. Brönnimann (1955, p. 30) confirms Kamptner's description:

> "The wall consists of tiny wedges or plates orientated more or less perpendicularly to the surface of the test. Their pointed ends are directed toward the axial canal or cavity."

However, he goes on to state:

> "the distribution of individual wedges in tangential sections of the test with large central cavity indicates that they are arranged along a gradually mounting spiral or spirals. Within the spiral or spirals, the wedges are aligned in rows perpendicular to the spiral and oblique to the axis of the test."

The individual elements he describes as (p. 30):

> "irregularly rhomboid" the "pointed inner ends, protrude slightly into the canal, thus producing a granulated inner surface (Pl. 1, figs. 1, 3). The outer ends appear to be flush with the surface."

His observations were made using a light microscope, whereas scanning electron microscopy has shown that the external surface is not smooth when well-preserved. Brönnimann (1955, p. 30) confirms Kamptner's (1931, p. 291) statement that:

> "the test has two terminal apertures opposite each other."

The pores which Kamptner (1938) describes are regarded correctly by Brönnimannn (1955, p. 30) as:

> "the pointed inner ends of the wedges."

The irregular shape of the wedges and the chaotic structure which arises from this irregularity is regarded as being responsible for the morphological variability of the genus (Farinacci 1964). This implies that, in contrast to previous authors, the wall shows no regular arrangement of the plates.

The most recent comment on the architecture of the nannoconid wall is by Tappan (1980, p. 729) who used Brönnimann's interpretation, adding that the elements are:

> "arranged in an apparent sinistral spiral, with the inclination of 30° from the horizontal."

Upon observation of SEM micrographs it was evident that the plates overlap in a clockwise or dextral manner, not in the sinistral spiral that is suggested by Tappan

(1980). Perch-Nielsen (1988) recognises changes in this dextral coiling/spiralling when describing 3 new species from the North Sea. In her species descriptions she remarks on changes in the width of the spiral and the angle of the spiral intersect to an imaginary horizontal plane.

6.3 A Reconstruction of the Nannoconid Wall

The use of scanning electron microscopy has facilitated modern observation of the ultrastructure of the nannoconid wall and consequently of the complex arrangement of the plates. Optical observation with the light microscope can provide a good understanding of the crystallographic nature of the individual plates. When observing a longitudinal section through a nannoconid in cross or partially-polarized light, a distinctive angle of inclination can be seen. This requires focusing on the nearside or, on the far side wall. Authors should use one of these two focusing techniques to be consistently systematic (see Plate 14, figs 10 & 11. *N. elongatus elongatus*).



Figure 6.9. *N. wassalli* in polarized light showing the "spiral" angle visible due to differential extinction of the plates (Plate 21, figure 1). Focused on furthest wall.

During routine LM study the following features were observed and recorded in longitudinal sections:

i) The angle of inclination of the "spiral" angle, in relation to the horizontal axis.
ii) The width of the individual spiral units, shown as brightly birefringent structures.

Micrometers with microscales and microprotractors were used at a later date to confirm the range in degrees of the angle and width of the different morphotypic categories which were found. The "spiral" angle observed in the light microscope was divided

into three categories based upon LM observations ($ß_1$ inclination):

1.	Low	$< 20°$
2.	Moderate/High	20-45°
3.	High	$> 45°$

The width of the "spiral" was recorded as three sub-categories (width of Cycle A):

.1)	Fine	< 0.5 µm
.2)	Medium	0.5-1 µm
.3)	Coarse	> 1 µm

Each species was found to have a characteristic "spiral" angle configuration, unique to the external and internal features of the skeletal body, e.g. *N. abundans* has a very low angle "spiral" unit, 15°, and each unit is < 0.5 µm in width. This species is therefore classified as morphogroup 1.1. The numbering of the morphogroups is as follows: *. refers to the class of "spiral" and .* to the width of the unit (where * represents class division of 1-3). This "spiral" angle is likely to have been the sole determining factor for the simple spiral model which has been widely accepted since it was proposed by Kamptner in 1931. This spiral feature has been correlated to scanning electron micrographs of the wall structure of different species. The results show the ultrastructure to have a more complex organisation than previously thought.

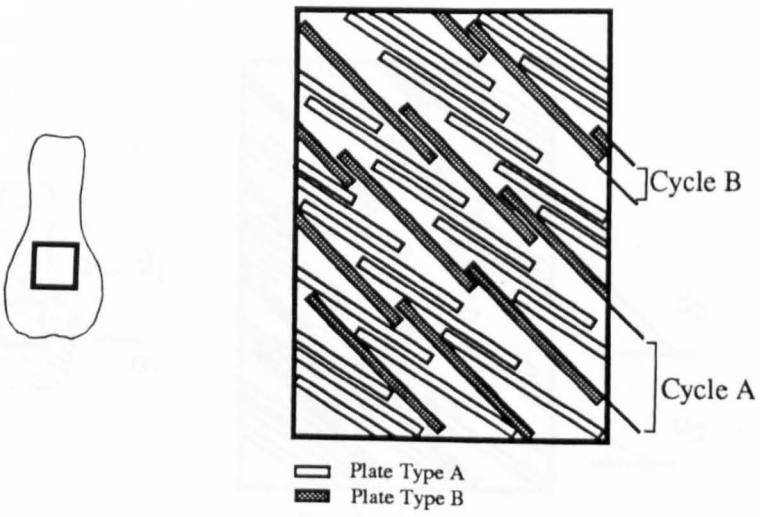


Figure 6.10 Schematic sketch of the nannoconid wall ultrastructure, showing the Cycles of plates present.

Two distinct units could be identified when looking at a surface scan of a specimen of

N. bonetii. These were defined upon the orientation of the plates to the horizontal axis of the specimen (termed α_2 & β_2 to distinguish them from the LM observations).

CYCLE A: - plates systematically overlapping in a dextral spiral in relation to the longitudinal axis of the specimen. The angle of inclination, or α_2, to the horizontal axis is 10°. The degree of plate contact or overlap can be up to approximately 80%

CYCLE B: - plates cutting across at a higher angle, β_2, of 35° between consecutive tiers of Cycle A. The plates appear to have the same dimensions but have a lesser plane of contact up to 20%. This gives the cycle a step-like appearance.

When observing a longitudinal section in the LM the extinction of Cycle B defines the "spiral" angle as observed by Kamptner (1931) and Brönnimann (1955). This shows the c-axis of the plates in Cycle B to be orientated vertical to the microscope. The width of the highly birefringent "spiral" is defined by Cycle A.

These features can only be seen in the LM if the focus is on the nearside or farside wall.

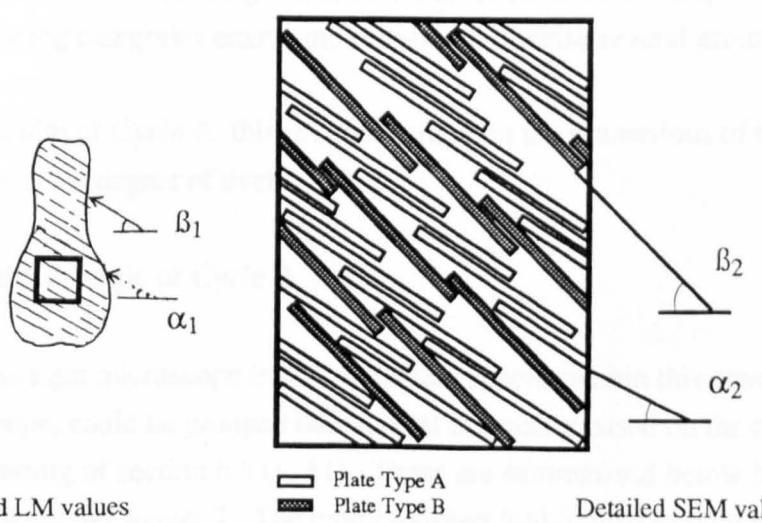


Figure 6.11 Schematic sketch of the wall showing the horizontal intercept angle of the plates in their respective cycles.

Within the cycles the two main orientations of the plates could be measured; the inclination of the cycle as seen in the LM (α_1 & β_1), and the inclination of the individual plates in the SEM (α_2 & β_2), refer to figure 6.11.

α_1: - only recognised by the extinction of Cycle B in the LM and birefringence of Cycle A. The inclination corresponds to β_1, but not to the true inclination of individual Type A Plates seen in the SEM.

α_2: - detailed inclination of Type A plates which can be measured in the SEM.

β_1: - inclination of Cycle B to the horizontal axis, defined by the combined extinction of Type B plates in the LM.

β_2: - detailed inclination of Type B plates which can be measured in the SEM.

The angle most useful for study in the LM is β_1 (= α_1) which defines the cycles. More specific measurement of the inclination of Type A and B plates would not be economical for routine study but is essential for research development. Variations in the following categories enable the author to recognise several groups based upon the:

i) width of Cycle A, this is dependent upon the dimensions of the individual plates and the degree of overlap;

ii) the β_1 angle of Cycle B.

Using the light microscope it was found that species within this genus, in material from NW Europe, could be grouped into several categories based on the classes outlined at the beginning of section 6.4 (p. 61). These are summarised below but are discussed in greater detail in Chapter 7. The morphogroups highlighted in bold have been observed in the sample material based upon LM observations. The actual variation in the β_2 inclination cannot be given at this stage due to insufficient micrographs of the wall structure for different species.

Morphogroup 1.1

Defining parameters: $\beta_1 < 20°$, width of Cycle A < 0.5 μm.

In total, 3 species and one *N.* sp/disc were assigned to this group.

Morphogroup 1.2

Defining parameters: $\beta_1 < 20°$, width of Cycle A 0.5-1 μm.

One species, *N. concavus* was assigned to this category.

Morphogroup 1.3

Defining parameters: $\beta_1 < 20°$, width of Cycle A >1μm.

Only one species, *N. sabinae*, is tentatively assigned to this category. No intact specimens of this species were observed in the studied material.

Morphogroup 2.1

Defining parameters: β_1 20-45°, width of Cycle A < 0.5 μm.

No species were assigned to this category.

Morphogroup 2.2

Defining parameters: β_1 20-45°, width of Cycle A 0.5-1 μm.

A total of eight species were assigned to this category.

Morphogroup 2.3

Defining parameters: β_1 20-45°, width of Cycle A >1 μm.

Twelve species were assigned to this category.

Morphogroup 3.1

Defining parameters: $\beta_1 > 45°$, width of Cycle A < 0.5 μm.

No species were found.

Morphogroup 3.2

Defining parameters: $\beta_1 > 45°$, width of Cycle A 0.5-1 μm.

No species were found.

Morphogroup 3.3

Defining parameters: $\beta_1 > 45°$ width of Cycle A >1 μm

A total of seven species are assigned to this group.

The complete range of possible morphogroups, based upon combinations of the β_1 inclination and width of Cycle A was not found. This was thought to be due to one main factor i.e. variations in the breadth of plates affecting the width of the cycle. Plates with a narrow breadth need significantly more plates to construct a cycle of 1 μm. In contrast plates with a wide breadth need only a few plates to produce the same width. This would explain the absence of species in Morphogroups 3.1 and 3.2 in the material studied due to particular combination of features required. Likewise, the overlap of thick plates will affect the inclination of β_1. Hence Morphogroup 2.1 is not represented because the individual plates have a greater breadth than those in Morphogroup 1.1.

In summary then we can see that there are three important features which are used to assign species of *Nannoconus* into the morphocategories outlined above:

i) inclination of β_1

ii) width of Cycle A

iii) the breadth of the individual plates which partially control i) and ii).

6.4 Mechanism of Wall Construction

The nature of the nannoconid wall is shown to be a highly complex interlocking array of plates (this study). The simple spiralling model of Kamptner (1931) emended by Brönnimann (1955) is thought to be no longer realistic. Knowledge of the organism which produced the skeletal remains of the palaeo-genus, *Nannoconus*, is non-existent. There is therefore no biological insight into the growth mechanism of these structures. A model must rely solely upon speculation as to the possible mechanical combinations of the plates which we can observe in the palaeontological record.

In scanning electron micrographs we can occasionally see complete overlap of Type B plates, as shown in figure 6.12. This is thought to indicate the initial opening/closing of a Cycle constructed of Type B plates. This may also be present in Cycle A but, due to the almost complete overlap of Type A plates within the cycle, this be difficult to recognise.

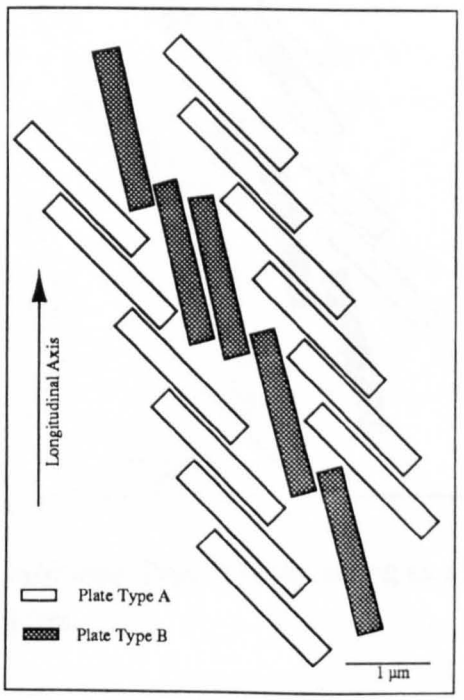


Figure 6.12. A schematic sketch of the almost complete overlap of Type B plates, thought to show the opening/closing of Cycle B.

In an ideal situation you could trace the plates in one cycle around the structure in a 360° rotation. However, this sporadic overlap of Type B plates may give an insight into the construction and the interlocking relationship of the cycles.

Individual Type B plates may provide a "ladder" between consecutive cycles of type A, refer to figure 6.13. This would account for the pattern of breakage into perfect discs. A greater number of plates are used in the construction of Cycle A, each plate with a contact surface of up to 80 % . Consequently Cycle A would be stronger than Cycle B which has a plate contact surface of up to 20 %. The lower α_2 inclination of Cycle A would be partially responsible for the disc-like appearance of parts of the nannoconid test..

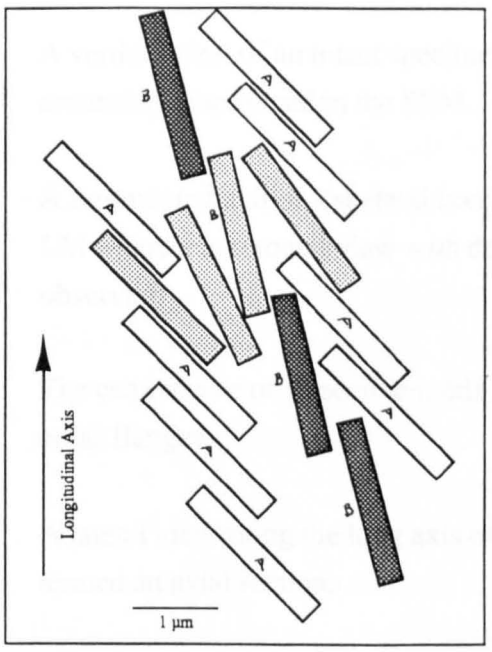


Figure 6.13. A model showing Type B plates acting as a ladder, connecting consecutive Type A cycles.

To date, the physical arrangement of the plates in the nannoconid individual has not been completely elucidated. Further work is required to observe a 360° view of a nannoconid individual to enable the cycles to traced. Computer modelling of foraminifera and gastropod coiling patterns is rapidly developing and may be applied to other, more complex disciplines in the near future.

6.5 Glossary of Terms Used to Describe *Nannoconus*

Recent developments in the observation of the fine structure of *Nannoconus* have led to the use of new terms in describing this genus. The following provides a synthesis of published terminology and new terms introduced (this study). Incorrect published terms are also included with their original diagnosis.

The data have been obtained from the following primary sources: Kamptner (1931), Brönnimann (1955), Perch-Nielsen (1988), Van Niel (this study). Terms which are not recommended are marked by a [].

6.5.1. Orientation

Top View: A vertical view of an intact specimen. This can only be accurately determined in the SEM.

Disc: A fragmented unit of a skeletal body. A term usually used in the LM where a horizontal view with decreased birefringence is observed.

Central Body: The central core of a specimen, this may imply breakage of the polar flanges.

Longitudinal View: A lateral view along the long axis of the specimen. Sometimes termed an axial section.

Proximal Pole: The pole of the nannoconid directed towards the centre of the cell. This is recognised as the narrowest end due to the orientation of individual nannoconids in apparently spherical arrangements of individuals (Trejo 1960).

Distal Pole: Polar side directed furthest from the cell, inferred from a wider apertural opening (Trejo 1960).
The terms distal and proximal should be used with caution, consistency of use is necessary to avoid confusion in the description and orientation of individuals.

6.5.2. Wall Components

Plate: Broad and thin (a=b>c). These may be rhomboidal to sub-triangular.

Plate Type A: Closely overlapping with a low horizontal intercept angle.

Plate Type B: Low amount of overlap, higher horizontal intercept angle than plates of Type A.

[Wedge]: Implies that each plate is a tapering of a=b=c (block). The observation of specimens in the SEM show the wall elements to be plate-type structures.

Contact Surface: Plane of contact between two crystal elements

6.5.3. Wall Structure

Wall: A structure composed of an interlocking arrangement of plates enclosing a central opening.

[Spiral]: An alignment of [wedges] oblique to the long axis of the specimen (Brönnimann 1955). This observation was made in the LM and is thought to correspond to Cycle A defined by the extinction of plates in Cycle B.

[Row]: Alignment of wedges orientated perpendicular to the spiral (Brönnimann 1955). Re-defined as the contact surface between Type A plates seen upon focusing on the axial section.

Cycle: A unit of plates in repetition.

Cycle A: A set of overlapping plates of Type A in crystallographic disposition, in a tier-type structure. Total plate contact can be up to 80%. This corresponds to the "width of rows" (Perch-Nielsen 1988).

Cycle B: Imbricating elements with low overlap up to 20%. The width of Cycle B is approximately proportional to the breadth of the component plates. Cycle B is located between consecutive tiers of Type A plates, which form A cycles. The horizontal intercept angle of these plates defines the "spiral" which has been observed in the light microscope (Kamptner 1931, Brönnimann 1955, Perch-Nielsen 1988).

Horizontal Intercept Angle: Inclination of the individual plates from the horizontal axis of the skeletal body of an individual i.e. at 90° to the axis of the central opening.

α_1: Inclination of Type A plates defined by the extinction in LM of Type B plates in the LM. This represents the [spiral angle].

α_2: Inclination of the individual plates of Type A to the horizontal plane. Accurate measurements can be made in the SEM.

β_1: Total inclination of Cycle B as seen in the LM, defining the [spiral angle]. This value differs by a few degrees to ß2 and shows the disposition of the plates in Cycle B.

β_2: The angle of inclination to the horizontal of individual Type B plates. Accurate measurements can be made in the SEM.

6.5.4. External Features

Outline: *Nannoconus* is highly variable in the external outline, the following shape guidelines were used:

Square: L=H.

Rectangular: L<H.

Globular: Sub-spherical.

Oval: Egg-shaped.

Conical: Cone-shaped.

Parallel-sided: External sides aligned.

Irregular-sided: External sides non-parallel.

External Structures:

Ridge: A raised surface visible on the external wall when viewed in the scanning electron microscope - overlap of long axis of the rhomboidal plates, directed externally.

Groove: Located between ridges, defined by the overlap of the short axis of the individual plates.

Flange: A vertical projection of plates, of wider a & b dimensions than the plates constructing the central body.

Single Flange: Flange present at one terminal pole only.

Double Flange: Flange located at both poles.

Regular Flange: Flange of equal diameter around the aperture.

Irregular Flange: Flange of unequal diameter around the aperture.

Bulb: A swelling of the external outline.

Single Bulb: A single swelling e.g. *N. borealis*.

Double Bulb: A double swelling e.g. *N. paskentiensis*.

Triple Bulb: A triple swelling e.g. *N. multicadus*.

Constriction: An external indentation of the wall.

6.5.5. Internal Contour

Central opening: A central gap, collective term for a canal or cavity.

Canal: central opening < 1 μm in total diameter.

Cavity: opening of the canal > 1 μm in total diameter.

Canal/Cavity Lining: The arrangement of the edges of the plates directed towards the central opening.

Aperture: The terminal opening of the canal/cavity to the exterior of the specimen.

Open Aperture: A distinct opening is visible in the LM, approx > 0.5μm.

Restricted Aperture: A very narrow pin-sized opening is present in the LM, approx < 0.5μm.

Apertural plates: plates surrounding the apertural opening, these may show variations in inclination from the horizontal axis of the specimen. These are termed High and Low angle apertural plates; may be useful for orientation purposes but further research is needed.

6.5.6. Extinction (top view/disc)

Sector extinction lines: Parallel-sided extinction pattern from the central opening to external wall.

Diffuse extinction lines: A fan-shaped extinction pattern, directed towards the exterior, representing plates in extinction.

6.5.7. Associations

Associations: A collection of individuals which imply an organised construction of biological origin.

Rosette: Collection of conical specimens lying side-by-side with the long axes radiating from a central point

Sphere: No convincing spherical associations have been illustrated - this term should be used with caution. *Nannosphaeroidina* was a term used to describe nannoconid 'spheres'

Monomorphic: *Nannosphaeroidina* found constructed only of one species of nannoconid individuals.

Double Structures: Two nannoconid individuals adhering at the poles with the wall ultrastructure in apparent crystallographic continuity throughout

the structure. Only two examplers have been recognised to date, *N. abundans* and *N. circularis* (this study).

6.5.8. Template for Taxonomic Descriptions

The following are arranged in descending order of taxonomic importance:

Top View:

1. maximum and minimum diameter measurements;
2. depth of focus, long or short (can indicate the approximate length of the specimen, care should be taken as the specimen may be broken);
3. are the plate edges discernable ?
4. type of extinction pattern.

Longitudinal view:

1. wall construction - the inclination and width of the cycles;
2. shape of the specimen;
3. dimensions;
4. central opening shape & dimensions;
5. nature of the apertural openings.

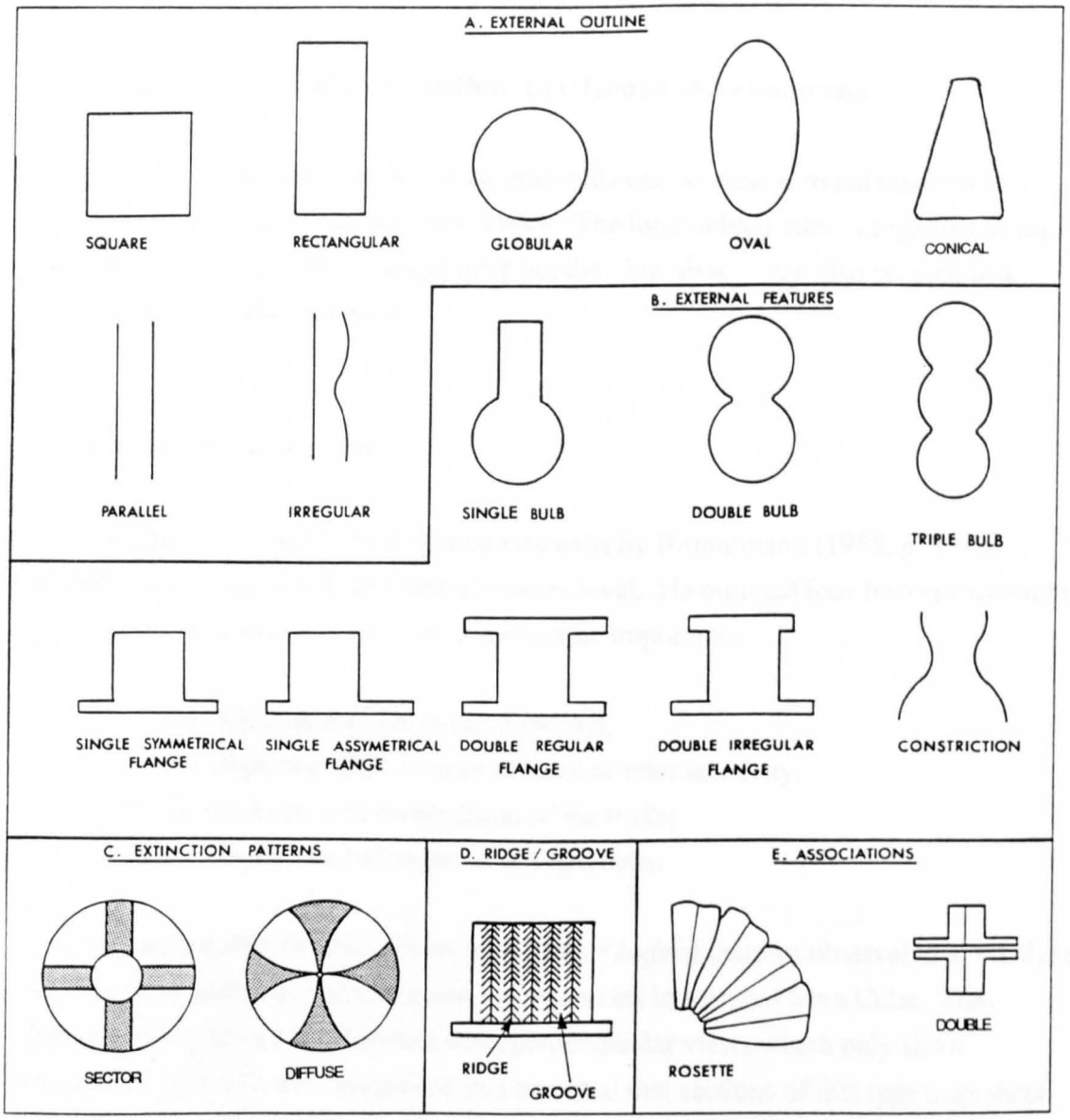


Figure 6.14. Descriptive terms for the genus *Nannoconus*.

Chapter 7.
Taxonomy

7.1 Species Classification within the Genus *Nannoconus*

There are two orientations in which nannoconids can be viewed to aid taxonomic identification: longitudinal and 'top' views. The longitudinal view is regarded as the diagnostic view for species assignments but the 'top view' can also be used to a minor degree for classification.

7.1.1 Longitudinal View

The longitudinal or axial canal section was used by Brönnimann (1955, p. 30) to identify these enigmatic organisms at species level. He outlined four features which he arranged in descending order of their taxonomic importance:

1) the outline and dimensions of the test;
2) the shape and size of the axial canal or internal cavity;
3) the thickness and composition of the walls;
4) the position and diameter of the apertures.

This simple but effective classification of morphological features observable in the light microscope enabled him to recognise 8 new species in material from Cuba. The difficulty of species determination from perpendicular views which only show characters 2) and 3) was recognised and he stated that sections of this type may show similarities in different species (*op. cit.* p. 30).

Subsequent species classifications have used Brönnimann's work as a template to construct diagrammatic schemes. Noël (1958) recognised four morphogroups based on the external outline of longitudinal sections and subdivided these using the width of the internal opening (i.e. canal or cavity). A total of 11 species were identified using these parameters, the final taxonomic determination based upon the length and diameter of the individual nannoconid specimen. Figure 7.1 illustrates the classification of nannoconids (Noël 1958). Similar methods of morphotype identification were used by

Farinacci (1964), however, she stated that the nannoconid shape is conditioned by the width and diameter of the canal/cavity.

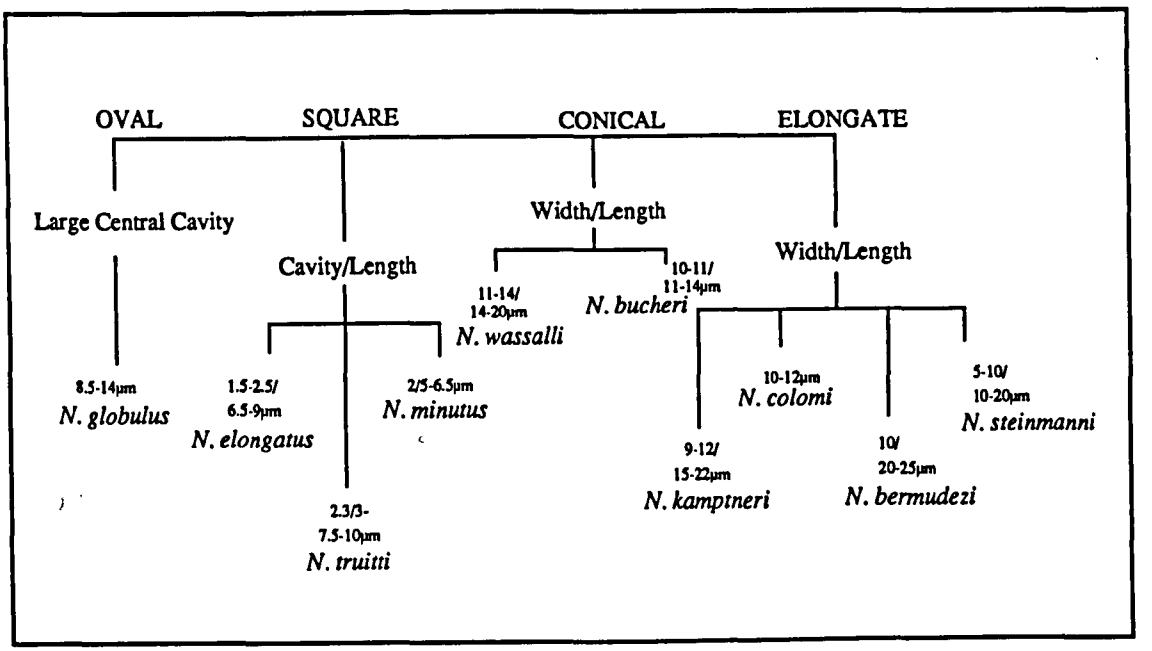


Figure 7.2 Classification of nannoconids (after Noël 1958).

Deres and Achériteguy (1972, Table. 1, p. 154) have used the scheme of Noël (1958 p. 175), modifying it to include a new morphogroup with a "collerette". A total of 21 species were identified from the Early Cretaceous of the Aquitaine Basin but no formal taxonomic descriptions were given and each morphospecies was assigned a number. Refer to figure 7.2 for the species classification scheme, redrawn from Deres and Achériteguy (1972).

Careful observations during the project and subsequent recognition of wall structure morphogroups within the genus *Nannoconus* enable a more rigorous classification of the morphospecies. The following characters of *Nannoconus* are arranged in descending order of their diagnostic importance for species identification (longitudinal section, LM observation):

1) The structure of the wall: i) an estimation of the angle of intersect between the horizontal axis and Cycle B, and ii) the width of Cycle A, place the specimens in one of the morphogroups recognised here.

2) External morphology and dimensions of the nannoconid body, including the development of flanges and constrictions in the external outline.

3) Internal morphology of the cavity/canal and relative dimensions in relation to the nannoconid body.

4) The dimensions of the apertural openings, which aid in establishing a standard orientation of the specimen. This orientation is hypothetical due to our lack of knowledge about the organism which produced nannoconids.

A summary of these diagnostic characters is given in fig. 7.3. Features 3 & 4 are only discernable in the light microscope which can hinder the correct identification of species in the scanning electron microscope, e.g. Wise & Cepek (1976) identified a scanning electron micrograph as *N. colomi* (syn. *N. steinmanni*), a species which would require the observation of the central canal in the light microscope to distinguish it from *N. kamptneri*.

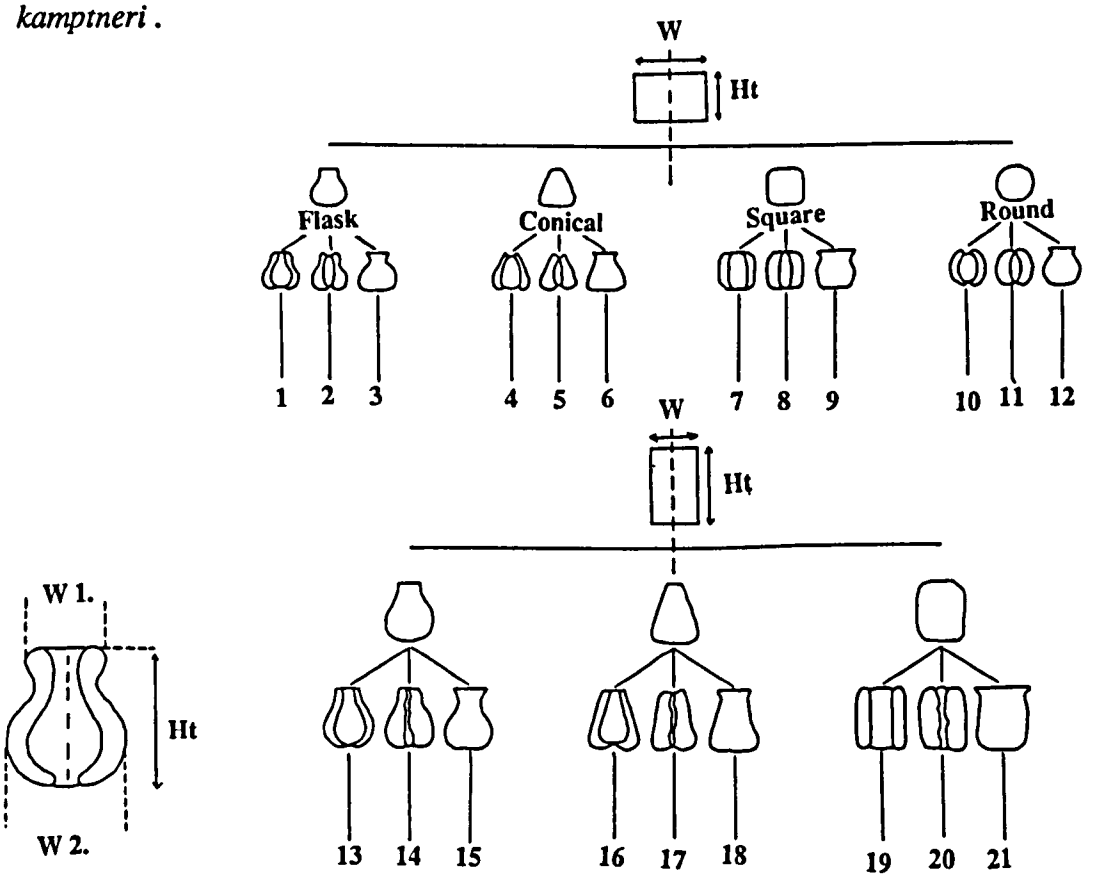


Figure 7.2 A morphotype classification, redrawn from Deres & Achériteguy (1980)

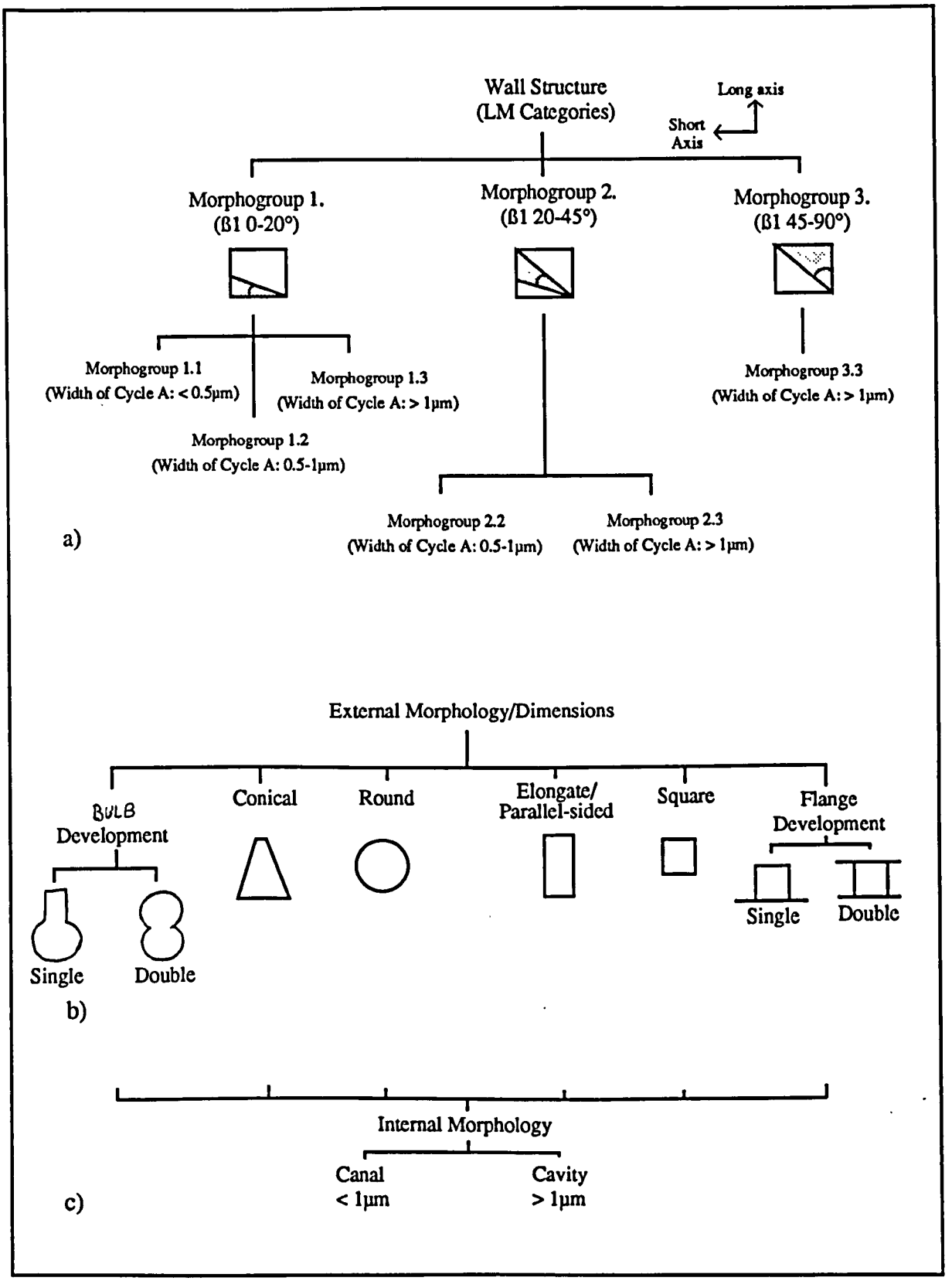


Figure 7.3. A proposed scheme to separate the nannoconid taxa identified in NW Europe (this study), based upon a longitudinal view.

Fig a) wall structure; b) external shape and size, applicable to all the morphogroups and c) internal morphology.

7.1.2 Top Views/Discs

The identification of top views or discs in the light microscope is more problematic than longitudinal views. Top views usually occur in the light microscope when the length is almost equal to the width or diameter of the specimen. Breakage of specimens can result in discs observed in top view, these cannot be readily distinguished from top views of complete specimens except for slight changes in the birefringence of the specimen. Species identification using this method of observation is therefore not always reliable. In an assemblage where longitudinal sections of nannoconids are available then inferences can be made as to the identification of top views. The following characters can aid morphogroup and inferred species identifications, combined with stratigraphic data.

1) the width and nature of the extinction lines from the central opening to the exterior of the top view;
2) maximum diameter;
3) dimensions of the internal diameter (i.e. the width of the central canal/cavity);
4) recognition of the individual elements in the wall; and
5) focal depth of the specimen, dependent upon the length of the specimen.

The extinction lines which we can observe in the light microscope show the orientation of the c-axes, of the individual plates to the optical axis of the microscope. The width of the lines and flaring towards the external margin are a product of:

1) the degree of overlap of plates in Cycle B;
2) dimensions of the individual plates and uneven arrangement of the plates from the center to exterior (decrease in the amount of dip, from the longitudinal axis towards the exterior) - this decreasing inclination results in flaring visible towards the external margin.

Specimens which usually have a very low α inclination and narrow Cycle A show very distinct flaring of the extinction lines, e.g. *N. abundans* (Pl. 8, fig. 1). The combination of: i) a short focal depth, ii) presence of a thin narrow flange, iii) very narrow central opening, and iv) no individual elements discernable in the wall, means that a top view can be assigned to species level. In contrast, increase in element size,

inclination and width of the cycles creates more clearly defined extinction lines, with minimal diffusion towards the external margin (thought to be due to the rigid nature of thicker plates maintaining a fixed inclination in the structure). This can be seen in the top view of *N. globulus globulus* (Pl. 20, fig. 7).

The ratio of canal/external outline can also be an invaluable tool for species identification purposes. In the scanning electron microscope, the optical details of the extinction lines are not available to aid identification, however, the specimen can be re-orientated to show an intact or broken nature. The same-specimen technique is ideal but is cost and time-ineffective. However, the greater amount of detail provided can allow more reliable taxonomic identifications to be made and should be used.

7.2 Nannoconid Taxonomy

The taxonomy of *Nannoconus* is problematic as is the classificatory position of the genus due to the lack of recognition of living forms. For the purposes of this study a floral affinity is adopted (refer to section 6.2) and consequently the International Code of Botanical Nomenclature was followed.

The study of *Nannoconus* species in the past has relied upon identification using gradational morphological characteristics, e.g. the shape of the external outline. This type of identification cannot be accurately used without strict biometric controls, which have not been exercised in previous works. Recognition of wall structure morphovariants during the course of the project (refer to Chapter 6) enables a qualitative approach with the observation of gradational characteristics. The reader is informed that new genera or sub-genera have not been erected on the basis of the wall variations until material is studied from the Tethys.

The following nannoconid taxonomy is based upon features which are easily visible in the light microscope, with scanning electron microscope study used only to confirm detail of the wall structure where preservation was good. Summary diagrams of species occurrence worldwide are given in addition to summary diagrams of the taxa (figs 7.22-7.25) a taxonomic list of the morphogroups recognised is given in section 7.3. An overall interpretation of the phylogenetic relationships of the morphogroups and individual taxa is outlined in Chapter 8.

Species are treated alphabetically within the morphogroups to which they have been assigned. Where appropriate the original diagnoses of a species is given, however, many authors have given descriptions and not formal diagnosis. Amendments to the original diagnoses and descriptions are based upon new observations. The diagnosis is related to morphological features after the "specimen" has been assigned to the individual wall-structure categories. A skeleton synonymy list is given in addition to the type reference for each taxon.

The term 'stratigraphic range' was used to represent the stratigraphical distribution data of the individual taxon obtained during the present study and from published sources. The main source and locality of the reference is indicated, where several authors quote similar results only a skeleton reference list is given. Only the well name is given for data obtained during this study as depths are available from the distribution charts. The ranges of the species studied in the material are correlated to the biostratigraphic scheme used and where possible the reliability of the occurrence data is shown by the following symbols:

——	documented range
----	range uncertain due to stage correlation difficulties

The α_2 and β_2 angles of the individual plates are given where measured from the scanning electron micrographs of well-preserved specimens, variations in the range of angles could not be given due to the lack of suitable micrographs of well-preserved material. The classification is based upon the light microscope groupings which were found to be easily identifiable.

The dimensions of the nannoconid individuals are recorded as shown:

Length (L): A measurement along the longitudinal axis of a specimen in an axial section. L_1: maximum measurement. L_2: Measurement of the central body, not inclusive of the length of the projection or bulb.

Width (W): A measurement across the horizontal axis of a specimen in a longitudinal view. W_1: maximum measurement. W_2: minimum measurement.

Wall (Wa): A measurement of the width of the wall in a longitudinal section, usually

the maximum value.

Cavity (C): A measurement of the diameter of the central opening in a longitudinal view.

Diameter (D): A transverse measurement of a top view or disc. (D_1): Maximum measurement. (D_2): Minimum measurement.

A compendium of nannofossils, other than nannoconids, found in the studied material is given in section 7.5 with reference to a good illustrative figure from published literature. Problematic species are discussed in the text.

The studied slides and photographic collection are housed in the Micropalaeontology Unit, University College London. Micrographs obtained during study of the Deflandre & Deflandre-Rigaud Collection (Laboratoire de Géologie du Muséum National d'Histoire Naturelle, Paris) are also housed in University College.

7.3 Taxonomic List of*Nannoconus*

		Page No:
Kingdom:	Plantae	
Order:	Incertae Sedis	
Family:	NannoconaceæDeflandre, 1959	85
Genus:	*Nannoconus* Kamptner, 1931	85

Morphogroup 1.1 ($ß_1$: < 20°, Width of Cycle A: < 0.5µm)

N. abundans Stradner & Grün, 1973 88
N. circularis Deres & Achériteguy, 1980 91
N. sp 1. sp. nov. 93
N. sp. (discs) [marker species for the Ryazanian - Crux, 1989] 94

Morphogroup 1.2 ($ß_1$: < 20°, Width of Cycle A: 0.5-1µm)

N. concavus Perch-Nielsen, 1988 95

Morphogroup 1.3 ($ß_1$: < 20°, Width of Cycle A: > 1µm)

N. sabinae Perch-Nielsen, 1988 97

Morphogroup 2.2 ($ß_1$: 20-45°, Width of Cycle A: 0.5-1µm)

N. aquitanicus Deres & Achériteguy, 1980 99
N. bucheri Brönnimann, 1955 100
N. dauvi llieri Deflandre & Deflandre-Rigaud ,1960 102
N. minutus Brönnimann, 1955 103
N. quadriangulus quadriangulus Deflandre & Deflandre-Rigaud, 1962 106
N. quadriangulus apertus Deflandre & Deflandre-Rigaud, 1962 108
N. truitti truitti (Brönnimann, 1955) subsp. emend. Deres & Achériteguy, 1980 110
N. truitti frequens Deres & Achériteguy, 1980 112
N. truitti rectangularis Deres & Achériteguy, 1980 114

Morphogroup 2.3 ($ß_1$: 20-45°, Width of Cycle A: > 1µm)

N. bermudezi Brönnimann, 1955 115
N. boneti Trejo, 1959 117
N. borealis Perch-Nielsen, 1979 119
N. elongatus elongatus (Brönnimann, 1955) subsp. emend. 122
N. elongatus minutus subsp. nov. 124

N. kamptneri kamptneri (Brönnimann, 1955) subsp. emend. Bralower, 1989 125
N. kamptneri minor Bralower, 1989 127
N. longus Perch-Nielsen, 1988 128
N. paskentaensis Bralower, 1990 128
N. steinmanni steinmanni (Kamptner, 1931) subsp. emend. Deres & Achériteguy,1980 130
N. steinmanni minor Deres & Achériteguy, 1980 133
N. sp 2. sp. nov. 133

Morphogroup 3.3 (β_1: > 45°, Width of Cycle A: > 1μm)

N. globulus globulus (Brönnimann, 1955) subsp. emend. Bralower, 1989 135
N. globulus minor Bralower, 1989 137
N. globulus A subsp. nov. 138
N. oviformis Perch-Nielsen, 1988 139
N. wassalli wassalli Brönnimann, 1955 subsp. nov. 141
N. wassalli minor comb. nov. 144
N. sp.3 (Deflandre & Deflandre-Rigaud Type Collection) 146

7.4 INCERTAE SEDIS

Nannoconaceae Deflandre 1959

Remarks: In 1959 Deflandre erected the Family Nannoconaceae to include nannoliths with a thick wall of wedges or plates of calcite orientated perpendicular to and radially around an axial cavity or canal. Three genera were assigned to this family by Tappan (1980); *Nannoconus* Kamptner 1931 (syn. *Brachiolithus* Noël 1958), *Conusphaera* Trejo 1969 (syn. *Cretaturbella* Thierstein 1971) and *Polycostella* Thierstein 1971. Perch-Nielsen (1985, p. 375) assigns the latter two genera to different families based upon morphological dissimilarities in structure. *Conusphaera* was assigned to the Crepidolithaceae Black 1971, a family which includes "elliptical coccoliths of substantial thickness consisting of a ring of calcite sectors without appreciable imbrication". *Polycostella* was placed in the Family Polycyclolithaceae Forchheimer 1972, containing cylindrical and block, star or rosette-shaped extinct nannoliths with or without distinct evolutionary links.

The Family Nannoconaceae is the host only to the genus *Nannoconus*. The affinities of this family are unknown

Nannoconus Kamptner 1931

Type species: *N. steinmanni* of Kamptner (1931, fig. 2).

Reference: "*Nannoconus steinmanni* nov. gen., nov. spec., ein Merkwürdiges mikrofossil aus dem jüngeren Mesozoikum der Alpen". *Palaeontologische Zeitschrift*, **13** (4), p. 289.

Synonym: *Faviconus* Bralower (1990).

Diagnosis: The author gave only a single description for the genus and species *N. steinmanni* described by him (please refer p. 130).

Remarks: The genus *Faviconus*, here regarded as a junior synonym, was described by Bralower (1990) from a single taxon *F. multicolumnatus*. He observed the structure to be composed of numerous stacked wedges, separated by thin axial canals and with

randomly arranged columns. Light microscope observation of type material and material from Turkey, containing specimens of *F. multicolumnatus* showed close similarities in wall structure to the genus *Nannoconus*. In longitudinal sections the wall of *F. multicolumnatus* appeared to show differential extinction, similar to the cycles observed in *Nannoconus*. The extinction of 'cycles' in *F. multicolumnatus* is used here to tentatively assign this species to Morphogroup 2.3 (Moderate β_1 inclination and wide Cycle A, approximately 1µm). However, further study, in the scanning electron microscope is needed to prove this hypothesis.

The different morphogroups recognised here are used to subdivide the genus *Nannoconus* into 5 Morphogroups using the β_1 intercept angle of Type B plates and width of Cycle A (LM categories). These groups have no formal taxonomic significance at present. The 'Morphogroups' might be considered as of subgeneric status but any decision is left open until further study of Tethyan and other species can be completed.

Stratigraphic Range: Upper Tithonian-Campanian.

Occurrence: Worldwide.

7.4.1 Morphogroup 1.

Defining Parameter: $\beta_1 < 20°$

The group is characterised by Boreal-endemic species with the exception of *N. circularis* (Morphogroup 1.1). All three Morphogroups were identified in this study, however, Morphogroup 1.1 contains the most taxa, with only one taxon representing groups 1.2 and 1.3.

Morphogroup 1.1

Species used to define morphogroup: *N. abundans*

Horizontal intercept angle: β_1: $< 20°$

Detailed measurements of the representative species: α_2: 7° and β_2: 13°

Width of spiral unit A: < 0.5μm

Remarks: The plates in the structure have a very narrow breadth which allows the orientation of the plates in the structure to be more flexible. A top view in the light microscope shows flaring extinction patterns (from the central opening outward) which is related to slight changes in the inclination of the individual plates to the optical axis. In the light microscope the $ß_1$ angle may appear to be almost zero, i.e. horizontal and Cycle A is very narrow .

Number of species recognised here: 3 shortbodied forms, 1 large disc of uncertain taxonomic importance.

Stratigraphic Range: Ryazanian-Aptian.

Distribution: *Nannoconus*. sp. 1 and *Nannoconus* sp. (discs) are rare and only observed in the Ryazanian-Valanginian interval. A gap in the stratigraphic distribution of this group is noted until the Barremian with the appearance of *N. abundans*. These earlier forms are endemic to NW Europe and it is not until the Early Aptian that *N. circularis* is known to migrate into the Western Tethys and Atlantic provinces.

Environmental Indicators: *N. abundans & N. circularis* can show very high, abundance percentages in the nannofossil assemblage. These peaks in abundance values are often sporadic which can infer peak production under favourable environmental stress conditions .

N. abundans, a major component of early Late Barremian assemblages, has a narrow central canal with distinctive single flange development (although variants have been found with a double flange). It obtains high abundance values throughout NW Europe, in particular in the Danish Central Trough where rare monospecific laminae of *N. abundans* have been observed. These laminae could not be placed in the seasonality cycle proposed by Thomsen (1989a &b). It is therefore suggested that partial depletion of surface waters in $CaCO_3$ by seasonal blooms of other nannofossil species, could be responsible for the blooms of *N. abundans*. Infrequent periods of cool water may also be closely related to the sporadic occurrence of these laminae.

N. circularis, increases in abundance in the Early Aptian and, in contrast to *N. abundans*, has a wide cavity apertural openings. The exact reason for the presence of a

wide cavity is not fully understood, one idea is that it may be related to water temperature as Tethyan nannoconids are dominated by forms with open cavities. This may explain why only this species was able to migrate from Boreal waters into the Tethyan realm.

A new morphospecies, *Nannoconus* sp.1 was recognised in the Valanginian. Only a few specimens were found, but it may represent one of the earliest species in Morphogroup 1. At first it was thought to be related to the thin, large discs described by Crux (1989) but no overlap in stratigraphic occurrence was found. This may indicate post-mortem loss due to partial calcification of the individuals.

N. abundans Stradner & Grün 1973
Pl. 7, figs 1-9; Pl. 8, figs 1-4.

Holotype: No. 71.234/9 of Stradner & Grün 1973.

Reference: "On *Nannoconus abundans* nov. spec. and on laminated calcite growth in Lower Cretaceous nannofossils". *Verhandlungen Geologische Bundesaustalt,* 2, p. 268.

Synonym: *N. boletus curtus* KAISER-Weidich & Schairer (1990, p. 381, table 1, fig. 15).

Diagnosis (original): A calcareous, cyclindrical to hyperboloidal body with the pillars of the same height and diameter with, a presumably, distal flaring flange up to twice the diameter of the pillar (a proximal flange can be present). The central canal is narrow with serrated sides and the central pillar shows clockwise obliquely situated grooves.

Horizontal Intercept angle: α_2: 7°, β_2: 13°.

Description: The straight axial canal has a uniform width along the longitudinal axis, restricted only by the narrow aperture of the proximal flange, the distal aperture being open. The central body is constructed of plates of uniform dimensions. In top view, the central barrel can appear to have a floral outline due to the external protrusion of the edges of the rhomboidal plates. In the SEM this clockwise array of plates defines the sub-vertical grooves and ridges which are visible on the external surface. The flange is

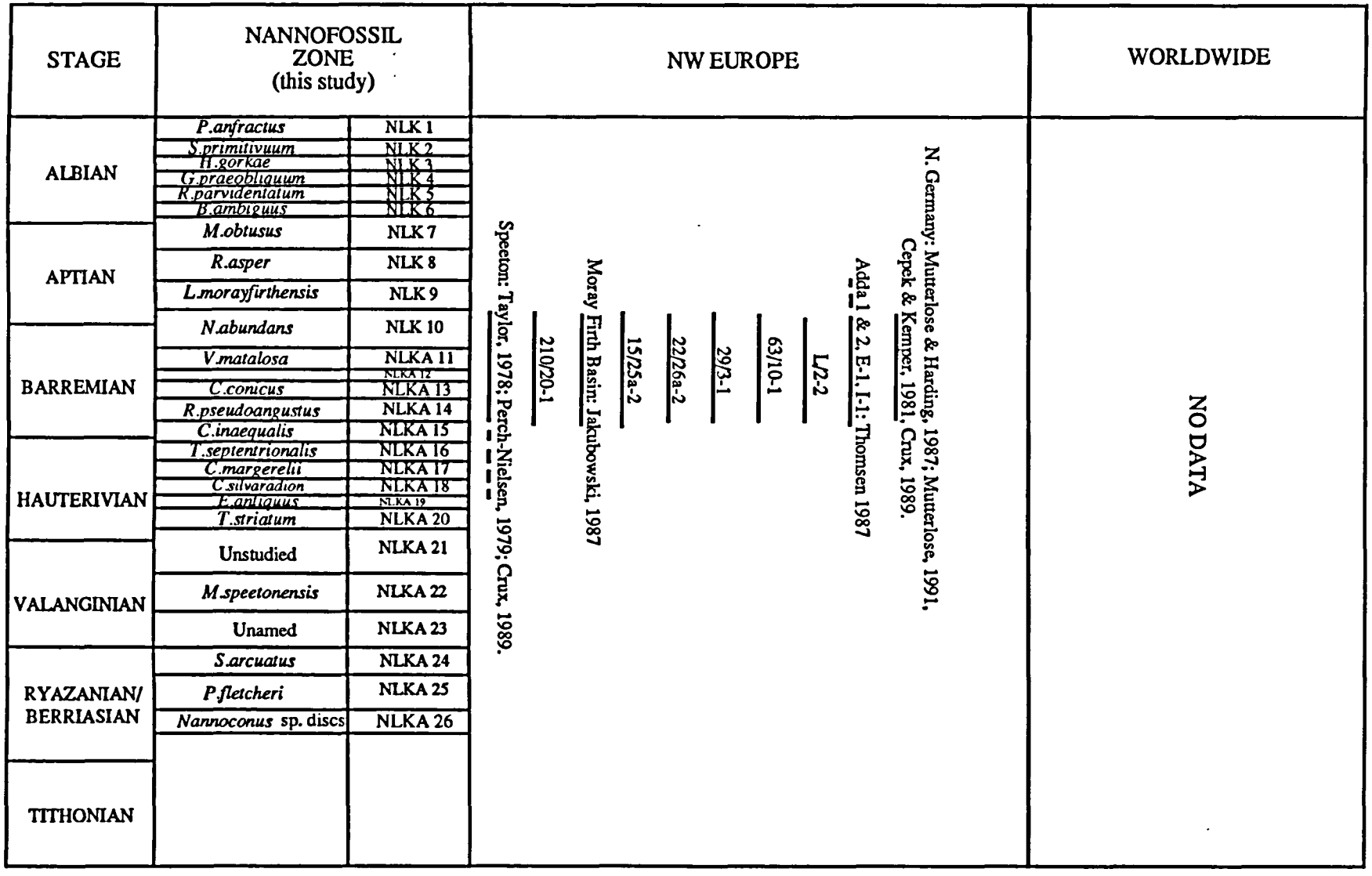


Figure 7.4. Worldwide distribution and range data for *N. abundans*

symmetrical and constructed of plates with a similar breadth to those in the central body but having greater dimensions.

Top View/Disc: Short focal depth through the specimen, intact specimens show central body with proximal flange as a thin, low birefringent disc (Pl. 7, fig. 3 & Pl. 8, figs 1 & 4). The extinction lines are diffuse and only a very narrow central canal observed. Disaggregated flanges are prone to selective dissolution and discs and top views are common, the central body frequently floral in outline (Pl. 7, figs 4 & 5). The individual elements can only be seen as feint plate edges in exceptionally well-preserved specimens. Aperture development is restricted at the proximal pole with only a pin-prick opening, the distal aperture being extremely restricted i.e. almost completely closed. Unusual double structures of *N. abundans* have been found in whole rock samples (Pl. 2, figs 6 & 7). For discussion of these structures please refer to section 6.1.2.

Dimensions: L_1: 4-8μm, W_1: 5-9μm, W_2: 4-6μm, Ca: < 1μm.

Published Dimensions: L_1: 8μm, W_1: 12μm.

Comparisons: *N. abundans* has previously been grouped with cylindrical-bodied morphoforms with two flanges. The proximal flange in this species can be up to twice the width of the central body, and the distal flange being only slightly developed. These latter forms may be assigned a subspecific status based upon the presence of two distinct flanges, but more specimens need to be studied. Due to the fragile nature of the flange, even slightly adverse preservational conditions can cause separation of the flange and central body. In top view of an intact specimen, the flange can be seen to encompass the central body (Pl. 7, fig. 3 and Pl. 8, figs 1 & 4). Stradner and Grün (1973) incorrectly relate *N. abundans* to morphogroups which show a constriction in their outline, *N. boletus* and *N. dauvillieri*. Both these species have here been assigned to morphogroup 2.2.

Remarks: A few specimens of *N. abundans* were found with distinct development of a flange at the distal pole in addition to the proximal pole. This distal flange was never observed to equal the proximal flange in size. Similar specimens have been illustrated, e.g. *N.* sp. 92 Perch-Nielsen (1979. p. 252, fig. 20); *N. abundans* in Mutterlose & Harding (1987. p. 211, Pl. 2, fig. 10, 11); *N.* sp. Thomsen (1987. Pl. 10, fig. 4-6 & Pl. 11, fig. 25). Further biometrical studies will aid in determining if this morphoform

is a subspecific taxa of *N. abundans*.

NW European Stratigraphic Range: Barremian. The top occurrence (TO) and base occurrence (BO) of this species are used to define the upper limit of Jakubowski's (1987) *N. abundans* zone (Late Barremian) and the lower limit of Crux's (1989) *N. abundans* zone (Early Barremian).

Occurrence: Figure 7.4

N. circularis Deres & Achériteguy 1980
Pl. 9, figs 1-6.

Holotype: Pl. 1, fig. 1 of Deres & Achériteguy 1980.

Reference: "Biostratigraphie des nannoconides". *Bulletin des Centres Recherches Exploration-Production Elf-Aquitane.* 4, p. 23.

Synonyms: *N.* sp. 1 Bouché (1965, pp. 134-135, tables 3 & 4).
N. wassalli Moshkovitz (1971, Pl. 2, fig. 14).
N. sp. Moshkovitz (1971, Pl. 3, figs 10-12 - top view, figs 13-15).
N. sp. 1 Moshkovitz (1972, pp. 17-21, Pl. 3, figs 9-15).
N. sp. 41 Deres & Achériteguy (1972, p. 157, Pl. 1, figs 19, 33).
N. sp. Crux (1989 p. 209, Pl. 8.14, figs 8, 9).
N. sp. 3 Weidich & Schairer (1990, p. 381, table 2, fig. 13).
N. minutus Mutterlose (1991, table 4, figs 2-4).

Diagnosis: (original): In longitudinal view the body is cyclindrical to quadriangular with convex sides. The axial canal is very wide with one open aperture and no opening apparent at the opposite pole. Fine striae can be seen in the wall.

Diagnosis (emended): A small, cylindrical nannoconid with truncated polar ends. *L* is equal to the*W*.

Description: A prominent feature of this species is the extremely well-developed central cavity encompassed by a narrow wall. The proximal aperture is slightly restricted by gently inclined plates from Cycle A attaining a lower angle of intersect than those at the opposite polar aperture. The distal aperture is characteristically very open,

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	ATLANTIC		PACIFIC
					NORTH	SOUTH	
ALBIAN	*P.anfractus*	NLK 1	211/21-2 Adda-2 N. Germany Mutterlose 1991 210/20-1 15/25a-2	Mozambique: D & A, 1980 Tunisia, Algeria, Sahara: D & A, 1980 SW & SE France, Mer d'Iroise, Spain: D & A, 1980	USA, Canada: D & A, 1980	DSDP 71: Mutterlose, 1989	Colombia: D & A, 1980
	S.primitivuum	NLK 2					
	H.gorkae	NLK 3					
	G.praeobliquum	NLK 4					
	R.parvidentatum	NLK 5					
	B.ambiguus	NLK 6					
APTIAN	*M.obtusus*	NLK 7					
	R.asper	NLK 8					
	L.morayfirthensis	NLK 9					
BARREMIAN	*N.abundans*	NLK 10					
	V.matalosa	NLKA 11					
		NLKA 12					
	C.conicus	NLKA 13					
	R.pseudoangustus	NLKA 14					
	C.inaequalis	NLKA 15					
HAUTERIVIAN	*T.septentrionalis*	NLKA 16					
	C.margerelii	NLKA 17					
	C.silvaradon	NLKA 18					
	E.antiquus	NLKA 19					
	T.striatum	NLKA 20					
VALANGINIAN	Unstudied	NLKA 21					
	M.speetonensis	NLKA 22					
	Unamed	NLKA 23					
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24					
	P.fletcheri	NLKA 25					
	Nannoconus sp. discs	NLKA 26					
TITHONIAN							

Figure 7.5. Worldwide distribution and range data for *N. circularis*

similar to a cup and the apertural plates are very steep (Type B Plates). Due to the narrow nature of the wall, and fine plates, no component elements are visible in the light microscope.

Top View/Disc: Species identification can be made on the high cavity/wall ratio, unique to this species within Morphogroup 1.1. The outer diameter varies from 7-12μm and the internal diameter can be up to 8μm. The focal depth is extremely short and the central cavity can show a low birefringent, granular texture (the proximal aperture plate arrangement).

Dimensions: L_1: 8-10μm, W_1: 7-12μm, Wa: 1-2μm.

Published Dimensions: L_1: 10-13μm, W_1: 10-18μm.

Remarks: Double structures of specimens attached by their "distal" apertures have been found, similar to *N. abundans* double structures. The apertural openings at the point of attachment appear to be open in contrast to the *N. abundans* structures which are very narrow, almost closed apertural openings. These are extremely rare and require exceptional preservation conditions such as is found in the Munk Marl, Danish Central Graben.

Stratigraphic Range: Barremian-Aptian in NW Europe and Aptian worldwide.

Occurrence: Figure 7.5.

Nannoconus sp. 1 sp. nov.
Pl. 8, figs 6 & 9.

Holotype: Pl. 8, fig. 6 of this study.

Type sample: 15/25a-2, 13071ft.

Type Level: Valanginian.

Diagnosis: The outline is comparable to a cross-sectional view of a blood corpuscle, with convex sides and a slight central depression at both poles. The width can be up to twice the length.

Description: The internal canal is poorly developed, but shows a slightly convex nature. The walls are distinctly convex and the individual cycles are well-defined, but the species is nevertheless considered to belong to Morphogroup 1.1.

Top View/Disc: This species may not always be seen in a longitudinal orientation due to the short longitudinal axis. Top views will appear as bright discs with a very short focal depth (smooth outline). The wall:cavity ratio is high and extinction lines flare towards the exterior. The individual elements are barely visible in the light microscope.

Dimensions: L_1: 4-5μm, W_1: 6-7μm, Ca: < 1μm.

Comparisons: *N. circularis* has a well-developed cavity with a greater length than breadth. *N. abundans* has a well-developed flange, however, a broken disc has a similar appearance except for the distinct polar indentations of this species.

Remarks: Only a few specimens of this species have been found in isolation from other nannoconid species. The specimens have been well-preserved with no signs of breakage. Initially an affinity of this species with the large discs of Crux (1989) was inferred but there is no evidence that they stratigraphically overlap. It may be that these early forms of Morphogroup 1.1 are the first endemic nannoconid species from NW Europe.

Stratigraphic Range: Valanginian, NLKA 23.

Occurrence: NW Europe.

Nannoconus sp. (discs) of Crux 1989
Pl. 8, fig.5 .

Description: These discs are very low in birefringence which implies they are only a few microns thick.

Remarks: These discs were first observed by Crux (1989) who utilized them in his Boreal zonation scheme due to their short stratigraphic range. No other nannoconids have been found in this interval, which is here interpreted as due to partial calcification of the skeletal body .

Stratigraphic occurrence: Late Ryazanian , NLKA 26.

Occurrence: NW Europe.

Morphogroup 1.2

During the course of the study a single taxon was assigned to this group. Few specimens were found and more need to be observed to reliably assign this species to Morphogroup 1.2.

N. concavus Perch-Nielsen 1988
Pl. 9, figs 7-12.

Holotype: Pl. 1, fig. 22 of Perch-Nielsen 1988.

Reference: "New Lower Cretaceous nannofossil species from England". *INA Newsletter*. **10**, p. 33.

Synonyms: *N. alvus* Perch-Nielsen (1988, Pl. 1, fig. 19, 20).
N. sp. 92 Perch-Nielsen (1979, p. 252, fig. 20).
N. sp. Mutterlose (1988, p. 207, table 11.4/3, fig. 8).
N. sp. 1 Crux (1989, p. 209, Pl. 8.14, fig. 16).
N. sp. Mutterlose (1991, table 21, fig. 18).

Horizontal Intercept Angle: α_2: 8°, β_2: 17°.

Diagnosis (original): A species of *Nannoconus* with "concave sides and apex, flat to concave basal part. The central canal is about 1/3 or less width in the central part. Thin flat rows of wedges".

Diagnosis (emended): A small species of *Nannoconus* with symmetrically concave sides and sub-concave poles. This species has the appearance of having minor symmetrical flanges at each pole.

Description: The wall is constricted centrally to give the mirror-image concave

outline. The apertural openings are small and are indistinct/restricted. The central canal is poorly developed in relation to the wall/cavity ratio. The proximal pole is slightly flatter in appearance and the elements surround the opening in a low angle barrier.

Top View/Disc: Due to its short body this species is often orientated as a top view which may be floral in outline. It has a short focal depth with a high wall:canal ratio. The extinction lines are distinct with very slight flaring towards the apertural opening.

Dimensions: L_1: 4-6μm, W_1: 6-8μm, W_2: 4-6μm.

Comparisons: The synonym *N. alvus* is described as "beehive-shaped with a very narrow central canal and very low angle rows of wedges". These features are observed when an oblique view of *N. concavus* is studied. *N. abundans* only has the development of a solitary, large flange, whilst *N. concavus* has two symmetrical flanges. The two species have been assigned to different Morphogroups here. Perch-Nielsen (1988) separated *N. quadratus* and *N. concavus* on the basis of the latter having a wider central canal.

Remarks: This species may have a longer range into the Barremian where a similar morphotype is recognised in the *N. abundans* zone of Jakubowski (1987). However, no comparable morphotypes have been found in the Valanginian-Hauterivian interval, which may suggest two different species or sporadic distribution related to non-calcification of the nannoconid individual or non-preservation/recognition in top view.

Stratigraphic Range: Late Ryazanian, NLKA 24/25.

Occurrence: NW Europe.

Morphogroup 1.3

The species *N. sabinae* is assigned to this morphogroup. However, due to the uncertain taxonomic status of the species the presence of this group is only tentatively proposed here. The morphogroup is characterized by thick rows of Type A plates, of very low inclination. The characteristic nature of the wall structure is that of a very low $ß_1$ angle and very wide Cycle A (related to large individual plates). No similar species occur in this stratigraphic interval.

N. sabinae Perch-Nielsen 1988
Pl. 8, figs 10-12.

Holotype: Pl. 1, figs 28, 29 of Perch-Nielsen 1988.

Reference: "New Lower Cretaceous nannofossil species from England". *INA Newsletter.* **10**, p. 35.

Diagnosis (original): "Flat to high species of nannoconid consisting of parallel lying wedges consisting of very thin parallel lying tiers and without a central canal".

Diagnosis (emended): This species is characterised by a sub-oval outline and very distinct coarse plates stacked into sub-horizontal cycles.

Description: In the light microscope this species is recognised by the very high birefringence and distinct wall structure. No cavity or canal can usually be seen due to the high birefringence of the wall, but a vague outline of an open cavity can often be observed. The structure appears highly susceptible to recrystallisation due to the coarse nature of the individual elements which are arranged in tiers. Breakage is common giving the beehive-shaped paratypes illustrated in Perch-Nielsen (1988. Pl.1, figs 28, 29).

Top View/Disc: The similarity of the coarse cycles of *N. sabinae* with those of discs found by Crux (1989) has been noted by Perch-Nielsen (1988). However, the discs contain a very narrow central opening in contrast to the cavity shown in *N. sabinae* in Perch-Nielsen (1988, fig. 30). The characteristics of the birefringence pattern also suggest that these forms are not comparable. The discs have a bright yellow birefringence with the easily discernable elements.

Dimensions: L_l: 10μm, W_l: 8μm, Ca: 4μm.

Published Dimensions: Not given.

Comparisons: The structure is unique to this species at this stratigraphic interval, however, it shows similarities to broken and overgrown specimens of *N. globulus globulus.*

Remarks: *N. sabinae* is very scarce and is usually found as broken, beehive-shaped specimens. The specimens show an E-2 degree of overgrowth, however, although the individual plates are overgrown they are still clearly discernable and the overgrowth enhance the orientation of the Type A and B plates in the light microscope. The large discs found in the Late Ryazanian have been suggested to be broken specimens of *N. sabinae* by Perch-Nielsen (1988).

Stratigraphic Range: Late Ryazanian, NLKA 24/25.

Occurrence: NW Europe.

7.4.2 Morphogroup 2.

Defining Parameter: β_1 20-45°.

This morphogroup encompasses the largest number of nannoconid species found here, containing some of the most elongate taxa. *Nannosphaeroidina*, constructed of *N. steinmanni* individuals, were found in samples from Cuba by Trejo (1960). A total of two Morphogroups, 2.2 and 2.3, were recognised in the material studied. No examples with of Morphogroup 2.1 were observed.

Morphogroup 2.2

Species used to define morphogroup: *N. bucheri*

Horizontal Intercept Angle: β_1 20-45°

Detailed measurements of the representative species: α_2: 5°, β_2: 20°.

Width of Spiral Unit A: 0.5-1μm.

Description: This morphogroup is distinguished from Morphogroup 2.3 by the slightly narrower dimensions of Cycle A. This is thought to be due to a slight difference in the breadth of the individual plates.
Number of Species: 9, varying from parallel-sided to slightly conical in outline.

Stratigraphic Range: Late Ryazanian/Berriasian-Albian.

Distribution: The species in this morphogroup are widespread in the Western Tethys and Atlantic. This group dominates the Aptian interval in NW Europe with the taxa: *N. truitti* group; *N. minutus*, and *N. quadriangulus* group.

N. aquitanicus Deres & Achériteguy 1980
Pl. 8, figs 7 & 8.

Holotype: Pl. 1, fig. 4 of Deres & Achériteguy 1980.

Reference: "Biostratigraphie des nannoconides". *Bulletin des Centre Recherches Exploration-Production Elf-Aquitane.* 4, p. 21.

Synonym: No good illustrations of this taxon.

Diagnosis (original): "The test is large with two asymmetrical poles, the base is rounded and the upper end is truncated with a slightly developed collar. The axial canal has an irregular contour and the walls show distinct striae".

Diagnosis (emended): The body is sub-conical with a slightly bulbous proximal pole. The wall has a near-median constriction which becomes concave towards the truncated terminal poles.

Description: The holotype micrograph is thought to misrepresent the species due to distortion of the distal pole, giving it the appearance of being markedly concave. A central canal has developed which maintains an elongate symmetrical nature, only slightly indented at the point of wall constriction. Apertural openings are semi-restricted.

Top View/Disc: Rarely seen.

Dimensions: L_1: 11-13.5μm, W_1: 8.5-10μm, W_2: 7-8.5μm.

Comparisons: *N. boletus curtus* is similar in outline but is smaller in dimensions and is here assigned to morphogroup 2.3.

Stratigraphic Range: Barremian.

Occurrence: NW Europe (? one specimen found in North Jens-1), Paris Basin .

N. bucheri Brönnimann 1955
Pl. 10, figs 3-11.

Holotype: Fig. 2 of Brönnimann 1955.

Reference: "Microfossils Incertae Sedis from the Upper Jurrassic and Lower Cretaceous of Cuba". *Micropaleontology.* **1**, p. 39.

Synonyms: *N. colomi* Baldi-Beke (1961, p. 177, table 1, figs 5, 6, 13, 16).
N. colomi Baldi-Beke (1962, p. 179, table 2, figs 7, 8).
N. steinmanni Baldi-Beke (1962, p. 179, table 2, figs 4, 5).
N. farinacae Bukry (1969, p. 67, Pl. 40, figs 9-12).
N. bronnimannii Deres & Achériteguy (1980, Pl. 2, figs 6, 13).
N. bronnimannii Manivit *et al.* (1986, p. 120, Pl. 2, fig. 2).

Horizontal Intercept Angle: α_2: 5°, β_2: 20°.

Diagnosis (original): "In an axial section the test is sub-ovoid, with a broad and flat basal portion. The walls enclose a large central cavity which opens into two terminal apertures. The top portion of the test is slightly rounded to flat".

Diagnosis (emended): The outline is sub-conical with a broad, truncated proximal pole and rounded distal pole.

Description: This species has a well developed sub-conical cavity which terminates in a restricted proximal aperture, enclosed by elements orientated at a low angle to the horizontal axis. The distal aperture is open with elements at a higher degree of inclination surrounding the apertural opening. The wall construction, and plate orientations within the cycles is easily visible.

Top View/Disc: Due to the slightly elongate nature of this species, longitudinal or

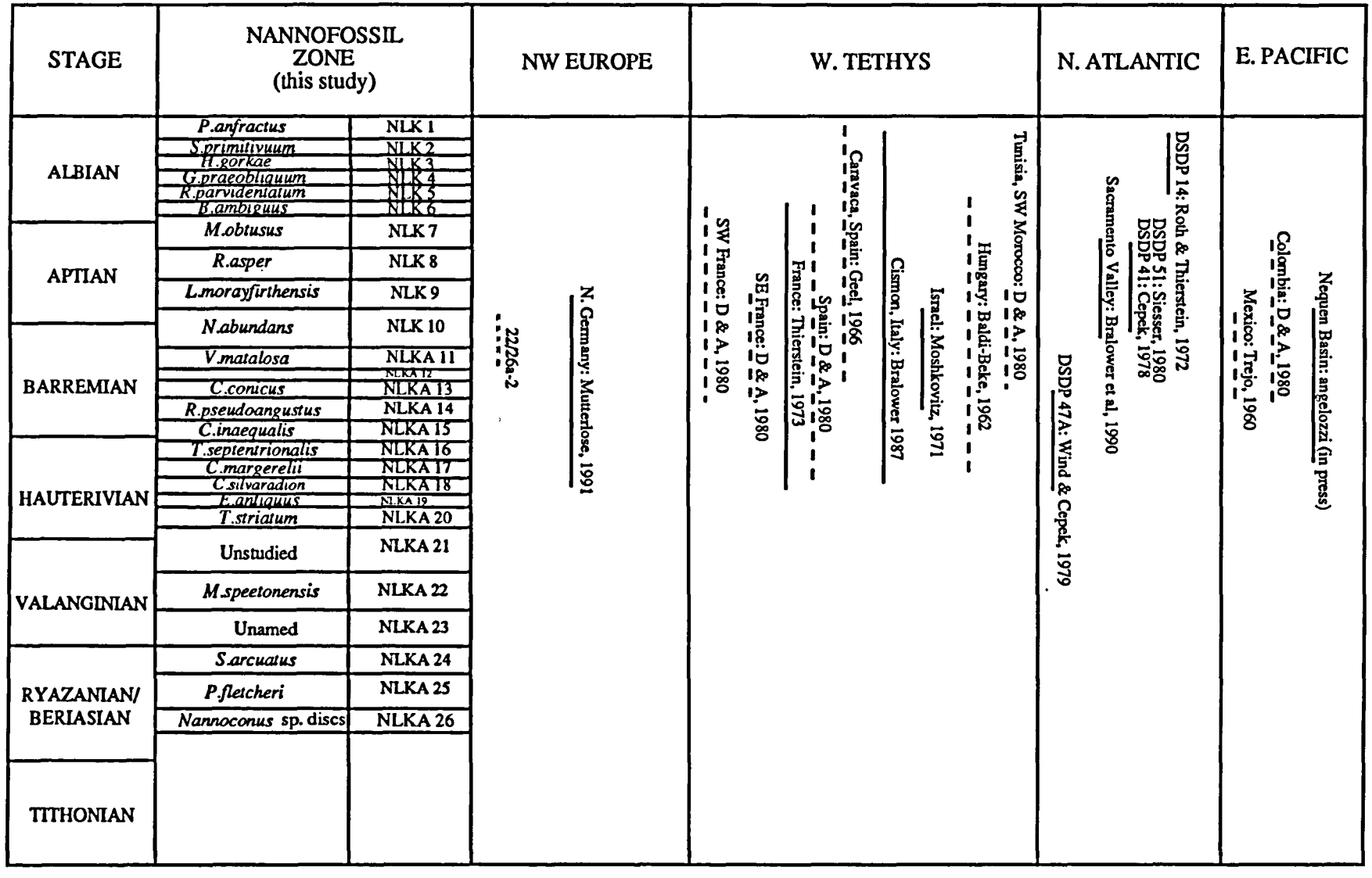


Figure 7.6 Worldwide distribution and range data for *N. bucheri*

slightly oblique sections are usually seen.

Dimensions: L_1: 7-14μm, W_1: 7-9μm, W_2: 4-6μm, Wa: 2-2.5μm.

Published Dimensions: L_1: 11-14μm, W_1: 10-11μm, Wa: 3-4μm (Brönnimann 1955).

Comparisons: *N. wassalli wassalli* differs in the wall structure and pear-shaped outline. *N. kamptneri minor* contrasts in having a distinct conical nature and a wider width of Cycle A. *N. farinaceae* is regarded as a synonym of the species described here and was originally identified using a transmission electron micrograph; the external outline, cavity and wall structure are comparable to *N. bucheri*. The stratigraphic range of *N. farinacae*, however, is recorded as Santonian.

Remarks: *N. bucheri* is one of the most common nannoconid species found in the nannofossil assemblages of the Hauterivian-Barremian interval.

Stratigraphic Range: Hauterivian-Aptian/ALBIAN.

Occurrence: Figure 7.6.

N. dauvillieri Deflandre & Deflandre-Rigaud 1960
Pl. 12, figs 3, 6, 8-11.

Holotype: Figs 22-23 of Deflandre & Deflandre-Rigaud 1960.
(Laboratoire de Géologie du Muséum National d'Histoire Naturelle, Paris référence no: BG. 59. Slide no: 18/27)

Reference: " Présence de Nannoconidés dans le Cretacé Superiéur du Bassin Parisien". *Revue de Micropaléontologie.* 2 (4), p. 177.

Horizontal Intercept Angle: α_2: 5°, β_2: 30°.

Diagnosis (Original): "The test is an elongated cyclinder with a single slightly rounded pole. The axial cavity is cylindrical and opens at both poles. Inclined superficial striae are present.

Diagnosis (emended): A species which has a sub-cylindrical outline with a flaring of the wall at the proximal pole.

Description: The terminal poles of the species are sub-rounded, but the proximal pole is flared with the greatest degree of rounding. Plates surrounding the apertural openings are at a high angle. The distal pole is parallel-sided to very slightly flared with the apertural elements at a high intercept angle surrounding the opening.

TopView/Disc: Rarely seen due to elongate outline.

Dimensions: L_1: 10-12μm, W_1: 6-9μm, W_2: 5-7μm , Wa: 1-2μm.

Published Dimensions: L_1: 12-14.5μm, W_1: 8.2-9μm, W_2: 5.5-6.7μm, Ca: 1.5-2.2μm (Deflandre & Deflandre-Rigaud 1960).

Comparisons: *N. dauvillieri* has slight flaring at the proximal pole in contrast to *N. paskentaensis* which has two distinct lobes. It is distinguished from *N. elongatus elongatus* in its lower $ß_1$ angle and slight flaring of the margin.

Stratigraphic Range: Barremian-Aptian/Albian (? Santonian, Deflandre & Deflandre-Rigaud, 1960).

Occurrence: NW Europe (North Jens-1, few specimens), W. Tethys (Paris Basin).

N. minutus Brönnimann 1955
Pl. 13, figs 1-12.

Holotype: Fig. 9 of Brönnimann 1955.

Reference: "Microfossils Incertae Sedis from the Upper Jurassic and Lower Cretaceous from Cuba". *Micropaleontology.* **1**, p. 38.

Synonyms: *N. colomi* Noël (1958, p. 177, Pl. 4, fig. 38).
N. truitti Baldi-Beke (1961, p. 177, Pl. 1, fig. 10).
N. truitti Baldi-Beke (1962, p. 179, Pl.2, fig. 15).
N. inconspicuus Deflandre & Deflandre-Rigaud (1962, p. 2639, fig. 10).

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC	E. PACIFIC
ALBIAN	*P.anfractus*	NLK 1				Colombia: D & A, 1980
	S.primitivuum	NLK 2				Mexico: Trejo 1960, Cantu Chapa 1989
	H.gorkae	NLK 3				Suriname: D & A, 1980
	G.praeobliquum	NLK 4				
	R.parvidentatum	NLK 5				
	B.ambiguus	NLK 6				
APTIAN	*M.obtusus*	NLK 7			DSDP 36: Wise & Wind, 1977	
	R.asper	NLK 8			DSDP 48: Muller, 1979	
	L.morayfirthensis	NLK 9				
	N.abundans	NLK 10			Canada: D & A, 1980	
BARREMIAN	*V.matalosa*	NLKA 11				
		NLKA 12			DSDP 534A: Bralower et al, 1989	
	C.conicus	NLKA 13				
	R.pseudoangustus	NLKA 14		Mozambique: D & A, 1980		
	C.inaequalis	NLKA 15			Sacramento Valley: Bralower et al, 1990	
	T.septentrionalis	NLKA 16		Algeria: D & A, 1980		
	C.margerelii	NLKA 17				
	C.silvaradion	NLKA 18		Tunisia, SW Morocco: D & A, 1980		
	E.antiquus	NLKA 19				
	T.striatum	NLKA 20		Hungary: Baldi-Beke, 1961		
HAUTERIVIAN	Unstudied	NLKA 21		Caravaca, Spain: Geel, 1966		
	M.speetonensis	NLKA 22		Spain: D & A, 1980		
	Unamed	NLKA 23				
				SE France: D & A, 1980		
				Mer d'Iroise: D & A, 1980		
				SW France: D & A, 1980		
				France: Thierstein, 1973, Bouche, 1965		
VALANGINIAN	*S.arcuatus*	NLKA 24				
	P.fletcheri	NLKA 25				
	Nannoconus sp. discs	NLKA 26				
RYAZANIAN/ BERIASIAN						
TITHONIAN			43/13-1	Skinnabanken: Crux, 1989		
			211/21-2	N. Germany: Mutterlose, 1988 & 91, Crux, 1989		
				Speeton: Crux, 1989		
				210/20-1		

Figure 7.7 Worldwide distribution and range data for *N. minutus*

N. sp. 2 Bouché (1965, p. 134-5, table 3/4).
N. cf *calpidomorphous* Geel (1966) p. 379, Pl. 11B).

Diagnosis (Original): "Its test has the form of a U-shaped square. In axial section it shows affinity to *N. truitti*, practically flat at the base and at the top. The parallel walls enclose a cavity with two terminal apertures of equal width present".

Diagnosis (emended): A small, sub-rectangular nannoconid with truncated terminal poles.

Description: This is one of the smaller species of nannoconid which shows the development of the canal symmetrically along the length of the specimen. The apertural openings are open although their small size can obscure the detail. The narrowest aperture is recognized by a slight constriction of the opening and plates orientated in a low angle cycle.

Top View/Disc: The minute nature of this specimen is characteristic in top view, with a relatively high ratio of cavity:wall. Elements are usually discernable and the extinction lines are well defined with no flaring towards the external wall.

Dimensions: L_1: 4-8µm, W_1: 3.5-7µm, Wa: 1-2µm.

Published Dimensions: *L*: Not given, W_1: 5-6µm, Wa: 2µm (Brönnimann 1955). L_1: 2µm, W_1: 3.5µm (Synonym, *N. inconspicuus*).

Comparisons: The unique dimensions and wall construction of this taxon distinguish it from other sub-rectangular species which are here assigned to different morphogroups. *N. inconspicuus* Deflandre & Deflandre-Rigaud 1962 is here regarded as a small form of *N. minutus* and the wall structure and stratigraphic ranges are comparable. Only a solitary dimension is given for the type specimen, which may not fall into the average dimensions for this species.

Remarks: *N. minutus* is not recorded in NW Europe until the Early Valanginian, but ranges from the Tithonian elsewhere (see fig. 7.7).

Stratigraphic Interval: TITHONIAN?/Berriasian-Aptian/Albian.

Occurrence: Figure 7.7.

N. quadriangulus Deflandre & Deflandre-Rigaud 1962

This new species was subdivided into two subspecies, *N. quadriangulus quadriangulus* and *N. quadriangulus apertus* in the same publication.

N. quadriangulus quadriangulus Deflandre & Deflandre-Rigaud 1962 Pl. 11, figs 1-6.

Holotype: Figs 11, 12 of Deflandre & Deflandre-Rigaud 1962.

Reference: "Remarques sur l'évolution des Nannoconidés à propos de quelques nouveaux types du Crétacé Inférieur de Haute-Provence". *Comptes Rendus des Séances de l'Academie des Sciences.* 255, p. 2639.

Diagnosis (original): The test is quadriangular, as wide as it is high, with the extreme parts of the test truncated. The internal cavity is cylindrical and the wall shows slightly inclined superficial striae.

Diagnosis (emended): A subspecies of *N.quadriangulus* in which the external outline is square to cylindrical with truncated poles, the central canal is narrow.

Description: The external outline is symmetrical with a developed central canal. The polar apertures are both open with only slight alteration in element orientation around the openings.

Top View/Disc: These are usually characterized by a floral outline due to the pronounced grooves and ridges visible in the scanning electron microscope (refer to Thomsen, 1987). Top views are very common due to the short body length.

Dimensions: L_1: 5-6μm, W_1: 5-7μm.

Published Dimensions: L_1: 5.5-5.7μm, W_1: 6μm (Deflandre & Deflandre-Rigaud 1962).

Comparisons: The holotype for this specimen is a sketch, which although accurate

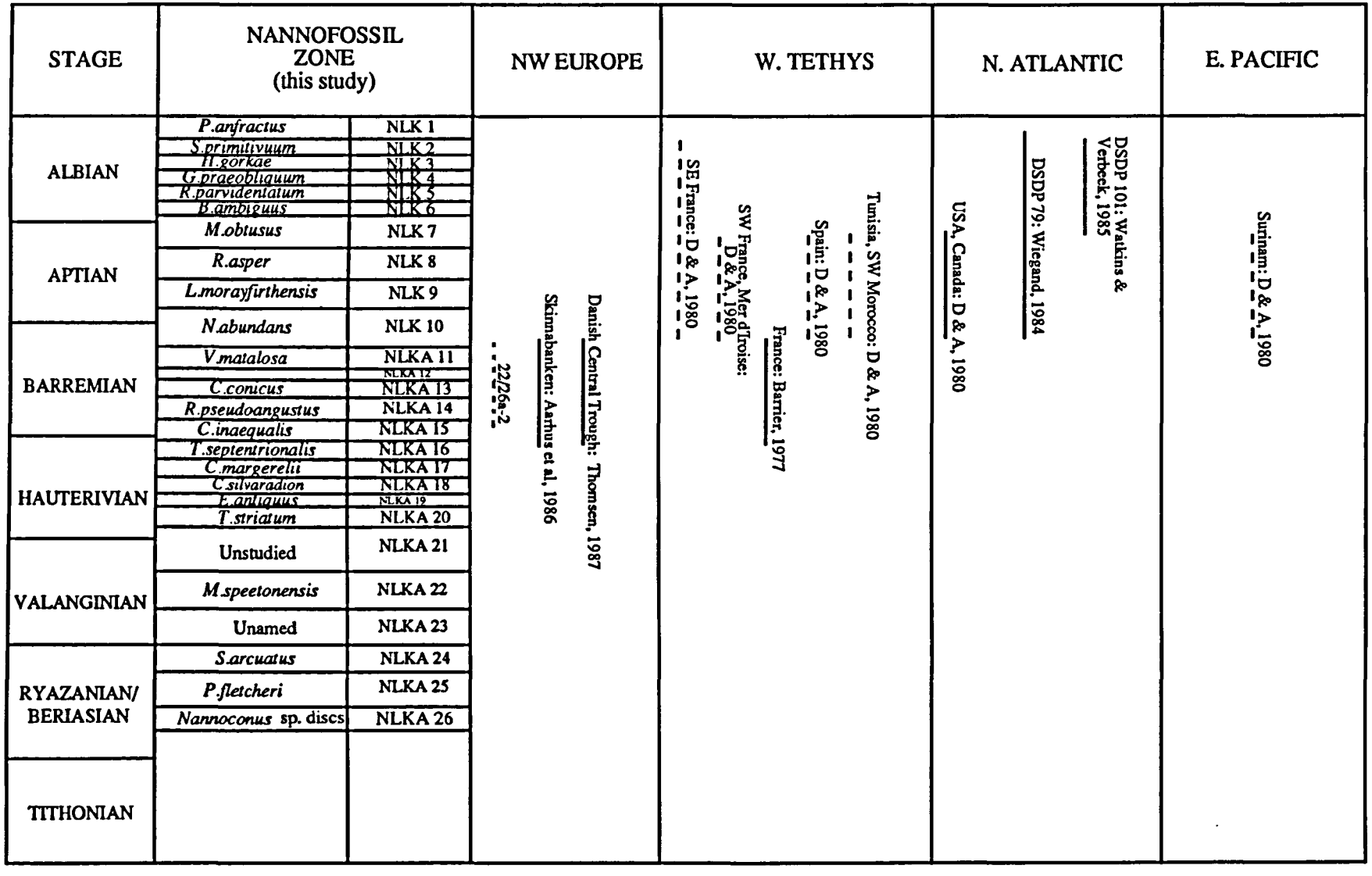


Figure 7.8 Worldwide distribution and range data for *N. quadriangulus quadriangulus*

cannot easily be compared with a type photograph. *N. elongatus elongatus* differs in being a more cylindrical form with a different wall structure morphology. The sub-species *N. quadriangulus apertus* is distinguished by the wider cavity and distal aperture opening. The figured specimen is from the type slide collection of Deflandre & Deflandre-Rigaud.

Remarks: *N. quadriangulus quadriangulus* first appears in the Barremian of NW Europe and is not recorded in the Western Tethys until the Aptian (Barrier shows it in the Barremian but his stratigraphy appears to be inaccurate).

Stratigraphic Range: Barremian-Aptian/ALBIAN

Occurrence: Figure 7.8.

N. quadriangulus apertus Deflandre & Deflandre-Rigaud 1962
Pl. 11, figs 7-12 & Pl. 12, figs 1-2, 4-5 & 7.

Holotype: Figs 13, 14 of Deflandre & Deflandre-Rigaud 1962.

Reference: "Remarques sur l'évolution des Nannoconidés à propos de quelques nouveaux types du Crétacé Inferieur de Haute-Provence". *Comptes Rendus des Séances l'Academie des Sciences.* **255**, p. 2639.

Synonym: *N. fragilis* Deres & Achériteguy (1980, p. 157, Pl. 2, fig. 15).

Diagnosis (original): A subspecies of *N. quadriangulus* but with a wider central cavity and slightly protruding distal aperture than *N. quadriangulus quadriangulus.*

Description: As for *N. quadriangulus quadriangulus* except for the wider canal..

Top View/Disc: The short-bodied nature of the species means that it is usually seen as a top view. Semi-distinct extinction sectors are visible in the narrow wall rim surrounding a large central opening.

Dimensions: L_1: 5-7µm , W_1: 6-7.5µm, Wa: 1-2µm.

Published Dimensions: L_1: 5-5.5µm , W_1: 6.5-7µm, W_2: 5.5µm (Deflandre &

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC	E. PACIFIC
ALBIAN	*P.anfractus*	NLK 1	Danish Central Trough: Thomsen, 1987	SE France: D & A 1980, Bamier 1977 SW France, Mer d'Troise: D & A 1980 Spain: D & A, 1980 Tunisia, SW Morocco: D & A, 1980	DSDP 79: Mutterlose & Wise, 1990 Canada: D & A, 1980	Colombia, Surinam: D & A, 1980
	S.primitivuum	NLK 2				
	H.gorkae	NLK 3				
	G.praeobliquum	NLK 4				
	R.parvidentatum	NLK 5				
	B.ambiguus	NLK 6				
APTIAN	*M.obtusus*	NLK 7				
	R.asper	NLK 8				
	L.morayfirthensis	NLK 9				
BARREMIAN	*N.abundans*	NLK 10				
	V.matalosa	NLKA 11				
		NLKA 12				
	C.conicus	NLKA 13				
	R.pseudoangustus	NLKA 14				
	C.inaequalis	NLKA 15				
HAUTERIVIAN	*T.septentrionalis*	NLKA 16				
	C.margerelii	NLKA 17				
	C.silvaradion	NLKA 18				
	E.antiquus	NLKA 19				
	T.striatum	NLKA 20				
VALANGINIAN	Unstudied	NLKA 21				
	M.speetonensis	NLKA 22				
	Unamed	NLKA 23				
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24				
	P.fletcheri	NLKA 25				
	Nannoconus sp. discs	NLKA 26				
TITHONIAN						

Figure 7.9 Worldwide distribution and range data for *N. quadriangulus apertus*

Deflandre-Rigaud 1962). L_1: 6-8µm , W_1: 7-9µm (synonym, *N. fragilis* Deres & Achériteguy 1980).

Comparisons: The cavity is distinctly developed and the distal aperture is wider (x2) than in *N. quadriangulus quadriangulus*. *N. fragilis* is regarded as a synonym, the external appearance and construction features are comparable with *N. quadriangulus apertus*.

Remarks: A similar distribution to *N. quadriangulus quadriangulus* can be seen.

Stratigraphic Range: Barremian-Aptian/ALBIAN

Occurrence: Figure 7.9.

N. truitti Brönnimann 1955

This taxon has been subdivided into three subspecies: *N. truitti truitti*, *N. truitti frequens* and *N. truitti rectangularis*. Please refer to *N. truitti truitti* for the original diagnosis of this taxon.

N. truitti truitti (Brönnimann 1955) subsp. emend. Deres & Achériteguy 1980
Pl. 10, fig. 2

Holotype: Fig. 2 of Brönnimann 1955.

Reference: "Microfossils Incertae Sedis from the Upper Jurassic and Lower Cretaceous of Cuba". *Micropaleontology*. **1**, p. 38.

Synonyms: *N. steinmanni* Baldi-Beke (1961, p. 177, Pl. 1, fig. 1).
N. steinmanni Baldi-Beke (1962, p. 179, table 2, fig. 1).
N. elongatus Moshkovitz (1971, Pl. 2, figs 1-3).
N. sp. Lambert (1987, Pl. 2, fig. 3).
N. sp. Angelozzi (*in press*, figs 15-16).

Diagnosis (original): In axial sections the outline is U-shaped to square with the basal portion slightly rounded and top flat. The walls are parallel and enclose a central

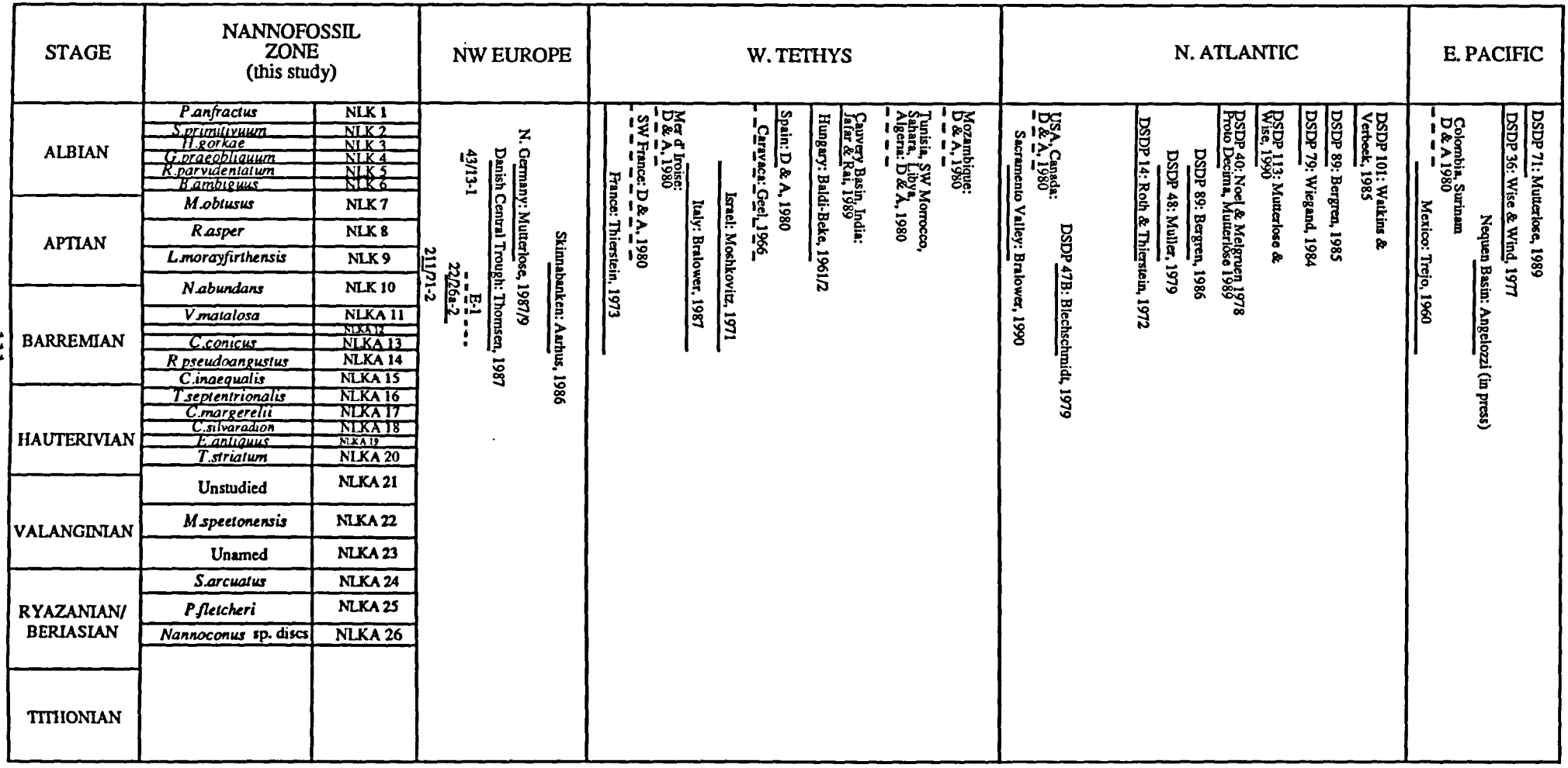


Figure 7.10 Worldwide distribution and range data for *N. truitti truitti*

cavity. The basal aperture is smaller than the apical one which is as large as the cavity opening.

Diagnosis (emended): A sub-species of *N. truitti* with an elongate, rectangular outline and semi-truncated poles and narrow central cavity.

Description: The proximal aperture is slightly restricted and is concave towards the exterior with high angle elements around the apertural opening. The distal apertural opening is open with elements at low angle. Cavity symmetrical, following the exterior outline.

Top View/Disc: Difficult to distinguish from species such as *N. bucheri* .

Dimensions: L_1: 7-9μm, W_1: 8-9μm, Wa: 2-2.5μm.

Published Dimensions: *L*: Not given, W_1: 7.5-10μm, Wa: 2.5-3μm (Brönnimann 1955).

Comparisons: *N. truitti truitti* is a morphologically variable species and frequently the sub-species are grouped together. The subspecies *N. truitti frequens* differs in being slightly more elongate in contrast to *N. truitti rectangularis* which is wider than high. *N. bucheri* is characteristically very conical in outline.

Stratigraphic Range: Late Barremian-Aptian/Albian.

Occurrence: Figure 7.10.

N. truitti frequens Deres & Achériteguy 1980

Not Illustrated

Holotype: Fig. 10 of Deres & Achériteguy 1980.

Reference: "Biostratigraphie des nannoconides". *Bulletin des Centres Recherches Exploration-Production Elf-Aquitane.* 4, p. 24.

Diagnosis (original): A subspecies of *N. truitti* with a more elongated, rectangular outline. The sides are convex and the poles slightly rounded.

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC	E. PACIFIC
ALBIAN	*P.anfractus*	NLK 1	Danish Central Trough: Thomsen, 1987	Sahara: D & A, 1980	Aptian: D & A, 1980	Colombia: D & A, 1980
	S.primitivuum	NLK 2				
	H.gorkae	NLK 3				
	G.praeobliquum	NLK 4				
	R.parvidentatum	NLK 5				
	B.ambiguus	NLK 6				
APTIAN	*M.obtusus*	NLK 7		Tunisia, SW Morocco: D & A, 1980	USA, Canada: D & A, 1980	
	R.asper	NLK 8				
	L.morayfirthensis	NLK 9				
BARREMIAN	*N.abundans*	NLK 10		Spain: D & A, 1980		
	V.matalosa	NLKA 11				
		NLKA 12				
	C.conicus	NLKA 13				
	R.pseudoangustus	NLKA 14				
	C.inaequalis	NLKA 15				
HAUTERIVIAN	*T.septentrionalis*	NLKA 16		France, Mer d'Iroise: D & A, 1980		
	C.margerelii	NLKA 17				
	C.silvaradion	NLKA 18				
	E.antiquus	NLKA 19				
	T.striatum	NLKA 20				
VALANGINIAN	Unstudied	NLKA 21				
	M.speetonensis	NLKA 22				
	Unamed	NLKA 23				
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24				
	P.fletcheri	NLKA 25				
	Nannoconus sp. discs	NLKA 26				
TITHONIAN						

22/26a-2

Figure 7.11 Worldwide distribution and range data for *N. truitti frequens*

Description: As for *N. truitti truitti* except for the more elongate nature.

Dimensions: L_1: 11μm , W_1: 8μm.

Published Dimensions: L_1: 11-13μm, W_1: 8-10μm (Deres & Achériteguy 1980).

Comparisons: *N. bucheri* is conical in outline in contrast to *N. truitti frequens* which is more elongate with only slight widening of the wall at the proximal pole. *N. elongatus elongatus* is comparable in shape but has a different wall structure.

Stratigraphic Interval: Aptian/Albian (see fig 7.11)

Occurrence: Figure 7.11.

N. truitti rectangularis Deres & Achériteguy 1980

Not Illustrated

Holotype: Fig. 11 of Deres & Achériteguy 1980.

Reference: "Biostratigraphie des nannoconides". *Bulletin des Centres Recherches Exploration-Production Elf-Aquitane.* 4, p. 25.

Diagnosis (original): A subspecies of *N. truitti* which is elongated along the horizontal axis i.e. sideways.

Description: The central canal is elongate and is open at both poles. Only a very slight inclination of elements occurs which causes the terminal apertures to have a slight depression.

Dimensions: L_1: 6μm, W_1: 10μm, Wa: 4μm.

Published Dimensions: L_1: 6-8μm, W_1: 9-11μm (Deres & Achériteguy 1980).

Comparisons: The width of the wall and squashed rectangular outline is greater than in *N. truittii* and *N. truitti frequens.*

Stratigraphic Distribution: Albian.

Occurrence: Similar published geographic and stratigraphic distribution to *N. truitti frequens*, Figure 7.11

Morphogroup 2.3

Type Specimen for Description: *N. borealis.*

Horizontal Intercept Angle: β_1 20-45°

Detailed inclination of plates from the representative species: α_2: 10°, β_2: 30°.

Width of Cycle A: > 1μm.

Description: The plates are slightly different in dimensions from those in Morphogroup 2.2, creating a wider Cycle A. Only slight grooves and ridges are visible on the exterior, relating to the angle of overlap of the longitudinal axis of each plate.

Number of Species: 12 species are recognised in this morphogroup. Some of the most elongate species constitute this group, which is dominated by conical species.

Distribution: Worldwide. Investigation of published literature of the earliest nannoconids suggests that these forms could be classified Morphogroup 2.3. subsequently this group has remained well-established and dominant in the nannoconid record.

Stratigraphic Range: Tithonian-Aptian/Albian.

N. bermudezi Brönnimann 1955
Pl. 17, fig. 6.

Holotype: Fig. 24 of Brönnimann 1955.

Reference: "Microfossils Incertae Sedis from the Upper Jurassic and Lower Cretaceous from Cuba". *Micropaleontology.* **1**, p. 37.

Synonyms: *N. colomi* Colom (1945, p. 129, fig. 2).

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC	E. PACIFIC
ALBIAN	*P.anfractus*	NLK 1	Skinnabanken: Aarhus et al, 1986	Hungary: Felegházy & Nagymarosy Tunisia, SW Morocco, Sahara: D & A, 1980 Israel: Moshkovitz, 1971 Bosso Valley, Italy: Bralower, 1989 Spain: D & A, 1980 Mer d'Iroise: D & A, 1980 SE France: D & A, 1980 Paris Basin: D & A, 1980 Broyon, France: Thierstein, 1973	DSDP 1: Thierstein, 1973 Canada: D & A, 1980 DSDP 534 A: Bralower et al, 1989	Mexico: Trejo, 1960
	S.primitivuum	NLK 2				
	H.gorkae	NLK 3				
	G.praeobliquum	NLK 4				
	R.parvidentatum	NLK 5				
	B.ambiguus	NLK 6				
APTIAN	*M.obtusus*	NLK 7				
	R.asper	NLK 8				
	L.morayfirthensis	NLK 9				
BARREMIAN	*N.abundans*	NLK 10				
	V.matalosa	NLKA 11				
		NLKA 12				
	C.conicus	NLKA 13				
	R.pseudoangustus	NLKA 14				
	C.inaequalis	NLKA 15				
HAUTERIVIAN	*T.septentrionalis*	NLKA 16				
	C.margerelii	NLKA 17				
	C.silvaradion	NLKA 18				
	E.antiquus	NLKA 19				
	T.striatum	NLKA 20				
VALANGINIAN	Unstudied	NLKA 21				
	M.speetonensis	NLKA 22				
	Unamed	NLKA 23				
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24				
	P.fletcheri	NLKA 25				
	Nannoconus sp. discs	NLKA 26				
TITHONIAN						

Figure 7.12 Worldwide distribution and range data for *N. bermudezi*

N. colomi Colom (1948, p. 252, fig. 7).

Diagnosis (original): "cone-shaped similar to *N. steinmanni* with the length ranging from 20-28μm and the maximum diameter is 10μm".

Diagnosis (emended): An extremely large conical nannoconid with a poorly defined central canal.

Description: The features are comparable to those of *N. steinmanni* with the exception of its elongated shape.

Top View/Disc: Not seen due to the length of the species.

Dimensions: L_l: 25μm , W_l: 11μm, Ca: < 1μm.

Comparisons: This species can attain up to twice the size of an average *N. steinmanni.*

Remarks: The morphological nature of *N. bermudezi* and *N. steinmanni* may indicate that the former species should perhaps be regarded as a subspecies of *N. steinmanni.* Only a few specimens were found in the studied material.

Stratigraphic Range: Ryazanian/Berriasian-Albian.

Occurrence: Figure 7.12.

N. boneti Trejo 1959
Pl. 15, figs 1-9.

Holotype: Fig. 2 of Trejo 1959.

Reference: "La familia Nannoconidae y su alcance estratigrafico en America. (Protozoa, Incertae Sedis)". *Bolletin Associacion Mexicana Geologos Petroleros.* **12,** pp. 259-314.

Synonym: *N. elongatus* Thomsen (1987, Pl. 8, fig. 8).

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC
ALBIAN	*P.anfractus*	NLK 1	Danish Central Trough: Thomsen, 1987 Moray Firth: Jakubowski, 1987 Speeton: Perch-Nielsen, 1979 E-1 22/26a-2	NO DATA	NO DATA
	S.primitivuum	NLK 2			
	H.gorkae	NLK 3			
	G.praeobliquum	NLK 4			
	R.parvidentatum	NLK 5			
	B.ambiguus	NLK 6			
APTIAN	*M.obtusus*	NLK 7			
	R.asper	NLK 8			
	L.morayfirthensis	NLK 9			
BARREMIAN	*N.abundans*	NLK 10			
	V.matalosa	NLKA 11			
		NLKA 12			
	C.conicus	NLKA 13			
	R.pseudoangustus	NLKA 14			
	C.inaequalis	NLKA 15			
HAUTERIVIAN	*T.septentrionalis*	NLKA 16			
	C.margerelii	NLKA 17			
	C.silvaradion	NLKA 18			
	E.antiquus	NLKA 19			
	T.striatum	NLKA 20			
VALANGINIAN	Unstudied	NLKA 21			
	M.speetonensis	NLKA 22			
	Unamed	NLKA 23			
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24			
	P.fletcheri	NLKA 25			
	Nannoconus sp. discs	NLKA 26			
TITHONIAN					

Figure 7.14 Worldwide distribution and range data for *N. boneti*

Diagnosis (original): "conical to flask-shaped outline, the height approximately twice the width. The poles are truncated and the walls are rounded, enclosing a cavity".

Diagnosis (emended): An elongate nannoconid with a weakly sub-conical nature due to widening of the proximal pole.

Description: The distal pole is truncated and the proximal pole is slightly rounded. An axial cavity, very similar in shape to the external outline is present. The distal aperture is open and the proximal aperture semi-restricted, with steeply inclined elements surrounding the opening. The wall construction is clearly visible.

Top View/Disc: Due to the elongate nature of the nannoconid, top views are rarely seen in the light microscope. Broken discs will have a low birefringence and distinct extinction lines, the elements being visible.

Dimensions: L_1: 13-20μm, W_1: 7-9μm, W_2: 6-7.5μm, Wa: 2-2.5μm.

Published Dimensions: L_1: 15-25μm, W_1: 12-15μm (Deres & Achériteguy, 1980).

Comparisons: *N. boneti* is a larger, elongate species with a less conical outline than *N. steinmanni* and has a well-developed cavity. *N. kamptneri* also has a distinctly conical outline and a cavity which shows a greater degree of development than this species.

Stratigraphic Range: BARREMIAN.

Occurrence: Figure 7.13.

N. borealis Perch-Nielsen 1979
Pl. 16, figs 5-9.

Holotype: Pl. 1, fig. 1-4 of Perch-Nielsen 1979.

Reference: "New Lower Cretaceous nannofossil species from England". *INA. Newsletter.* **10**, p. 35.

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC
ALBIAN	*P.anfractus*	NLK 1	Danish Central Trough: Thomsen, 1987 Moray Firth: Jakubowski, 1987 Speeton: Perch-Nielsen, 1979 E-1 22/26a-2	NO DATA	NO DATA
	S.primitivuum	NLK 2			
	H.gorkae	NLK 3			
	G.praeobliquum	NLK 4			
	R.parvidentatum	NLK 5			
	B.ambiguus	NLK 6			
APTIAN	*M.obtusus*	NLK 7			
	R.asper	NLK 8			
	L.morayfirthensis	NLK 9			
BARREMIAN	*N.abundans*	NLK 10			
	V.matalosa	NLKA 11			
		NLKA 12			
	C.conicus	NLKA 13			
	R.pseudoangustus	NLKA 14			
	C.inaequalis	NLKA 15			
HAUTERIVIAN	*T.septentrionalis*	NLKA 16			
	C.margerelii	NLKA 17			
	C.silvaradion	NLKA 18			
	E.antiquus	NLKA 19			
	T.striatum	NLKA 20			
VALANGINIAN	Unstudied	NLKA 21			
	M.speetonensis	NLKA 22			
	Unamed	NLKA 23			
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24			
	P.fletcheri	NLKA 25			
	Nannoconus sp. discs	NLKA 26			
TITHONIAN					

Figure 7.14 Worldwide distribution and range data for *N. borealis*

Synonym: *N. borealis* Thomsen (1987, p. 60, Pl. 8, figs 1-6).

Diagnosis (original): An elongate nannoconid with the development of a bulb at one pole. The canal is poorly developed.

Diagnosis (emended): An elongate nannoconid with a bulbous development at the proximal pole. *L* is x 2 the width of the central body, the bulbous projection can be up to 75 % the length.

Description: The proximal bulb is very difficult to focus through and is up to 1.5 x the width of the central body. The distal polar termination is slightly rounded and can show a slight bulbous flaring. The canal is weakly developed (although not to the extent where it can be called a cavity), the lining is highly irregular. The opening of the proximal aperture is not seen except with careful focusing, which shows it to be restricted by elements arranged at a high angle.

Top View/Disc: Rarely seen.

Dimensions: L_1: 10-17μm , W_1: 6.5-9μm, W_2: 2-7μm, Wa: 2-2.5μm.

Published Dimensions: L_1: 20-26μm, W_1: 13-15μm, W_2: 8-10μm (Deres & Achériteguy, 1980).

Comparisons: Distinct in having a large bulbous proximal pole and cylindrical central body.

Stratigraphic Range: Barremian.

Occurrence: Figure 7.14.

N. elongatus Brönnimann 1955

Two subspecies, *N. elongatus elongatus* and *N. elongatus minutus* could be defined on size characteristics in this study. Please refer to the original diagnosis of *N. elongatus elongatus*.

N. elongatus elongatus (Brönnimann 1955) subsp. emend.
Pl. 14, figs 7-12.

Holotype: Fig. 10 of Brönnimann 1955.

Reference: "Microfossils Incertae Sedis from the Upper Jurassic and Lower Cretaceous from Cuba". *Micropaleontology.* **1**, p. 38.

Synonyms: *N. elongatus* var. *cylindralithus* Deflandre & Deflandre-Rigaud (1959, p. 2373. figs 8-10).
N. elongatus cylindralithus Deflandre & Deflandre-Rigaud (1960, p. 176, Pl. 1, figs 20, 21).
N. elongatus macrolithus Deflandre & Deflandre-Rigaud (1960, p. 177, Pl. 1, figs 18, 19).

Diagnosis (original): A U-shaped nannoconid, longer than wide with the diameter of the cavity slightly less than that of the walls. Two terminal apertures are present, equal in width to the cavity.

Diagnosis (emended): A subspecies of *N. elongatus* which has an elongate, sub-rectangular outline with truncated polar ends.

Description: The cavity is well-developed, PARALLEL with the external outline. The apertures are semi-restricted and are almost equal in dimension. The proximal and distal apertural openings can be easily recognised by the angle of the elements surrounding the openings. Proximally the elements are arranged at a shallow angle, the distal apertural plates surround these opening at a high angle.

Top View/Disc: Not easily recognised and may tend to occur as discs due to breakage. Thought to have a lower birefringence (due to breakage into discs) with distinct extinction lines. Ratio of the wall to central cavity is approximately 1:1.

Dimensions: L_1: 8-15μm, W_1: 6.5-10μm, Wa: 2-4.5μm.

Published Dimensions: L_1: 10-12.5μm, W_1: 6.5-9μm, Ca: 1.5-2.5μm (Brönnimann 1955).

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC	E. PACIFIC
ALBIAN	*P.anfractus*	NLK 1			USA, Canada: D & A, 1980	Mexico: Trejo, 1960
	S.primitivuum	NLK 2			Sacramento Valley: Worsley 1979, Bralower 1990	
	H.gorkae	NLK 3			DSDP 101: Watkins & Vebeek, 1985	
	G.praeobliquum	NLK 4				
	R.parvidentatum	NLK 5			DSDP 36: Wise & Wind, 1977	
	B.ambiguus	NLK 6				
APTIAN	*M.obtusus*	NLK 7			DSDP 79: Wiegand, 1984	
	R.asper	NLK 8				
	L.morayfirthensis	NLK 9			DSDP 48: Muller, 1979	
BARREMIAN	*N.abundans*	NLK 10		Algeria: D & A, 1980		
	V.matalosa	NLKA 11				
		NLKA 12		Hungary: Baldi-Beke, 1961/2		
	C.conicus	NLKA 13				
	R.pseudoangustus	NLKA 14		Israel: Moshkoviz, 1971		
	C.inaequalis	NLKA 15				
HAUTERIVIAN	*T.septentrionalis*	NLKA 16		Spain: Geel, 1966		
	C.margerelii	NLKA 17				
	C.silvaradion	NLKA 18				
	E.antiguus	NLKA 19		Banat: Filepscu & Dragastan, 1963		
	T.striatum	NLKA 20				
VALANGINIAN	Unstudied	NLKA 21	Skinnabanken: Aarhus et al, 1986			
	M.speetonensis	NLKA 22		Mer d'Troise: D & A, 1980		
	Unamed	NLKA 23	N. Germany: Mutterlose, 1987/8 & 91			
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24		SW & SE France: D & A, 1980		
	P.fletcheri	NLKA 25	Adda 1 & 2: Thomsen, 1987			
	Nannoconus sp. discs	NLKA 26		France: Mutterlose 1987/88 & 91, Thierstein 1973, Bouche 1965		
TITHONIAN			E-1			
			210/20-1	Pietari: Filepscu & Dragastan, 1963		

Figure 7.15 Worldwide distribution and range data for *N. elongatus elongatus*

Comparisons: The subspecies of Deflandre & Deflandre-Rigaud are clearly the product of recrystallisation of the wall, confirmed when the type material was observed. *N. elongatus minutus* is similar in characteristics but very small in size.

Stratigraphic Range: - VALANGINIAN —Aptian/Albian.

Occurrence: Figure 7.15.

***N. elongatus minutus* subsp. nov.**
Pl. 14, figs 1-6.

Holotype: pl. 14, fig. 1 of this work (Ref. no: 3193/17).

Type Sample: E-1, 8208.5 m

Type Level: Barremian.

Diagnosis: A very small elongate/rectangular nannoconid, similar in characteristics to *N. elongatus elongatus.*

Description: This species has a characteristically low birefringence and can be easily overlooked in the assemblage. This may be a result of susceptibility to dissolution due to the small size. The outline is regular with truncated poles and a distinct central cavity approximately equal to the width of an individual wall. The apertures are open.

Dimensions: L_1: 4-9μm, W_1: 2-5μm.

Comparisons: There is no evidence that this is part of a broken nannoconid. The apertures appear always to be intact.

Remarks: This species appears to be susceptible to dissolution as deduced from the low birefringent nature of the specimens investigated. If the smear slides are too thick this species is often overlooked.

Stratigraphic Range: Late Barremian-Aptian.

Occurrence: NW Europe (I-1, 22/26a-2).

N. kamptneri Brönnimann 1955

This species has been subdivided into *N. kamptneri kamptneri* and *N. kamptneri minor* on the basis of size. Please refer to the diagnosis for *N. kamptneri kamptneri.*

N. kamptneri kamptneri (Brönnimann 1955) subsp. emend. Bralower 1989

Pl. 16, figs 1-4

Holotype: Fig. 16 of Brönnimann 1955.

Reference: "Microfossils Incertae Sedis from the Upper Jurassic and Lower Cretaceous from Cuba". *Micropaleontology.* **1**, p. 38.

Synonyms: *N. colomi* Noël (1958, p. 177, Pl. 4, figs 31, 37).
N. colomi Canuti & Marcucci (1969, p. 86, fig. 2, Pls 3, 4, 6).
N. bermudezi Moshkovitz (1971, Pl. 1, fig. 14).
N. wassalli Moshkovitz (1971, Pl. 2, figs 12 & 15).
N. aff. fragilis KAISER-Weidich & Schairer (1990, p. 383, table 3, fig. 3).

Horizontal Intercept Angle: α_2: 15°, β_2: 40°.

Diagnosis (original): A nannoconid with a cone-shaped test with a rounded base. A central cavity is present which opens into a terminal aperture.

Diagnosis (emended): A subspecies of *N. kamptneri* in which the external outline is conical with a well-developed central cavity.

Description: The cavity follows the external outline and ends in semi-open terminal apertures. At the base of the cone the elements are arranged at a low angle, partially-restricting the proximal aperture, thus forming a slightly concave base. The distal aperture is less restricted with elements inclined at a high-angle towards the opening.

Top View/Disc: Rare, as for *N. steinmanni steinmanni.*

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC	E. PACIFIC
ALBIAN	*P.anfractus*	NLK 1	Skinnabanken: Aarhus et al, 1986 N. Germany: Mutterlose, 1988 211/21-2 210/20-1	SW Morocco, Sahara: D & A, 1980 Tunisia: D & A, 1980 Roumania: Baldi-Beke, 1962 Hungary: Baldi-Beke, 1961/2 Israel: Moshkovitz, 1971 Spain: Geel 1966, D & A 1980 S. Germany: Weidich, 1985 Cismon, Italy: Bralower et al, 1987 Mer d'Iroise: D & A, 1980 Basses Alpes: Baldi-Beke 1962, Thierstein 1973, Bouche 1965 Paris Basin: D & A, 1972/80 Bernas: Bralower et al, 1989	DSDP 51: Siesser, 1980 Canada: D & A, 1980 DSDP 48: Muller, 1979 DSDP 47A: Wind & Cepek, 1979 DSDP 93: Covington & Wise, 1987	Colombia, S. America: D & A, 1980 Nequen Basin: Angelozzi (in press) Mexico: Trejo, 1960
	S.primitivuum	NLK 2				
	H.gorkae	NLK 3				
	G.praeobliquum	NLK 4				
	R.parvidentatum	NLK 5				
	B.ambiguus	NLK 6				
APTIAN	*M.obtusus*	NLK 7				
	R.asper	NLK 8				
	L.morayfirthensis	NLK 9				
	N.abundans	NLK 10				
BARREMIAN	*V.matalosa*	NLKA 11				
		NLKA 12				
	C.conicus	NLKA 13				
	R.pseudoangustus	NLKA 14				
	C.inaequalis	NLKA 15				
HAUTERIVIAN	*T.septentrionalis*	NLKA 16				
	C.margerelii	NLKA 17				
	C.silvaradion	NLKA 18				
	E.antiquus	NLKA 19				
	T.striatum	NLKA 20				
VALANGINIAN	Unstudied	NLKA 21				
	M.speetonensis	NLKA 22				
	Unamed	NLKA 23				
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24				
	P.fletcheri	NLKA 25				
	Nannoconus sp. discs	NLKA 26				
TITHONIAN						

Figure 7.16 Worldwide distribution and range data for *N. kamptneri kamptneri*

Dimensions: L_1: 8-24μm, W_1: 6-9μm, W_2: 4-6.5μm, Wa: 2μm.

Published Dimensions: L_1: 15-20μm, W_1: 9-12μm, Ca: 4-5μm, Aperture: 2-3μm (Brönnimann 1955).

Comparisons: Differs from *N. steinmanni steinmanni* by having a well-developed central cavity. Workers should not try to distinguish between these two species in the scanning electron microscope, as both are comparable in external morphology. *N. kamptneri minor* is smaller in size.

Stratigraphic Distribution: Tithonian-Aptian.

Occurrence: Figure 7.16.

N. kamptneri minor Bralower 1989

Not illustrated.

Holotype: Pl. 8, fig. 27 of Bralower 1989.

Reference: "Calcareous nannofossil zonation of the Jurassic-Cretaceous boundary interval and correlation with geomagnetic polarity timescale". *Marine Micropaleontology.* **11**, p. 293-310.

Diagnosis (original): "identical form to N. kamptneri but smaller in size. The test is cone-shaped with narrow walls and a wide axial canal"

Description: As for *N. kamptneri kamptneri* but smaller dimensions.

Dimensions: L_1: 7-9μm, W_1: 4-6μm, Wa: 1.5-2μm.

Published Dimensions: L_1: 6-10μm, W_1: 4-6μm (Bralower 1989).

Remarks: Only a few specimens were found. This species becomes more elongate stratigraphically.

Stratigraphic Range: Late Tithonian Ryazanian/Berriasian

Occurrence: NW Europe, W. Tethys, N. Atlantic

N. longus Perch-Nielsen 1988
Pl. 19, figs 7-9 & 12.

Holotype: Pl. 1, fig. 35 of Perch-Nielsen 1988.

Reference: "New Lower Cretaceous nannofossil species from England". *INA Newsletter.* **10**, p. 33-34.

Horizontal Intercept Angle: α_2: 10°, β_2: 40°.

Diagnosis (original): "Very elongate, parallel-sided species of nannoconid, the total length being more than twice the total width".

Description: In the type description Perch-Nielsen notes the presence of a bulbous end, however, this is not always present. The axial canal is poorly developed and extends throughout the length. Careful focusing shows the canal to be present in the bulbous end, as opposed to the original observations.

Dimensions: L_1: 15-30μm, W_1: 6-10μm, Wa: 2-2.5μm.

Comparisons: *N. dolomiticus* has a comparable morphology with *N. longus* but differs by the smaller dimensions and its stratigraphic occurrence in the Late Tithonian. *N. elongatus elongatus* has a wider cavity and smaller dimensions.

Stratigraphic Interval: Late Barremian, NLK 10.

Occurrence: NW Europe (22/26a-2).

N. paskentaensis Bralower 1990
Pl. 19. figs 1-6.

Holotype: Fig. 10. bb of Bralower 1990.

Reference: "Lower Cretaceous calcareous nannofossil stratigraphy of the Great

Valley Sequence, Sacramento Valley, California". *Cretaceous Research.* **11**, pp. 101-123.

Synonyms: *N. multicadus* Deflandre & Deflandre-Rigaud (1959. p. 2373, fig. 4).
N. multicadus Manivit (1968. p. 285, Pl. 2, fig. 9).
N. multicadus Tappan (1980. p. 730, figs 9.33, 13, 14).
N. boneti Thomsen (1987. Pl. 8, fig. 9, 10. Pl. 9, figs 1-3).
N. boneti Thomsen (1987. Pl. 11, figs 5-7, 18).
N. multicadus Mutterlose (1991. table 21, fig. 21).

Diagnosis (original): Elongate nannoconid with two connected bowl-shaped segments. The central canal has nearly parallel-sides but becomes narrower where the segments join".

Description: The species appears to have an hour glass shape, enhanced by the central cavity which has parallel margins except at midpoint where the external outline is constricted to give the appearance of two lobes. The distal and proximal apertures are open.

Top View/Disc: Due to the elongate nature of the species top views are not seen.

Dimensions: L_l: 8-16μm, W_l: 5-10μm, Wa: 2-4μm.

Published Dimensions: L_l: 10-18μm, W_l: 5-8μm (Bralower 1990).

Comparisons: Bralower (1990 p.) implies that this is not the two-bowled *N. multicadus* due to the lack of constricted walls between the segments. In the holotype (fig. 10 bb of Bralower 1990) the specimen clearly shows similar constrictions in the external outline. This species is therefore regarded as a sub-species of *N. multicadus*.

Stratigraphic Range: Hauterivian-Barremian.
Occurrence: NW Europe (22/26a-2, E-1), California (Sacramento Valley, Bralower 1990).

N. steinmanni Kamptner 1931

Two subspecies are recognised, *N. steinmanni steinmanni* and *N. steinmanni minor*, defined by size. Please refer to diagnosis for *N. steinmanni.*

N. steinmanni steinmanni (Kamptner 1931) subsp. emend. Deres & Achériteguy 1980

Pl. 17, figs 7-9.

Holotype: Fig. 2 of Kamptner 1931.

Reference: "*Nannoconus* steinmanni nov. gen., nov. spec. Ein Merkwürdiges Gesteinbildendes mikrofosil aus dem jüngeren Mesozoikum der Alpen". *Palaeontologische Zeitschrift.* 4, p. 252.

Synonyms: *Lagena colomi* Lapparent (1925. p. 105, fig. 1).
N. sp. Brönnimann (1955. p. 32, fig. 3, n-r).
N. colomi Noël (1956. p. 330, Pl. 5, figs 41-43).
N. colomi Noël (1958. p. 177, Pl. 4, figs 29, 30, 32, 34, 35).
N. dolomiticus Pasquaré (1960. p. 505, table 1, fig. a).
N. colomi Trejo (1960. p. 290, fig. 6, a-f).
N. colomi Baldi-Beke (1962. p. 177, table 1, figs 5-7).
N. colomi Filipescu & Dragastan (1963. p. 195, Pl. 1, figs 5-7, 9).
N. colomi Bouché (1965. p. 134, table 3. p. 135, table 4).
N. colomi Geel (1966. p. 379, Pl. 1A, fig. b. p. 379, Pl. 2B, fig. b).
N. colomi grp Canuti & Marcucci (1969. p. 86, fig. 2).
N. bermudezi Moshkovitz (1971. Pl. 1, figs 11, 12, 15).
N. colomi grp Thierstein (1971. Pl. 3, fig. 16).
N. colomi Thierstein (1976. p. 341, Pl. 2, fig. 28).
N. colomi Perch-Nielsen (1979. p. 252, fig. 20).
N. colomi Weidich & Schairer (1990. p. 379, table 1, figs 6-8).
N. cf farinaccae Weidich & Schairer (1990. p. 380, table 2, fig. 11, 17).
N. bermudezi Angelozzi (in press) fig. 32, 36, 37.

Diagnosis (original): A conical-shaped nannoconid with a very narrow central canal and broad walls. The central canal flares at the distal margin and a depression at the proximal margin.

Figure 7.17 Worldwide distribution and range data for *N. steinmanni steinmanni*

Diagnosis (emended): A subspecies of *N. steinmanni* characterised by a large conical nannnoconid with a poorly developed central canal.

Description: The conical outline is distinct with only a small, poorly developed canal evident in a longitudinal section. The canal is uniform in width along it's length and has an irregular lining. Two restricted terminal apertures are present, the proximal aperture being located in the base of the cone. The polar ends are sub-truncated, not rounded. Individual wall elements can usually be seen.

Top View/Disc: Due to the elongate nature of this species, top views are not often seen. Discs when found are likely to be broken and therefore will have a short focal depth and low birefringence. The extinction lines will be slightly fan-shaped towards the very narrow central canal.

Dimensions: L_1: 11-25μm, W_1: 5-8μm, W_2: 4-5μm, Wa: 2-2.5μm.

Published Dimensions: L_1: 10-20μm, Ca: 2-5μm, Wa: 2-5μm (Brönnimann 1955, for *N. colomi*).

Comparisons: *N. colomi* has always been regarded as a separate species based on the original plates and descriptions of De Lapparent (1931). The lack of a proximal aperture in the type photograph and sketch is due to them showing an oblique view of the nannoconid specimens, distorting the true outline of the cavity. This is clear when we note that he was studying random thin sections which are prone to inappropriate orientations for taxonomic purposes. *N. steinmanni* is here considered as a synonym of *N. colomi.*

N. steinmanni steinmanni can be distinguished from *N. kamptneri kamptneri* by the poorly developed central canal and consequently narrower apertural openings. A similar species in shape and stratigraphic distribution is *N. bermudezi*, however, this differs in having a greater length and an extremely poorly developed central canal.

Stratigraphic Range: Berriasian/Ryazanian-Aptian; reported from the Albian of France and Mexico.

Occurrence: Figure 7.17.

N. steinmanni minor Deres & Achériteguy 1980
Not illustrated

Holotype: Pl. 1, fig. 7 of Deres & Achériteguy 1980.

Reference: "Biostratigraphie des nannoconides". *Bulletin Centre Recherches SNEA.* 4, p. 1-53.

Synonym: *N. steinmanni* Moshkovitz (1971. Pl. 1, figs 1-4).

Diagnosis (original): Similar in outline to *N. steinmanni steinmanni* but smaller in size with an earlier stratigraphic range.

Dimensions: L_1: 8-10μm, W_1: 7-9μm.

Comparison: Smaller in size than *N. steinmanni* and shows the presence of a narrow central canal which distinguishes this species from *N. kamptneri minor.*

Stratigraphic Distribution: Tithonian-Valanginian

Occurrence: NW Europe, W. Tethys.

***Nannoconus* sp. 2 sp. nov.**
Pl. 18, figs 1-3 & 6.

Holotype: pl. 18, fig. 2 of this work (ref no: 2910/23).

Type sample: North Jens-1, 11637 ft.

Type level: Barremian.

Diagnosis: The external outline is strongly bilobed distally and proximally with a narrow waist between. Both poles are distinctly truncated.

Description: The nannoconid body is symmetrical along the longitudinal axis. The median constriction is evident in the cavity by the wall remaining equal in width along the longitudinal axis. The cavity terminates in a wide open distal aperture, which is

surrounded by elements of a very low inclination. The proximal aperture is slightly convex and is slightly restricted by elements.

Top View/Disc: The length of the longitudinal axis is approximately twice the width, therefore there is a tendency for longitudinal or oblique views to be present in light microscope preparations. Discs may show a high cavity : wall ratio with distinct extinction lines.

Dimensions: L_1: 12-14μm, W_1: 7-8μm.

Comparisons: *N. paskentaensis* has notably bulbous polar terminations in addition to a central constriction of the wall. *N. dauvillieri* only has a single protrusion with slightly rounded apical apertures (no evidence for this protrusion being distal or proximal in orientation).

Stratigraphic Range: Upper Barremian.

Occurrence: NW Europe (North Jens-1).

7.4.3 Morphogroup 3.

The component crystal plates are at a considerably higher angle of inclination than visible in the other morphogroups. Each individual plate has a larger breadth than in the other morphogroups, forming a compact rigid wall structure. No species were found which could be assigned to Morphogroups 3.1 and 3.2.

Morphogroup 3.3

Type Specimen for Description: *N. globulus globulus.*

Horizontal Intercept Angle: $ß_1 > 45°$.

Detailed inclination of the plates in the representative species: α_2: 45°, β_2: 70°.

Width of Cycle A: 1μm.

Description: The individual wall construction is clearly visible in the scanning electron images. The increased dimensions of the individual plates and degree of overlap of type A elements allows the spiral unit to be clearly visible in the light microscope.

Total Number of Species: 6. All the species are globular to sub-globular in outline with well developed central cavities.

Distribution: Worldwide, dominant in NW Europe as far as is known.

Stratigraphic Range: Ryazanian-Aptian. The species of Morphogroup 3.3 dominate the Hauterivian-Albian interval.

N. globulus Brönnimann 1955

Three subspecies could be recognised, *N. globulus globulus*, *N. globulus minor* and *N. globulus* nov. subsp. A, defined by size and external outline.

N. globulus globulus (Brönnimann, 1955) subsp. emend. Bralower 1989

Pl. 20, figs 6-11.

Holotype: Figs 13, 18, 23 of Brönnimann 1955.

Reference: "Microfossils Incertae Sedis from the Upper Jurassic-Lower Cretaceous of Cuba". *Micropaleontology.* **1**, p. 37.

Synonyms: *N. bucheri* Moshkovitz (1971. Pl. 3, fig. 4).
N. circularis Weidich & Schairer (1990. p. 392, table 3, figs 6, 8).

Horizontal Intercept Angle: α_2: 45°, β_2: 70°.

Diagnosis (original): The test is low barrel-shaped, occasionally more or less globular with two terminal apertures. The more or less ring-like sections perpendicular to the axis display a subcircular cavity. The spiral disposition of the wall elements can be clearly recognised in sections tangental to the inner surface.

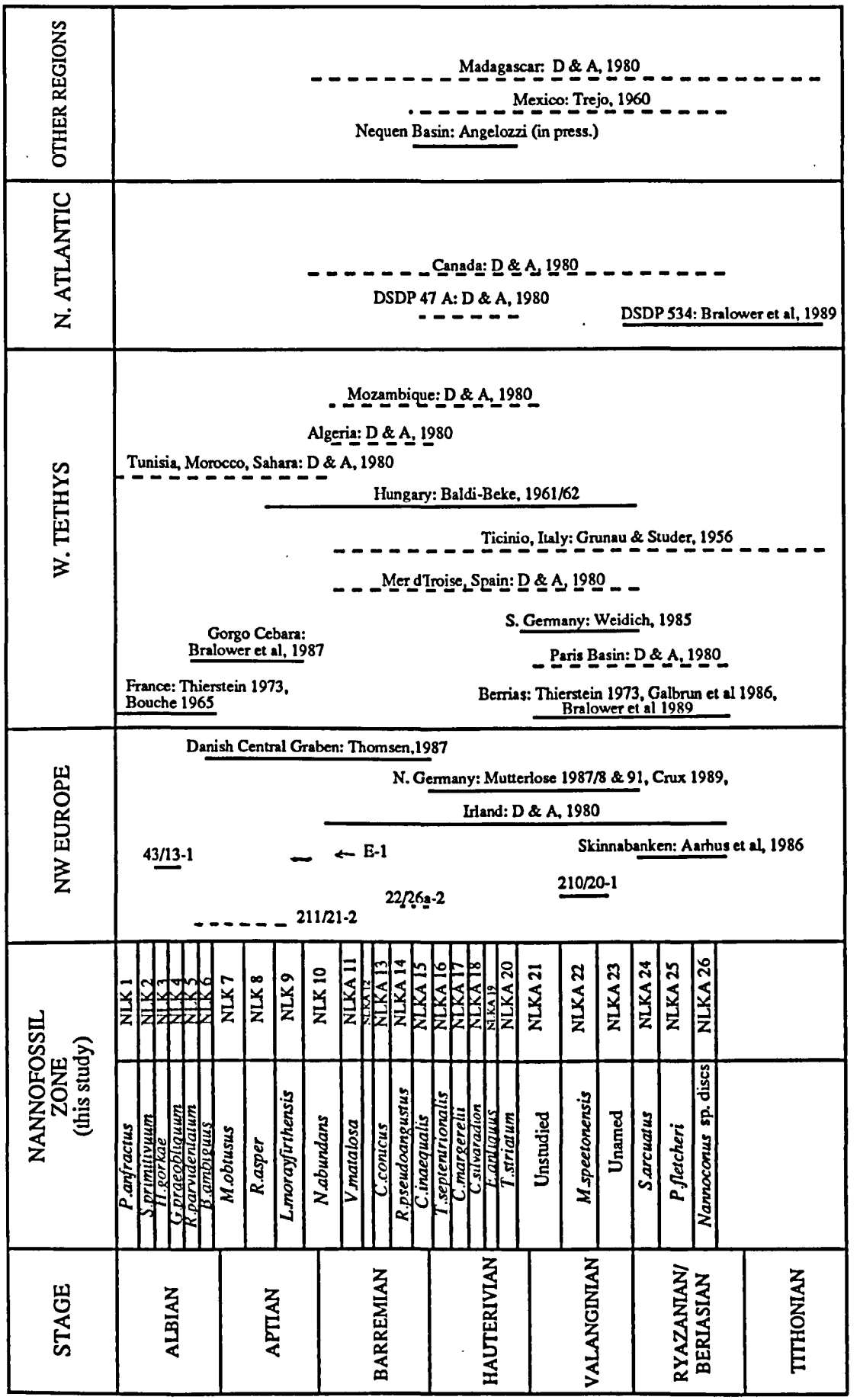


Figure 7.18 Worldwide distribution and range data for *N. globulus globulus*

Diagnosis (emended): A subspecies of *N. globulus* with a globular/barrel-shaped external outline, where L is approximately equal to W.

Description: The apertures are clearly defined and are open to an approximately equal extent. The proximal aperture is recognised by the steeply dipping plates surrounding a slightly narrower apertural opening. The cavity is well-developed and shows an irregular cavity lining. The cyclic nature of the plates and individual components are clearly discernable when focusing on the near or far surfaces of the wall. Variations in the external outline are here assigned to subspecies level variants.

Top View/Disc: Due to the size dimensions specimens of this species are often orientated obliquely or as a top view in the light microscope. An oblique view would mask the presence of two terminal apertures and distort the true angle of the crystal units A and B. A top view is of a short focal depth and high birefringence. Individual elements are clearly discernable, with the extinction lines being abrupt and approximately consistent in width towards the center.

Dimensions: L_1: 5-12μm, W_1: 7-14μm, Wa: 1.5-3.5μm.

Published Dimensions: W_1: 8.5-14μm, Wa: 1-2.5μm, Apertures: 2μm (Brönnimann 1955).

Comparisons: *N. globulus globulus* can be distinguished from the morphovariants of this species by its characteristic globular outline. *N. globulus minor* has smaller dimensions and appears earlier in the TITHONIAN. Brönnimann (1955) noted the presence of smaller forms in earlier assemblages, these have been assigned to a subspecies by Bralower (1989).

Stratigraphic Range: TITHONIAN – ALBIAN.

Occurrence: Figure 7.18.

N. globulus minor Bralower 1989

Not Illustrated

Holotype: Pl. 8, fig. 23 of Bralower 1989.

Reference: "Calcareous nannofossil zonation of the Jurassic-Cretaceous boundary interval and correlation with the geomagnetic polarity timescale". *Marine Micropaleontology*. **14**, p. 153-235.

Diagnosis (original): A small globular nannoconid comparable in shape and structure to *N. globulus globulus*, differing only in smaller dimensions. The test is globular to barrel-shaped with moderately thin wall. There is a large oval central cavity and wide basal and apical apertures.

Description: As for *N. globulus globulus* but smaller in size.

Top View/Disc: Variations in external and internal size dimensions from *N. globulus globulus*.

Dimensions: L_1: 3-6µm, W_1: 4-8.5µm.

Remarks: Brönnimann (1955) noted the presence of these smaller species but did not classify them. The subspecies has not been widely recognised in NW Europe because of the relative scarcity of accessible marine Late Jurassic/Earliest Cretaceous deposits.

Stratigraphic Range: TITHONIAN - Upper Ryazanian.

Occurrence: Western North Atlantic, Tethys and NW Europe.

***N. globulus* A subsp. nov.**
Pl. 20, figs 3-5

Holotype: Pl. 20, figs 3 & 4 of this work..

Type locality: 29/7-1, 10596 ft.

Type Level: Barremian.

Synonyms: *N. sp.* 107 Perch-Nielsen (1979. p. 252, fig. 20).
N. sp. Mutterlose (1988. p. 207, table 11.4/3, fig.10).
N. sp. Mutterlose (1991. table 21, fig. 20).

Diagnosis: A very large sub-square nannoconid with semi-truncated terminal poles. *L* is equal to *W*.

Description: The external outline wall shows slight curves and is not a regular square. The cavity is well-developed, closely following the exterior outline. The terminal apertures are open, but the proximal aperture shows slight restrictions when compared to the distal aperture. Focusing through the specimen in longitudinal section can be difficult. Invariably the wall structure is obscure and only plate angles are only faintly visible. This species is very prone to overgrowth of the elements due to the large plate size. The ß angle can reach almost 90° and in the light microscope the width of the Cycle A can be over 1µm.

Dimensions: L_l: 9-19µm, W_l: 9-18.5µm, Wa: 2-3.5µm.

Comparisons: *N. globulus* subsp. nov. A differs from *N. globulus globulus* in its characteristically less globular and more square outline. The size is also larger and wall structure less coherent in *N. globulus* subsp. nov. A due to the coarser nature of the elements.

Remarks: Perch-Nielsen noted a similar morphotype, *N.* sp 107 in samples from NW Europe. Although rare in NW Europe this subspecies can be easily distinguished.

Stratigraphic Range: Upper Barremian.

Occurrence: NW Europe (211/21-2, 22/26a-2).

N. oviformis Perch-Nielsen 1988
Pl. 21, figs 10-11.

Holotype: Pl. 1, figs 33, 34 of Perch-Nielsen 1988.

Reference: "New Lower Cretaceous calcareous nannofossil species from England". *INA. Newsletter.* **10**, p. 30-36.

Synonym: *N.* sp 3 Bouché (1965. p. 134/135, table 3/4).

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC
ALBIAN	*P.anfractus*	NLK 1	210-20-1 — 22/26a-2 - - - E-1 - 29/7-1: Perch-Nielsen, 1988	NO DATA	NO DATA
	S.primitivuum	NLK 2			
	H.gorkae	NLK 3			
	G.praeobliquum	NLK 4			
	R.parvidentatum	NLK 5			
	B.ambiguus	NLK 6			
APTIAN	*M.obtusus*	NLK 7			
	R.asper	NLK 8			
	L.morayfirthensis	NLK 9			
	N.abundans	NLK 10			
BARREMIAN	*V.matalosa*	NLKA 11			
		NLKA 12			
	C.conicus	NLKA 13			
	R.pseudoangustus	NLKA 14			
	C.inaequalis	NLKA 15			
HAUTERIVIAN	*T.septentrionalis*	NLKA 16			
	C.margerelii	NLKA 17			
	C.silvaradion	NLKA 18			
	E.antiquus	NLKA 19			
	T.striatum	NLKA 20			
VALANGINIAN	Unstudied	NLKA 21			
	M.speetonensis	NLKA 22			
	Unamed	NLKA 23			
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24			
	P.fletcheri	NLKA 25			
	Nannoconus sp. discs	NLKA 26			
TITHONIAN					

Figure 7.19 Worldwide distribution and range data for *N. oviformis*

Horizontal Intercept angle: α_2: 22°, β_2: 53°.

Diagnosis (original): Large, ovoid species of *Nannoconus* with a wide central cavity and a few thick rows of wedges at a high angle to the central canal.

Description: This species has a well-developed cavity which closely follows the exterior outline. The terminal apertures are open, although the proximal aperture is slightly restricted. The cavity surface has a tendency to be irregular due to the coarse nature of the elements.

Top view/Disc: Very high birefringence due to common overgrowth of the wall structure. The extinction lines are well-defined and do not taper towards the cavity.

Dimensions: L_1: 7-15μm, W_1: 6-11μm, Wa: 1.5-3.5μm.

Comparisons: Differs from *N. globulus globulus* in the extended nature of the longitudinal axis giving it an oval shape. The length can be up to twice the width of the specimen.

Stratigraphic Range: Ryazanian-Aptian.

Occurrence: Figure 7.19.

N. wassalli Brönnimann 1955

This species has been subdivided into *N. wassalli wassalli* and *N. wassalli minor*. Please refer to the diagnosis of *N. wassalli wassalli*.

N. wassalli wassalli (Brönnimann 1955) subsp. emend.
Pl. 21, figs 1-9.

Holotype: Fig. 8 of Brönnimann 1955.

Reference: "Microfossils Incertae Sedis from the Upper Jurassic-Lower Cretaceous of Cuba". *Micropaleontology*. **1**, p. 39.

Synonyms: *N. boletus* Deflandre & Deflandre-Rigaud (1962. p. 2639, figs 6-8).
N. calpidomorphous Deflandre & Deflandre-Rigaud (1962. p. 2639, fig. 5).
N. sp. 4 Weidich & Schairer (1990. p. 381, table 2, figs 8, 10).

Diagnosis (original): The pear-shaped test is relatively large for this genus with thick walls enclosing a large, pear-shaped, sometimes ovoid central cavity. Two relatively small terminal apertures are present.

Diagnosis (emended): A subspecies of *N. wassalli* characterised by a relatively large, pear-shaped outline, with a wide central cavity.

Description: The well-developed cavity is pear-shaped to sub-ovoid in shape, terminating in slightly truncated open, terminal apertures. The proximal aperture is slightly restricted by almost flat-lying plates from Cycle A. The opposite pole is characterized by an open aperture with steeply dipping elements around the apertural opening.

Top view/Disc: Relatively large in diameter with a bright yellow birefringent wall. Careful focusing through the specimen can show slight changes in the diameter of the top view along the longitudinal axis of the specimen.

Dimensions: L_1: 8-10μm, W_1: 7-9μm, W_2: 5μm.

Published Dimensions: L_1: 14-20μm,W_1: 11-14μm, Wa: 3μm, Aperture: 2.5-3μm (Brönnimann 1955). L_1: 9.5-15.5μm, W_1: 9-13.5μm (Deflandre & Deflandre-Rigaud 1962). L_1: 9.5-13μm, W_1: 8.5-10μm (*N. boletus* Deflandre & Deflandre-Rigaud 1962).

Comparisons: *N. boletus* is thought to be synonymous with *N. wassalli* due to similar external and internal features. In addition a similar stratigraphic range for *N. boletus* is recorded. Investigation and photography of the Deflandre & Deflandre-Rigaud type slides and sample material have shown that these species cannot be distinguished with accuracy. The type plate for *N. boletus* is an interpretative sketch of the authors' observations, the specimens drawn with their proximal apertures at the top of the page (Deflandre & Deflandre-Rigaud, 1962, p.2639, figs 6-8). A clearer type photograph in addition to the sketch would have been helpful. Some of the

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC	OTHER REGIONS
ALBIAN	*P.anfractus*	NLK 1	Skinnabanken: Aarhus et al, 1986	Tunisia, Sahara: D & A, 1980 Hungary: Baldi-Beke, 1962 Caravaca, Spain: Geel 1966, Moreno de Castro Spain: D & A, 1980 SE France: D & A, 1980 SW France, Mer d'Iroise: D & A, 1980 France: Bouche 1965, Thierstein 1973	Canada: D & A, 1980 DSDP 52: Siesser, 1980 DSDP 47B: Blechschmidt, 1979 Mexico: Trejo 1960, Canuti Chapa 1989	NO DATA
	S.primitivuum	NLK 2				
	H.gorkae	NLK 3				
	G.praeobliquum	NLK 4				
	R.parvidentatum	NLK 5				
	B.ambiguus	NLK 6				
APTIAN	*M.obtusus*	NLK 7				
	R.asper	NLK 8				
	L.morayfirthensis	NLK 9				
	N.abundans	NLK 10				
BARREMIAN	*V.matalosa*	NLKA 11				
		NLKA 12				
	C.conicus	NLKA 13				
	R.pseudoangustus	NLKA 14				
	C.inaequalis	NLKA 15				
HAUTERIVIAN	*T.septentrionalis*	NLKA 16				
	C.margerelii	NLKA 17				
	C.silvaradion	NLKA 18				
	E.antiquus	NLKA 19				
	T.striatum	NLKA 20				
VALANGINIAN	Unstudied	NLKA 21				
	M.speetonensis	NLKA 22				
	Unamed	NLKA 23				
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24				
	P.fletcheri	NLKA 25				
	Nannoconus sp. discs	NLKA 26				
TITHONIAN						

Figure 7.20 Worldwide distribution and range data for *N. wassalli wassalli*

variations in the dimensions from Deflandre & Deflandre-Rigaud (1962) may be due to confusion of different taxonomic groupings.

N. calpidomorphous is also considered a synonym. The original sketch appears to have exaggerated some of the morphology, possibly associated with viewing oblique specimens. The external outline is comparable in photographs from the type slides and the sample material. In the sketch the apertural openings are shown to be much wider than those of the *N. boletus* type illustration. This is attributed to species variation and inappropriate observation in the light microscope. *N. wassalli wassalli* has a similar stratigraphic distribution to the synonymous forms above.

Stratigraphic Range: Barremian-Albian.

Occurrence: Figure 7.20.

***N.wassalli* minor comb. nov.**
Pl. 22 figs. 1-6

Holotype: *N. boletus curtus* Deflandre & Deflandre-Rigaud 1962 (Fig. 9).

Synonyms: *N. carniolensis carniolensis* Deflandre & Deflandre-Rigaud (1962. p. 2639, figs 1-4).
N. carniolensis lata Deres & Achériteguy (1980. pl. 2 , fig. 8).

Diagnosis: A small nannoconid with a pear-shaped exterior outline, comparable to *N. wassalli* in characteristics but with smaller dimensions.

Description: As for *N. wassalli wassalli.*

Top view/Disc: Prone to being observed in top view due to its short length and consequently focal depth. Very slight changes in the external diameter may be observed when focusing through the specimen.

Dimensions: L_1: 7-9 µm W_1: 8-10 µm Wa: 2-2.5 µm

Published Dimensions: L_1: 8.5 µm W_1: 11.5 µm (Deflandre & Deflandre-Rigaud 1962).

STAGE	NANNOFOSSIL ZONE (this study)		NW EUROPE	W. TETHYS	N. ATLANTIC
ALBIAN	*P.anfractus*	NLK 1		SW France, Mer d'Iroise, Spain, Tunisia, SW Morocco, Mozambique: D & A, 1980 France: D & A, 1980	USA, Canada: D & A, 1980
	S.primitivuum	NLK 2			
	H.gorkae	NLK 3			
	G.praeobliquum	NLK 4			
	R.parvidentatum	NLK 5			
	B.ambiguus	NLK 6			
APTIAN	*M.obtusus*	NLK 7			
	R.asper	NLK 8			
	L.morayfirthensis	NLK 9			
	N.abundans	NLK 10			
BARREMIAN	*V.matalosa*	NLKA 11			
		NLKA 12			
	C.conicus	NLKA 13			
	R.pseudoangustus	NLKA 14			
	C.inaequalis	NLKA 15			
HAUTERIVIAN	*T.septentrionalis*	NLKA 16			
	C.margerelii	NLKA 17			
	C.silvaradon	NLKA 18			
	E.antiquus	NLKA 19			
	T.striatum	NLKA 20			
VALANGINIAN	Unstudied	NLKA 21			
	M.speetonensis	NLKA 22			
	Unamed	NLKA 23			
RYAZANIAN/ BERIASIAN	*S.arcuatus*	NLKA 24			
	P.fletcheri	NLKA 25			
	Nannoconus sp. discs	NLKA 26			
TITHONIAN					

Figure 7.21 Worldwide distribution and range data for *N. wassalli minor*

Remarks: A new subgeneric species classification was chosen to incorporate several synonymous species; *N. carniolensis carniolensis, N. carniolensis lata* and *N. boletus curtus*. These earlier taxa were illustrated with line drawings in different orientations and, apparent different points of focus within each specimen. All the taxa appear to show a similar inclination of the 'striae' and comparable outline and cavity features.

Stratigraphic Range: Barremian-Albian.

Occurrence: Figure 7.21.

Nannoconus sp. nov. 3
Pl. 22, figs 10 & 11

Remarks: During observation of type locality sample material from Haute Province in the collection of Deflandre & Deflandre-Rigaud in Paris an undescribed *Nannoconus* species was observed. The outline is sub-rectangular with slightly concave walls and internally the cavity is well-developed with truncated polar terminations. The apertures are unrestricted, except for the proximal pole which is surrounded by very thin cycle of low-angle elements around the apertural opening.

Comparisons: *N. wassalli* has a greater conical external outline than *N.* sp 3, this species being more comparable to a barrel. Only a few specimens were found in the sample and it may therefore be a variant of *N. wassalli wassalli. N. boletus curtus* has a greater diameter cavity and is wider than the specimens of *Nannoconus* sp.3.

Dimensions: L_1: 9.5-10.5 μm, W_1: 7.5-8.5 μm, Wa: 2 μm.

Stratigraphic Range: Barremian

Occurrence: W. Tethys.

MORPHOGROUP	1.1 ß1: < 20° Cycle A: < 0.5µm				1.2 ß1: < 20° Cycle A: 0.5-1µm	1.3 ß1: < 20° Cycle A: > 45°
SKETCH	 α:7° ß2: 13°				 α: 8° ß2: 17°	
SHAPE	sub-square, proximal flange	cylindrical with truncated poles	rectangular along the horizontal axis, concave sides with depressed poles	large, thin disc poorly birefringent	Sub-square with two symmetrical flanges	beehive-shaped
CENTRAL OPENING	canal	cavity	canal	canal	canal	cavity ?
DIMENSIONS	L: 4-8µm W1: 5-9µm W2: 4-6µm	L: 8-10µm W: 7-12µm	L: 4-5µm W: 6-7µm	W: 10-14µm	L: 4-6µm W1: 6-8µm W2: 4-6µm	L: 10µm W: 8µm
RANGE	Barremian NLK 10-NLKA 14	Barremian- Aptian	Valanginian NLKA 23	Upper Ryazanian NLKA 26	Upper Ryazanian NLKA 24/25	Upper Ryazanian NLKA 24/25
OCCURRENCE	NW Europe	NW Europe W. Tethys	NW Europe	NW Europe	NW Europe	NW Europe
SPECIES	*N. abundans*	*N. circularis*	*Nannoconus* sp. 1	*Nannoconus* sp. (discs)	*N. concavus*	*N. sabinae*
COMMENTS	Double structures found				jun. syn. *N. alvus*	validity of species uncertain

Figure 7.22. A summary of the main characteristics of the taxa found in Morphogroup 1.1, 1.2 and 1.3.

MORPHOGROUP	2.2 ß1: 20-45° Cycle A: 0.5-1µm								
SKETCH		 α: 5° ß: 20°	 α: 5° ß: 30°						
SHAPE	sub-conical median constriction	sub-ovoid broad truncated poles	sub-cylindrcal flaring at proximal pole	small, sub-rectangular with truncated poles	Sub-rectangular along shot axis truncated poles, narrow cavity	Sub-square truncated poles, wide cavity	sub square/conical narrow cavity	elongate-sub-rectangular	rectangular along short axis
CENTRAL OPENING	cavity	cavity	cavity	canal	narrow cavity	cavity	narrow cavity	cavity	cavity
DIMENSIONS	L: 11-13.5µm W1: 8.5-10µm W2: 7-8.5µm	L: 7-14µm W1: 7-11µm W2: 7-8.5µm	L: 10-14.5µm W1: 6-9µm W2: 5-7µm	L: 4-8µm W: 3.5-7µm	L: 5.5-5.7µm W: 5-7µm	L: 5-7µm W: 6-7µm	L: 7-9µm W: 7.5-10µm	L: 11-13µm W: 8-10µm	L: 6-8µm W: 9-11µm
RANGE	Barremian	Hauterivian / Aptian	Barremian-Aptian/Albian	Tithonian/ Ryazanian-Aptian/Albian	Barremian-Aptian	Barremian-Aptian	Upper-Barremian-Albian	Aptian/ Albian	Aptian/ Albian
OCCURRENCE	NW Europe W. Tethys	NW Europe W. Tethys N. Atlantic	NW Europe W. Tethys	NW Europe W. Tethys N. Atlantic	NW. Europe W. Tethys	NW Europe W. Tethys	NW Europe W. Tethys N & S. Atlantic	NW Europe W. Tethys N & S. Atlantic	NW Europe W. Tethys N & S. Atlantic
SPECIES	*N. aquitanicus*	*N. bucheri*	*N. dauvillieri*	*N. minutus*	*N. quadriangulus quadriangulus*	*N. quadriangulus apertus*	*N. truitti truitti*	*N. truitti frequens*	*N. truitti rectangularis*
COMMENTS				jun. Syn. *N. inconspicuus*		jun. syn. *N. fragilis*	double structures		

Figure 7.23. A summary of the main characteristics of the taxa found in Morphogroup 2.2.

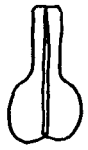
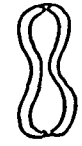
MORPHOGROUP	2.3 ß1: 20-45° Cycle A: > 1µm								
SKETCH		 α: 10° ß: 30°				 α: 15° ß: 40°		 α: 10° ß: 40°	
SHAPE	Large conical outline very narrow canal	elongate with a proximal lobe	conical-flask-shaped	sub-rectangular	small, sub-rectangular	conical with well-developed cavity	small, conical & well-developed cavity	elongate parallel-sided	elongate with two proximal lobes
CENTRAL OPENING	narrow canal	narrow canal	cavity	cavity	canal	cavity	cavity	canal	canal
DIMENSIONS	L: 25µm W: 11µm	L: 10-26µm W: 6.5-15µm	L: 13-25µm W1: 7-15µm W2: 6-7.5µm	L: 8-15µm W: 6.5-10µm	L: 4-9µm W: 2-5µm	L: 8-24µm W: 6-12µm	L: 6-10µm W: 4-6µm	L: 15-30µm W: 6-10µm	L: 8-18µm W: 5-10µm
RANGE	Ryazanian-Albian	Barremian NLKA 11-15	Barremian	Valanginian-Aptian/ Albian	Upper Barremian-Aptian	Valanginian-Aptian	Tithonian-Ryazanian/ Berriasian	Upper Barremian	Hauterivian-Barremian
OCCURRENCE	NW Europe W. Tethys N. Atlantic	NW Europe	NW Europe W. Tethys N. Atlantic	NW Europe W. Tethys N. Atlantic	NW Europe	NW Europe W. Tethys N & S. Atlantic	NW Europe W. Tethys N & S. Atlantic	NW Europe	NW Europe N. Atlantic
SPECIES	*N. bermudezi*	*N. borealis*	*N. boneti*	*N. elongatus elongatus*	*N. elongatus minutus*	*N. kamptneri kamptneri*	*N. kamptneri minor*	*N. longus*	*N. paskentensis*
COMMENTS	Thought to be a morphotype of *N. steinmanni steinmanni*			Syn. *N. elongatus var. cylindralithus* *N. elongatus var. macrolithus*	very low birefringence				

Figure 7.24. A summary of the main characteristics of the taxa found in Morphogroup 2.3.

MORPHOGROUP	2.3 ß1: 20-45° Cycle A: > 1µm			3.3 ß1: > 45° Cycle A: > 1µm					
SKETCH				 α:45° ß: 70°			 α: 22° ß: 53°		
SHAPE	Conical Narrow canal	small conical narrow canal	Egg-timer outline truncated poles	globular outline	small globular-outline	large sub-square with very wide cavity	oval	pear-shaped	small pear-shaped
CENTRAL OPENING	canal	canal	cavity	cavity	cavity	cavity	cavity	cavity	cavity
DIMENSIONS	L: 11-25µm W1: 5-8µm W2: 4-5µm	L: 8-10µm W: 7-9µm	L: 12-14µm W: 7-8µm	L: 5-12µm W: 7-14µm	L: 3-6µm W: 4-8.5µm	L: 9-19µm W: 9-18.5µm	L: 7-15µm W: 6-11µm	L: 8-10µm W: 7-9µm	L: 7-9µm W: 8-11.5µm
RANGE	Ryazanian/ Berriasian- Barremian	Upper Ryazanian- Valanginian	Upper Barremian	Tithonian / Berriasian- Aptian	TITHONIAN Upper Ryazanian	Barremian	Ryazanian/ Berriasian- Aptian	Barremian- Albian	Aptian- Albian
OCCURRENCE	NW Europe W. Tethys N & S. Atlantic	NW Europe W. Tethys N & S. Atlantic	NW Europe	NW Europe W. Tethys N & S. Atlantic	NW Europe W. Tethys N & S. Atlantic	NW Europe	NW Europe	NW Europe W. Tethys N & S. Atlantic	NW Europe N. Atlantic
SPECIES	*N. steinmanni steinmanni*	*N. steinmanni minor*	*Nannoconus* sp. 2	*N. globulus globulus*	*N. globulus minor*	*N. globulus* subsp. A	*N. oviformis*	*N. wassalli wassalli*	*N. wassalli minor*
COMMENTS						very poor preservation overgrowth of the cycles		jun. syns. *N. boletus* *N. calpidomorphous*	jun. syn. *N. boletus curtus*

Figure 7.25. A summary of the main characteristics of the taxa found in Morphogroup 2.3 and 3.3.

7.5 Nannofossil Taxonomic Index

Calcareous nannofossils, other than nannoconids are well-documented for NW Europe and a taxonomic index of the taxa cited in the text are recorded in alphabetical order. Each species is referred to a good taxonomic reference and plate. Problematic species are discussed in the remarks. A total of 83 nannofossil taxa, excluding the genus *Nannoconus*, listed in a separate species list were recognised in the sample material.

Assipetra **Roth 1973**

A. infracretacea **(Thierstein, 1973) Roth 1973:**
Crux 1989, p. 209, pl. 8.14, figs 3, 4.

Axopodorhabdus **Wind & Wise *in* Wise & Wind 1977**

A. dietzmannii **(Reinhardt, 1965) Wind & Wise 1983:**
Crux 1989, p. 186-7, pl. 8.3, fig. 8 (SEM); p. 203, pl. 8.11, figs 18-20 (LM).

Biscutum **Black *in* Black & Barnes 1959**

B. ellipticum **(Górka, 1957) Black *in* Black & Barnes 1959:**
Crux 1989, p. 200, pl. 8.10, figs 21-24 (LM).

Braarudosphaera **Deflandre 1947**

B. batilliformis **Trölsen & Quadros 1971:**
Perch-Nielsen 1985, p. 360, fig. 22, pls 3, 4 (LM).

B. bigelowii **(Gran & Braarud, 1935) Deflandre 1947:**
Perch-Nielsen 1985, p. 360, fig. 22, pls 1, 2 (LM).

B. hockwoldensis **Black 1973:**
Perch-Nielsen 1985, p. 359, fig. 21 (sketch in table).

B. stenorhetha **Hill 1976:**
Perch-Nielsen 1985, p. 359, fig. 21 (sketch in table).

Bukrylithus **Black 1971**

B. ambiguus **Black 1971:**
Crux 1989, p. 193, pl. 8.6, figs 1, 2 (SEM); p. 205, pl. 8.12, fig. 15 (LM).

Ceratolithina **Perch-Nielsen 1988:**

Individual species were not always recognised due to breakage.

Chiastozygous **Gartner 1968**

***C. cepekii* Crux 1987:**

Crux 1989, p. 191, pl. 8.5, figs 4-7 (SEM); p. 205, pl. 8.12, figs 10-14 (LM).

Conusphaera **Trejo 1969**

***C. rothii* (Thierstein, 1971) Jakubowski 1986:**

Crux 1989, p. 207, pl. 8.13, figs 31/2 (LM).

Corollithion **Stradner 1961**

***C. geometricum* (Górka 1957) Manivit 1971:**

Crux 1989, p. 191, pl. 8.5, fig. 12 (SEM); p. 207, pl. 8.13, fig. 21 (LM).

***C. rhombicum* (Stradner & Adamiker, 1966) Bukry 1969:**

Crux 1989, p. 191, pl. 8.5, fig. 11 (SEM); p. 207, pl. 8.13, fig. 25 (LM).

***C. silvaradion* Filewiz *et. al. in* Wind & Wise 1977:**

Crux 1989, p. 191, pl. 8.5, fig. 10 (SEM); p. 207, pl. 8.13, figs 23, 24 (LM).

Cretarhabdus **Bramlette & Martini 1964**

***C. angustiforatus* Black (1971) Bukry 1973:**

Crux 1989, p. 202, pl. 8.11, figs 9-11 (LM).

***C. conicus* Bramlette & Martini 1964:**

Crux 1989, p. 202, pl. 8.11, figs 12, 13 (LM): Crux 1989, p. 188, pl. 8.4, fig. 1 (SEM).

***C. inaequalis* Crux 1987:**

Crux 1989, p. 202, pl. 8.11, figs 14, 15 (LM): Crux 1989, p. 188, pl. 8.4, figs 7-10 (SEM).

***C. madingleyensis* Black 1971:**

Crux 1989, p. 202, pl. 8.11, figs 9-11 (LM): Crux 1989, p. 188, pl. 8.4, fig. 3 (SEM).

Crucibiscutum Jakubowski 1986

C. salebrosum (Black, 1971) Jakubowski 1986:

Crux 1989, p. 185, pl. 8.2, figs 8, 9 (SEM); p. 201, pl. 8.10, fig. 28 (LM).

Cruciellipsis Thierstein 1971

C. cuvillieri Thierstein 1971:

Crux 1989, p. 203, pl. 8.11, figs 1,2 (LM).

Cyclagelosphaera Noël 1965

C. margerelii Noël 1965:

Crux 1989, p. 183, pl. 8.1, fig 3, 7 (SEM); p. 201, pl. 8.10, fig. 13, 14 (LM).

Cylindralithus Bramlette & Martini 1974

C. laffiteti (Noël, 1957) Black 1973:

Crux 1989, p. 199, pl. 8.9, fig. 8 (SEM); p. 207, pl. 8.13, figs 29, 30.

Diazomatolithus Noël 1965

D. lehmannii Noël 1965:

Crux 1989, p. 185, pl. 8.2, figs 7, 10 (SEM); p. 201, pl. 8.10, figs 1-5 (LM).

Discorhabdus Noël 1965

D. ignotus (Górka, 1957) Perch-Nielsen 1968:

Crux 1989, p. 185, pl. 8.2, figs 1-3 (SEM); p. 201, pl. 8.2, fig. 25 (LM).

Eiffellithus Reinhardt 1965

E. turriseiffelii (Deflandre *in* Deflandre & Fert, 1954) Reinhardt 1965:

Perch-Nielsen 1985, p. 368, figs 35, 12 (LM).

Eprolithus Stover 1966

Remarks: *Eprolithus* was described with 8 rays but two forms were found with 11 and 16 rays, termed here *E.* sp 11 and *E.* sp 16 respectively.

E. antiquus Perch-Nielsen 1979:

Crux 1989, p. 199, pl. 8.9, figs 9, 12 (SEM); p. 209, pl. 8.14, figs 13, 18, 23 (LM).

E. apertior **Black 1973:**
Jakubowski 1987, p. 118, pl. 3, figs 1-2 (LM).

E. floralis **(Stradner & Grün, 1962) Stover 1966:**
Perch-Nielsen 1985, p. 389, fig. 56, pls 19-24 (LM & SEM).

E. orbiculatus **(Forcheimer, 1972) Crux *in* Crux *et. al.* 1982:**
Perch-Nielsen 1985, p. 389, fig. 56, pl. 10 (SEM).

E. varolii **Jakubowski 1986:**
Jakubowski 1987, p. 118, pl. 3, figs 5-6 (LM).

Gartnerago **Bukry 1969**

G. praeobliquum **Jakubowski 1986:**
Jakubowski 1987, p. 114, pl. 1, figs 20-21 (LM).

Glaukolithus **Reinhardt 1964**

G. compactus **(Bukry, 1969) Perch-Nielsen 1984:**
Crux 1989, p. 204, pl. 8.12, figs 25-27 (LM).

Grantarhabdus **Black 1971**

G. meddii **Black 1971:**
Crux 1989, p. 189, pl. 8.4, figs 11/2 (SEM); p. 203, pl. 8.11, figs 16/7 (LM).

Hemipodorhabdus **Black 1971**

H. gorkae **(Reinhardt, 1969) Grün *in* Grün & Allemann 1975:**
Crux 1989, p. 186, pl. 8.3, fig. 12 (SEM): Crux 1989, p. 202, pl. 8.11, fig. 21 (LM).

Holococcolith sp:
Crux 1989, p. 200, pl. 8.10, figs 33-35 (LM).

Kokia **Perch-Nielsen 1988**
Remarks: Observation of scanning electron micrographs have shown that a central poreor very thin diaphragm is present.

K. borealis **Perch-Nielsen 1988:**

Holotype: pl. 1, fig. 8 (LM).

***K. curvata* Perch-Nielsen 1988:**
Holotype: pl. 1, fig. 11 (LM)

***Kokia* sp.**
Species of *Kokia* which differ from the above by the number of segments and degree of tapering of the individual rays.

***Lithraphidites* Deflandre 1963**

***L.* carniolensis Deflandre 1963:**
Crux 1989, p. 195, pl. 8.7, fig. 12 (SEM); p. 207, pl. 8.13, figs 34/5 (LM).

***L. morayfirthensis* Jakubowski 1986**
Jakubowski 1987, p. 114, pl. 1, fig. 2-3 (SEM).

***Manivitella* Thierstein 1971**

***M. pemmmatoidea* (Deflandre *in* Manivit, 1965) Thierstein 1971:**
Crux 1989, p. 183, pl. 8.1, figs 11/2 (SEM); p. 201, pl. 8.10, figs 6,7 (LM).

***Micrantholithus* Deflandre *in* Deflandre & Fert 1954**

***M. hoschulzii* (Reinhardt, 1966a) Thierstein 1971:**
Jakubowski 1987, p. 118, pl. 3, fig. 4 (LM).

***M. obtusus* Stradner 1978:**
Crux 1989, p. 209, pl. 8.14, figs 1, 2 (LM).
Remarks: A morphological variation of this species is noted towards the top of the range. A distinct reduction in size occurs and the individual plates become very incised.

***M. speetonensis* Perch-Nielsen 1979:**
Jakubowski 1987, p. 118, pl. 3, figs 11-12 (LM).

***Microstaurus* Black 1971**

***M. chiastius* (Worsley, 1971) Grün *in* Grün & Allemann 1975:**
Crux 1989, p. 189, pl. 8.4, fig. 6 (SEM); p. 203, pl. 8.11, figs 3, 4 (LM).

Perissocyclus Black 1971

P. fletcheri Black 1971:

Crux 1989, p. 187, pl. 8.3, fig. 1 (SEM).

P. noeliae Black 1971:

Crux 1989, p. 203, pl. 8.11, figs 22/3 (LM).

P. plethotretus Wind & Cepek 1979:

Crux 1989, p. 203, pl. 8.11, figs 24-27 (LM).

Phanulithus Wind & Wise *in* Wise & Wind 1977

P. anfractus Jakubowski 1986:

Jakubowski 1987, p. 114, pl. 1, figs 8-9 (LM).

Prediscosphaera Vekshina 1959

P. columnata (Stover, 1966) Perch-Nielsen 1974:

Perch-Nielsen 1985, p. 393. fig. 61, 13 (LM).

Repagulum Forcheimer 1972

R. parvidentatum (Deflandre & Fert, 1954) Forcheimer 1972:

Perch-Nielsen 1985, p. 412, figs 91 (SEM).

Rhagodiscus Reinhardt 1967

R. angustus (Stradner, 1963) Reinhardt 1971:

Perch-Nielsen 1985, p. 395, figs 62, 10-16 (LM & SEM).

R. asper (Stradner, 1963) Reinhardt 1967:

Perch-Nielsen 1985, p. 395, figs 62, 6 (SEM).

R. pseudoangustus Crux 1987:

Holotype: p. 196, pl. 8.8, 10, 11 (SEM), p. 206, pl. 8.13, fig. 16-19 (LM).

Rhombolithion Black 1973

Rhombicum bifurcatum (Noël, 1973) Grün & Zweili 1980:

Thomsen 1987, pl. 17, fig. 13 (SEM).

Scapholithus Deflandre *in* Deflandre & Fert 1954

***Scapholithus fossilis* Deflandre *in* Deflandre & Fert 1954:**

Crux 1989, p. 195, pl. 8.7, fig. 9 (SEM).

***Seribiscutum* Filewicz *et. al. in* Wise & Wind 1977:**

***S. primitivum* (Thierstein, 1974) Filewicz *et. al. in* Wise & Wind 1977:**

Jakubowski 1987, p. 114, pl. 1, figs 12-13 (LM).

***Sollasites* Black 1967**

***S. arcuatus* Black 1971:**

Perch-Nielsen 1985, p. 397, figs 65, 2 (SEM).

***S. hayi* (Black, 1973) Perch-Nielsen 1984:**

Perch-Nielsen 1985, p. 397, figs 65, 10 (SEM).

***S.horticus* (Stradner*et al. in* Stradner & Adamiker, 1966) Cepek & Hay 1969:**

Crux 1989, p. 184, pl. 8.2, fig. 6 (SEM): Crux 1989, p. 200, pl. 8.10, fig. 10 (LM).

***Speetonia* Black 1971**

***S. colligata* Black 1971:**

Crux 1989, p. 187, pl. 8.3, fig. 7 (SEM); p. 203, pl. 8.11, figs 29, 30.

***Staurolithites* Caratini 1963**

***S. crux* (Deflandre *in* Deflandre & Fert, 1954) Caratini 1963:**

Crux 1989, p. 193, pl. 8.6, figs 3-6 (SEM); p. 205, pl. 8.12, figs 17/8.

***S. mutterlosei* Crux 1989:**

Holotype: p. 193, pl. 8.6, figs 7,8 (SEM); p. 205, pl. 8.12, figs 16, 21 (LM).

***Stradnerlithus* Black 1971**

***S. comptus* Black 1971:**

Crux 1989, p. 207, pl. 8.13, fig. 20-28 (LM).

***Tegulalithus* Crux 1986**

***T. septentrionalis* Stradner 1963**

Crux (1986) p. 199, pls 1-3, 5, 6 (SEM); p. 209, pls 19-22, figs 24-27 (LM).

Tegumentum **Thierstein *in* Roth & Thierstein 1972**

T. octiformis **(Köthe 1961) Crux 1989:**

Crux 1989, p. 190, pl. 8.5, figs 2,3 (SEM): P. 204, pl. 8.12, figs 6, 7 (LM).

T. striatum **(Black 1971) Crux 1989:**

Crux 1989, p. 190, pl. 8.5, fig. 1 (SEM): p. 204, pl. 8.12, figs 1-5 (LM).

T. stradneri **Thierstein *in* Roth & Thierstein 1972:**

Jakubowski 1987, p. 114, pl. 1, figs 18, 19 (LM).

Tranolithus **Stover 1966**

T. gabalus **Stover 1966:**

Perch-Nielsen 1985, p. 408, figs 83, 9-11 (LM & SEM).

T. phacelosus **Stover 1966:**

Perch-Nielsen 1988, p. 408, fig. 83, pl. 13-17 (LM & SEM).

T. salilium **(Noël, 1965) Crux 1981:**

Perch-Nielsen 1988, p. 408, fig 8.3, pl. 12 (LM).

Triquetorhabdulus **Martini 1965**

T. shetlandensis **Perch-Nielsen, 1988:**

Holotype: pl. 1, fig. 15, 16 (LM).

Vagalapilla **Bukry 1969**

V. matalosa **(Stover, 1966) Thierstein 1973:**

Crux 1989, p. 205, pl. 8.12, fig. 23, 24 (LM).

Viminites **Black 1975**

V. swinnertonii **(Black, 1971) Black 1975:**

Crux 1989, p. 197, pl. 8.8, figs 6, 9 (SEM); p. 207, pl. 8.13, figs 3-5 (LM).

Watznaueria **Reinhardt 1964**

W. barnesae **(Black *in* Black & Barnes, 1959) Perch-Nielsen 1968:**

Crux 1989, p. 183, pl. 8.1, figs 1, 2 (SEM); p. 201, pl. 8.10, fig. 11 (LM).

***W. ovata* Bukry 1969:**
Crux 1989, p. 183, pl. 8.1, fig. 9 (SEM); p. 201, pl. 8.10, figs 8-10 (LM).

***Zeugrhabdotus* Reinhardt 1965**

***Z. embergeri* (Noël, 1959) Perch-Nielsen 1984:**
Perch-Nielsen 1985, p. 409, figs 84, 9, 10 (LM)

***Z. erectus* (Deflandre *in* Deflandre & Fert, 1954) Reinhardt 1965:**
Perch-Nielsen 1987, p. 409, figs 84, 11-13 (LM & SEM).

***Z. sisyphus* Gartner 1968:**
Crux 1989, p. 195, pl. 187, fig. 1 (SEM); p. 205, pl. 8.12, fig. 30 (LM).

PHOTOGRAPHIC PLATES

All photographic negative numbers are housed at University College London.

The Deflandre-Type Collection Slides were photographed in the Laboratoire de Géologie du Muséum National d'Histoire Naturelle, Paris.

PLATE 1

Figs 1-3. *N. circularis* Deres & Achériteguy, 1980.

Barremian. Site: 15/25a-2, 13259 ft. Light Microscope, all x1344.

Fig. 1. Crossed-nicols. Focusing on the nearside wall showing slight inclination of the wall structure. Catalogue No: 3320/17.

Fig. 2. Crossed-nicols. Focusing at the midpoint showing detail of the central cavity dimensions and apertural openings. Catalogue No: 3320/16.

Fig. 3. Partially-polarised light. Focusing on the furthest wall (note the change in orientation of the cycles of elements in comparison to fig. 1). Catalogue No: 3320/15.

Figs 4-6. *Nannoconus* spp.

Barremian. Top view/discs. Light Microscope, all x1344.

Fig. 4. Crossed-nicols. Dissagregated flange from *N. abundans* showing a flaring extinction pattern. Site: Adda-2, 7774 m. Catalogue No: 3219/16.

Fig. 5. Partially-polarised light. *N. minutus* top view/disc clearly showing the plates. Site: Adda-2, 7774m. Catalogue No: 3219/27.

Fig. 6. Partially-polarised light. *N. circularis* top view/disc showing distinct sector extinction. Site: 63/10-1, 1255m. Catalogue No: BVN 12.2.91/11.

Figs 7 & 9. *N. steinmanni steinmanni* (Kamptner, 1931) subsp. emend. Deres & Achériteguy, 1980.

Barremian. Site: North Jens-1, 7560.3 m. Scanning Electron Microscope.

Fig. 7. Detail of the distal aperture, individual plates showing evidence of etching on the external surface. Plate overlap is in a clockwise direction. x12132. Catalogue No: 2895/8.

Fig. 9. Oblique longitudinal view. x3958. Catalogue No: 2895/7.

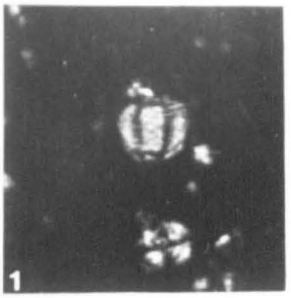
Figs 8 & 10. *N. abundans* Stradner & Grün, 1973.

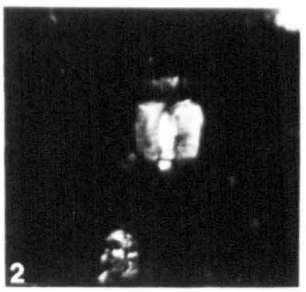
Barremian. Site: North Jens-1, 7560.11 m. Scanning Electron Microscope, all x12132. Catalogue No: SF 1/6.

Fig. 8. Sketch of figure 10. showing the c-axes direction of the individual plates.

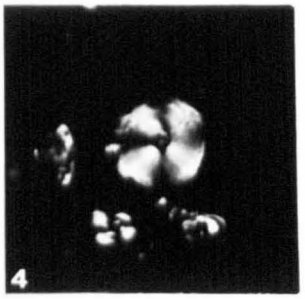
Fig. 10. Proximal view of the flange.

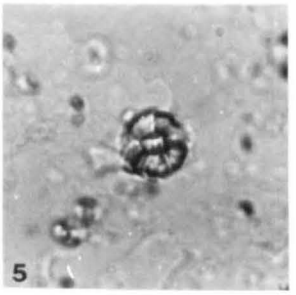
Pl.1

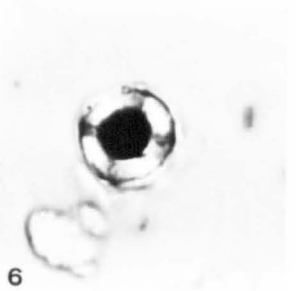

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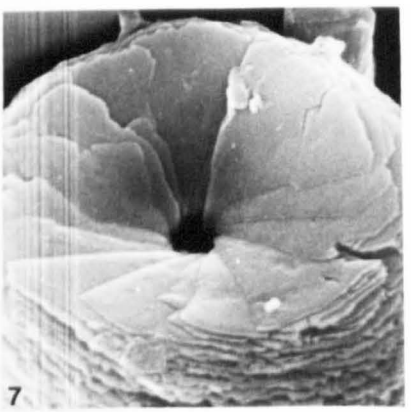

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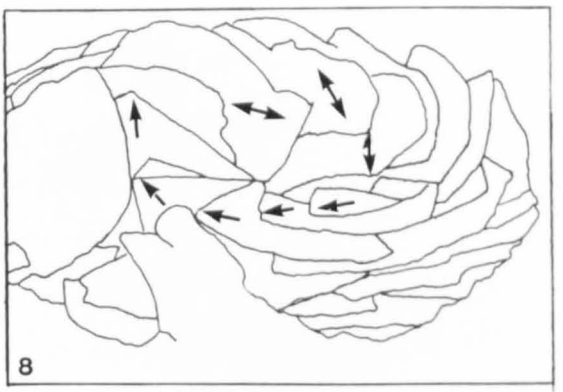

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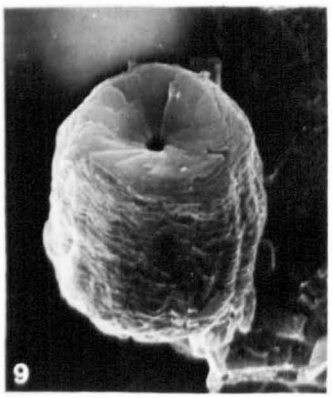

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PLATE 2.

Figs 1-3. *N. truitti truitti* (Brönnimann, 1955) subsp. emend. Deres & Achériteguy, 1980.

Early Aptian. Site: E-1, 8207.6 m. Double specimen in the Light Microscope, all x1344.

Fig. 1. Crossed-nicols, focusing on the nearside wall which appears to show crystallographic continuity of the "spiral" structure. Catalogue No: 3227/5.

Fig. 2. Partially-polarised, focusing on the nearside wall. Catalogue No: 3227/2.

Fig. 3. Partially-polarised, focusing on the central cavity. Catalogue No: 3193/36.

Figs 4 & 5. *N. circularis* Deres & Achériteguy, 1980.

Aptian. Site: E-1, 8193 m. Double structure in the light microscope, all x1344.

Fig. 4. Crossed-nicols, focusing on the central constriction. Catalogue No: 3234/17.

Fig. 5. Sketch of figure 4 showing the authors interpretation of the structure.

Figs 6 & 7. *N. abundans* Stradner & Grün, 1973.

Barremian. Site: North Jens-1, 7560.11 m. Monospecific lamina showing double structures of *N. abundans*, Scanning Electron Microscope.

Fig. 6. Two specimens of *N. abundans* adjacent along the proximal pole of the individuals. x2708. Catalogue No: 2954/11.

Fig. 7. Plan view of the lamina which contains three double structures of *N. abundans*. x1750. Catalogue No: 2954/13.

Figs 8, 9, 12. *N.* aff. *truitti* Brönnimann, 1955.

Barremian. Site: E-1, 8200 m. Double structure in the Scanning Electron Microscope.

Fig. 8. Surface of lamina with double specimen in the top left corner, below a single specimen of *N. aff truitti truitti* can be observed. x1750. Catalogue No: 3285/20.

Fig. 9. Longitudinal view of the double structure. x3828. Catalogue No: 3285/21.

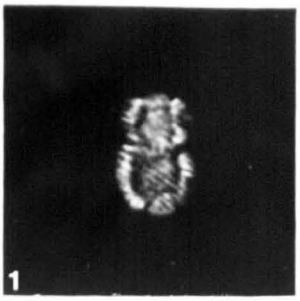
Fig. 10. Detail of the midpoint. x8281. Catalogue No: 3285/22.

Figs 10, 11. *Nannoconus* sp.

Barremian. Site: E-1, 8200 m. Scanning Electron Microscope.

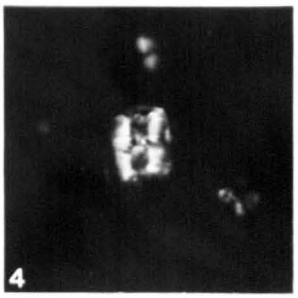
Fig. 10. Longitudinal view. x7500. Catalogue No: 3285/25.
Fig. 11. Detail of the wall structure. A change in orientation of the individual cycles of the plates is apparent. x9062. Catalogue No: 3285/26.

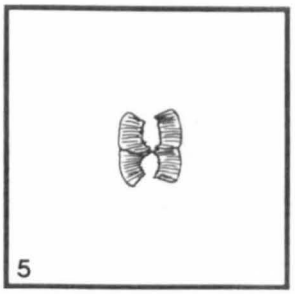
Pl. 2


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PLATE 3.

Figs 1-3. *Kokia borealis* Perch-Nielsen, 1988.

Valanginian. Site: North Jens-1, 7950 m. Scanning Electron Microscope.

Fig. 1. View of whole nannolith. x3958. Catalogue No: 2830/4.

Fig. 2. Detail of central structure, pore or membrane covering a central depression. x17500. Catalogue No: 2830/5.

Fig. 3. Intact nannolith with shorter rays, here assigned to the same species. x3958. Catalogue No: 2843/2.

Figs 4 & 5. *N. bucheri* Brönnimann, 1955.

Barremian. Site: North Jens-1, 7561.11 m. Scanning Electron Microscope.

Fig. 4. Longitudinal view of a poorly preserved specimen. Patchy overgrowth is present on the surface. x4048. Catalogue No: 2930/5.

Fig. 5. Detail of the overgrowth surface, note the smooth appearance masking detail of the wall structure (classified as O-2). x6154. Catalogue No: 2930/6.

Fig. 6. *N. abundans* Stradner & Grün, 1973.

Barremian. Site: Speeton, LB5D. Some etching of the surface has occurred removing the ridges and grooves and overgrowth has also obscurred some of the wall structure detail. Scanning Electron Microscope, x7343. Catalogue No: 2813/25.

Figs 7-9. *N. quadriangulus quadriangulus* Deflandre & Defandre-Rigaud, 1962.

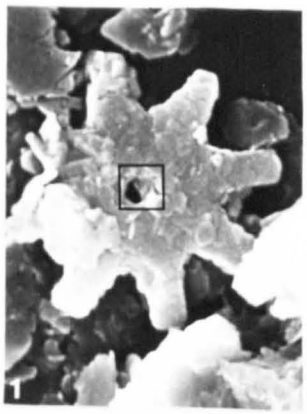
Site: Haute Provence, Deflandre Type Collection Catalogue No: BZ 92. Scanning Electron Microscope.

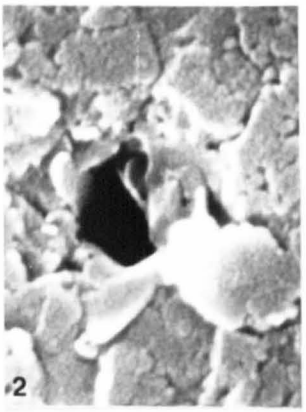
Fig. 7. Detail of square 1, figure 8. Surface of specimen coated by massive overgrowth. x7500. UCL Catalogue No: 3409/8.

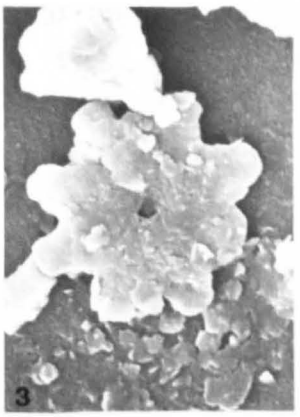
Fig. 8. Longitudinal view. x3047. Catalogue No: 3409/6.

Fig. 9. Detail of square 2, figure 8. x7500. Catalogue No: 3409/7.

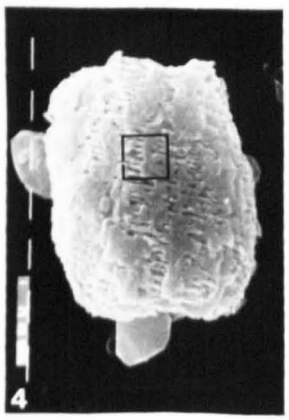
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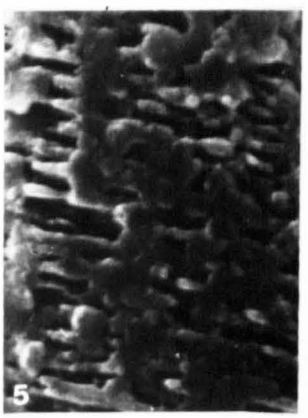




K. borealis



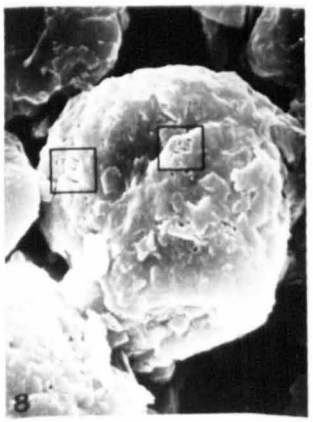
N. bucheri





N. abundans





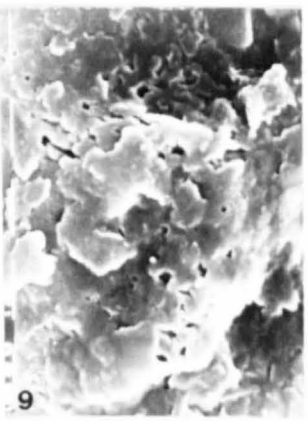


PLATE 4.

Figs 1-2. Faecal Pellet of *Pseudolithraphidites* Keupp, 1976.

Barremian, Munk Marl. Site: North Jens-1, 7561.11 m.

Fig. 1. Plan view of the faecal pellet. x175. Catalogue No: 2953/1.

Fig. 2. Detail showing the pellet to be composed of a monospecific assemblage of *Pseudolithraphidites*. x2500. Catalogue No: 2953/2.

Figs 3-9. Surface of bioturbated lamina.

Barremian. Site: E-1, 8200 m. Scanning Electron Microscope.

Fig. 3 & 4. Infill of burrow a, monospecific assemblage of *N. circularis*. x1750. Catalogue No: 3285/6 & 7.

Fig. 5. Plan view of the bedding plane surface showing bioturbation. Labelling refers to the location of detailed study. x55. Catalogue No: 3285/18.

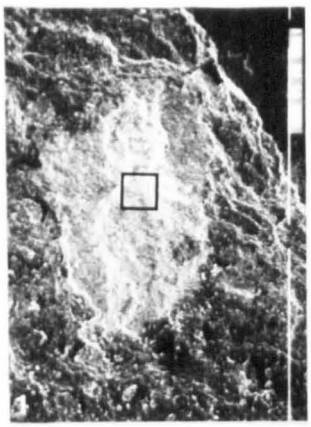
Fig. 6. Detail of a circular burrow. x175. 3285/9.

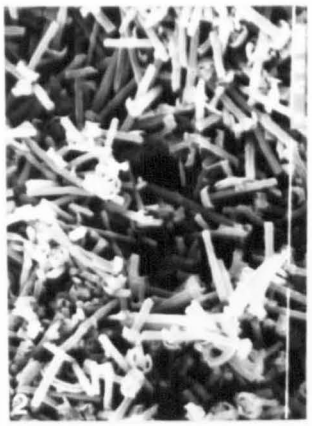
Fig. 7. Detail of burrow c, monospecific assemblage of *Nannoconus* sp. x1750. Catalogue No: 3285/13.

Fig. 8. Detail burrow c, *N. circularis*, *Cretarhabdus* sp. are the main assemblage components. x1750. Catalogue No: 3285/16.

Fig. 9. Detail of circular burrow in figure 6, pyrite spheres. Often associated with the breakdown of organic carbon. x2500. Catalogue No: 3285/11.

Pl.4

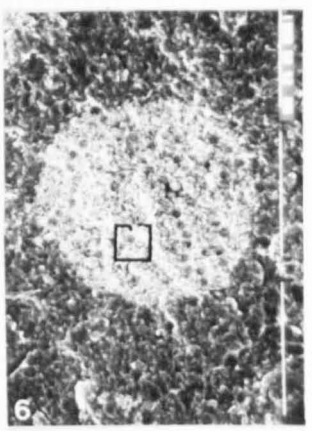
















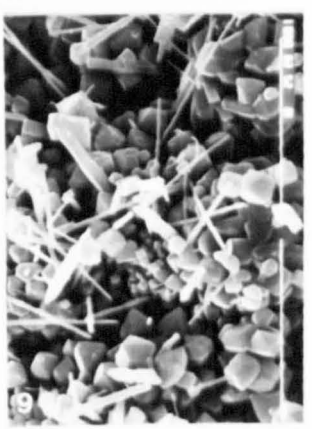


PLATE 5.

Figs 1-7. Surface of bedding plane showing bioturbation.

Barremian. Site: E-1, 8200 m. Scanning Electron Microscope.

Fig. 1. Plan view of bedding plane surface. x55. Catalogue No: 3284/1.

Fig. 2. Detail of a monospecific assemblage of *R. asper* x2500. Catalogue No:3284/18.

Fig. 3. Detail of b. Mixed assemblage. x2500. Catalogue No: 3284/19.

Fig. 4. Detail of c. Mixed assemblage. x2500. Catalogue No: 3284/3.

Fig. 5. Detail of d. Mixed assemblage. x2500. Catalogue No: 3284/2.

Fig. 6. Detail of d. Mixed assemblage. *Nannoconus* spp, *C. geometricum.* x2500. Catalogue No: 3284/20.

Fig. 7. *Corollithion* sp. x17500. Catalogue No: 3285/27.

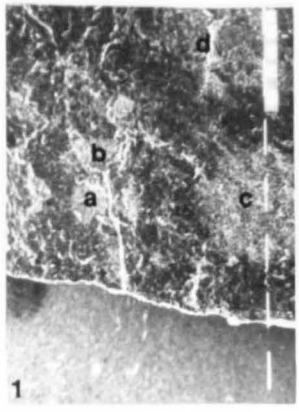
Figs 8-9. Monospecific lamina of *N. abundans* Stradner & Grün, 1973.

Barremian. Site: North Jens-1, 7561.11 m. Scanning Electron Microscope.

Fig. 8. Plan view of lamina. x175. Catalogue No: 2953/16.

Fig. 9. Detail of lamina, *N. abundans* (note the double structures). x1000. Catalogue No: 2954/5.

Pl.5



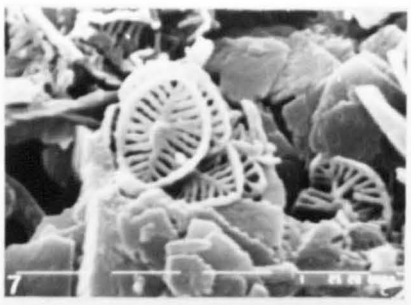












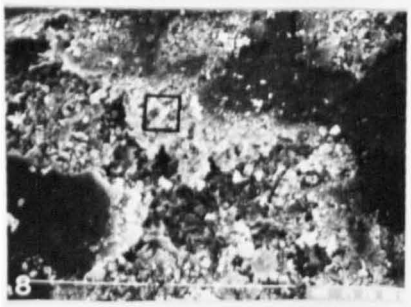




PLATE 6.

Figs 1-3. *N. abundans* Stradner & Grün, 1973.

Barremian. Site: North Jens-1, 7561.11 m. Morphogroup 1. representative species in the Scanning Electron Microscope.

Fig. 1. Longitudinal view. x3750. Catalogue No: 2915/22.

Fig. 2. Detail of surface area within the box indicated in figure 1. x17500. Catalogue No: 2915/23.

Fig. 3. Sketch of surface area. x17500.

Figs 4, 6, 8. *N. boneti* Trejo, 1959.

Barremian. Site: North Jens-1, 7561.11 m. Morphogroup 2. representative species, Scanning Electron Microscope.

Fig. 4. Longitudinal view. x3750. Catalogue No: 2885/13.

Fig. 6. Detail of the surface area. x17500. Catalogue No: 2885/12.

Fig. 8. Sketch of surface area. x17500.

Figs 5, 7, 9. *N. globulus globulus* (Brönnimann, 1955) subsp. emend. Bralower, 1989.

Barremian. Site: North Jens-1, 7442 m. Morphogroup 3. representative species, Scanning Electron Microscope.

Fig. 5. Longitudinal view. x3750. Catalogue No: 2915/22.

Fig. 7. Detail of surface. x17500. Catalogue No: 2915/23.

Fig. 9. Sketch of the surface area. x17500.

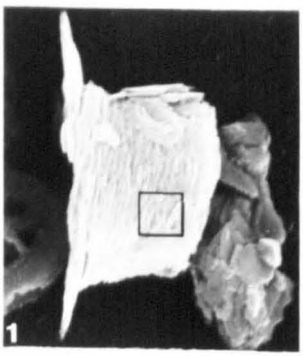
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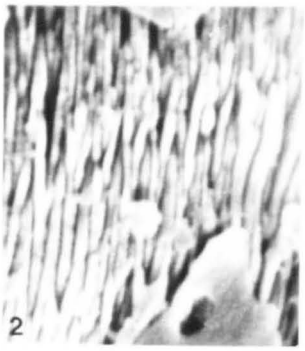
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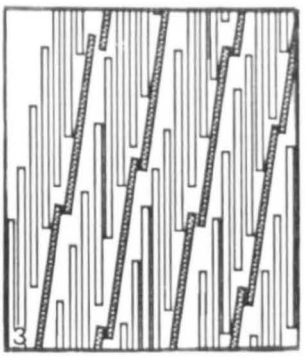
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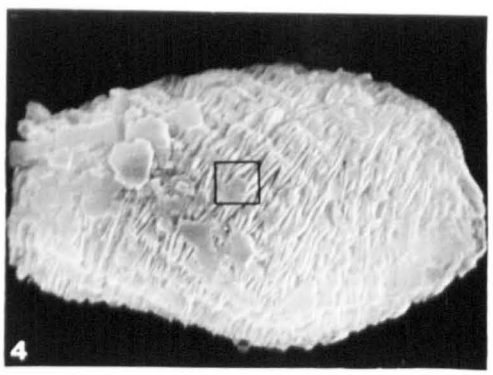
Angle of inclination refers to the inclination of the plates in relation to the horizontal axis of the specimen, standard direction of N-S in this plate.

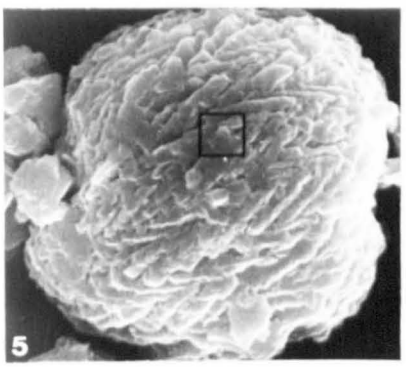
Pl. 6

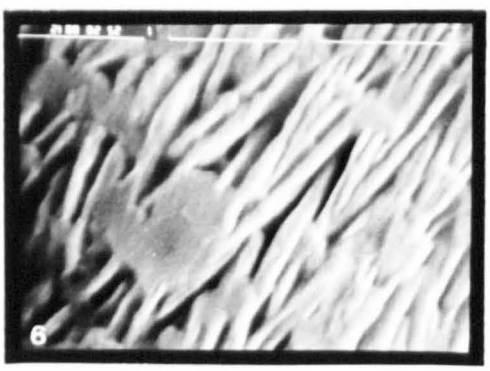


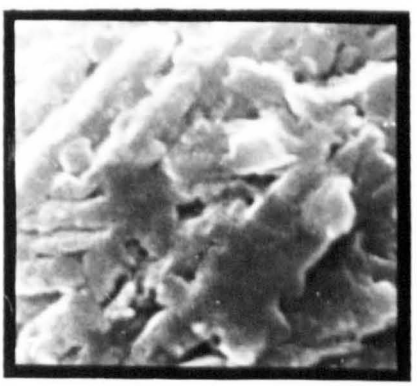


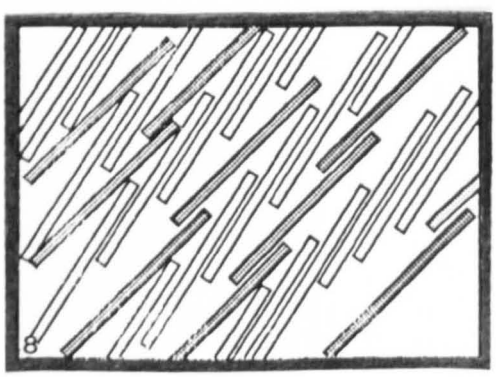












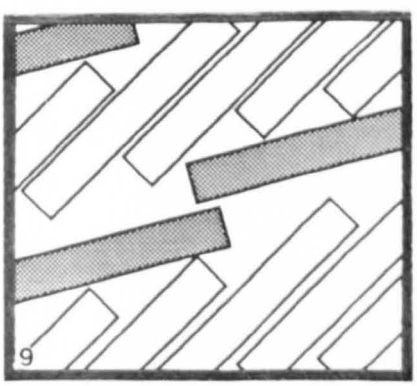


PLATE 7.

Figs 1-9. *N. abundans* Stradner & Grün, 1973.

Barremian. Scanning Electron Microscope.

Fig. 1. Longitudinal view. x3750. Site: North Jens-1, 7561.11 m. Catalogue No: 2887/13.

Fig. 2. Detail, same specimen. x17500. Catalogue No: 2887/14.

Fig. 3. Top view showing the proximal flange in plan view. x3750. Site: North Jens-1, 7561.11 m. Catalogue No: 2930/19.

Fig. 4. Longitudinal view (note the grooves and ridges). x3750. Site: North Jens-1, 7561.11 m. Catalogue No: 2884/29.

Fig. 5. Detail, same specimen. x17500. Catalogue No: 2884/30.

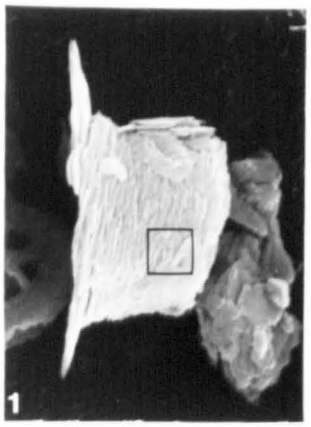
Fig. 6. Proximal flange. x3750. Site: North Jens-1, 7980 m. Catalogue No: 2886/9.

Fig. 7. Broken specimen, central barrel. x3750. Site: North Jens-1, 7408 m. Catalogue No: 2917/22.

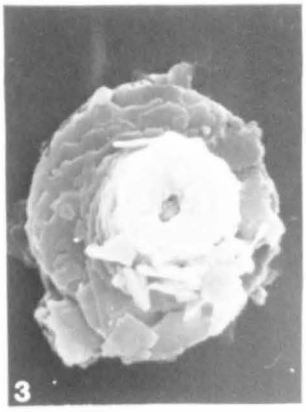
Fig. 8. Detail, same specimen. x17500. Catalogue No: 2917/23.

Fig. 9. Top view of broken specimen. x3750. Site: Speeton, LB5D. Catalogue No: 2813/30.

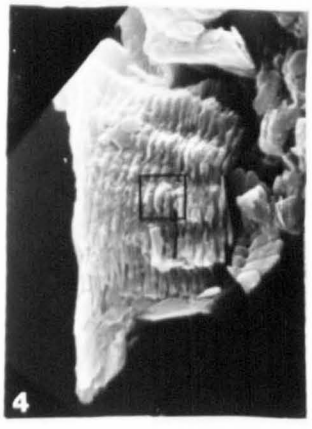
PI. 7

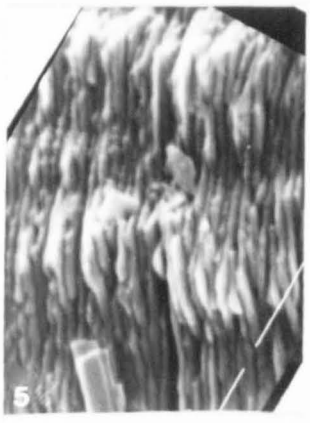

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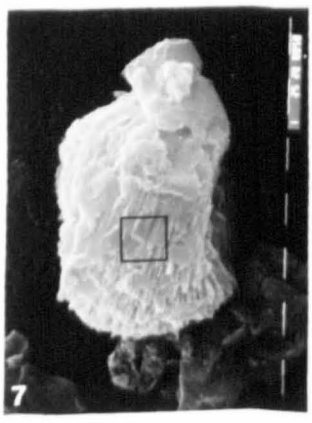

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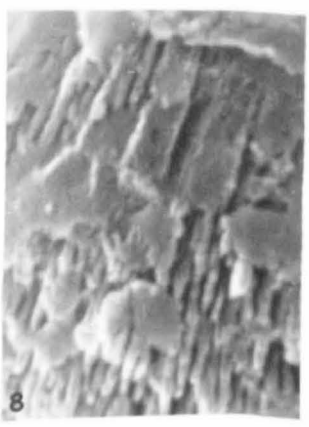
N. abundans abundans


4


5


6


7


8

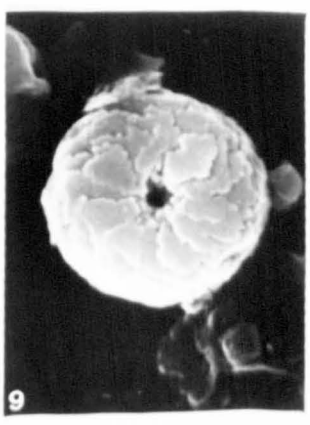

9

PLATE 8.

Figs 1-4. *N. abundans* Stradner & Grün, 1973.

Barremian. Site: North Jens-1, 7561.11 m. Light Microscope, all x1344.

Figs. 1 & 4. Top view showing intact proximal flange.

Fig. 1. Crossed-nicols. Catalogue No: 2980/9.

Fig. 4. Partially-polarised light. Catalogue No: 2980/8.

Fig. 2. Crossed-nicols. Longitudinal view, left section of flange broken. Catalogue No: 2926/4.

Fig. 3. Sketch of figure 2..

Fig. 5. *Nannoconus* sp/disc Crux, 1989.

Upper Ryazanian. Site: North Jens-1, 7800 m. Catalogue No: 2881/6.

Figs 6 & 9. *Nannoconus* sp. 1.

Barremian. Site: 15/25a-2, 13071 ft. Light Microscope, all x1344.

Fig. 6. Partially-polarised light. Longitudinal view. Catalogue No: 3319/35.

Fig. 9. Sketch of figure 6.

Figs 7 & 8. *N. aquitanicus* Deres & Achériteguy, 1980.

Barremian. Site: 15/25a-2, 13126 ft. Light Microscope, all x1344.

Fig. 7. Partially-polarised light. Longitudinal view. Catalogue No: 3401/27.

Fig. 8. Sketch of figure 7.

Figs 10-12. *N. sabinae* Perch-Nielsen, 1988.

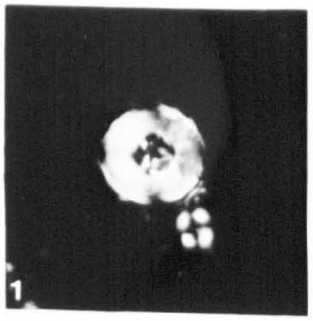
Upper Ryazanian. Site: 29/7-1, 10544 ft. Light Microscope, all x1344.

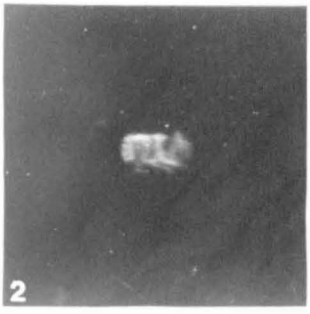
Fig. 10. Crossed-nicols. Oblique view. Catalogue No: 3403/1.

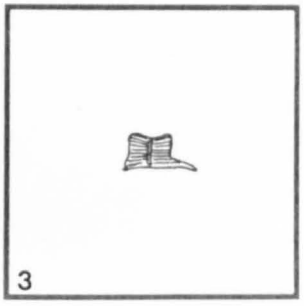
Fig. 11. Partially-polarised light. Catalogue No: 3403/3.

Fig. 12. Sketch of figure 11.

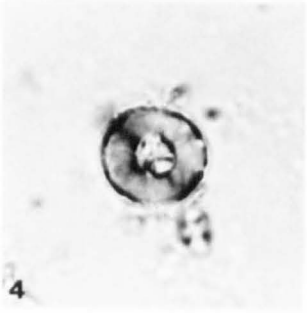
Pl.8





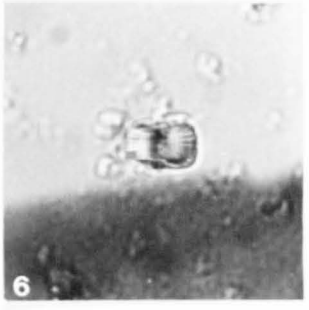


N. abundans abundans





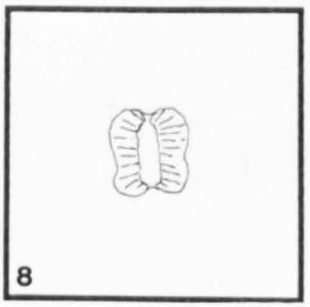
Nannoconus disc

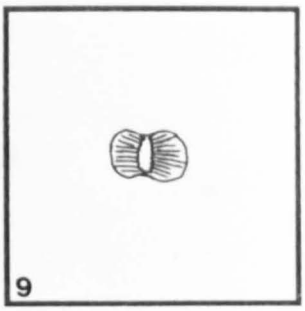


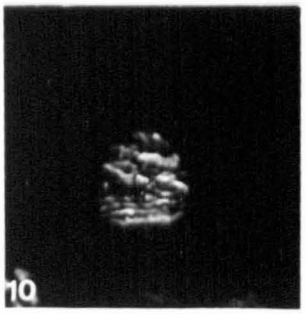
N. sp 1

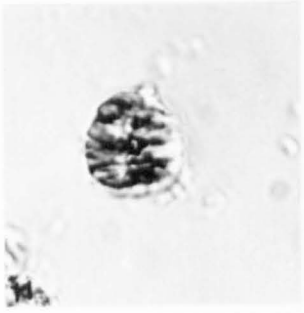


N. aquitanicus









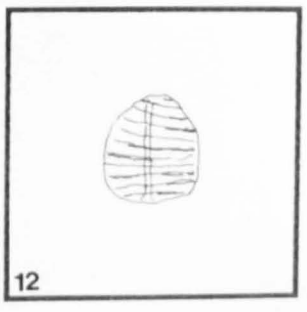


PLATE 9.

Figs 1-6. *N. circularis* Deres & Achériteguy, 1980.

Light Microscope, all x1344.

Fig. 1. Crossed-nicols. Focus on nearside wall to show the low inclination of the elements. Barremian. Site: E-1, 8200 m. Catalogue No: 3283/3.

Fig. 3. Sketch of figure 1.

Fig. 2. Partially-polarised light. Top view. Aptian, *R. asper* Zone. Site: E-1, 8193 m. Catalogue No: 3233/23.

Fig. 4. Crossed-nicols. *N. circularis* double structure. Aptian, *R. asper* Zone. Site: E-1, 8193 m. Catalogue No: 3234/17.

Fig. 5. Partially-polarised light, same specimen. Catalogue No: 3234/15.

Fig. 6. Partially-polarised light, top view.

Figs 7-12. *N. concavus* Perch-Nielsen, 1988.

Barremian. Site: L/2-2, 1672 m. Light microscope, all x1344..

Fig. 7. Crossed-nicols, longitudinal view. Catalogue No: 3239/16.

Fig. 8. Partially-polarised light. Catalogue No: 3239/15.

Fig. 9. Sketch of figure 8.

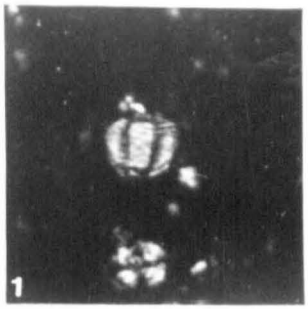
Scanning Electron Microscope. Barremian. Site: North Jens-1, 7442 m.

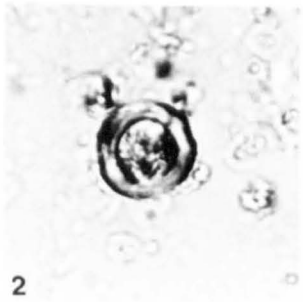
Fig. 10. Longitudinal view. x3750. Catalogue No: 916/20.

Fig. 11. Detail of wall. x17500. Catalogue No: 2916/21.

Fig. 12. Oblique view showing the distal apertural opening. x3750. Catalogue No: 2916/22.

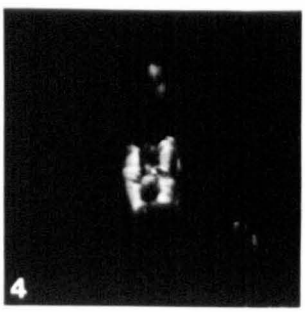
Pl. 9



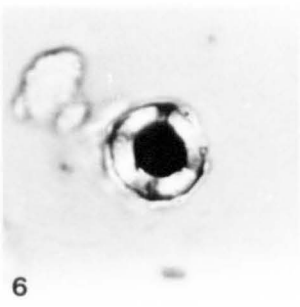


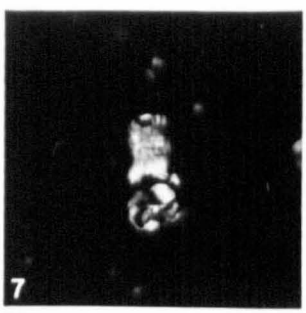


N. circularis

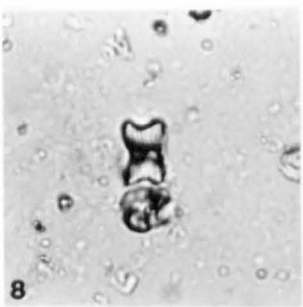


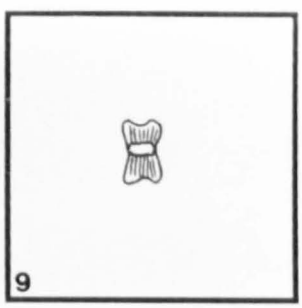


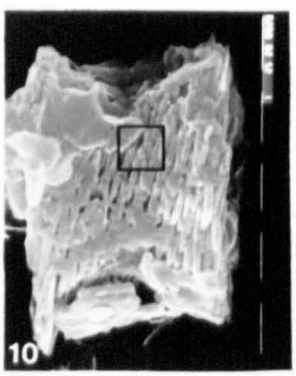


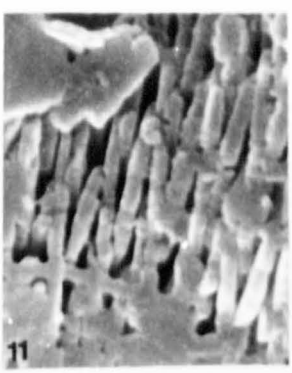


N. concavus









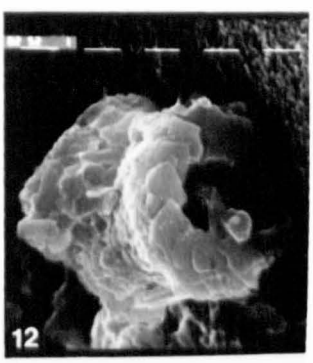


PLATE 10.

Fig. 1. ***N. dolomiticus*** **Cita & Pasquare, 1959.**

Stratigraphic age not given. Gran Falcon, Italy. Original paratype sketches. x1400. x1400.

Fig. 2. ***N. truitti truitti*** **Brönnimann, 1955.**

Albian. Las Villas Province, Cuba. Original paratype sketches. x2000.

Figs 3-11. ***N. bucheri*** **Brönnimann, 1955.**

Figs 3 & 6. Original paratype sketches. Sratigraphic age not known. Las Villas Province, Cuba. x2000.

Figs 4 & 5. Light Microscope. Deflandre Type Collection Catalogue No: BZ 92.

Fig. 4. Crossed-nicols, note central overgrowth. x1344. UCL Catalogue No: 3408/10.

Fig. 5. Partially-polarised light, same specimen. x1344. 3408/9.

Figs 7-8, 10-11. Same specimen in Light Microscope and Scanning Electron Microscope. Upper Ryazanian-Lower Valanginian. Site: 202/8-1, 5080 ft.

Fig. 7. Light Microscope, crossed-nicols. Longitudinal view. x1344. Catalogue No: 3321/22.

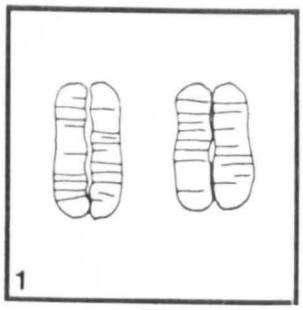
Fig. 8. Light Microscope, partially-polarised light. x1344. Catalogue No: 321/20.

Fig. 10. Scanning Electron Microscope. Longitudinal view. Catalogue No: 2917/17.

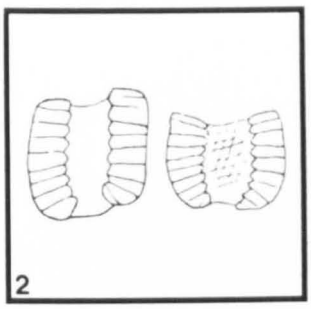
Fig. 11. Detail of surface. Catalogue No: 2917/18.

Fig. 9. Light microscope, partially-polarised light. Longitudinal view. x1344.
Barremian. Site: E-1, 8193 m. Catalogue No: 3233/30.

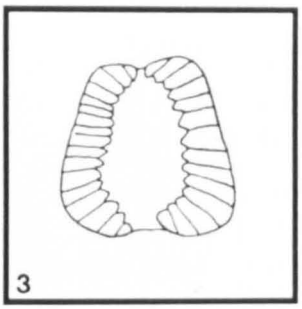
Pl. 10



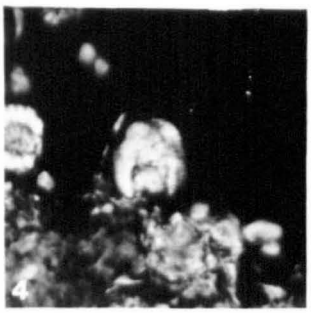
N. dolomiticus



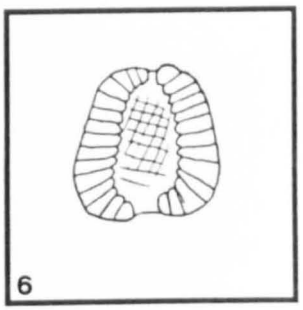
N. truitti truitti

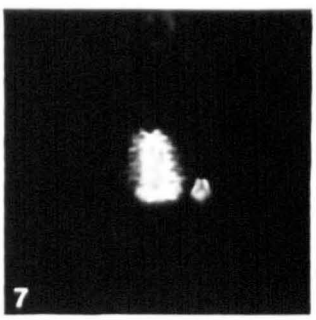


N. bucheri



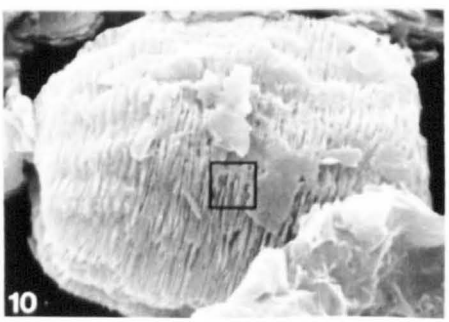












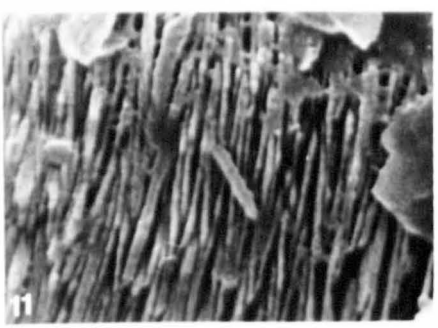


PLATE 11.

Figs 1-6. *N. quadriangulus quadriangulus* Deflandre & Deflandre-Rigaud, 1962.

Stratigraphic age not given. Haute Provence, France. Light Microscope, all x1344.

Fig. 1. Crossed-nicols. Longitudinal view. Deflandre Type Collection Catalogue No: CN 2. UCL Catalogue No: 3408/16.

Fig. 2. Partially-polarised light, same specimen. Catalogue No: 3408/15.

Fig. 3. Original holotype sketch. x2000.

Fig. 4. Crossed-nicols. Longitudinal view. Albian. Site: I-1, 9493.1 m. Catalogue No: 3202/6.

Fig. 5. Partially-polarised light, same specimen. Catalogue No: 3202/4.

Fig. 6. Partially-polarised light. Longitudinal view. Deflandre Type Collection Catalogue No: BZ 92. UCL Catalogue No: 3421/13.

Figs 7-12. *N. quadriangulus apertus* Deflandre & Deflandre-Rigaud, 1962.

Light Microscope, all x1344. Deflandre Type Collection Catalogue No: BZ 92.

Fig. 7. Crossed-nicols. Longitudinal view. Catalogue No: 3408/16.

Fig. 8. Partially-polarised light. Catalogue No: 3408/14.

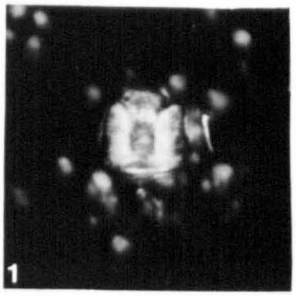
Fig. 9. Original holotype sketches. x2000.

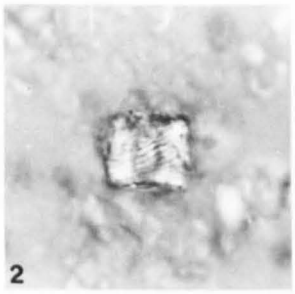
Fig. 10. Crossed-nicols. Longitudinal view. Catalogue No: 3408/4.

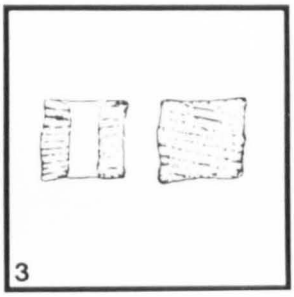
Fig. 11. Partially-polarised light, focus on nearside wall. Catalogue No: 3408/3.

Fig. 12. Partially-polarised light, focus midpoint. Catalogue No: 33408/2.

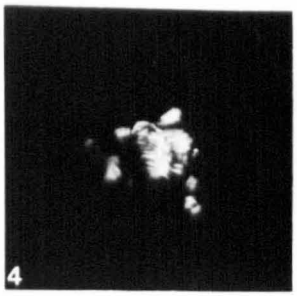
Pl.11

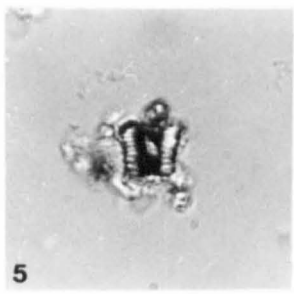


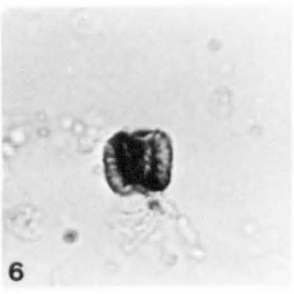


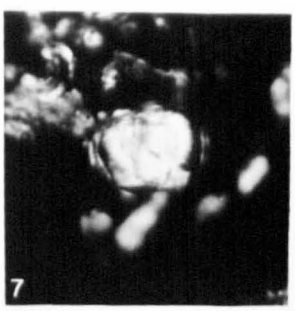


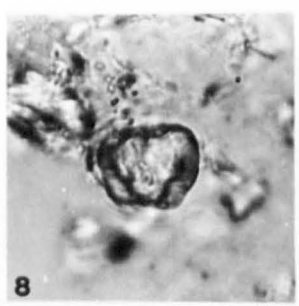
N. quadriangulus quadriangulus





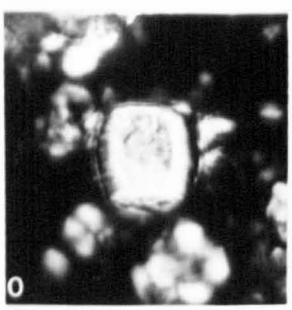


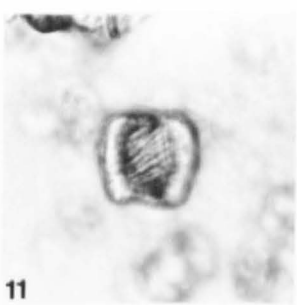






N. quadriangulus apertus





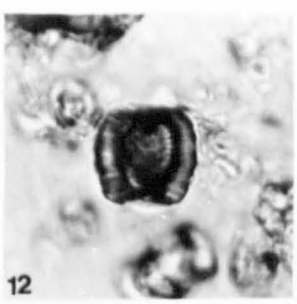


PLATE 12.

Figs 1-2, 4-5, 7. *N. quadriangulus apertus* Deflandre & Deflandre-Rigaud, 1962.

Fig. 1. Crossed-nicols, top view. x1344. Barremian. Site: E-1, 8208.5 m. Catalogue No: 3193/1.

Fig. 2. Partially-polarised light, same specimen. x1344. Catalogue No: 3193/2.

Fig. 4. Scanning Electron Microscope. Longitudinal view. x5000. Deflandre & Deflandre-Rigaud Type Collection Catalogue No: BG 59. Haute Provence. UCL Catalogue No: 3409/13.

Fig. 5. Scanning Electron Microscope. Top view showing the distal aperture. x5000. Catalogue No: 3409/9.

Fig. 7. Whole rock sample showing poorly preserved specimens. x5000. Barremian. Site: E-1, 8200m. Catalogue No: 3284/32.

Figs 3, 6, 8-11. *N. dauvillieri* Deflandre & Deflandre-Rigaud, 1960.

Figs 3 & 6. Original holotype sketches. Stratigraphic age not given. Paris Basin. x2000.

Figs 8-11. Barremian. Site: North Jens-1, 7561.11 m.

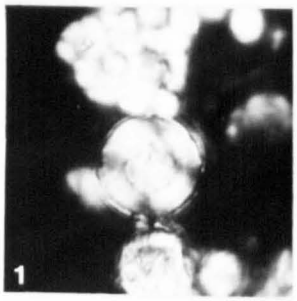
Fig. 8. Scanning Electron Microscope. Longitudinal view. x5000. Catalogue No: 2902/4.

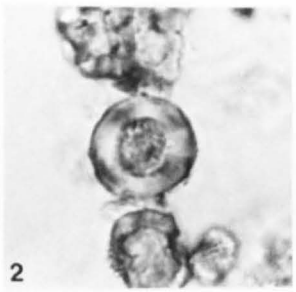
Fig. 9. Detail of surface. x17500. Catalogue No: 2902/5.

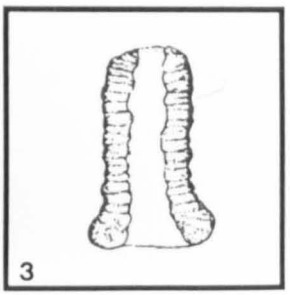
Fig. 10. Scanning Electron Microscope. Longitudinal view. x5000. Catalogue No: 2989/8.

Fig. 11. Detail of surface. x17500. Catalogue No: 2989/9.

Pl.12

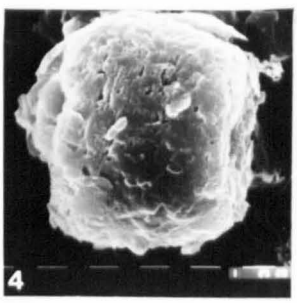


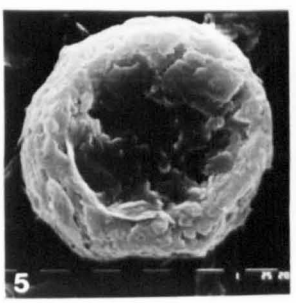


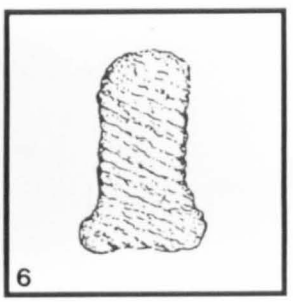


N. quadriangulus apertus

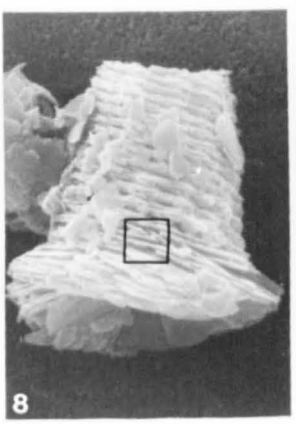
N. dauvillieri

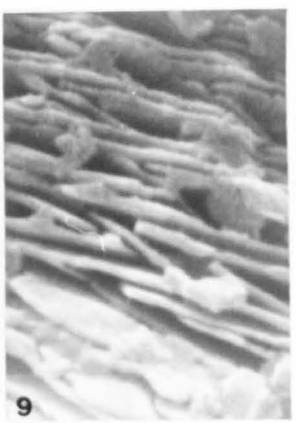












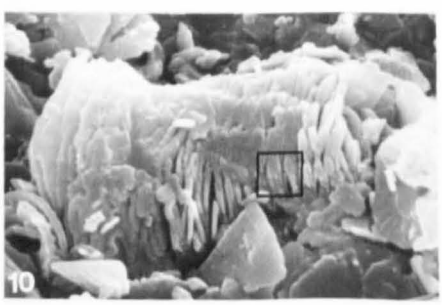




PLATE 13.

Figs 1-12. ***N. minutus*** **Brönnimann, 1955.**

Light Microscope, all x1344.

Fig. 1. Crossed-nicols. Longitudinal view. Barremian. Site: E-1, 8193 m. Catalogue No: 3234/25.

Fig. 2. Partially-polarised light, same specimen. Catalogue No: 3234/22.

Fig. 3. Original paratype sketches. Stratigraphic age not given. Las Villas Province, Cuba. x2000.

Fig. 4. Crossed-nicols. Stratigraphic age not given. Deflandre Type Collection Catalogue No: BG 59. UCL Catalogue No: 3421/3.

Fig. 5. Partially-polarised light. Deflandre Type Collection Catalogue No: BG 59. UCL Catalogue No: 3408/26.

Fig. 6. Partially-polarised light, same specimen. Catalogue No: 3408/25.

Figs 7 & 8. Barremian. Site: North Jens-1, 75605.9 m.

Fig. 7. Crossed-nicols. Catalogue No: 3211/33.

Fig. 8. Partially-polarised light, same specimen. Catalogue No: 3211/32.

Fig. 9. Partially-polarised light. Deflandre Type Collection Catalogue No: BG 59. UCL Catalogue No: 3421/4.

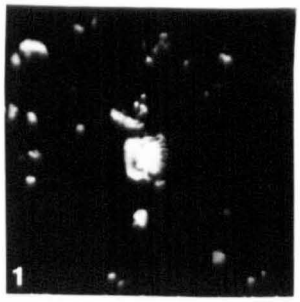
Figs. 10-12. Barremian. Site: 29/3-1, 11305 ft.

Fig. 10. Crossed-nicols. Focus on furthest wall to show the inclination of elements. Catalogue No: 3237/12.

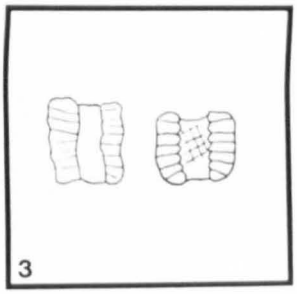
Fig. 11. Partially-polarised light, same specimen. Focus on furthest wall. Catalogue No: 3237/10.

Fig. 12. Partially-polarised light, same specimen. Focus on central cavity. Catalogue No: 3237/11.

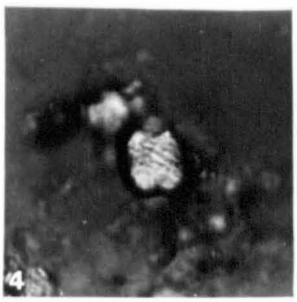
Pl.13

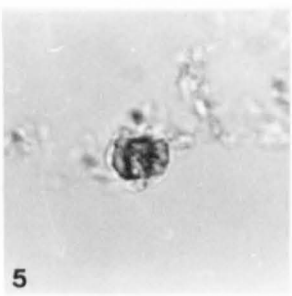

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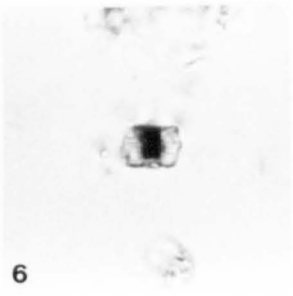

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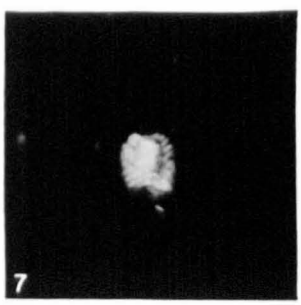

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N. minutus

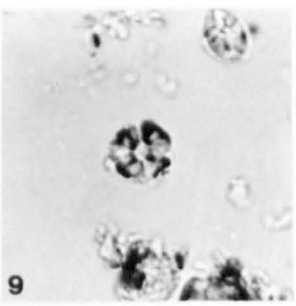

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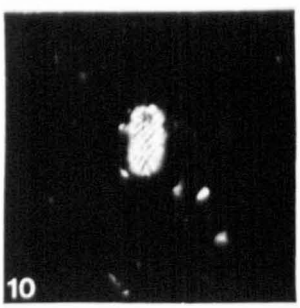

5


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10


11


12

PLATE 14.

Figs 1-6. *N. elongatus minutus* nov. subsp.

Barremian. Light Microscope, all x1344.

Fig. 1. Crossed-nicols. Longitudinal view. Site: E-1, 8208.5 m. Catalogue No: 3193/17.

Fig. 2. Partially-polarised light, same specimen. Catalogue No: 3193/16.

Fig. 3. Sketch of figure 2.

Fig. 4. Crossed-nicols. Longitudinal view. Site: Adda-2, 7750 m. Catalogue No: 3219/15.

Fig. 5. Partially-polarised light, same specimen. Catalogue No: 3219/14.

Fig. 6. Sketch of figure 5.

Figs 7-12. *N. elongatus elongatus* (Brönnimann, 1955) subsp. emend.

Barremian. Site: L/2-2, 1672 m. Light Microscope, all x1344.

Fig. 7. Crossed-nicols. Longitudinal view. Catalogue No: 3236/36.

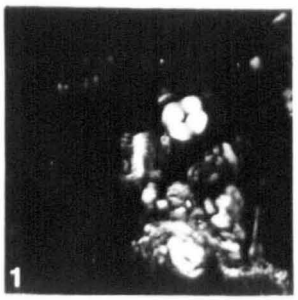
Fig. 8. Partially-polarised light, same specimen. Catalogue No: 3236/33.

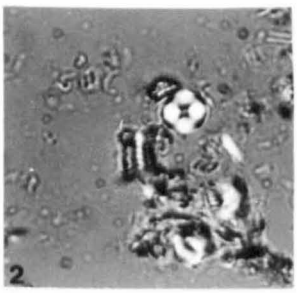
Fig. 9 & 12. Original paratype sketches. x2000.

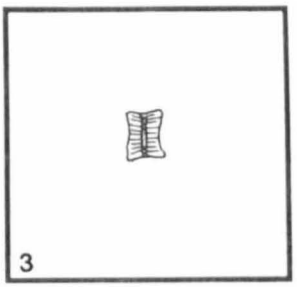
Fig. 10. Crossed-nicols. Catalogue No: 3236/35.

Fig. 11. Partially-polarised light. Catalogue No: 3236/32.

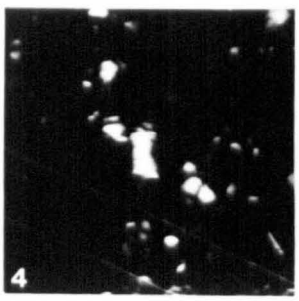
Pl. 14



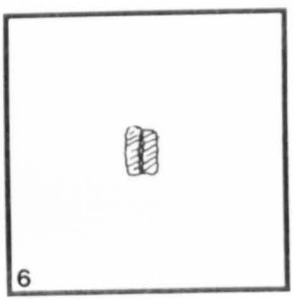


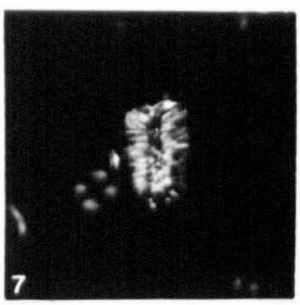


N. elongatus minutus

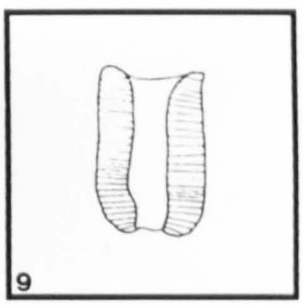




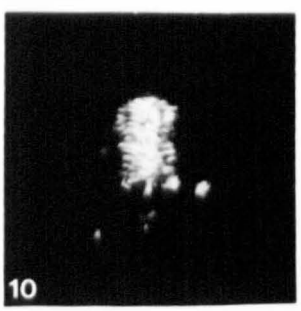








N. elongatus elongatus





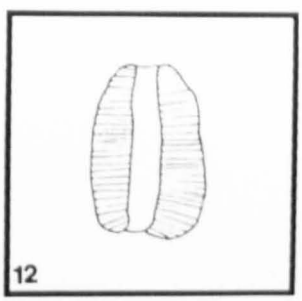


PLATE 15.

Figs 1-9. ***N. boneti*** **Trejo, 1959.**

Fig. 1. Light Microscope, crossed-nicols. Longitudinal view. x1344. Barremian. Site: E-1, 8211.3 m. Catalogue No: 3225/16.

Fig. 2. Light Microscope, partially-polarised light, same specimen. x1344. Catalogue No: 3225/15.

Figs. 3-6. Same specimen in the Light Microscope and Scanning Electron Microscope. Barremian. Site: E-1, 8211.3 m.

Fig. 3. Scanning Electron Microscope. Longitudinal view. x2500. Catalogue No: 3286/25.

Fig. 4. Light Microscope, crossed-nicols. x1344. Catalogue No: 3267/12.

Fig. 5. Light microscope, partially-polarised light. x1344. Catalogue No: 3267/10.

Fig. 6. Scanning Electron Microscope. Detail of surface. x17500. Catalogue No: 3286/26.

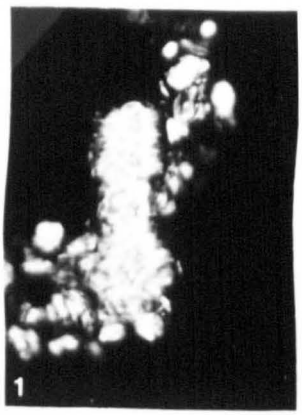
Figs. 7-9. Scanning Electron Microscope. Barremian. Site: North Jens-1, 7561.11 m.

Fig. 7. Oblique view. x2500. Catalogue No: 2887/21.

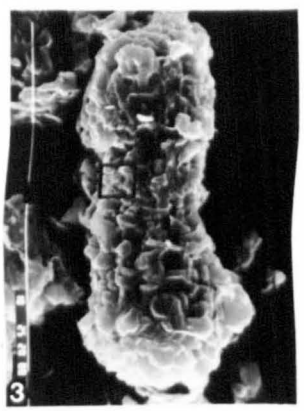
Fig. 8. Longitudinal view. x2500. Catalogue No: 2887/18.

Fig. 9. Detail of surface. x17500. Catalogue No: 2887/19.

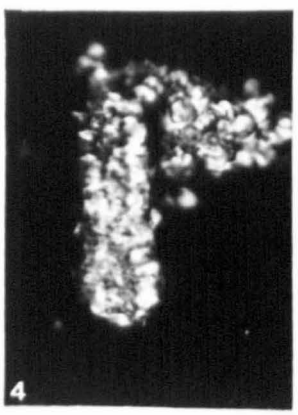
Pl.15

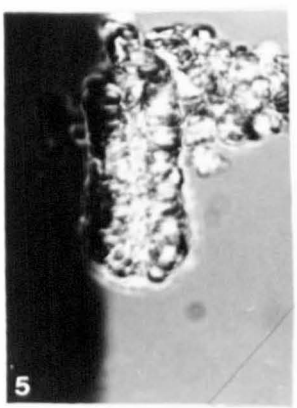


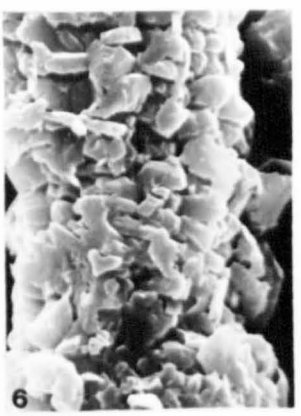


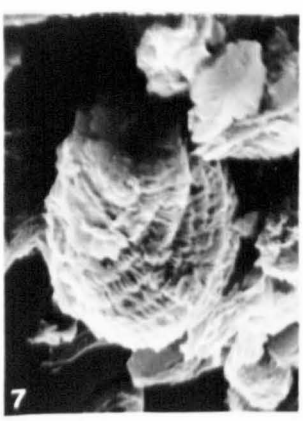


N. boneti









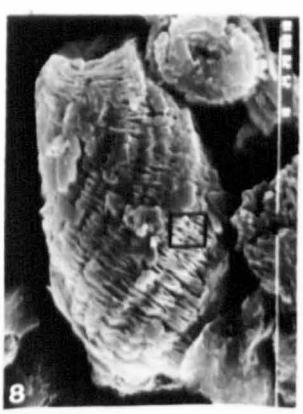




PLATE 16.

Figs 1-4. *N. kamptneri kamptneri* (Brönnimann, 1955) subsp. emend. Bralower, 1989.

Barremian. Site: 29/7-1, 10210 ft. Light Microscope, all x1344.

Fig. 1. Crossed-nicols. Longitudinal view. Catalogue No: 3320/3.

Fig. 2. Partially-polarised light, same specimen. Catalogue No: 3320/1.

Fig. 3. Partially-polarised light. Catalogue No: 3402/25.

Fig. 4. Crossed-nicols, same specimen. Catalogue No: 3402/29.

Figs 5-9. *N. borealis* Perch-Nielsen, 1979.

Barremian.

Fig. 5. Light Microscope, crossed-nicols. x1344. Site: North Jens-1, 7561.11 m. Catalogue No: 2880/10.

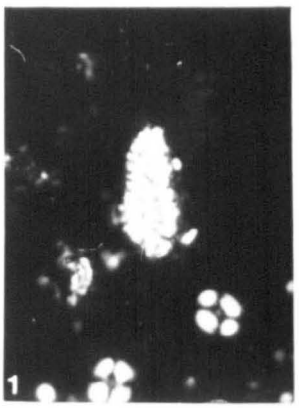
Fig. 6. Light Microscope, partially-polarised light, same specimen. x1344. Catalogue No: 2880/11.

Fig. 7. Scanning Electron Microscope. Longitudinal view. x4650. Site: North Jens-1, 7522.2 m. Catalogue No: 2917/7.

Fig. 8. Detail of surface. x10000. Catalogue No: 2917/8.

Fig. 9. Longitudinal view. x4650. Site: North Jens-1, 7522.2 m. Catalogue No: 2925/31.

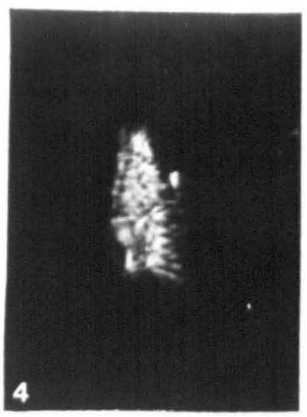
Pl.16

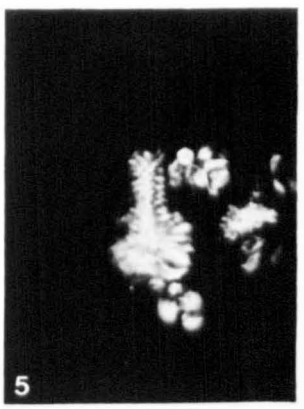


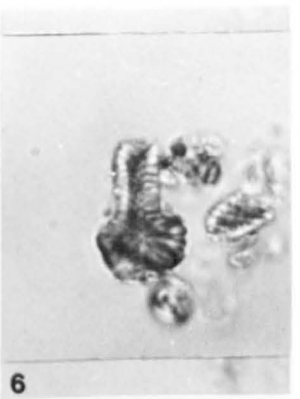




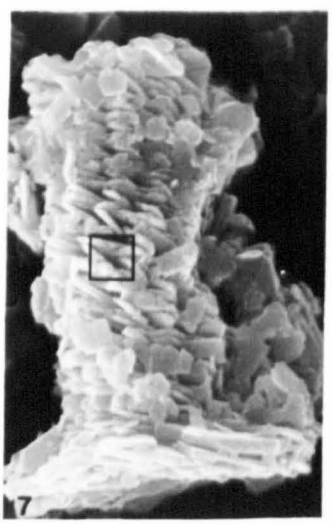
N. kamptneri kamptneri







N. borealis





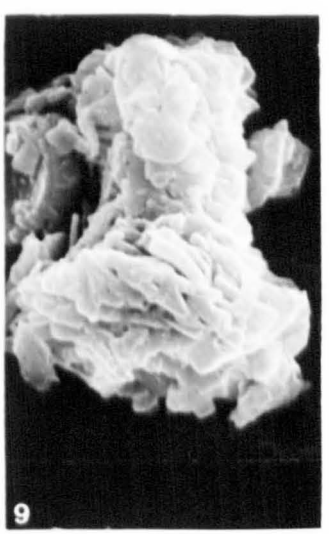


PLATE 17.

Figs 1-5. *N. kamptneri kamptneri* (Brönnimann, 1955) subsp. emend. Bralower, 1989.

Barremian. Light Microscope, all x1344.

Fig. 1. Crossed-nicols. Site: 29/7-1, 10210 ft. Catalogue No: 3402/23.

Fig. 2. Partially-polarised light, same specimen. Catalogue No: 3402/22.

Fig. 3. Original paratype sketch. x2000.

Fig. 4. Crossed-nicols. Site: E-1, 8211.3 m. Catalogue No: 3225/23.

Fig. 5. Partially-polarised light, same specimen. 3225/21.

Fig. 6. *N. bermudezi* Brönnimann, 1955.

Lower Cretaceous. Las Villas Province, Cuba. Original paratype sketch. x2000.

Figs 7-9. *N. steinmanni steinmanni* (Kamptner, 1931) subsp. emend. Deres & Achériteguy, 1980.

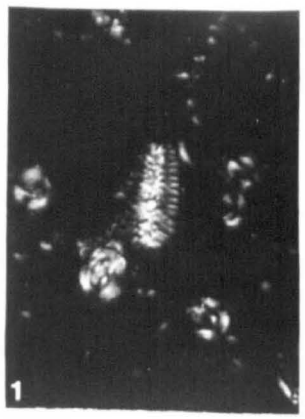
Barremian. Site: North Jens-1, 7605.9 m.

Fig. 7. Light Microscope, crossed-nicols. x1344. Catalogue No: 2905/7.

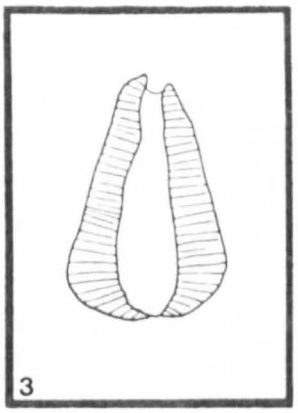
Fig. 8. Scanning Electron Microscope. Longitudinal view. x4650. Catalogue No: 2919/1.

Fig. 9. Detail of surface. x17500. Catalogue No: 2919/3.

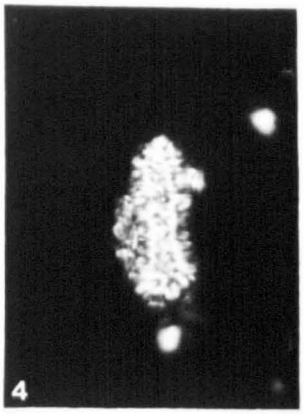
Pl.17







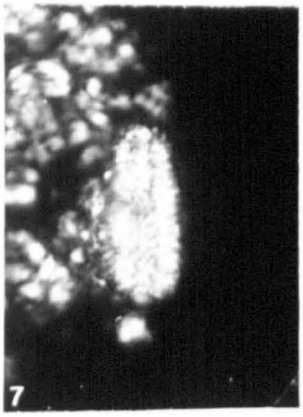
N. kamptneri kamptneri

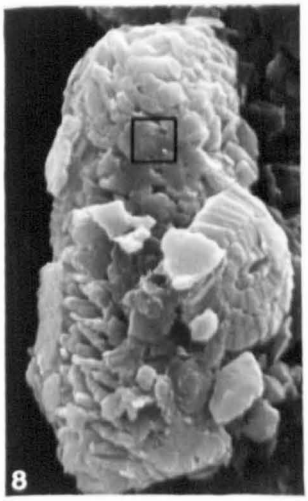






N. steinmanni steinmanni





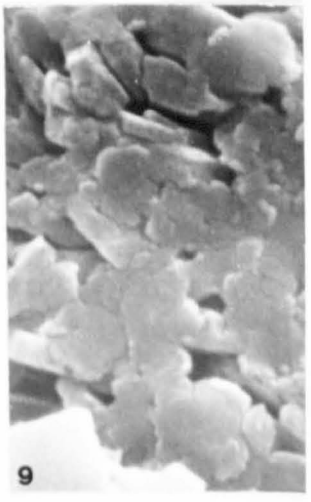


PLATE 18.

Figs 1-3, 6. *Nannoconus* sp. 2.

Barremian. Site: North Jens-1, 11637 m.

Fig. 1. Light Microscope, crossed-nicols. Catalogue No: 2901/22.

Fig. 2. Light Microscope, partially-polarised light, same specimen. Catalogue No: 2901/23.

Fig. 3. Sketch of figure 2.

Fig. 6. Light Microscope, partially-polarised light, same specimen. Catalogue No: 2901/21.

Fig. 4. Scanning Electron Microscope. Longitudinal view. x4650. Catalogue No: 3286/1.

Fig. 5. Light Microscope, crossed-nicols. x1344. Catalogue No: 3210/5.

Figs 7-9. *N. paskentaensis* Bralower, 1989.

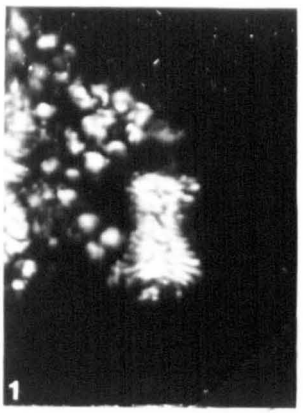
Barremian. Site: E-1, 8211.3 m. Same specimen in the Light and Scanning Electron Microscope.

Fig. 7. Oblique view. x2500. Catalogue No: 3286/35.

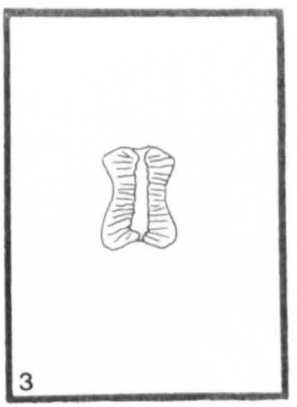
Fig. 8. Longitudinal view. x2500. Catalogue No: 3286/33.

Fig 9. Crossed-nicols. x1344. Catalogue No: 3267/15.

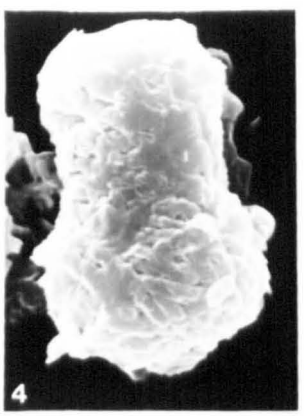
Pl.18

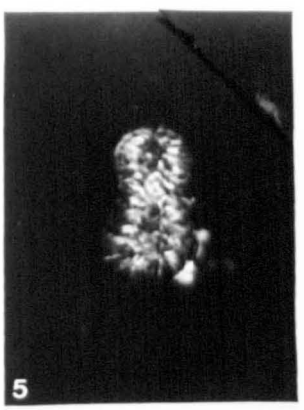


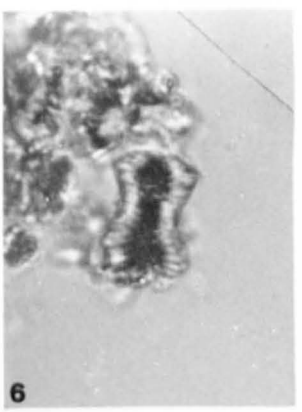


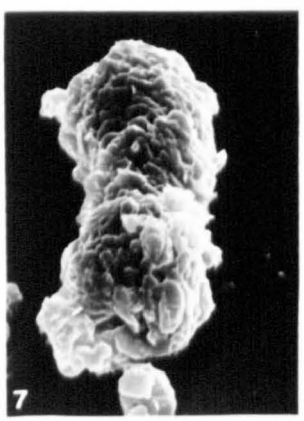


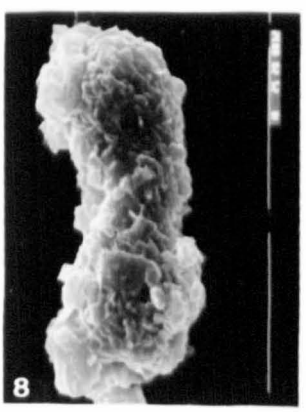
N. sp 2











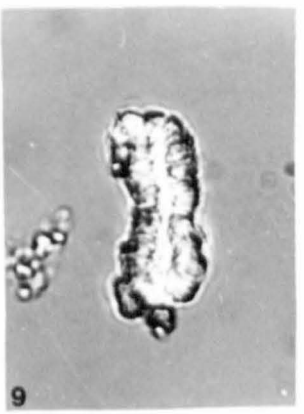


PLATE 19.

Figs 1-6. ***N.* aff.** ***paskentaensis***

Barremian. Site: E-1, 8211.3 m.

Fig. 1. Light Microscope, crossed-nicols. x1344. Catalogue No: 3267/24.

Fig. 2. Light Microscope, partially-polarised light, same specimen. x1344. Catalogue No: 3267/22.

Fig. 3. Light Microscope, partially-polarised light, same specimen. x1344. Catalogue No: 3267/23.

Fig. 4. Scanning Electron Microscope. Detail of surface. x10000. Catalogue No: 3286/25.

Fig. 5. Scanning Electron Microscope. Longitudinal view. x4650. Catalogue No: 3286/23.

Fig. 6. Detail of surface. x10000. Catalogue No: 3286/24.

Figs 7-9. ***N. longus*** **Perch-Nielsen, 1988.**

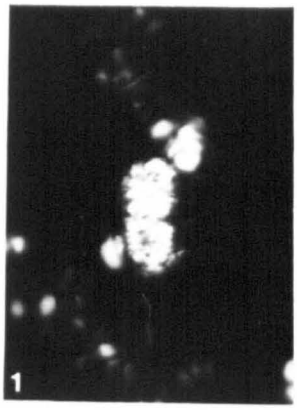
Barremian. Site: North Jens-1, 7538 m. Same specimen in the Light and Scanning Electron Microscope.

Fig. 7. Light Microscope, crossed-nicols. x1344. Catalogue No: 3225/26.

Fig. 8. Scanning Electron Microscope. Longitudinal view. x4650. Catalogue No: 2895/28.

Fig. 9. Detail of surface. x17500. Catalogue No: 2895/29.

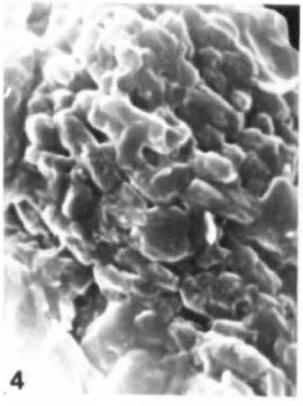
Pl.19

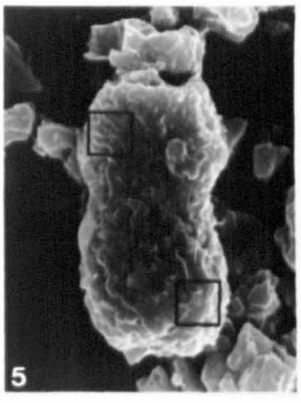

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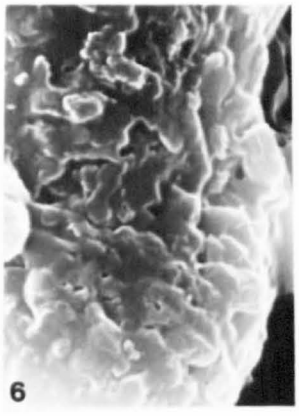

2


3

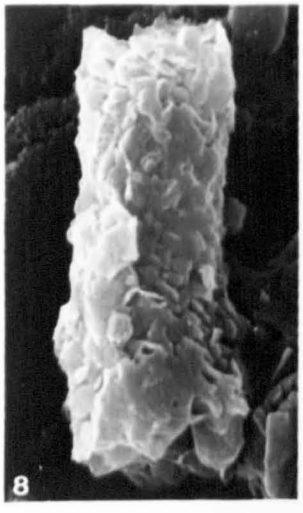
N. paskentiensis


4


5


6


7


8

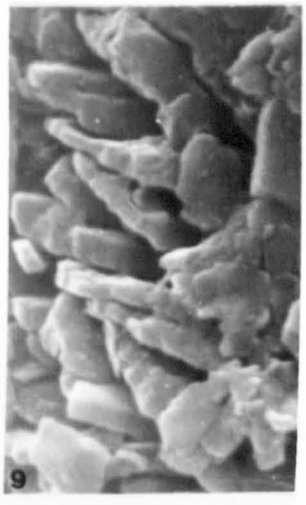

9

PLATE 20.

Figs 1-2. ***Nannoconus*** **aff. sp. 2.**

Barremian. Site: I-1, 9493.1 m. Light Microscope, all x1344.

Fig. 1. Crossed-nicols. Catalogue No: 3210/3.

Fig. 2. Partially polarised light, same specimen. Catalogue No: 3210/1.

Figs 3-5. ***N. globulus*** **subsp. nov. A.**

Barremian. Site: 29/7-1, 10596 m. Light Microscope, all x1344.

Fig. 3. Sketch of longitudinal view.

Fig. 4. Crossed-nicols. Catalogue No: 3400/11.

Fig. 5. Partially-polarised light, same specimen. Catalogue No: 3400/10.

Figs 6-11. ***N. globulus globulus*** **(Brönnimann, 1955) subsp. emend. Bralower, 1989.**

Barremian.

Fig. 6. Original paratype sketch. Las Villas Province, Cuba. x2000.

Fig. 7. Light Microscope, crossed-nicols. Top view. x1344. Site: 29/7-1, 10544 ft. Catalogue No: 3403/2.

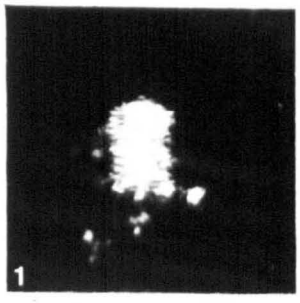
Fig. 8. Light Microscope, partially-polarised light, same specimen. x1344. Catalogue No: 3403/4.

Fig. 9. Partially-polarised light. x1344. Site: 29/7-1, 10544 ft. Catalogue No: 3403/21.

Fig. 10. Scanning Electron Microscope. Longitudinal view. x3750.
Site: North Jens-1, 7442 m. Catalogue No: 2915/22.

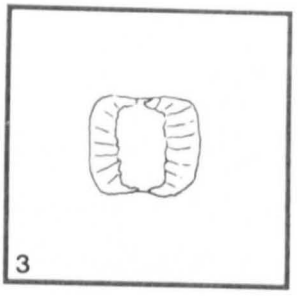
Fig. 11. Detail of surface. x17500. Catalogue No: 2915/23.

Pl. 20

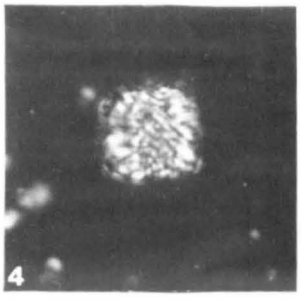


N. sp

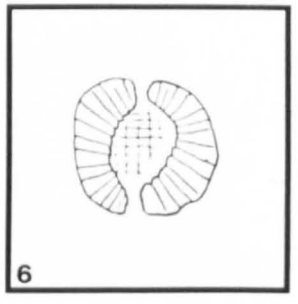




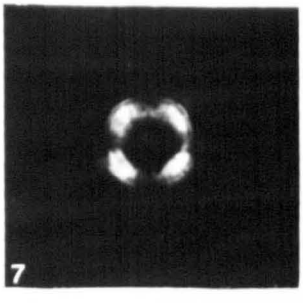
N. globulus sub sp. A

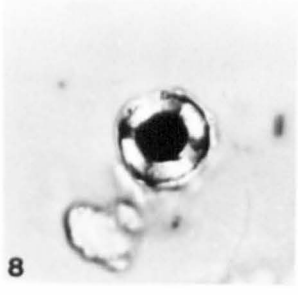




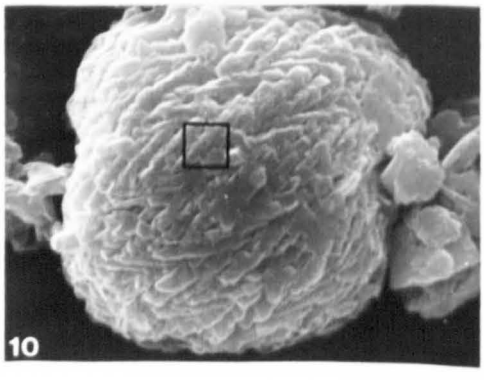


N. globulus globulus









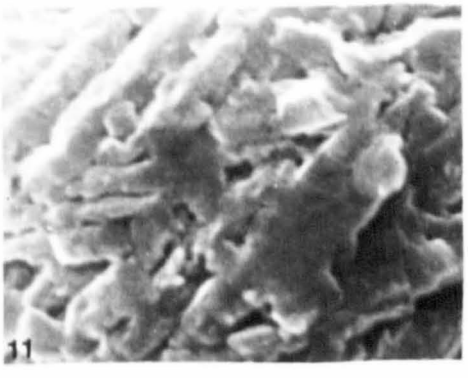


PLATE 21.

Figs 1-9. ***N. wassalli wassalli*** **(Brönnimann, 1955) subsp. emend.**

Barremian. Light Microscope, all x1344.

Fig. 1. Crossed-nicols. Focus on furthest wall. x1344. Site: 15/25a-2, 13259 ft. Catalogue No: 2980/13.

Fig. 2. Partially-polarised light, same specimen. x1344. Catalogue No: 2980/12.

Figs. 3 & 6. Original paratype sketches. x2000.

Fig. 4. Crossed-nicols. Deflandre Type Collection Catalogue No: BZ 92. Catalogue No: 3421/25.

Fig. 5. Partially-polarised light, same specimen. x1344. Catalogue No: 3421/24.

Fig. 7. Crossed-nicols. Deflandre Type Collection Catalogue No: BZ 92. Catalogue No: 3408/13.

Fig. 8. Partially-polarised light, same specimen. Catalogue No: 3408/12.

Fig. 9. Partially-polarised light, same specimen. Focus midpoint. Catalogue No: 3408/11.

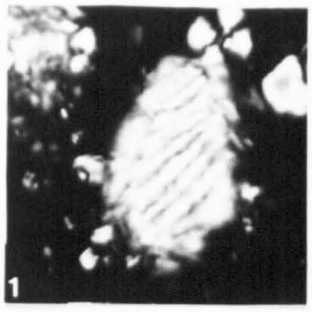
Figs 10-11. ***N. oviformis*** **Perch-Nielsen, 1988.**

Barremian. Site: North Jens-1, 7605.9 m. Scanning Electron Microscope.

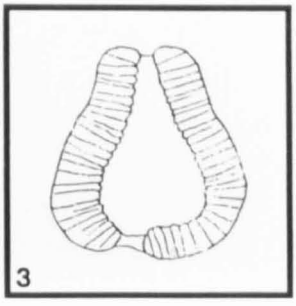
Fig 10. Longitudinal view. x2500. Catalogue No: 2919/17.

Fig. 11. Detail of surface. x17500. Catalogue No: 2919/18.

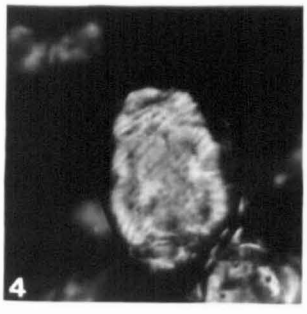
Pl.21

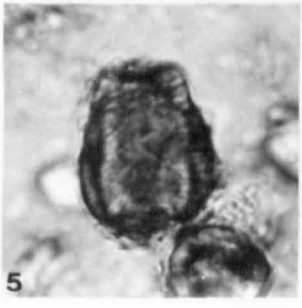


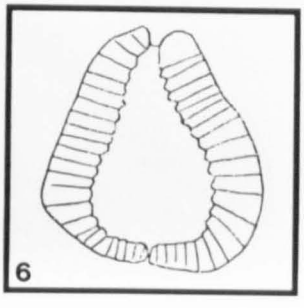




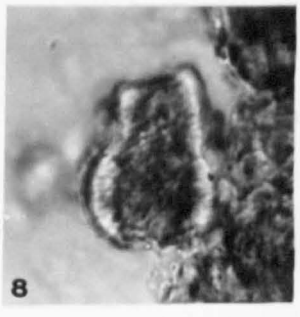
N. wassalli wassalli

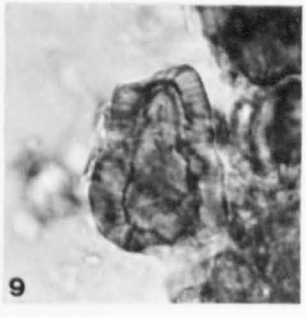


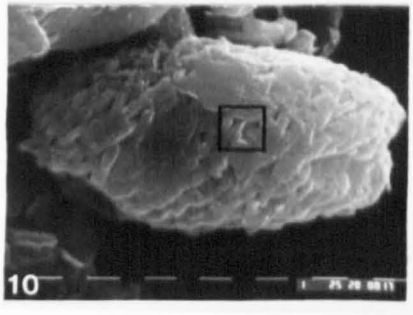












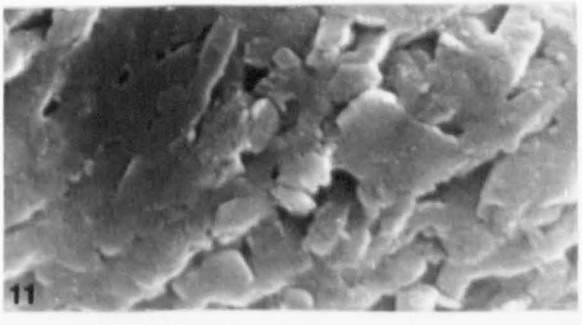


PLATE 22.

Figs 1-5. ***N. wassalli minor*** **subsp. nov.**

Barremian. Site: Haute Provence, France. Deflandre & Deflandre-Rigaud Type Collection Catalogue No: CN 2. Light microscope, all x1344.

Fig. 1. Crossed-nicols. UCL Catalogue No: 3423/4.

Fig. 2. Partially-polarised light. Catalogue No: 3423/3.

Fig. 3. *N. carniolensis* (syn. *N. wassalli minor*) Deflandre & Deflandre-Rigaud, 1962. Original Holotype sketch. x2000.

Fig. 4. Crossed-nicols. Deflandre & Deflandre-Rigaud Type Collection Catalogue No: BZ 92. UCL Catalogue No: 3421/24.

Fig. 5. Partially-polarised light, same specimen. Catalogue No: 3421/22.

Fig. 6. Partially-polarised light, same specimen. Catalogue No: 3421/23.

Figs 6-9, 12. ***Nannoconus*** **sp. 3.**

Barremian. Site: Haute Province. Light Microscope, all x1344.

Fig. 7. Crossed-nicols. Deflandre & Deflandre-Rigaud Type Collection Catalogue No: BZ 92. UCL Catalogue No: 3408/29.

Fig. 8. Partially-polarised light, same specimen. Catalogue No: 3408/28.

Fig. 9. Partially-polarised light. Deflandre & Deflandre-Rigaud Type Collection Catalogue No: CN 2. UCL Catalogue No: 3423/35.

Fig. 12. Crossed-nicols, same specimen. Catalogue No: 3423/34.

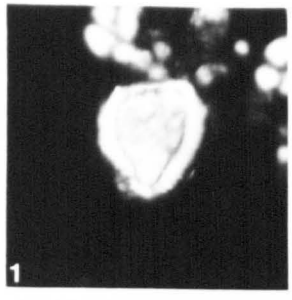
Figs 10-11. ***N.*** **aff.** ***wassalli wassalli.***

Barremian. Site: Adda-2, 7750 m. Light Microscope, all x1344.

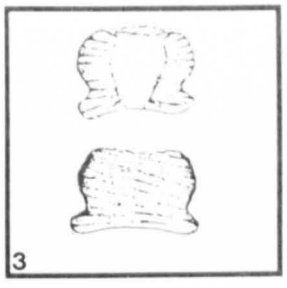
Fig. 10. Partially-polarised light. Catalogue No: 3219/10.

Fig. 11. Crossed-nicols, same specimen. Catalogue No: 3219/8.

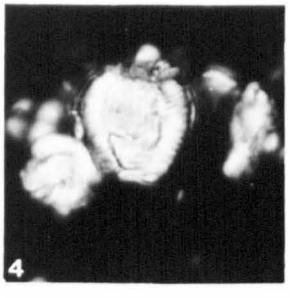
Pl. 22

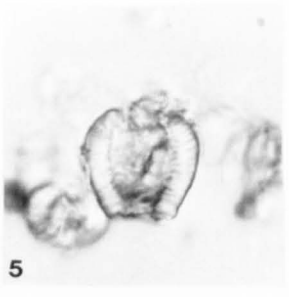


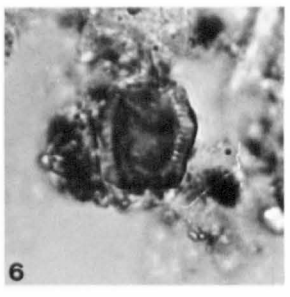


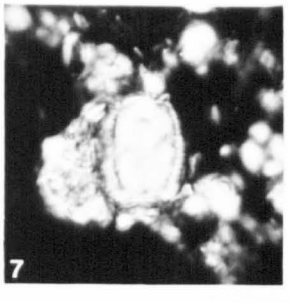


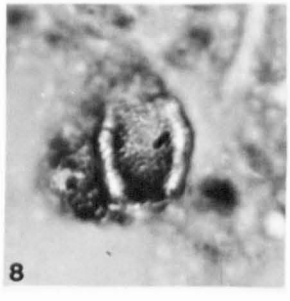
N. wassalli minor





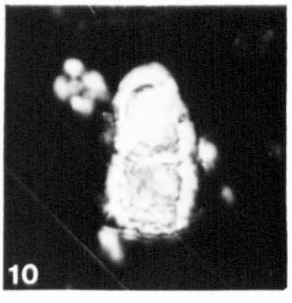




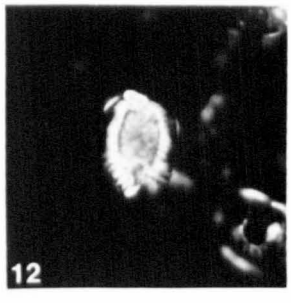




N. sp 3







N. sp

Chapter 8.
Phylogenetic Development of *Nannoconus*

8.1 Historical Review

Since the first observation of *Nannoconus* in 1925, very few authors have discussed the possible phylogenetic origin and evolutionary development of this genus. The earliest attempt at lineage reconstruction was by Baldi-Béke (1961) and the relationship between the external (outline) and internal morphology (canal development) provided the basis for a model of evolutionary development. She proposed *N. dolomiticus* as the earliest species of the genus from which subsequent diversification can be traced and suggested that *N. bronnimannii* also evolved, slightly later, during the same time period. However, she did not recognise an evolutionary lineage embracing all the (then) known species.

Deres & Achériteguy (1980) also suggested *N. dolomiticus* as one of the earliest species but in addition noted that 4 other species originate in the Tithonian. No accurate time indication of the evolution of these species is given by the authors (stage level only). The parameters used in the interpretation of the lineages were the external and internal morphocharacteristics. Their diagram (pp. 12 & 13, table 5) fails to provide a clear-cut, indisputable evolutionary model for the origins of this genus.

Recognition of several distinct and primitive nannoconid types in samples from the Western North Atlantic by Wind (1978) led to the most recent discussion of ancestral forms in the phylogenetic development of *Nannoconus* by Bralower *et al.* (1989). Studying material from DSDP sites 391C and 534A, Western North Atlantic, Bralower linked the stratigraphic range of 7 species to the time scale of the sections, erecting 1 new genus (*Faviconus*), 4 new species and 1 new sub-species within the lineage; the genus and 3 of the new species are here considered as junior synonyms for reasons discussed below:

1) The genus *Faviconus* Bralower (1989) was described based on the single species *F. multicolumnatus* Bralower (1989), the structure of which is described as numerous stacked wedges separated by a thin axial canal, the columns of which may have a random arrangement. He described this genus as differing from *Nannoconus* in the

number of wedge stacks, but does not give a value. The species description states that earlier forms have a unicolumnar structure (see Bralower 1989, Pl. 8, fig. 6), which develop into multicolumar species. Observation of the light micrographs of the type species shows a pattern of differential, partial-extinction of elements in the wall. This pattern is thought to show two crystal element orientations, similar to those observed in light micrographs of *Nannoconus*. The genus *Faviconus* is therefore almost certainly a junior synonym of *Nannoconus*, with *multicolumnatus* perhaps representing the earliest nannoconid species. Two terminal apertures are present in *multicolumnatus* with an extremely poorly defined axial canal. The multicolumnar morphotypes illustrated by Bralower (1989, Pl. 8, fig 6.) appear to represent an aggregate or rosette of several individuals. Further study of scanning electron micrographs of *Faviconus* (senior syn. *Nannoconus*) will prove to be of considerable interest in understanding the evolution of wall structure.

2) *N. compressus* Bralower (1989) is here regarded as a junior synonym of *N. dolomiticus*, as the type photographs of Bralower (1989, Pl. 8, figs 7-12) are slightly oblique views which distort the internal contours and shape of the apertures. A distinct axial canal is present on a horizontal plane in the figures, and the oblique view provides a ghost image of rounded terminal poles; these were the only features used to distinguish the species from *N. dolomiticus*.

3) *N. winteri* Bralower (1989) is a junior synonym of *N. bronnimannii*, the width of the basal aperture alone being insufficient to characterise a species, and the structure, external and internal contours, and stratigraphic ranges of the two taxa are comparable.

In discussing the possible phylogenetic relationships of the individual nannoconid species in the Tithonian, Bralower *et al.* (1989) proposed the lineage *N. steinmanni minor - N. kamptneri minor - N. steinmanni steinmanni*. All these forms have a conical external morphology, the subspecific taxa being recognised by their smaller dimensions. The lineage is, however, inconsistent in terms of the phylogenetic development of the axial canal. Bralower *et al.* (1989) suggest that *N. steinmanni minor* (narrow canal) developed into *N. kamptneri minor* (wide cavity). This seems reasonable except that *N. kamptneri minor* (wide cavity) is considered a direct predecessor of *N. steinmanni steinmanni* (narrow canal). A more logical approach, based on the morphological nature of the axial canal development, is that *N. steinmanni minor* (narrow canal) is the precursor to *N. steinmanni steinmanni* (narrow canal) and that *N. kamptneri minor* (wide cavity) is the precursor to *N. kamptneri kamptneri* (wide cavity). See figure 8.1.

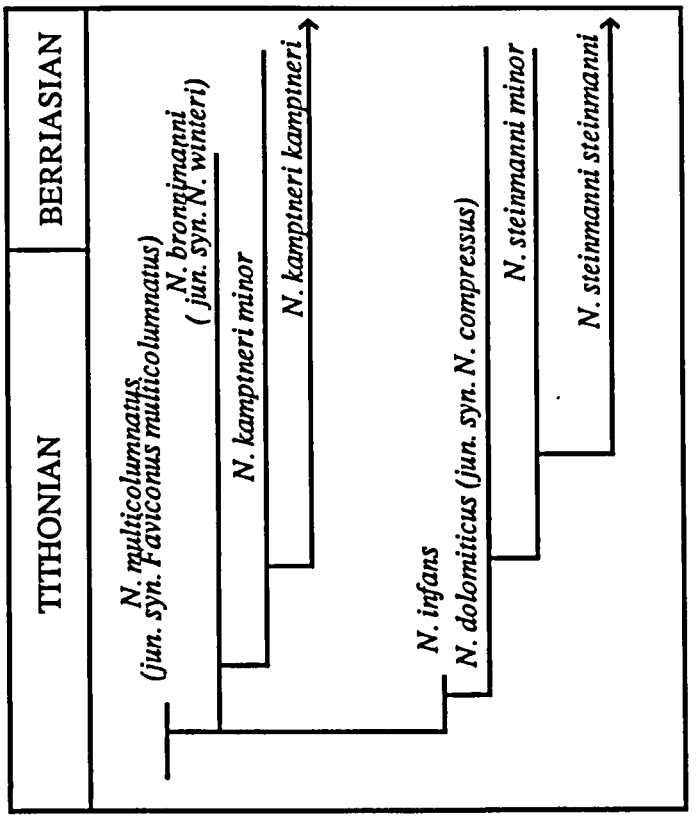


Figure. 8.1. Tentative phylogeny of the early nannoconids (range data from Bralower *et al.* 1989).

The initial recognition of different wall structure morphogroups (this study) is used to present a preliminary compilation of published information. A complete evolutionary lineage of *Nannoconus* is not given because a full survey of *Nannoconus* taxa was beyond the scope of this thesis.

The characteristics for a forerunner to *Nannoconus* are a conical outline and possible construction of plates in two orientations. A discussion and consideration of conical calcareous nannofossils in the Mesozoic is given by Bown & Cooper (1989), concentrating on the 4 genera *Eoconusphaera, Conusphaera, Mitrolithus* and *Pseudoconus*. The first three genera are comparable to *Nannoconus* in external outline and show a similar construction pattern to each other with an outer casing of thin, vertical elements and an inner core of radially arranged plates. These three conical genera occur at discrete stratigraphic levels through the Mesozoic and all are common in the Western Tethys during their respective ranges. They are interpreted by Bown &

Cooper (1989) as homeomorphs which possibly occupied similar environmental niches at different times. *Nannoconus* can be perhaps be considered homologous with the conical nannoliths discussed above, based upon its external shape and dominance in the Tethys during the Early Cretaceous. *Nannoconus* differs quite significantly, however, in the lack of vertical sheath of elements. The elements in the nannoconid structure appear to be consistent in size within an individual (disregarding species with external constrictions or projections in their outline). It appears unlikely that *Conusphaera* within the Late Jurassic/Early Cretaceous evolved into *Nannoconus*, as this would require the outer rim elements to change relative dimensions and orientation and to become incorporated into the central core.

The genus *Pseudoconus* Bown & Cooper (1989) from the mid Jurassic also shows similar characteristics to conical nannoconids. Only a very thin, poorly developed canal appears to be present, but this may be an optical illusion due to the external median furrow which can be observed in scanning electron micrographs of *P. enigma* Bown &Cooper (1989. Pl. 5.2, fig.13) . The outline of the individual component plates is unclear but they appear to be equidimensional. The structure of the type specimens is unclear, possibly due to adverse preservation. However, a semblance of plate organisation can be observed as parallel rows inclined very slightly to the horizontal axis of the specimen. As an ancestor to *Nannoconus* a difficulty arises when we look at the stratigraphic range, of *Pseudoconus*, which has a restricted range in the middle Jurassic whereas the earliest nannoconids did not evolve until the late Early Tithonian (*N. multicolumnatus*, previously *Faviconus multicolumnatus*). It is possible that the scarcity of this or other likely precursors to *Nannoconus* is related to a gap in records due to preservation or lack of recognition of the genus *Pseudoconus*.

If we consider *Pseudoconus* as the evolutionary predecessor to *Nannoconus* then the earliest structure is a set (or sets) of crystal plates orientated at an angle of $< 15°$ to the horizontal axis of the specimen. If two plate orientations are present then they have not yet been clearly determined due to the preservational state of the figured specimens. Each crystal unit or row in *Pseudoconus* has a width up to approximately 0.2 μm. A break in the lineage is present between the Middle Jurassic and Late Jurassic with the appearance of *N. multicolumnatus*. The light microscope images of *N. multicolumnatus* also show a species with two inferred plate orientations (see above) and easily recognisable wall components, i.e. the typical nannoconid wall structure established in this thesis.

8.2 Morphogroup Evolution

As discussed above in chapter 8.1 the earliest nannoconids are thought to be classified as Morphogroup 2.3, that is characteristic β_1 angle (20-45°) and wide Cycle A (approx. 1 μm). Throughout the Early Cretaceous the greatest nannoconid morphological diversity was represented by species with wall structures belonging to Morphogroup 2., with some of the most elongate, heavily calcified species, e.g. *N. bonetii*. Species representing other morphogroups appear to evolve from this morphogroup. *N. bucheri* (Morphogroup 2.2) is tentatively postulated as arising from this lineage in the Valanginian, with the first specimen showing a reduction in the width of Cycle A, associated with a decrease in the component plate dimensions.

In the Late Tithonian, canal development appears to have been weak until the evolutionary appearance of *N. bronnimannii* and *N. kamptneri minor*, coupled with species diversification. The earliest morphogroup evolution is represented by the appearance of *N. globulus minor* in the Late Tithonian of the Tethys (Morphogroup 3.3; very high β_1 angle, wide Cycle A). This species is not recognised in NW Europe until the Ryazanian, due to provincialism. The species within this group are all globular with clearly developed cavities and form an important component in Boreal nannofossil assemblages.

The presence of *Nannoconus* sp. (discs) and *N. sabinae* in the Late Ryazanian are thought to represent the first species with a sub-horizontal β_1 angle and wide Cycle A (Morphogroup 1.3). No scanning electron microscope images have been published of these species and its nature is not fully understood, but it appears to be a short-lived lineage, a precursor to other low-angled Morphogroups 1.1 (very narrow Cycle A, e.g. *N. circularis*) and 1.2 (intermediate width Cycle A, e.g. *N. concavus*). Only the Morphogroup 1.1 is of any importance in NW Europe, attaining monospecific blooms in the late Barremian; these morpho-species are all small and contain either a narrow central canal (*N. abundans*) or well-developed cavity (*N. circularis*).

It is recognised that the evolutionary model presented here is a simple one based upon changes in the component plate orientations and is preliminary in nature. Further study of Tethyan material is essential before detailed species lineages can be postulated. It does, however, show that the lineage representing Morphogroup 2. dominantly contains elongate, well-calcified structures with the Type B plates orientated at an angle of 20-45° to the horizontal. The reason for this is not clear but may be due to some

environmental stimulus, these species having attained high abundance levels in the Tethys.

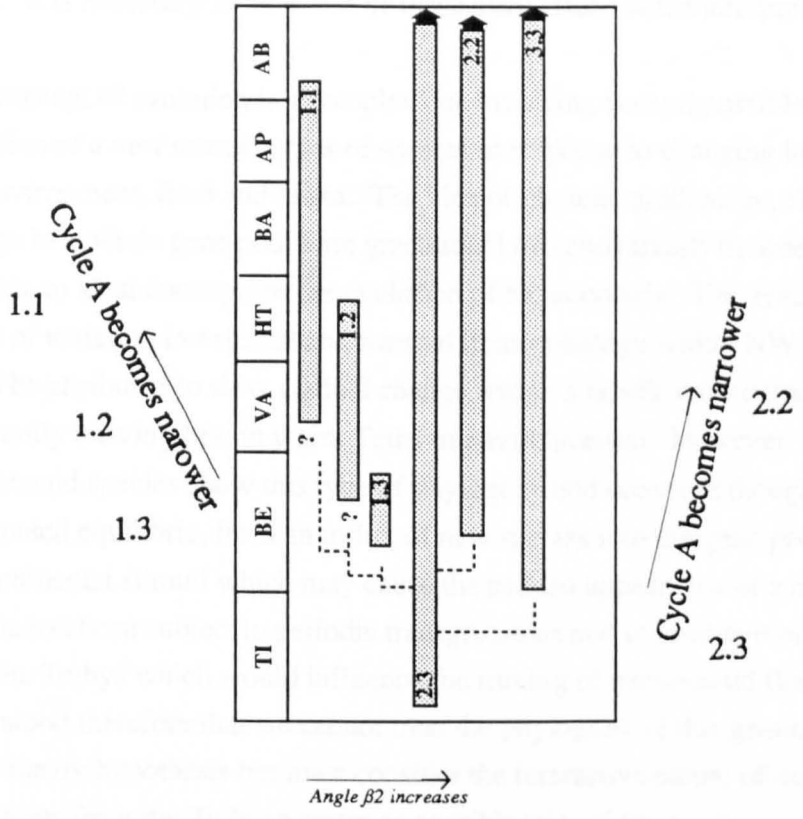


Figure 8.2 Preliminary model for the evolution of the wall structure morphogroups.

8.3 Individual Morphogroup Phylogeny

I have attempted above to review the possible early evolution of nannoconids and give a generalised evolutionary diagram of the individual morphogroups, using published literature for the former and observations (this study) for the latter. The lack of Tithonian sediments in this study and scarcity of suitable sample material inhibited the study of the early phylogenetic developments which occurred in the Western Tethys and Atlantic, outside the study area. The following lineages therefore represent hypotheses for the phylogeny of *Nannoconus* in NW Europe. These hypotheses are based upon palaeontological information only, since the lack of living representatives of *Nannoconus* means that the proposed evolutionary models cannot be tested. In the

fossil record we can only observe palaeo-species based upon the morphological characteristics of the skeletal remains. In a true biological sense the term species may encompass several of our morpho-species in one bio-species, based upon the genetic unity. It is necessary to be aware of these distinctions when interpreting the data.

The concept of evolution is a complex one involving several possible stimuli for the initiation of a new morphotypes or species in response to changing interactions between the environment, flora and fauna. The idea of phyletic gradualism, slow methodical change in a whole gene pool with gradational morphovariants between species, initially appears an ideal concept for the evolution of nannoconids. The genus shows a wide range of variation in external and internal in morphology within NW Europe which could be attributed to slow gradual change within a hostile environment (*Nannoconus* apparently thriving best in warm Tethyan environments). However, not all the nannoconid species show this type of phylogeny and some are thought to arise due to punctuated equilibria, from an influx of new species into the gene pool or as a result of environmental stimuli which may cause the sudden appearance of a new stock. NW Europe has been subject to periodic transgressions and intermittent marine connections with the Tethys which would influence the mixing of nannoconid flora. It needs to be understood therefore that we cannot treat the phylogeny of this genus with one evolutionary hypothesis but must consider the interactive nature of the environment and migrations from the Tethyan realm as possible stimuli for species evolution e.g. new genus, competition etc. When studying the morpho-species we must also be aware that the individuals in a cell may be apparently monomorphic in nature during the Tithonian (from the evidence of Trejo 1960) but could evolve in relation to:

1) number of individuals surrounding a cell (assuming an affinity to the coccolithophorids);
2) nature of the individuals in a sphere (are they of one morphospecies ?);
3) different individuals in one sphere may have had different functions;
4) growth stages.

Slight variations in the genotypic expression of the hardparts of individual specimens of a species can also be considered important when determining their distribution patterns. The morphology of an individual may also indicate response to cool waters i.e. ecophenotypic patterns.

It was initially thought that the wall structure of *Nannoconus* was of fundamental

importance in phylogeny, however, the generalised evolutionary model shows little change after the branching of the morphogroups during the Tithonian-Ryazanian interval. Once these primary patterns in wall construction were established in the genus then the environmental stress on a restricted gene pool may have been responsible for the appearance of a number of individual species lineages. Morphological variability is recognised to be greatest at the margin between NW Europe and the Western Tethys, where periodic mixing of the flora creates a wider gene pool within which morphological variability can occur.

The data used in the following phylogenetic models proposed are a compilation of range data from published sources worldwide and results from this study. The solid lines represent the known range of the species in NW Europe and the broken lines show the early ranges of the species as obtained from published data sets outside NW Europe. It is recognised that the earlier workers were not always precise as to the species ranges and hence the proposed models are calibrated to the zonation used for the North Sea (this study). The ranges incorporate the taxonomic ideas of the author and the reader is referred to Chapter 7 for reference to partial synonomy lists for individual species.

The first migration of nannoconids recognised in NW Europe is found in the Late Ryazanian sediments of the southern North Sea with forms classified as belonging to Morphogroup 2.3. The evolutionary lineages are discussed in the order of the morphogroup ranking and not the evolutionary/migratory appearance.

8.3.1 Morphogroup 1.1

The *N.* sp. (discs) found in the Late Ryazanian are considered to belong to the Morphogroup 1.1 due to the similarity in the birefringence patterns of these discs to disagregated *N. abundans* flanges. The first appearance of these discs has not been found in conjunction with any other nannoconid species to date. It is possible that rare nannoconid species present in this interval have not been found to-date. In connection with the influx of *Nannoconus* into a new ecological niche, associated with the opening of a marine pathway between the Tethyan and Boreal realm, environmental controls may have led to partial calcification and new morphotypic surface expressions of the nannoconid individual. The geological record may only preserve the flange or calcified disc. Figure 8.3 shows the evolutionary models suggested for Morphogroup 1.1 and

1.2. The similarities in the structure of these discs is thought to infer that the discs were arranged in a similar manner to those of *N. abundans* and that *N. concavus*, a morpho-species with two flanges (Morphogroup 1.2), may have been ancestral to these *Nannoconus* sp. (discs).

The species (complete individuals rather than discs) which have been assigned to this category are all short-bodied forms with thin, flexible calcitic plates. In top view the focal depth of the individuals is narrow and the individual plates can rarely be seen in the LM. With the exception of *N. circularis* cavity development is very poor and are endemic to the Boreal Realm with very high abundance levels.

After the last appearance of the *Nannoconus* sp. (discs) an intact, blood-corpuscle shaped morpho-species, *N.* sp 1 is found in Late Ryazanian-Late Valanginian samples. There is a gap in the lineage between these discs and the first appearance of *N.* sp. 1 but this has been attributed to the lack of material studied in this interval. There was no evidence of co-occurrence of these *Nannoconus* sp. (discs) and *N.* sp. 1. The small nature and low abundance levels of *N.* sp. 1 may imply problems of calcification or incompatibility with the external environment leading to the extinction of this species.

N. circularis shows a similar sub-globular outline to *N.* sp. 1 but the central canal has developed into a wide cavity. The first appearance of this species is in N. Germany (Mutterlose 1991) in the *discofalcatus* zone of Late Hauterivian age. This appears to be slightly earlier than the first appearance recorded in the rest of the world, suggesting rapid colonisation of this species into other water masses. The Barremian interval is well-known to have been a period of warm surface waters in NW Europe, which may have been responsible for the cavity development and rapid colonization of the Tethys by *N. circularis* in contrast to other species in this morphogroup.

N. abundans is a common constituent of Barremian assemblages and is distinctive in having a single well-developed flange and narrow axial canal. As previously mentioned, the *N.* sp. (discs) found in the Upper Ryazanian may be a direct predecessor, with total calcification of this species being of primary importance for its abundance. Another morphologically similar species is *N. concavus* (Morphogroup 1.2), and similar development of flanges may have provided the source for the phenotypic evolution of *N. abundans*. A direct predecessor is not clear at present and a ? indicates the possible phylogenetic links.

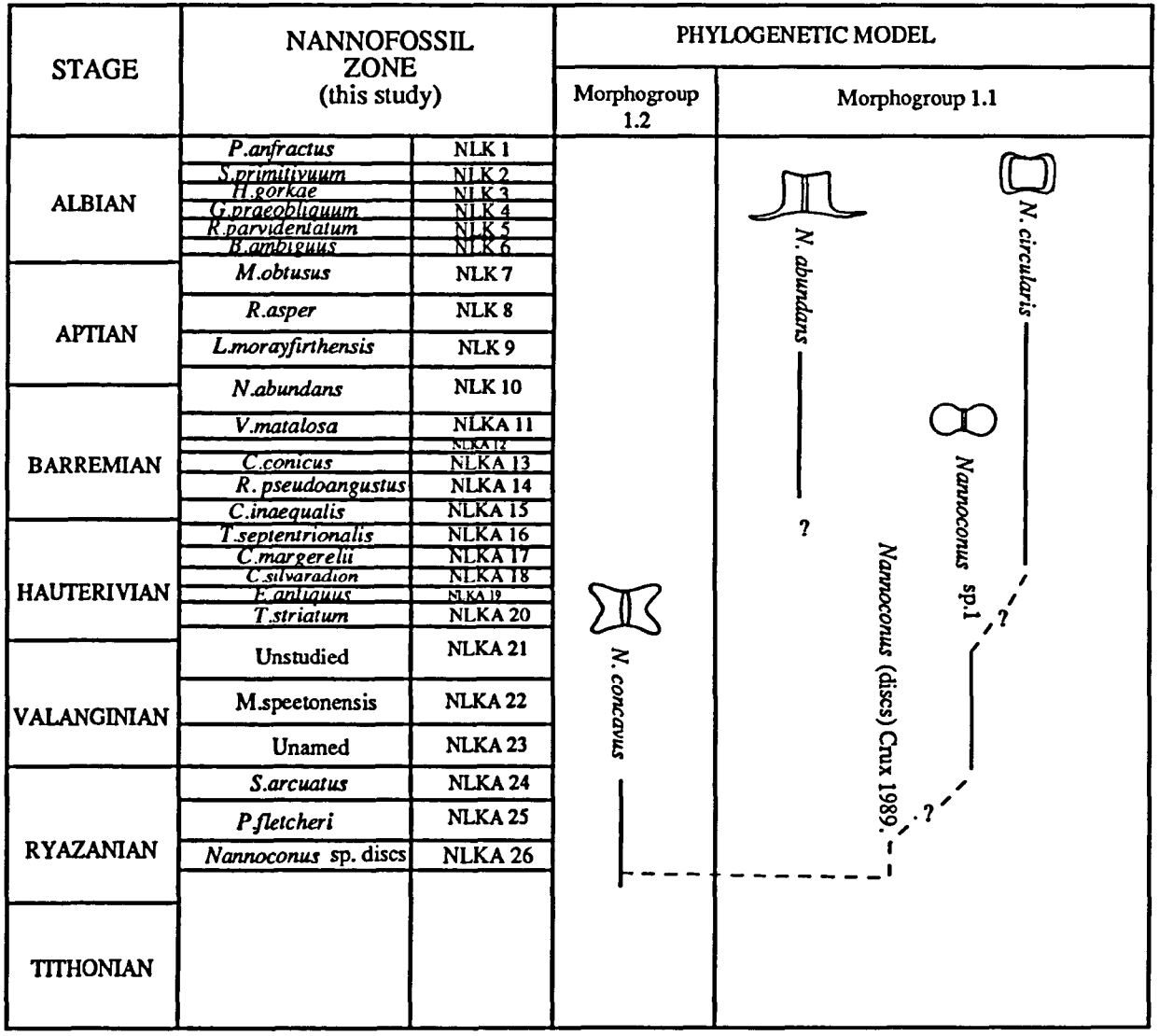


Figure 8.3 Evolutionary Model for Morphogroup 1.1 and 1.2. Legend:— known range;- - - - postulated range.

8.3.2 Morphogroup 1.2

The validity of this group is not clear due to the lack of observed specimens of *N. concavus*. It may be that this species can be regarded as the end member of Morphogroup 1.1 (since *N. concavus* is borderline in the definitions for the light microscope). *N. concavus* has a first and last occurrence in the Upper Ryazanian but has not been recognised in the *N. sp.* (discs) zone. *N. concavus* is endemic to NW Europe and is characterised by the development of two symmetrical flanges at the polar extremes of a short central body. This species is thought to have developed into the species of Morphogroup 1.1 (refer to fig. 8.3).

8.3.3 Morphogroup 1.3

A single species, *N. sabinae*, has the characteristics of this morphogroup. As with some other species, the validity of this assignment is still under review due to lack of perfectly preserved, intact specimens in the material studied. The broken individuals observed from the Upper Ryazanian. A precursor or phylogenetic root is unknown for this species. Perch-Nielsen (pers. comm.) believes broken specimens to show similarities to *Nannoconus sp.* (discs), but there is no direct evidence for this.

8.3.4 Morphogroup 2.2

The earliest species classified with the wall structure of this morphogroup is *N. minutus* from the Valanginian of the Tethys. The predecessor of this species is not known but it is thought to have arisen from Morphogroup 2.3. *N. bucheri* is here suggested to have descended from *N. minutus* in the Valanginian. However, similarities in the morphostructure to *N. kamptneri kamptneri* (Morphogroup 2.3) are recognised. This may show parallel evolution in external and internal morphological shape, with differences evident in the wall construction and size dimensions.

The *N. truitti* group is here considered as a collection of morphological variants of *N. truitti truitti*. *N. minutus* is here proposed as the root stock for *N. truitti* and the other 2.2 taxa, due to similarities in the external outline and development of the cavity. Further study of Tethyan material is needed before these lineages can be determined with greater certainty.

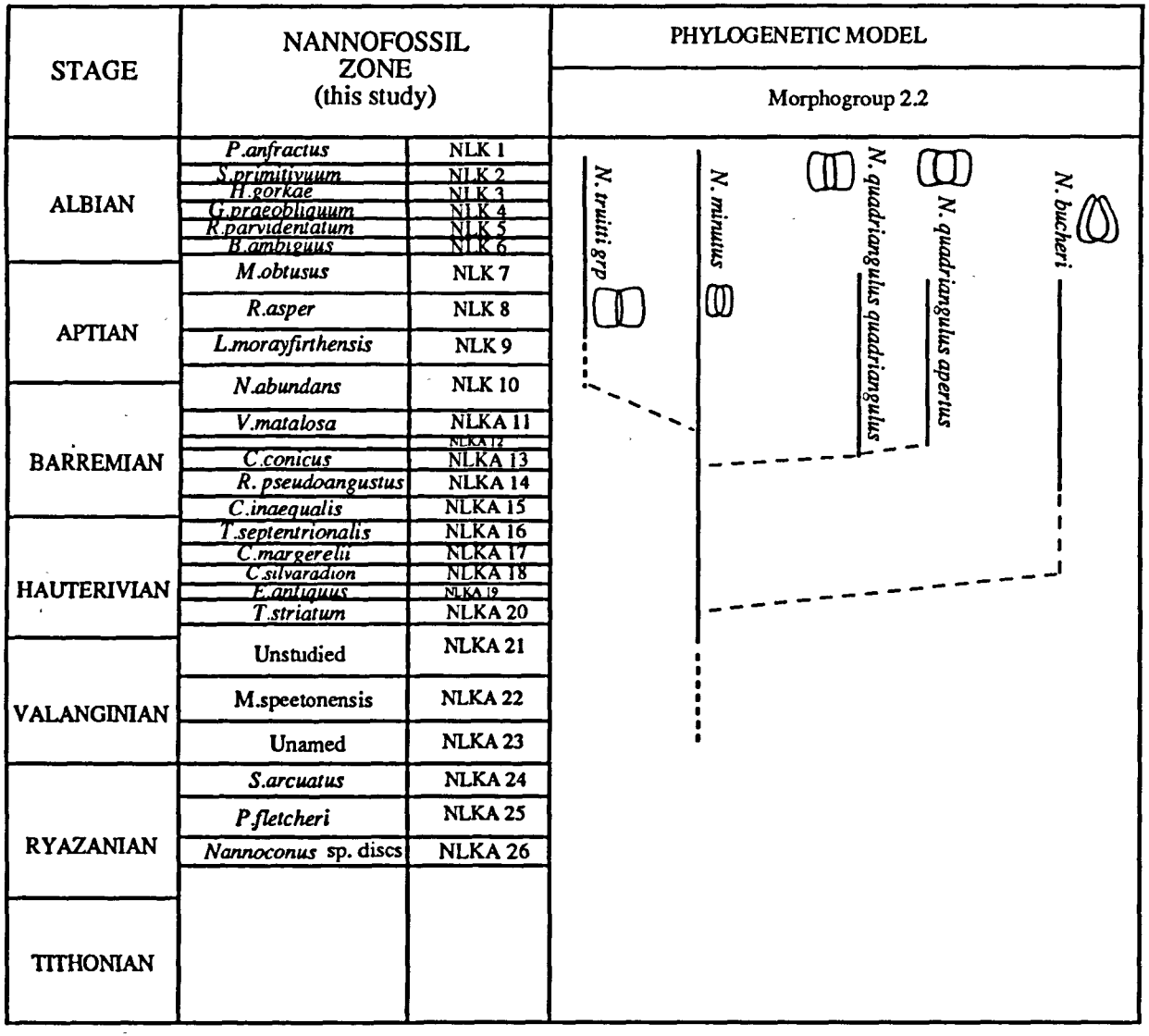


Figure 8.4 Evolutionary Model for Morphogroup 2.2.

The *N. quadriangulus* group is thought to have evolved from *N. bucheri* in NW Europe during the Late Barremian with a major increase in cavity development. Figure 8.4 shows the evolutionary model proposed for some of the species classified in this morphogroup. Some species are not included in the model due to the lack of range data.

8.3.5 Morphogroup 2.3

Two separate phylogenetic lineages are inferred in this group, characterised by the presence or absence of an axial cavity or canal. Parallel lineages showing similar external conical morphology can be seen, separated by differences in the dimensions of the internal canal/cavity. Refer to figs 8.5 & 8.6.

Lineage A. (Fig. 8.5)

All the species in this lineage show a well-developed central cavity. The earliest species present in NW Europe is *N. kamptneri minor*, of which only a few specimens were found here, often associated with a larger form of comparable morphology, *N. kamptneri kamptneri* in Tethyan regions. These species, with *N. kamptneri kamptneri* remaining well-established until the late Early Valanginian when a morphologically distinct species appeared, *N. boneti*. Subsequent radiation of *Nannoconus* in the Barremian is thought to have been responsible for gradational morphotypes *N. paskentiensis* and *N.* sp 2, both of which show the development of a central constriction and two lobes but differ in the degree of curvature at the poles of the nannoconid body and relative dimensions.

Lineage B (Fig. 8.6)

Evolution of *N. steinmanni minor* to *N. bermudezi* is based upon a gradational increase in length of the longitudinal axis of the specimens. The conical exterior is comparable to the *N. kamptneri* lineage which shows parallel morphological occurrence patterns, however, the axial canal is poorly developed in lineage B. In the Barremian interval elongate, parallel-sided species: *N. longus*, *N. elongatus elongatus* and *N. elongatus minutus* evolved. The diversity of the gene pool is also thought to have resulted in the appearance of *N. borealis*, a species with a poorly developed axial canal and bulbous extension at the proximal pole.

These changes in dimension of the conical morphology, of both Lineage A and B show

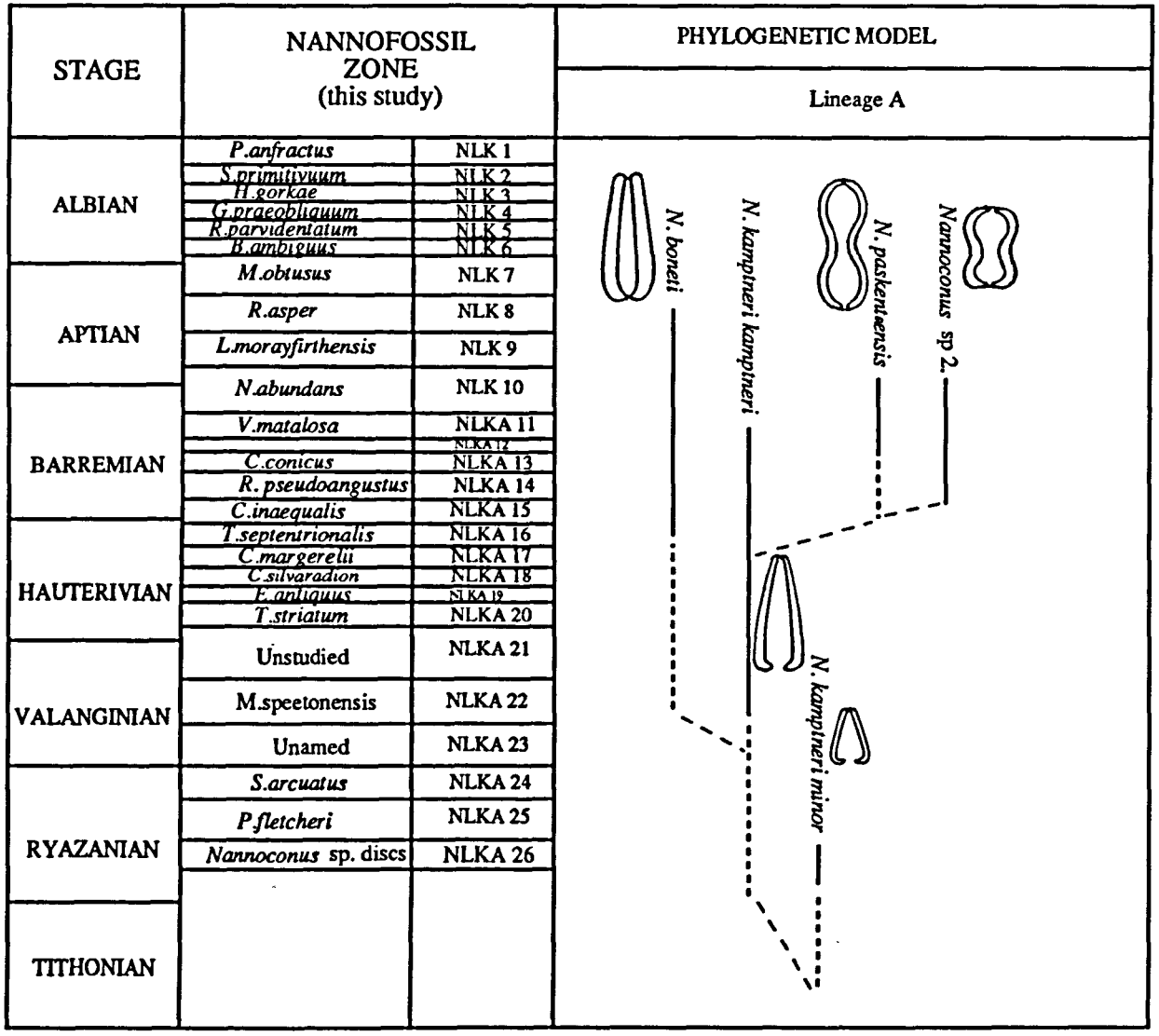


Figure 8.5 Evolutionary Model for Morphogroup 2.3, Lineage A.

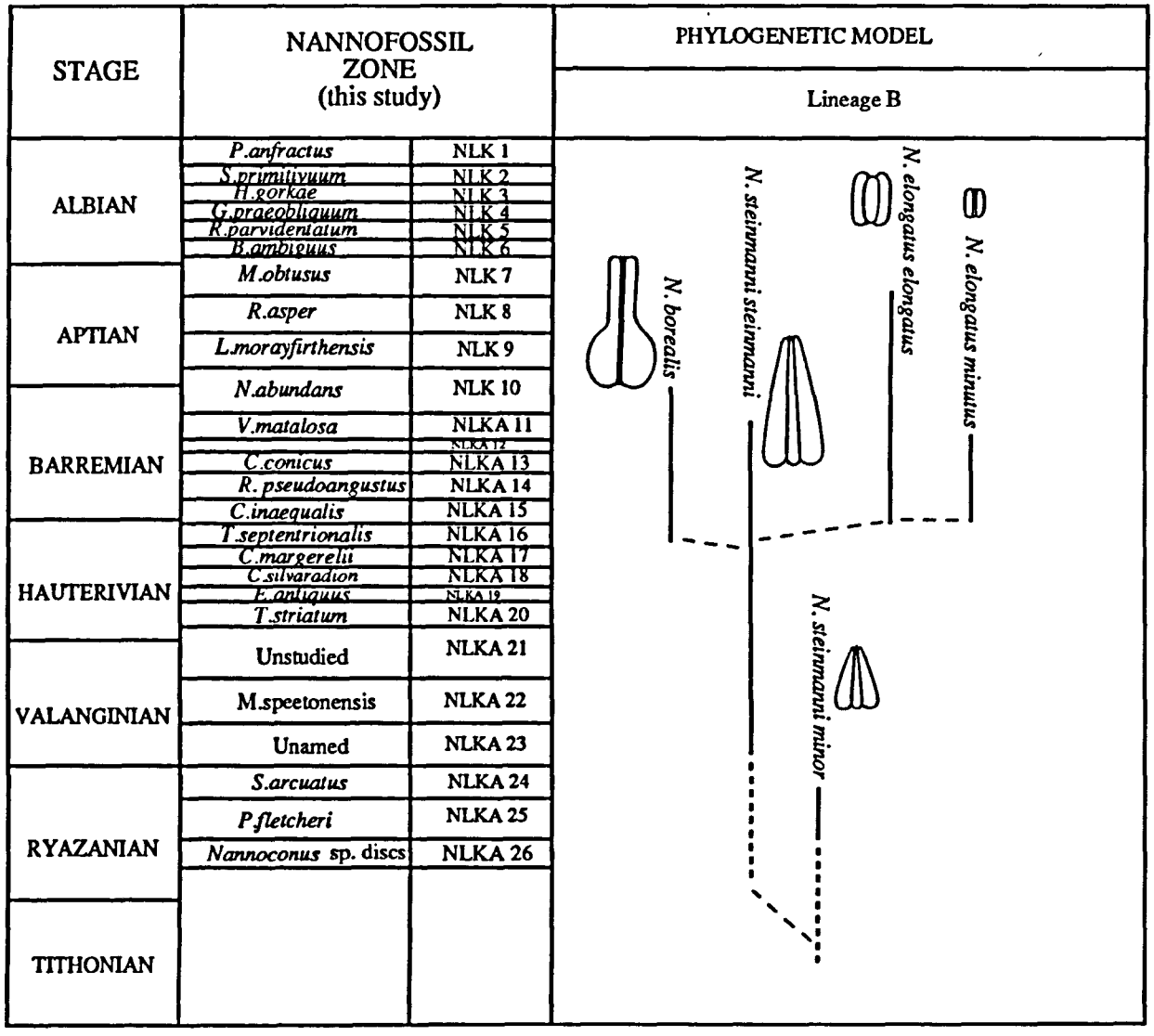


Figure 8.6 Evolutionary Model for Morphogroup 2.3, Lineage B.

similar distribution and evolutionary patterns. These are here considered as variation within a population, controlled by similar external events, the dimensions of the central opening used here to distinguish phylogenetic developments in this morphogroup.

8.3.6 Morphogroup 3.3

All the species in this morphogroup show a very well-developed cavity and recognition the morpho-species depends upon distinctive external features related to the degree of curvature of the walls and the change in outline from globular to oval or pear-shaped. An ancestral form for this morphogroup is unclear, and speciation may have taken place due to calcium-rich conditions in the Tethyan Realm since the wall structure consists of large, rigid plates. The first specimens of the *N. globulus* group are likely to have migrated into NW Europe from the Tethys. Due to the cool environment of NW Europe, speciation of endemic morphotypes *N. globulus* subsp. A and *N. oviformis* took place. *N. wassalli* is first recorded from the Tethys and is assumed to have evolved from *N. globulus globulus*.

In summary, the evolutionary lineages of the morphogroups recognised in NW Europe can be combined as in Figure 8.8.

STAGE	NANNOFOSSIL ZONE (this study)		PHYLOGENETIC MODEL
			Morphogroup 3.3
ALBIAN	*P.anfractus*	NLK 1	
	S.primitivuum	NLK 2	
	H.gorkae	NLK 3	
	G.praeobliquum	NLK 4	
	R.parvidentatum	NLK 5	
	B.ambiguus	NLK 6	
APTIAN	*M.obtusus*	NLK 7	
	R.asper	NLK 8	
	L.morayfirthensis	NLK 9	
	N.abundans	NLK 10	
BARREMIAN	*V.matalosa*	NLKA 11	
		NLKA 12	
	C.conicus	NLKA 13	
	R. pseudoangustus	NLKA 14	
	C.inaequalis	NLKA 15	
HAUTERIVIAN	*T.septentrionalis*	NLKA 16	
	C.margerelii	NLKA 17	
	C.silvaradion	NLKA 18	
	E.antiquus	NLKA 19	
	T.striatum	NLKA 20	
VALANGINIAN	Unstudied	NLKA 21	
	M.speetonensis	NLKA 22	
	Unamed	NLKA 23	
RYAZANIAN	*S.arcuatus*	NLKA 24	
	P.fletcheri	NLKA 25	
	Nannoconus sp. discs	NLKA 26	
TITHONIAN			

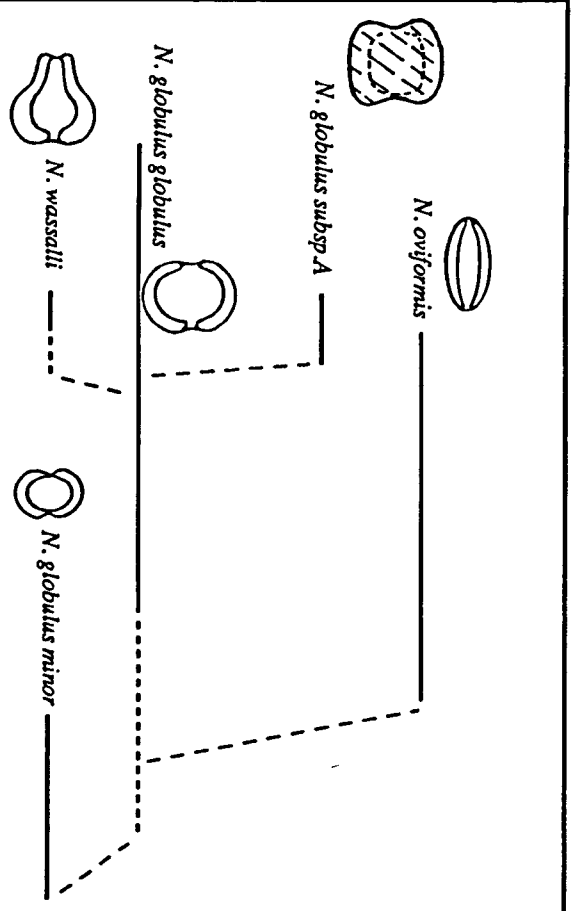


Figure 8.7 Evolutionary Model for Morphogroup 3.3.

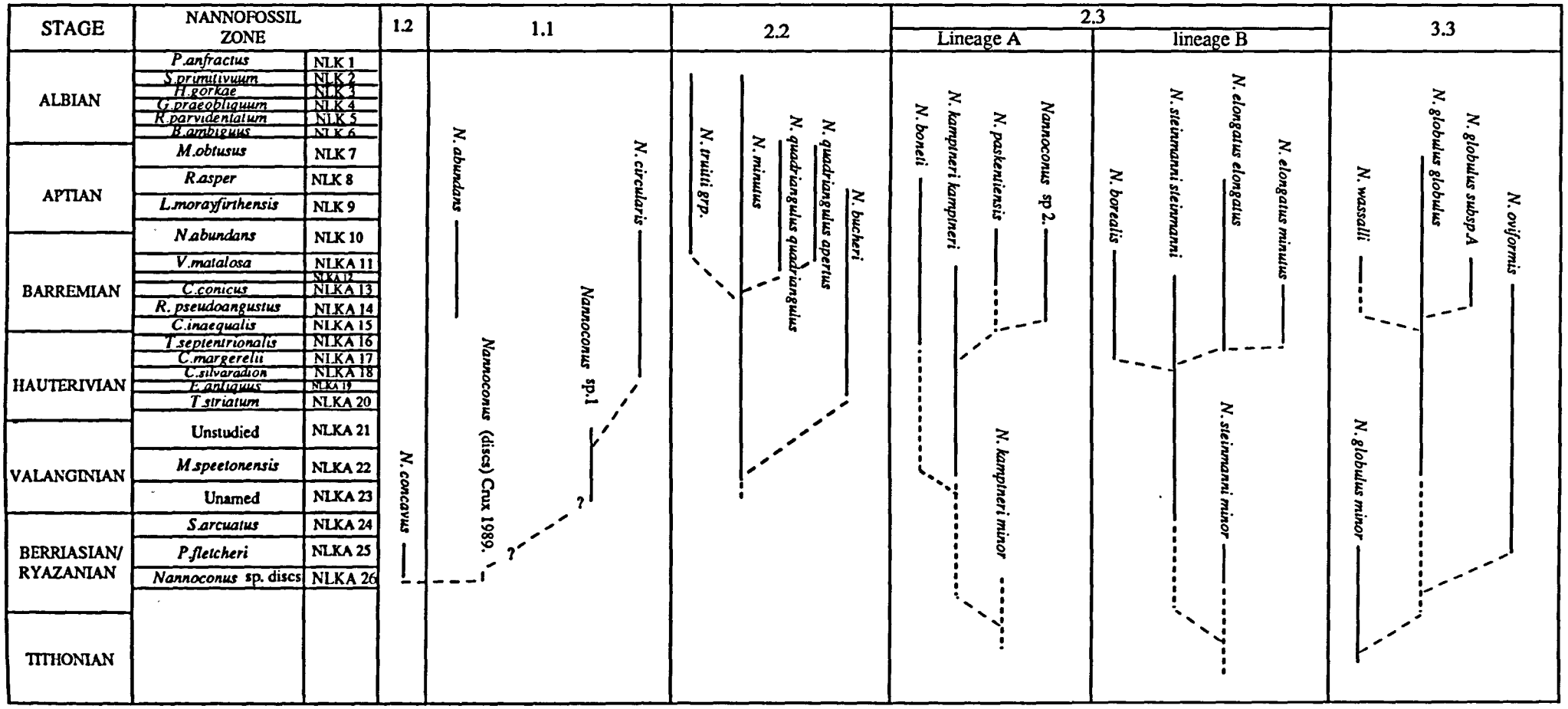


Figure 8.8 A summary of the evolution of Nannoconus. Legend: — known range, --- postulated range.

Chapter 9.
Biostratigraphy

9.1 Correlation of NW European Biostratigraphic Schemes

The data for the occurrence and distribution patterns of *Nannoconus* in NW Europe were tied into existing nannofossil schemes, no other micro- or macrofossil data were available. A correlation of the existing schemes available is shown in figure 9.1.

North Sea nannofossil biostratigraphic schemes for the Early Cretaceous have only been developed since the 1980's. The first scheme published was by Taylor (1982) based upon observations of onshore section material from Speeton (England). The scheme uses the Top Occurrence (TO) and Base Occurrence (BO) of nannofossil species from the Ryazanian-Albian interval which she subdivided into 8 zones.

The potential for a more comprehensive nannofossil scheme was recognised by Jakubowski (1987). This scheme combined the work of Taylor (1982) with well section data from the Moray Firth Basin. This scheme was developed for commercial biostratigraphy and therefore concentrates on the TO of species events. This scheme has a total of 19 zones and 11 sub-zones which subdivide the Ryazanian-Albian interval. This scheme is particularly useful to the sample material studied, however, no direct external micro- or macrofossil control is available for this scheme.

Crux (1989) introduced the latest scheme for the whole of NW Europe, based upon the study of UK and German onshore and Norwegian offshore sections. The most significant feature of his scheme is the correlation of the nannofossil events with Boreal ammonite and belemnite zonal schemes. A total of 16 nannofossil zones are proposed for the Late Ryazanian-Late Barremian interval. However, the scheme contains an unstudied interval in the Hauterivian. The nannofossil zones are defined to a large extent upon the BO of the marker species. The study of well sections can be hindered by the lack of reliability of datum levels due to the effects of caving and drilling mud contamination.

Another recent scheme available is by Mutterlose (1989) which concentrates on data obtained from onshore sections in NW Germany. A total of 13 zones are proposed

with 3 influx horizons of nannoconid assemblages apparently restricted to NW Germany (see Fig. 9.1).

9.2 Biostratigraphic Methodology

All the sections were studied in an industrial stratigraphical manner, working downhole, and also in an evolutionary manner, working up-hole to test the validity of certain marker species. Some sections contained a high percentage of drilling mud contamination which made correctly establishing the BO of certain marker species difficult.

The distribution charts are represented as TO's of species due to the plotting limitations of the Shell computer system EPIPAL which was used. The relative abundance of the species is given as symbols. A key to the symbols used is given at the base of each chart and the enclosure number is referred to the chapter on locality and section data, with the geographic location of the section.

The open nomenclature used in the distribution charts and text was standardized in the following manner:

aff.	new undescribed species/subspecies but data insufficient for the description of a new taxa, e.g. *A.* aff. *dietzmanni.*
cf.	determination uncertain (poor preservation/provisional determination).
?	provisional determination, greater degree of uncertainty than 'cf'.
sp.	cannot be related to established species due to oblique view (species identification not attempted).
spp.	collective term for several species.

The charts show a segregation of nannofossil data (excepting nannoconid discs, oblique views and 'sp.' data - due to limitations on the number of categories which could be printed in EPIPAL). The category classifications correspond to those in the Taxonomy (Chapter 7). Within these groups the TO of species is printed first in a similar manner to the nannofossil data. Where oblique specimens only were observed

the morphocategory was identified as far as possible.

9.3 Discussion of zones Used

An integrated scheme was constructed from nannofossil events in Jakubowski (1987 for the Cenomanian/Albian-Barremian interval) and Crux (1989 for the Barremian-Ryazanian interval). A margin of error may exist in combining these schemes due to the lack of macrofossil control in Jakubowski's (1987) scheme and geographical extent; the two schemes overlap in the Barremian interval.

A total of 26 interval zones and 6 intervals are used to subdivide the Albian-Ryazanian interval with an unstudied interval in the upper Valanginian (Crux 1989). Corresponding range charts of the biostratigraphically useful species are given by Jakubowski (1987, p. 108, fig. 5) and Crux (1989, p. 166, fig. 8.12 & p. 167, fig. 8.13). A brief resumé of the combined zonal scheme and individual biostratigraphical event characteristics is given below. The NLK numbers were assigned to the zones by Jakubowski (1987). The zones of Crux (1989) are here given an NLKA number to distinguish them from the NLK zones of Jakubowski (1987) in the Late Barremian-Late Ryazanian interval.

Phanulithus anfractus Zone. NLK 1.

Author: Jakubowski (1987).
Original Definition: The interval between the TO of *Phanulithus anfractus* and the TO of common/abundant *Seribiscutum primitiv um.*
Range: Early Cenomanian-Late Albian.
Remarks: This zone is only recognised in the central North Sea and is associated with common *E. turriseiffelii, B. enormis* and few/common *T. salium/phacelosus.* Nannoconids are very rare in this zone.

Seribiscutum primitiv um Zone. NLK 2.

Author: Jakubowski (1987).
Original Definition: From the TO of common/abundant *Seribiscutum primitiv um* to the TO of *Hemipodorhabdus gorkae.*
Range: early Late Albian.

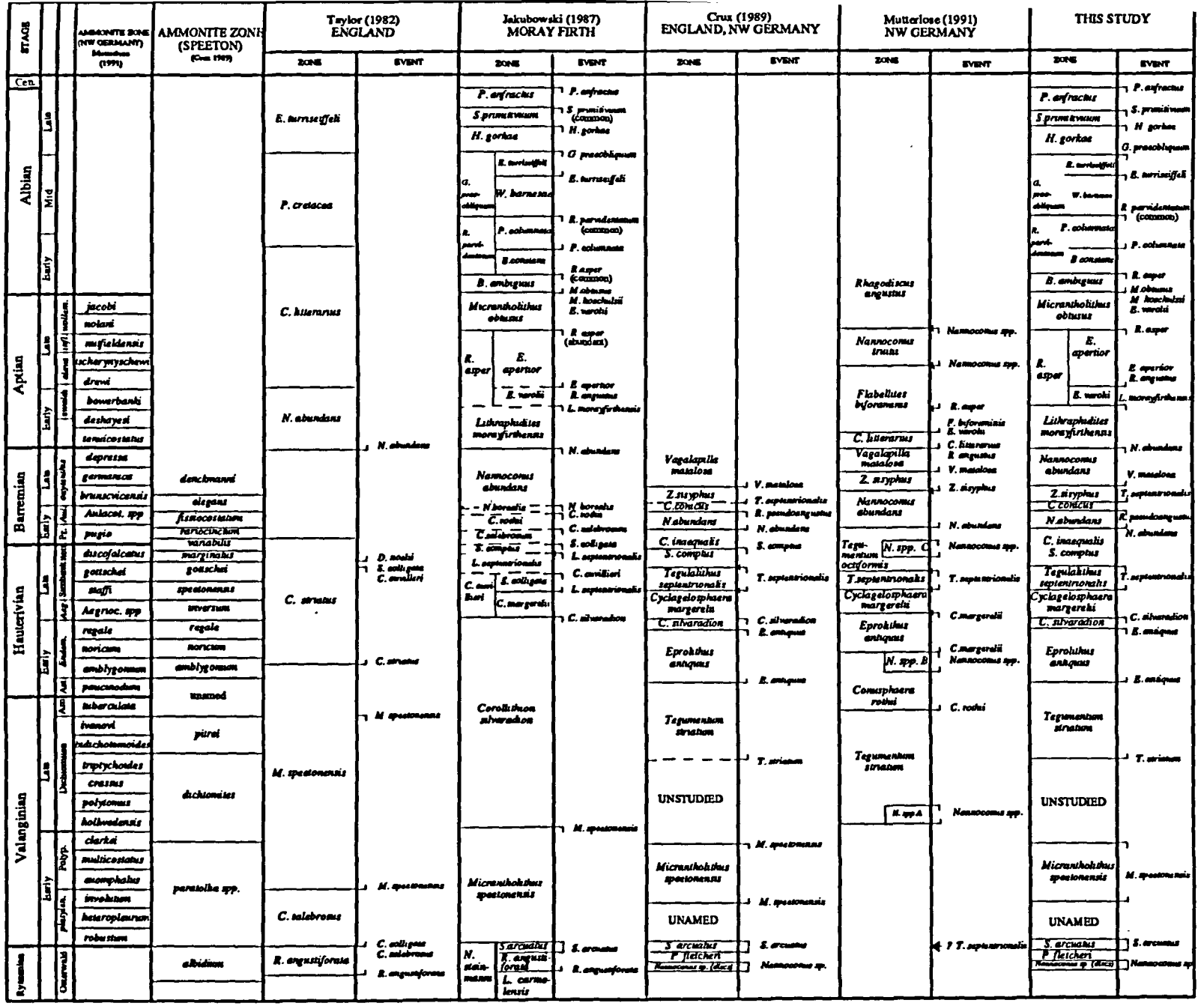


Figure. 9.1 Correlation of Boreal Zonal Schemes.

Remarks: *Z. sisyphus, T. salium, R. splendens* are common within this zone in the central North Sea. This zone is not recognised elsewhere due to the difficulty of distinguishing between zones NLK 1-4 in condensed sequences, in particular in the Shetland Basin.

Hemipodorhabdus gorkae Zone. NLK 3.

Author: Jakubowski (1987).
Original Definition: The interval between the TO of *Hemipodorhabdus gorkae* and the TO of *Gartnerago praeobliquum.*
Range: early Late Albian-late Mid Albian.
Remarks: *H. gorkae* was not found to be a common constituent of the assemblages of this datum level, therefore the upper boundary was not recognised with certainty.

Gartnerago praeobliquum Zone. NLK 4.

Author: Jakubowski (1987).
Original Definition: The interval between the TO of *Gartnerago praeobliquum* and the TO of common/abundant *Repagulum parvidentatum.*
Range: Mid Albian.
Remarks: This zone has been subdivided into two sub-zones by Jakubowski (1987), he remarks that due to a regional hiatus these subdivisions cannot be found in the Dutch sector of the North Sea. No evidence of this zone was found in L/2-2.

Eiffellithus turriseiffelii Subzone. NLK 4A.

Author: Thierstein (1971), emend. Jakubowski (1987).
Original Definition: The interval between the TO of *Gartnerago praeobliquum* and the BO of *Eiffellithus turriseiffelii.*
Range: Late Albian.
Remarks: *E. turriseiffelii, S. primitiv um* were found to be common components of the assemblages in the Fastnet Basin.

Watznaueria barnesae Subzone. NLK 4B.

Author: Jakubowski (1987).
Original Definition: The interval between the BO of *Eiffellithus turriseiffelii* and the TO

of common/abundant *Repagulum parvidentatum.*
Range: early Late Albian-late Mid Albian.

Repagulum parvidentatum Zone. NLK 5.

Author: Jakubowski (1987).
Original Definition: The interval between the TO of common/abundant *Repagulum parvidentatum* and the TO of common/abundant *Rhagodiscus asper.*
Range: early-Mid Albian.
Remarks: This zone can be subdivided into two subzones, but was very rarely identified. A regional hiatus during this time interval results in the absence of this zone from the central North Sea and Moray Firth Basin.

Prediscosphaera columnata Subzone. NLK 5A.

Author: Thierstein (1971), emend. Jakubowski (1987), non Manivit (1971).
Original Definition: The interval between the TO of common/abundant *Repagulum parvidentatum* and the BO of *Prediscosphaera columnata.*
Range: Early Albian.

Biscutum constans Subzone. NLK 5B.

Author: Jakubowski (1987).
Original Definition: The interval between the BO of *Prediscosphaera columnata* and the TO of common/abundant *Rhagodiscus asper.*
Range: Early Albian.

Bukrylithus ambiguus Zone. NLK 6.

Author: Jakubowski (1987).
Original Definition: The interval between the TO of common/abundant *Rhagodiscus asper* and the TO of *Micrantholithus obtusus, Micrantholithus hoschulzii* and/or *Eprolithus varolii.*
Range: Early Albian.
Remarks: Mainly used for local correlation in the Moray Firth Basin (Jakubowski, 1987) but was also recognised here in the central North Sea where there is no regional hiatus.

Micrantholithus obtusus Zone. NLK 7.

Author: Jakubowski (1987).
Original Definition: The interval between the TO of *Micrantholithus obtusus, Micrantholithus hoschulzii* and/or *Eprolithus varolii* and the TO of common/abundant *Rhagodiscus asper.*
Range: Late Aptian
Remarks: Small species of *M. obtusus* with deeply incised plates are recognised at the extinction boundary (TO) of this species range.

Rhagodiscus asper Zone. NLK 8.

Author: Jakubowski (1987).
Original Definition: The interval between the TO of common/abundant *Rhagodiscus asper* and the TO of common *Lithraphidites morayfirthensis.*
Range: late Early Aptian.
Remarks: This interval is thought to represent an influx of warm, Tethyan water and in the Dutch sector of the North Sea it has a high abundance nannoconid population. This is confirmed by Mutterlose (1991) who recognises the influx of *N. truitti* group in the upper part of this zone. *R. asper*, usually a common component of the assemblages, was found to be sparse in the Shetland Basin area. This may be indicative of an environmental influence on the distribution of this species and may warrant further study.

Eprolithus apertior Subzone. NLK 8A.

Author: Jakubowski (1987).
Original Definition: The interval from the TO of common/abundant *Rhagodiscus asper* to the BO of *Eprolithus apertior* or *Rhagodiscus angustus.*
Range: Late Aptian.
Remarks: This subzone corresponds to the *N. truitti* zone of Mutterlose (1991). In NW Germany the TO of *M. hoschulzii* is recognised in this zone. Crux (1989) records the presence of similar forms in the Barremian, but he recognised the non-typical granular texture of the central area and calls these forms *R. pseudoangustus.* *Eprolithus* sp. with several rays (11 & 16) were identified in the assemblage.

***Eprolithus varolii* Subzone. NLK 8B.**

Author: Jakubowski (1987).
Original Definition: The interval between the BO of *Eprolithus apertior* and *Rhagodiscus angustus* and the TO of *Lithraphidites morayfirthensis.*
Range: Early Aptian.
Remarks: *L. morayfirthensis* was rare in other NW European sections, being only of value in the Moray Firth and some central North Sea sections.

***Lithraphidites morayfirthensis* Zone. NLK 9.**

Author: Jakubowski (1987).
Original Definition: The interval between the TO of common *Lithraphidites morayfirthensis* and the TO of *Nannoconus abundans.*
Range: Early Aptian-Late Barremian.
Remarks: Condensed lower Aptian sequences and the patchy local occurrence of *L. morayfirthensis* made this zone difficult to detect and correlate across NW Europe.

***N. abundans* Zone (JAK). NLK 10.**

Author: Taylor (1982), emend. Jakubowski (1987).
Original Definition: The interval between the TO of *Nannoconus abundans* and the TO of *Nannoconus borealis.*
Range: Late Barremian.
Remarks: This zone is widely correlatable across NW Europe. However, it is often dificult to recognise in the condensed Aptian-Barremian sequences of the Shetland Basin. To avoid confusion with the *N. abundans* zone of Crux (1989) the authors initials are given behind the species name. The lower boundary of this zone was found to overlap with the *Vagalapilla matalosa* Zone (NLKA 11) of Crux (1989).

In the central North sea common *B. ellipticum* and *Z. sisyphus* occur, with *D. ignotus* becoming common in the upper part of this zone. *N. truitti* group and *N. quadriangulus* group have their BO in this interval.

***Vagalapilla matalosa* Zone. NLKA 11.**

Author: Crux (1989).

Original Definition: The interval between the top of the studied interval (a datum level is not given by Crux) and the BO of *Vagalapilla matalosa.*
Range: Late Barremian.
Remarks: This zone corresponds to the lower part of the *N. abundans* Zone of Jakubowski (1987), the exact limits remain undefined. Small forms of *V. matalosa* are recognised at the BO of this species associated with larger forms of the species. In the central North Sea abundant *B. ellipticum* characterise this zone. This zone is not recognised in the condensed sequences of the Shetland Basin.

Zeugrahabdotus sisyphus Zone. NLKA 12

Author: Crux (1989).
Original Definition: The interval from the BO of *Vagalapilla matalosa* to the abundant occurrence of *Zeugrhabdotus sisyphus* and/or the re-entry of *Tegulalithus septentrionalis.*
Range: Late-Early Barremian.
Remarks: Common species present in the assemblage are *S. horticus, D. lehmanii, S. crux.* Mutterlose (1991) remarks that *N. abundans* and *N. borealis* are common in this zone with *N. elongatus* present.

Cretarhabdus conicus Zone. NLKA 13.

Author: Crux (1989).
Original Definition: The interval from the re-entry of *Tegulalithus septentrionalis* and the TO of *Rhagodiscus pseudoangustus.*
Range: Early Barremian.
Remarks: Jakubowski uses the extinction of *C. rothii* in this interval but this species is too rare across NW Europe to be used as a reliable marker. The re-entry of *T. septentrionalis* (mentioned by Crux 1989) was not recognised, the species being rare, but present below this interval.

Rhagodiscus pseudoangustus Zone. NLKA 14.

Author: Taylor (1982), emend. Crux (1989).
Original Definition: The interval from the TO of *Rhagodiscus pseudoangustus* to the BO of *Nannoconus abundans.*
Range: Lower Barremian

Remarks: The zone was renamed from the *N. abundans* zone proposed by Crux (1989) to prevent confusion with the *N. abundans* Zone (NLK 10) recognised by Jakubowski (1987). *A. infracretacea, S. crux, B. ellipticum, C. conicus* are common in this interval. Jakubowski (1987) uses the TO of *Crucibiscutum salebrosum* to subdivide this Zone, however, he applied a strict taxonomic concept because small forms are found above this interval. *N. abundans* is a very important constituent of the assemblage, especially in NW Germany where it forms up to 5 % of the nannofossils (Mutterlose & Harding, 1987). *N. elongatus* and *N. borealis* are also present.

Cretarhabdus inaequalis Zone. NLKA 15.

Author: Crux (1989).
Original Definition: The interval between the BO of *Nannoconus abundans* and the TO of *Stradnerlithus comptus.*
Range: Early Barremian.
Remarks: *B. ellipticum* and *D. lehmanii* are common in the assemblage. *S. comptus* was not identified in this interval due to the scarcity of this species in the sections studied. Mutterlose (1987) recognises an influx of nannoconids (*Nannoconus* spp.-Horizon C) in the upper part of this zone in NW Germany. The nannoconid assemblage consists of *N. minutus, N. circularis, N.* aff. *N. circularis, N. globulus, N. kamptneri.* The nannoconids can form up to 10 % of the assemblage in this interval (Mutterlose,1989).

Stradnerlithus comptus Zone. NLKA 16.

Author: Jakubowski (1987), emend. Crux (1989).
Original Definition: The interval between the TO of *Stradnerlithus comptus* and the TO of common *Tegulalithus septentrionalis.*
Range: Early Barremian-Late Hauterivian
Remarks: *C. laffittei, D. ignotus* and *D. lehmanii* are dominant in the assemblage. The absence of *S. comptus* and the scarcity of *T. septentrionalis* in the studied sections made it impossible to recognise NLKA Zones 15-17. The appearance of few/common morphologically diverse nannoconid flora were used to identify this interval.

Tegulalithus septentrionalis Zone. NLKA 17.

Author: Jakubowski (1987), emend. Crux (1989).
Original Definition: The interval from the TO of common *Tegulalithus septentrionalis* to the BO of *Tegulalithus septentrionalis.*
Range: Late Hauterivian.
Remarks: Recognition of this interval was based upon the scarcity of nannoconids and the rare specimens of *T. septentrionalis* found. *S. colligata* has its TO in this zone. Common *Micrantholithus* sp. and *C. salebrosum* were found in the assemblages of central North Sea.

Cyclagelosphaera margerelii Zone. NLKA 18.

Author: Jakubowski (1987), emend. to zonal status, Crux (1989).
Original Definition: The interval from the BO of *Tegulalithus septentrionalis* to the TO of *Corollithion silvaradion.*
Range: Late-Early Hauterivian.
Remarks: Relatively sparse nannofossil assemblages dominated by *Watznaueria barnesae.*

Corollithion silvaradion Zone. NLKA 19.

Author: Jakubowski (1987), emend. Crux (1989).
Original Definition: The interval between the TO of *Corollithion silvaradion* to the TO of *Eprolithus antiquus.*
Range: Early Hauterivian.
Remarks: *C. salebrosum, C. silvaradion, C. laffittei* and *C. margerelii* are common in this biozone with common *S. crux* and *D. ignotus* in the Danish Central Trough. In NW Germany Mutterlose (1991) recognised the lower boundary of this zone by a marked decrease in nannoconids (*N. minutus, N.* sp.) in this interval.

Eprolithus antiquus Zone. NLKA 20.

Author: Crux (1989).
Original Definition: The interval between the TO and BO of *Eprolithus antiquus.*
Range: Early Hauterivian-Late Valanginian.
Remarks: *T. striatum* and *Scapholithus fossilis* are important in this zone. The marker

species can be rare and strict taxonomic control is needed for this zone to be useful. Mutterlose (1991) recognises a nannoconid influx (*Nannoconus* spp.-Horizon B) in the upper part of this interval in NW Germany; the assemblage is composed of *N. kamptneri, N. globulus, N. bucheri, N. circularis* and *N.* sp.

Tegumentum striatum Zone. NLKA 21.

Author: Taylor (1982), emend. Crux (1989).
Original Definition: The interval between the BO of *Eprolithus antiquus* and the BO of *Tegumentum striatum.*
Range: ? Early Hauterivian-Early Valanginian.
Remarks: Few/common *Eprolithus* sp., *Z. erectus* and *S. crux* are important components in the assemblages of the Danish North Sea. *M. chiastius* and *T. gabalus* are common in the central North Sea.

Unstudied Interval (Crux). NLKA 22.

Author: Crux (1989).
Original Definition: The interval between the BO of *Tegumentum striatum* and the TO of *Micrantholithus speetonensis.*
Range: Late-Early Valanginian.
Remarks: This interval was not studied by Crux (1989) and no complete sections of this interval were found during this project.

Micrantholithus speetonensis Zone. NLKA 23.

Author: Taylor (1982), emend. Crux (1987).
Original Definition: The interval between the TO and BO of *Micrantholithus speetonensis.*
Range: Early Valanginian.
Remarks: The upper boundary is poorly defined, as a result of the lack of upper Valanginian material in the study by Crux, thus it may be possible that *M. speetonensis* has a longer range. The assemblage has common *S. horticus, C. salebrosum* and *Kokia* sp.

Unnamed Zone. NLKA 24.

Author: Jakubowski (1987), emend. Crux (1989).
Original Definition: The interval between the BO of *Micrantholithus speetonensis* and the TO of *Sollasites arcuatus*.
Range: ?Early Valanginian-Late Ryazanian.
Remarks: *Kokia* sp., *P. fletcheri, C. silvaradion* and *M. brevis* are stratigraphically important in this interval. Mutterlose (1991) records the earliest nannoconid influx in NW Germany (*Nannoconus* spp.-Horizon A) in the uppermost part of this unamed zone; this influx consists of *N. minutus* and *N. globulus*.

***Sollasites arcuatus* Zone. NLKA 25.**

Author: Crux (1989).
Original Definition: The interval between the TO and BO of *Sollasites arcuatus*.
Range: Late Ryazanian.
Remarks: The marker species was found to be too scarce in the sections studied to be of any biostratigraphic value and no other marker was found to discriminate this zone.

***Perissocyclus fletcheri* Zone. NLKA 26.**

Author: Crux (1989).
Original Definition: The interval between the BO of *Sollasites arcuatus* and the TO of *Nannoconus* sp. (discs).
Range: Late Ryazanian.
Remarks: *B. ellipticum, M. obtusus, C. crenulatus* and *Z. embergeri* are important in the assemblage. The upper boundary of this zone could not be distinguished from NLKA 25.

***Nannoconus* sp. (discs) Zone. NLKA 27.**

Author: Crux (1989).
Original Definition: The interval between the TO and BO of *Nannoconus* sp. (discs).
Range: Late Ryazanian.
Remarks: These discs are a very distinctive component in this interval and are easy to recognize in the assemblage. The interval was found to contain few other nannoconid flora.

9.4 *Nannoconus* in Stratigraphy

The biostratigraphical application of this genus is now widely accepted in Tethyan, Cosmopolitan and Boreal zonal schemes. A review of the nannoconid zones is given below.

9.4.1 *Nannoconus* in Tethyan Schemes

Nannoconus was one of the first nannofossil species to be used in stratigraphy, by Brönnimann (1955) using nannoconid assemblage zones from Cuba. He suggested that the first occurrence of *Nannoconus* in Cuba pre-dated the first appearance in NW Europe after investigating material from southern Switzerland. He proposed a total of three *Nannoconus* assemblage zones to date the Lower Cretaceous:

Association 1. *N. steinmanni, N.* aff. *globulus, N. colomi.*
Neocomian (Valanginian-Hauterivian).

Association 2. *N. steinmanni, N. colomi, N. kamptneri, N. bermudezi, N. globulus.*
Barremian.

Association 3. *N. truitti, N. minutus, N. elongatus, N. bucheri, N. wassalli.*
Aptian-Albian.

Assemblage zones 1 and 2 were recognised to be gradational in contrast to zones 2 and 3 which had abrupt floral change between them.

Since this date several authors have recognised the potential of this genus biostratigraphically. Some discrepancy exists as to the boundary of the Brönnimann zones in different Tethyan regions as indicated in figure 9.2 (Bouché 1963, Baldi-Beke 1964, Geel 1963, Manivit 1969, Moshkovitz 1972). Trejo (1960) proposed a new scheme of six nannoconid assemblage zones based upon drill cutting material from Mexico:

Zone A. *N. bronnimanni, N. steinmanni* and occasionally *N. globulus.*
Late Tithonian.

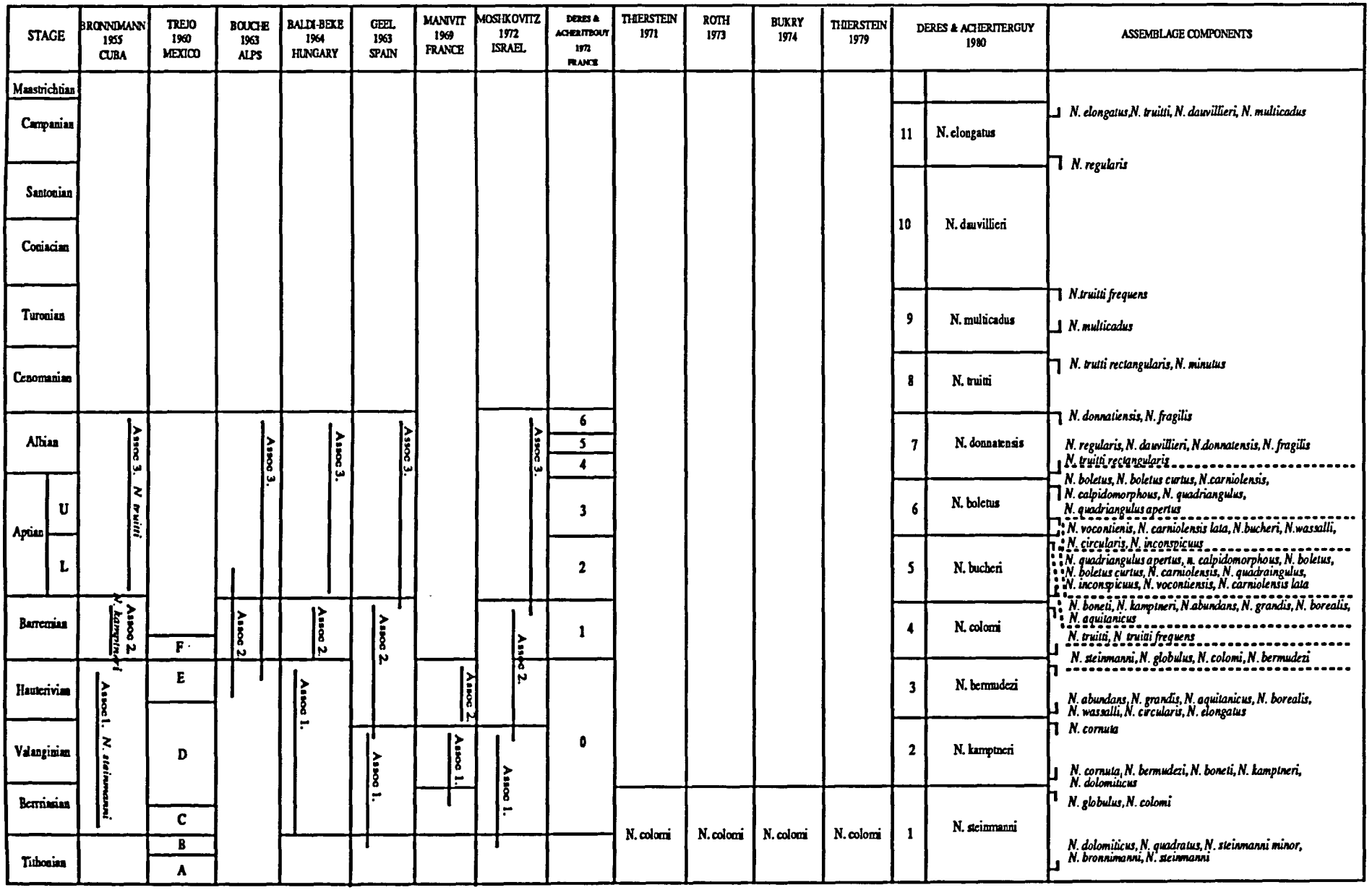


FIGURE 9.2. The use of Nannoconus in Tethyan Zonal Schemes.

Zone B. *N. steinmanni, N. globulus.*
Late Tithonian.

Zone C. *N. steinmanni, N. globulus* and frequently *N. bermudezi.*
Early Berriasian.

Zone D. *N. steinmanni, N. globulus, N. bermudezi* and a variety of *N. colomi, N. kamptneri* and *N. boneti.*
Early Berriasian-Early Hauterivian.

Zone E. *N. wassalli, N. bucheri, N. truitti, N. minutus* and frequent *N. boneti, N. kamptneri, N. elongatus* and rare *N. colomi.*
Late Hauterivian.

Zone F. *N. truitti, N. minutus* and frequent *N. bucheri, N. elongatus* and *N. wassalli.*
Mid Barremian. However Trejo (1960) comments that *N. wassalli* terminates at the base of the Albian.

These zones were an elaboration of the assemblage zones of Brönnimann (1955). It was not until 1972 that, upon recognition of several new species, Deres & Achériteguy submitted a new scheme composed of seven nannoconid assemblage zones from France.

Association 0. *N. steinmanni, N. bermudezi, N. colomi, N. kamptneri, N. globulus, N.* sp. 107.
Neocomian.

Association 1. *N. steinmanni, N. bermudezi, N. colomi, N. globulus* and the appearance of *N. wassalli, N. bucheri.*
Barremian.

Association 2. *N. steinmanni, N. colomi, N. bermudezi* and the appearance of *N. kamptneri* and *N. wassalli.*
Early Aptian.

Association 3. *N. boletus, N. quadriangulus, N. carniolensis.* This is subdivided into:

Zone 3a. Additional groups of *N. wassalli* and *N. bucheri.*
early Late Aptian.

Zone 3b. Additional groups of *N. boletus, N. carniolensis, N. quadriangulus, N. truitti.*
late Late Aptian.

Association 4. *N. truitti* group with different appearance events of the dominant species for association 5 & 6.

This preliminary scheme was updated in 1980, with 11 nannoconid assemblage zones for the Berriasian-Campanian interval.

Assemblage zones have not always been used in the Tethyan biostratigraphic schemes. *N. colomi* has been widely used to date the Upper Tithonian (Thierstein 1971 & 1979, Roth 1973, Bukry 1974).

Nannoconids have provided an important biostratigraphic framework for Tethyan workers who have used both nannoconid assemblage zones and single species events.

9.4.2 *Nannoconus* in Cosmopolitan Schemes

Nannoconus species have not proved to be successful markers in cosmopolitan zonal schemes due to the diachronous nature of several species events. The first occurrence of *N. colomi* (senior syn. *N. steinmanni*) is suggested to roughly correlate with the Jurassic/Cretaceous boundary. The last occurrences of *N. steinmanni* and *N. kamptneri* are also suggested to be potentially useful by Perch-Nielsen (1979) see Figure 9.3.

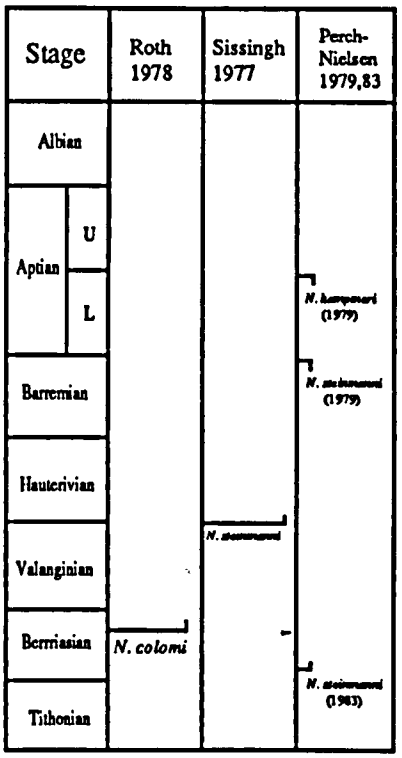


Figure 9.3. The use of *Nannoconus* in Cosmopolitan Zonal Schemes.

9.4.3 *Nannoconus* in Boreal schemes

The relative scarcity of nannoconids in the Boreal Realm has not hindered attempts to use them stratigraphically (Figure 9.4). Taylor (1982) used a widespread event of the BO of *N. abundans*, which is still commonly used in the modern schemes. Jakubowski (1987) introduced another Boreal endemic species, *N. borealis* into his Moray Firth zonation, the TO of which marks the base of NLK 10 in the Early Barremian. Both *N. abundans* and *N. borealis* represent single species events which are easy to recognise and biostratigraphically important. Crux (1989) also used the *N. abundans* datum level and also the occurrence of very large, low birefringent discs to mark the latest Ryazanian in his scheme. He does not, however, recognise the reliability of the *N. borealis* event and suggests this is diachronous across NW Europe. Mutterlose (1989, 1991) in studying material from NW Germany proposed the use of nannoconid influx horizons to aid the identification of particular basin evolution events. The applicability of these events across NW Europe is discussed in Chapter 11.2 on the Palaeobiogeography of NW Europe. The events are shown in Figure 9.4 with 3 species groups used:

N. spp. A. *N. globulus, N. minutus.*
N. spp. B. *N. kamptneri, N. globulus, N. bucheri, N. circularis.*
N. spp. C. *N. minutus, N. circularis, N. globulus, N. kamptneri.*

In addition to these influxes he also incorporates the base occurrence of *N. abundans* in the Early Barremian and a *N. truitti* Zone in the Late Aptian.

The extremely robust nature of the nannoconid wall and brief appearances of certain species have been shown to be a potentially useful tool in stratigraphy of NW Europe. The problem that arises when studying this genus is the taxonomic one of the degree of variability within and/or between individual species, especially in NW Europe in comparison with Tethyan waters. Nannoconid assemblage events are perhaps therefore a more useful means of biostratigraphical application of this genus except for a few reliable single species events e.g. *N. abundans* Zone in NW Europe.

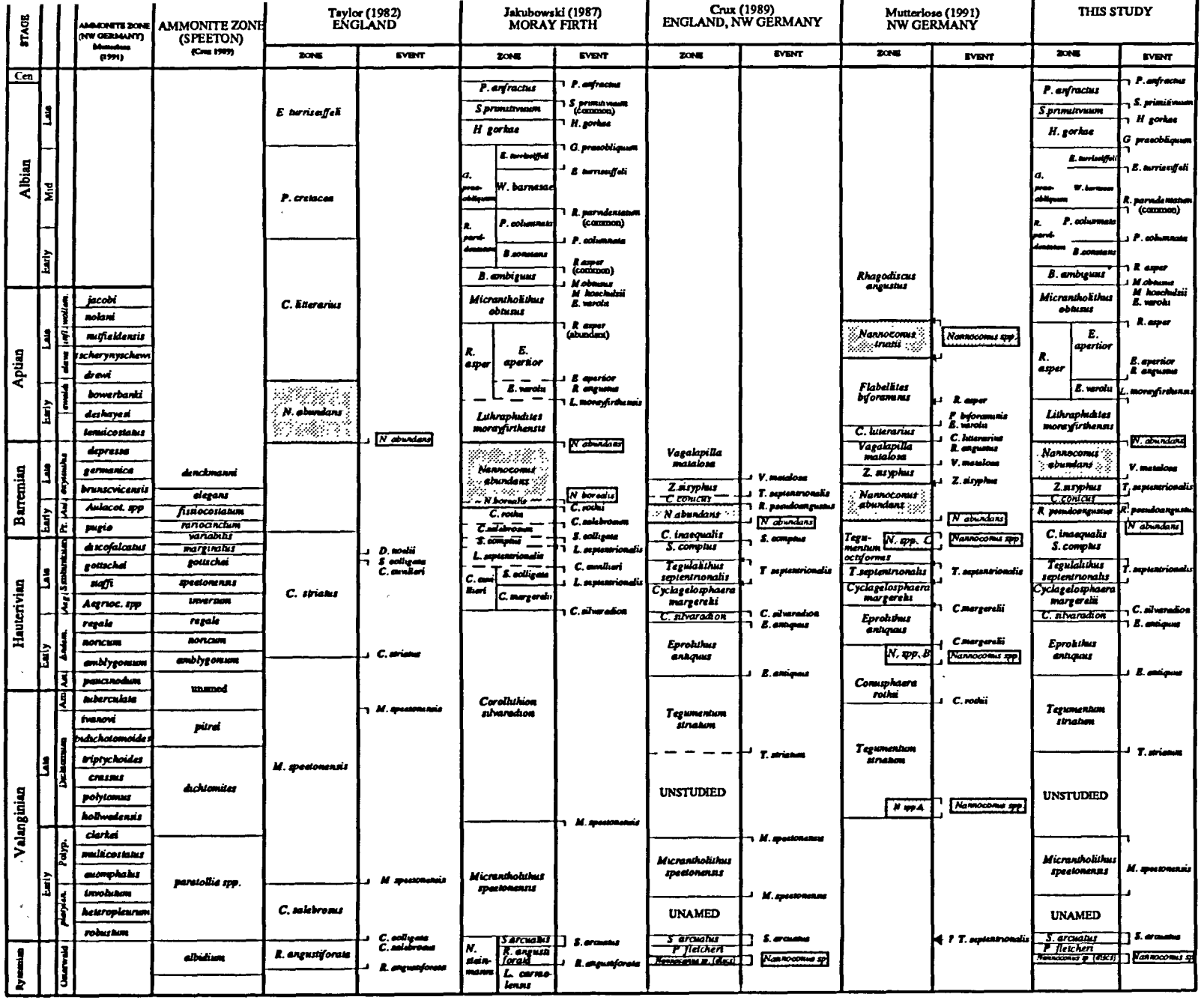


Figure 9.4 Correlation of Boreal Zonal Schemes Highlighting the use of Nannoconids in Stratigraphy.

Chapter 10.
Palaeoseasonality

10.1 Seasonal Variation in the Boreal Early Cretaceous

The occurrence of seasonal blooms of algae in the modern oceans and the factors controlling their appearance are still not fully understood. The oceans form a complex environment which interacts with the atmosphere and reflects global climate, it is therefore difficult (and probably unrealistic) to identify a single factor stimulating algal blooms. Four parameters which have a complex interplay in the oceans have been recognised to have a direct impact on algal bloom dynamics: 1) Meteorology; 2) Biological interaction; 3) Hydrodynamics and 4) Chemical oceanography-increase in nutrient availability. However, we can identify certain primary controls which may moderate or increase environmental impact e.g. spring warming, associated with increased nutrient supply from rainfall runoff, may be a key factor in stimulating a bloom. How then can we recognise or interpret the influences on blooms observed in the fossil record which have undergone subsequent post-mortem information loss? To answer this question we need to consider the factors which affect the preservation of nannofossil blooms.

The main influences on the thanatocoenoses are the effects of selective post-mortem dissolution of fragile species. Breakage or loss of these species biases palaeontological information available. Horizontal transport of the sinking organisms is the second important factor as, size or density sorting may have taken place (Okada & Mc Intyre 1979). Perfect preservation of a bloom via the palaeontological process is therefore a very complex process and interpretation of such assemblages are open to some degree of uncertainty.

Seasonal blooms of living algae (including coccoliths) have been recognised for many years but it is only recently that the seasonal variations in nannofossil assemblages have been observed and interpreted as such (refer to table 10.1). The only known record of Early Cretaceous seasonality, outside NW Europe, is discussed by Lambert (1987). He recognised monospecific assemblages from a Late Albian laminated facies with calcareous lenses from Cameroon. No interpretation of a possible seasonal turnover of individual floral content of these blooms is given by the author but he recognizes a lamina consisting of *N.* aff. *fragilis* (senior syn. *N. quadriangulus apertus*).

Jurassic	Lower Cretaceous	Middle/Upper Cretaceous	Modern
POSIDONIENSCHIEFER: Kauffman (1978) SCHISTES CARTON: Goy et al. (1971) Goy (1981) KIMMERIDGE CLAY: Gallois (1976) Gallois & Medd (1979)	HAUPTBLATTERTON: Mutterlose (1984, 1991) Cepek & Kemper (1981) Mutterlose & Harding (1987) Kemper & Zimmerle (1978) Kemper (1987) FISCHSCHIEFER : Mutterlose & Harding (1987) Mutterlose (1991) MUNK MARL: Thomsen (1989a & b)	CAMEROON: Lambert (1987) N. AMERICA (U. CRET): Hattin (1975) BLAKE BAHAMA BASIN: Robertson & Beefnick (1983) ATLANTIC: Ogg et al. (1987) GENERAL: Schlanger & Cita (1982)	BLACK SEA: Bukry et al. (1970) Bukry (1974) Müller & Blaschke (1969) Ross et al. (1970) Ross & Degens (1974) PACIFIC: Honjo (1976) Honjo (1982) Cole et al.(1985) OLIGOCENE: Müller & Blaschke (1971) Stradner (1987)

Table 10.1 Representative studies of short-term nannofossil fluctuations.

Lower Cretaceous laminated facies have been correlated across NW Europe: From the Lower Saxony Basin Hauptblätterton (*Aulacteuthis* zone) to the Munk Marl of the Danish Central Trough and across the North sea to the upper Lower B Beds of Speeton (*Rude-Fissiocostatum* zone) of England. In addition to these main laminated units dated as Early/Middle Barremian, a series of minor laminated units, Blätterton and Fischschiefer, have been recognised in the Lower Saxony Basin. The age assignments of these units are discussed in section 10.1.1. All of these units have been shown to contain fine laminae with alternating calcareous (nannofossil-rich) and argillaceous layers which are interpreted as seasonal variations. The assemblages show remarkable preservation with only minimal clay mineral matrix. Routine light microscope study cannot be used to observe these lamina due to the destruction of individual laminae during preparation. The only effective means by which these nannofossil laminae can be studied is by analysis of the surface of untreated sediment in the SEM.

A review of the literature available on Lower Cretaceous seasonal bloom dynamics from NW Europe is discussed below (table 10.1) and comments are given on the seasonal variations observed in nannoconids (this study) in core material from the Danish Central Trough. Lack of adequate core and sidewall core material prevented a detailed study of seasonality in nannofossils in this project.

10.1.1. NW Germany

Kemper and Zimmerle (1978) were the first workers to study the beds in detail from the Ryazanian to Aptian black shale facies of the Lower Saxony Basin, NW Germany. They found two main laminated facies: The Hauptblätterton (Barremian) and Fischschiefer (Lower Aptian). Both these facies contain undisturbed alternating laminae of incipient chalks (almost completely composed of calcareous nannofossils) interlaminated with black shales containing a higher clastic and pyrite content than the pale chalks. The authors discuss the macroscopic, microscopic and sedimentological nature of the facies, which are treated as one laminated unit due to the difficulty of separation. The facies are interpreted as shallow-water and have been correlated across the West Netherlands Basin and Central Graben, with comparable sediments having been described by Rawson & Mutterlose (1983) from the Lower Barremian of Speeton (NE England).

Mutterlose and Harding (1987), in discussing the anoxic sediments from the Barremian

of NW Germany, consider the division of the Barremian laminated facies into the Hauptblätterton and Blätterton. The term 'Blätterton' facies describes the incipient chalk-shale laminated facies. 'Hauptblätterton' refers to a thick, main unit which is described from the *Aulacoteuthis* spp. zone, and 'Blätterton' describes thinner units which occur above the Hauptblätterton or a layer which has been observed below by Bender (1960).

Mutterlose & Harding (1987) confirm that the Haüptblätterton is a synchronous sediment across NW Europe, of late Early Barremian age. Thinner Blätterton laminae are noted in the Late Barremian (Mutterlose 1983 & 1987) with the youngest Blätterton layers found in the *germanica* Zone of the uppermost Barremian (Mutterlose & Harding 1987).

Cepek and Kemper (1981) consider the black shale component of the laminae to be kenoxic (moderate concentration of oxygen) in contrast to previous authors who describe the basin as having had periods of anoxia, reflected by the deposition of black shales. A lamina of *N. abundans* from the Hauptblätterton is illustrated by Cepek and Kemper (1981, pl. 2, fig. 2). This almost monospecific assemblage also contains a few specimens of *C. bifurcatum* and *C. rhombicum*. Mixed and monospecific assemblages are identified by the authors, with the former thought to relate to slight water column mixing during deposition. Mutterlose (1991) also illustrates an *N. abundans* assemblage from the *Aulacoteuthis* Zone in the Early Barremian of the Lower Saxony Basin.

10.1.2. Danish Central Trough

The most comprehensive interpretation of nannofossil assemblages thought to reflect seasonality is from the Danish Central Trough by Thomsen (1989a & b). These are compared to modern laminated marls from the Black Sea which record annual variations in nannofossil production. The species composition of the individual lamina were studied by Thomsen (1989a, b) using scanning electron micrographs. The species composition of individual and consecutive lamina was shown to fluctuate strongly with some species monopolizing a single lamina. He demonstrated a sequence of nannofossil production with *W. barnesae* and *M. obtusus* dominating the lower and upper part of the lamina, with a central core of *A. dietzmanni* and *R. asper*. Each lamina is interpreted as a record of the annual production of nannofossils, with the

individual changes in the assemblage corresponding to the seasonal production/ dominance of individual species or associations.

The environment of the Danish Central Trough during the Early Cretaceous has been interpreted as a shallow shelf sea setting, comparable to the Lower Saxony Basin. Preservation of the thanatocoenoses is completely reliant upon the calm anoxic bottom waters, essentially devoid of benthic life, to preserve record of the surface fertility cycles. The assemblages showed an absence of damage to the fine structure of the coccoliths, with the preservation of some intact coccospheres and clusters of crushed coccospheres. These observations imply that at the time of deposition the water turbulence was negligible to non-existent.

The lamina studied by Thomsen (and in this study) are a constituent of the Upper Barremian Tuxen Formation and Lower Aptian Sola Formation. These are very difficult to distinguish from each other in facies nature and geographic distribution (Thomsen 1989a). The Barremian laminae were found to consist of continuous nannofossil layers in the Upper Barremian Munk Marl, while the Lower Aptian Sola Formation contained laminae consisting of discrete lenses of nannofossils. These lenses are interpreted by Thomsen (1989a) as representing faecal pellets. Each calcareous lens is elliptical to sub-circular in outline and may contain a completely different nannofossil flora from others along the same bedding plane. Similar faecal pellets and burrows were observed here, these are illustrated in Pls 4 &5.

In the 1989a paper Thomsen notes that no nannoconids are recognised in the Munk Marl, except as a component of mixed laminae. However, observation here of laminae from North Jens-1 (7561.11 m) revealed rare, solitary laminae composed of *N. abundans*. The individual specimens were well-preserved with intact flanges and unusual "double structures", which are discussed in Section 6.2 and illustrated in Pl. 2, fig. 6 & 7. These laminae can be correlated to those recognised by Cepek & Kemper (1981) in the Hauptblätterton of the Lower Saxony Basin. The illustrated assemblage (Cepek & Kemper 1981, Pl. 2, fig. 2), however, appears to contain a high percentage of *Corollithion* sp. in addition to *N. abundans* and cannot be interpreted as a true monospecific assemblage. The laminae found in the material from North Jens-1 were rare and hence the occurrence could not be tied into the model proposed by Thomsen (1989). The sporadic distribution of these *N. abundans* laminae may imply that a particular environmental stimulus, e.g. calcium carbonate availability, salinity, water temperature, etc. is required for the dominance of this species during a particular

season. Seasonal blooms of monospecific assemblages may deplete the surface waters in a particular element or nutrient and without constant renewal of surface water nutrients from a nearby upwelling or land source this may provide an environmental stimulus for the dominance of one species to the exclusion of others. However, this may be because it is the only species which can survive in these conditions or because it is more rapidly successful in utilising the available resources to the exclusion of other species. However, this is a circular argument and at present there is insufficient evidence to interpret the controls on the bloom dynamics of this genus.

In addition to the recognition of the monospecific laminae of *N. abundans* other nannoconid species such as *N. bucheri* were also found in abundance. These never attained an exceptionally high abundance but were associated with high percentages of *Cretarhabdus* sp. and minor *N. abundans, R. asper* and *Corollithion* sp. Monospecific assemblages of *N. circularis* were also recognised a bioturbated lamina from E-1 (Pl. 4, fig. 3, 4 & 8), however, no individual laminae were found consisting exclusively of this species. Little is understood about the seasonal cycles which have been recognised across NW Europe and further detailed study of untreated sediment surfaces is necessary to extend information available to us.

10.1.3. Speeton

The laminated sediments from the upper Lower B Beds at Speeton are comparable in lithology and macrofossil content to the Blätterton facies and Munk Marl (Rawson & Mutterlose 1983). To date no work has been published on the nannofossil content of this facies.

10.2 Environmental Indications

Colom (1952) noted that nannoconids were absent from nearshore environments, a fact which may indicate that this genus requires calm, clear water with minimal detrital input (Tappan 1980, p. 279). This may aid the understanding of the timing and significance of basin downwarping in relation to the occurrence of *Nannoconus*.

Water Depth

The water depth significance of nannoconid communities has been related to the

occurrence of nannoplankton in the near surface, neritic waters by Baldi-Beke (1962). Roth & Krumbach (1986) also recognised this neritic link based upon the high abundance of *Micrantholithus* spp. and *Nannoconus* spp. using factor analysis on sediments from the Aptian/Albian of the Atlantic. A similar study by Mutterlose (1989) of Hauterivian sediments from NW Germany showed these genera to be restricted to pale horizons thought by the author to be warm water ingression causing rhythmic bedding. However, oceanography is here considered a complex interplay of several controlling factors which are related to water depth e.g. light penetration, pressure etc. The robust structure of the nannoconid sphere (with reference to the spheres of *N. steinmanni*, Colom 1965) seem to make it unlikely that the cell would float near the surface of the water column (unless it was surrounded by a huge mass of frothy protoplasm). The cell to nannoconid plate ratio would be very low and therefore the buoyancy within the water mass would be minimal, i.e. the individual nannoconids are very dense in comparison to coccoliths. If the sphere was present in the lower section of the water mass then this could perhaps account for the clear waters needed for the distribution of this genus, the heavily calcified bodies acting as intense light receptors. Our lack of knowledge on the life cycle and ecological habitat can only lead us to speculate on the factors controlling their distribution in the water column but a preference for shelf waters is apparent.

Lithology

The lithology provides an important information data set. Mutterlose (1991) mentions that within the pale and dark rhythms of the Frielingen and Gott sections (Late Hauterivian, *Discofalcatus* Zone) changes in the abundance and distribution of nannoconids can be observed in which they show a distinct affinity to the pale marls.

Water Temperature

The earliest species are recorded from the Tethyan Realm in the Late Tithonian and their subsequent dominance of the nannofossil assemblages, for example in the Maiolica Formation, implies that *Nannoconus* preferred warm waters of equable climates. The occurrence of nannoconids is closely linked to the appearance of Tethyan-derived nannofossil and foraminiferal assemblages (Erba 1987, Mutterlose 1989) except for the Boreal-Endemic taxa. This fact has enabled the use of nannoconids in the recognition of periodic influxes of Tethyan-derived water currents into the Boreal waters of NW Europe, in response to the changing palaeogeographic and palaeoceanographic configuration of NW Europe during the Tithonian-Albian interval.

10.3 Palaeobiogeography

Nannofossil assemblages recovered from the palaeontological record reflect surface water fertility, salinity and temperature as long as the assemblage has not been significantly modified by dissolution. Surface water temperature is widely used to characterise assemblages which are endemic to a particular environment. Mapping the distribution of endemic species can show the development of biogeographic provinces in modern and fossil oceans. The distribution of a species is reliant upon the environmental conditions essential to its survival and this determines the balance of species forming an assemblage. One of these controlling factors is the distribution of water masses in the modern oceans which has divided the modern oceans into tropical, sub-tropical, temperate, sub-arctic and sub-antartic realms closely related to temperature of the water mass. These realms have been recognised in the fossil record and several workers have assigned groupings to distinguish the palaeobiogeographic habitat of particular genera and species. A simplistic summary of these categories is given below:

Cosmopolitan

This term is used to characterise species which are present in the Boreal and Tethyan Realms. These species are suggested as being of a eurythermal nature.

Tethyan

The distinctive feature of these species is their predominance in waters reflecting warm, equable climates but they may occur in the Boreal Realm during periods of warm water circulation or climatic fluctuations.

Boreal

Species which are stenothermal and evolved in the Boreal Realm are classified under this heading; some endemic nannoconids have evolved from originally Tethyan taxa.

The palaeobiogeographic nature of nannoconids was first discussed by Perch-Nielsen (1979) who suggested that this genus was cosmopolitan due to its distribution from Speeton, Spitsburgen, Falkland Plateau and Mexico. A year later the extensive work of Deres & Achériteguy (1980) showed the genus to be dominantly Tethyan in character with high abundances, even rock-forming in some areas of the Tethys. This idea has been maintained here but several species are now recognised to have evolved in the Boreal Realm and some species have been re-classified as cosmopolitan. Table 10.2 summarizes the palaeobiogeographic occurrence of some nannoconid species. The data

are compiled from published material (Crux 1989 & 1992, Mutterlose 1991) indicated by an * and results from this study. A full listing can not be compiled until the Tethyan nannoconid taxa are studied.

BOREAL	TETHYAN
N. abundans *	*Nannoconus* spp. *
N. borealis *	
N. concavus	
N. sp 1.	
N. sp. (discs) after Crux (1989) *	
COSMOPOLITAN	
N. steinmanni	
N. kamptneri	
N. globulus	
N. bucheri	
N. truitti	
N. minutus	

Table 10.2 Summary of the palaeobiogeographical preferences of some nannoconid taxa.

As shown above some endemicity can be recognised within this essentially Tethyan genus. It is essential to recognize this before we interpret the distribution patterns of individual species, associated with opening and closing of seaways between the Tethyan and Boreal seaways. Blooms of Boreal-Endemic *N. abundans* do not record an influx of warm Tethyan waters. In contrast, the first high abundance values of *N. truitti* group in the Boreal Realm suggest an influx of this taxa via warm water currents, associated with the opening of a seaway to the south. Dominance of this species during the Aptian of both realms may imply general warming of the Boreal Realm due to warm current circulation. An alternative to this theory is that this species is eurythermal in nature and can tolerate the water temperature variations.

Chapter 11.
Distribution Patterns

11.1 Worldwide Palaeoceanographic Implications of the Distribution Patterns of the genus *Nannoconus*

An assimilation of data from previous authors who have recorded *Nannoconus* was used to construct a series of global distribution maps. The occurrence of individual taxa was plotted in stage time increments for the Early Cretaceous. The sources of data used in the construction of these maps are recorded in Appendices I, II and III (locality, author and nannoconid taxa present). The aim of the interpretation of these data sets was to allow the palaeoenvironmental constraints on the global distribution of *Nannoconus* spp. to be discussed in order to obtain a comprehensive understanding of the criteria which affect the distribution of this genus in NW Europe. It was also hoped that the distribution patterns of this genus might give a proxy record of climate and oceanography during the Early Cretaceous.

The palaeogeographic base maps were plotted in time increments of 20 my (taken from Barron *et al.* 1981). Time slices at 100, 120 and 140 my provided the framework for the global distribution of *Nannoconus* in the Early Cretaceous. The highest, reliable resolution obtainable for the spatial and temporal patterns was using stage time-slice maps: 140 my to represent the Tithonian-Valanginian stages; 120 my for the Hauterivian-Aptian interval and 100 my for the Albian. The data obtained from published literature was plotted in an analogous manner, relative to the distribution of the palaeocontinents during the stage time-interval.

A more refined zonal distribution, to individual nannofossil or ammonite zone level, was not feasible due to the common lack of detailed information from published literature. The geographic location of the sections was sometimes also vague, as in the work by Deres and Achériteguy (1980) who record individual species occurrences as continents, e.g. Canada (due to the confidentiality of the data source). Written communication with nannofossil workers worldwide has highlighted the lack of available nannofossil data from the; North Sea (Verdenius, pers. comm.), Philipines (Leon Marietta, pers. comm.), etc. This review must therefore consider the missing information and negative records when interpreting the available data.

Prior to the interpretive discussion of the data, an outline of the worldwide palaeogeography, palaeoceanography and palaeoclimatology is given for the Early Cretaceous. The constraints on the extent and nature of the provinces used in the discussion are also given.

11.1.1 Palaeogeographic Configuration of the Continents

Mesozoic global reconstruction maps are limited to the palaeocontinent maps produced by Smith and Briden (1977). Palaeogeographic maps based on fixed continents reconstruct the global extent of marine sediments during a time interval, for example by Strakhow (1948) and Termier and Termier (1952). Barron *et al.* (1981) have used data from sea floor spreading, palaeomagnetic evidence for continental movement, and a more comprehensive data set obtained since the earlier reconstructions. Debate still exists about the initial fit of the continents and Barron *et al.* (1981) give a comprehensive account of the geological and geophysical constraints on the timing and palaeogeographic configuration of the reconstructions. The Early Cretaceous saw the opening of the South Atlantic, Indian and Arctic oceans, the timing of which has been determined using plate break-up events and the opening of new marine pathways.

11.1.2 Palaeoceanography

Ager (1981a) was the first to recognize the constancy of major climate-sensitive facies on a global scale, the controls on which are: climate, relief, relative sea level and ocean circulation patterns. Only a few authors have attempted to reconstruct globally the pattern of events in Mesozoic oceans. The greatest resolution and accuracy relies on the integration of data from marine micropalaeontology, sedimentology and geochemistry. The reader is referred to the excellent summaries for the Cretaceous by Sancetta (1987) and Roth (1989).

One of the tools used in interpreting palaeoceanography was stable isotope geochemistry of the sediments. Oxygen isotope studies were regarded as an ideal medium from which to interpret surface and horizontal water mass temperature conditions. A measure of surface water productivity and bottom water ventilation relied upon stable carbon and sulphur isotope studies. The reliability of this method has been to some extent revised since it became apparent that diagenesis could give misleading

data in a whole rock analysis (Thierstein & Roth 1980 & 1989, Thierstein 1983). In the early 1980's it was shown that nannofossils and other fauna (e.g. foraminifera) could be used as palaeoceanographic tools, which, in conjunction with geochemical studies provide a firmer understanding of marine conditions in the Cretaceous (Roth & Bowdler, 1981; Thierstein, 1981). The constraints on the distribution of nannofossils to certain water-masses has in recent oceans have been determined by the: temperature of the surface waters, nutrient availability, and to a lesser extent salinity gradients (Roth & Coulbourn, 1982). These modern data are applied to the sediments in addition to preservational patterns of nannofossils which are used to infer: preferential predation, sediment redeposition and the carbonate chemistry of the bottom and interstitial waters (Roth, 1989). Combined lithological and nannofossil data therefore provide an invaluable tool for the reconstruction of past oceanic conditions.

Data for water mass circulation patterns prior to the Aptian/Albian is meagre, Roth & Bowdler (1981) discuss marine connections during this interval and Roth (1989, p. 117, fig. 2) diagrammatically shows water mass movements for the Atlantic and Pacific based upon geochemical and nannofossil data. Connections of the South Atlantic with only the Pacific across Central America were shallow and intermittently restricted causing periodic exchange of deep and intermediate waters (Berggren & Hollister, 1974 & 1977). The North Atlantic during this time interval had good surface water connections with the Western Tethys and moderate connections with the restricted Pacific (Roth & Bowdler, 1981). The mid-Cretaceous interval had apparently major upwelling off NW Africa, in the S. Atlantic and the Equatorial Pacific, the vertical mixing and surface water fertility contributing to major nannofossil carbonate production (Roth, 1989). Poor circulation with sluggish mixing of the water column and consequently a decrease in bottom water ventilation may have led to increased nannofossil speciation (high diversity, low numbers) events due to competition for nutrients. These "anoxic" events are major peaks in nannofossil diversification according to Roth (1989). On a global scale carbon-rich shales are recognised throughout the middle Cretaceous representing periods of poor ocean ventilation, and high sea-level stand (Roth, 1989). These tectonically related events are known as Fischer cycles, occurring on a frequency of a few to tens of million years. Similar cycles are also recognised, these are, Milankovitch cycles which are astronomically controlled events which reflect nannofossil abundance changes but not speciation events. These cycles are not discussed here due to the lack of suitable data from the literature and the material studied.

11.1.3 Palaeoprovinces, their constraints.

There has been a tendency by authors to use different terminologies which can lead to confusion in interpretation and correlation. It was therefore considered necessary to outline the geographical parameters of the provinces used. Palaeobio-provinces were used in conjunction with modern physiographic provinces to enable the reader to relate, with a greater accuracy, to the geographic position of the data. The type of province and countries included for purposes of this work are given below, figure 11.1 shows the location of the provinces.

Palaeobio-provinces:

1) Boreal Realm: United Kingdom, North Sea, Holland, NW Germany, Denmark, Norway.

2) Tethys:

a) Western Tethys: France, S. Germany, Switzerland, Spain, Italy, Roumania, Hungary, Yugoslavia, Israel, Algeria, Morocco, Tunisia.

b) Eastern Tethys: Australia, Japan.

Physiographic Provinces:

1) N. Atlantic: Cameroon, N. America, Canada, Trinidad, Mexico, Cuba, Surinam.

2) S. Atlantic: S. America, Brazil.

3) E. Pacific: Colombia.

4) Indian Ocean: Madagascar, Mozambique.

The recognition of the palaeobio-provinces is related to the characteristic biota, migrational patterns into different provinces being inferred by the appearance of previously "endemic" biota into new environmental niches. This is often the result of the opening of pre-existing barriers and consequent re-orientation of current circulation

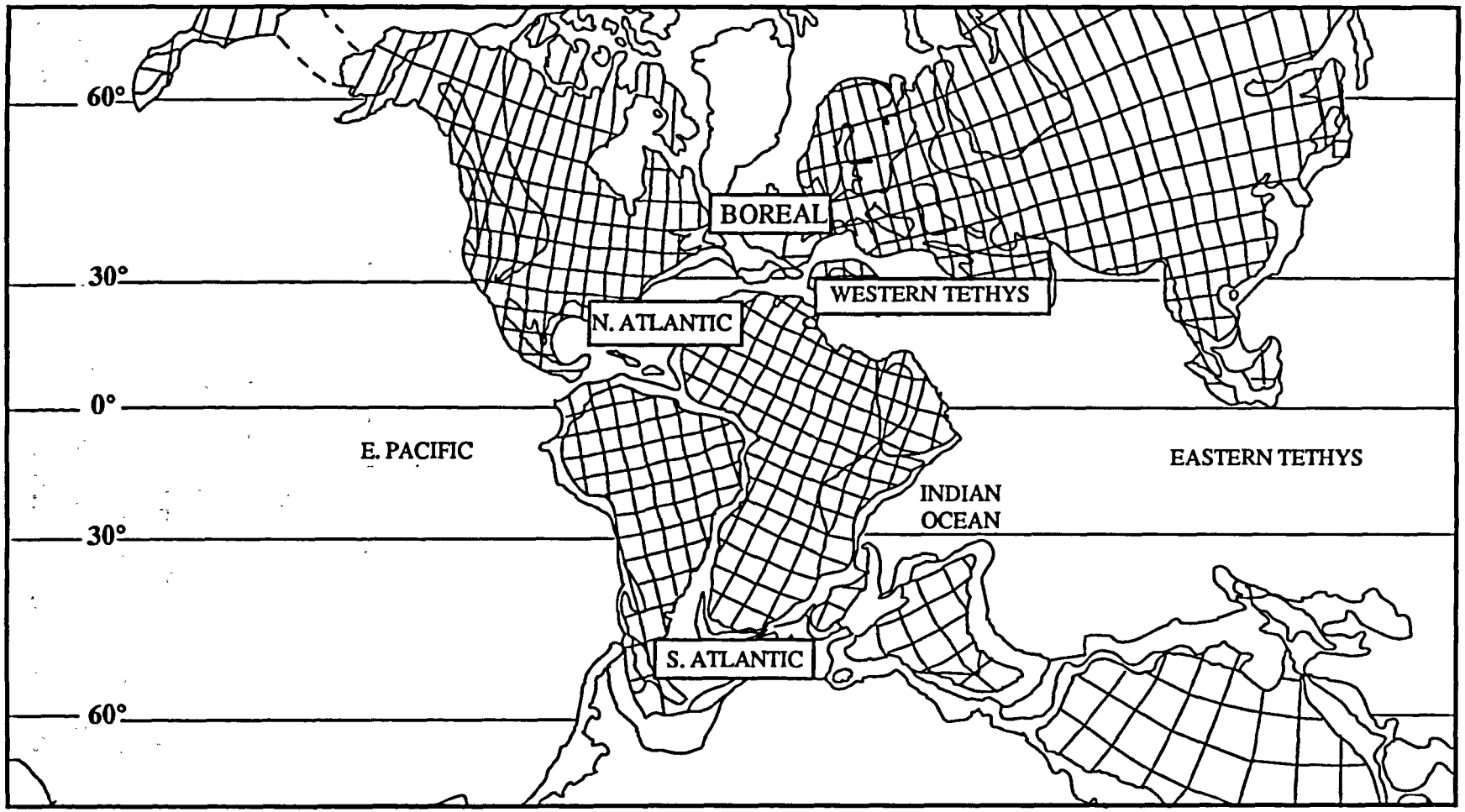


Figure 11.1. Location of the Provinces used in the interpretation of the global distribution of Nannoconus. Base maps from Barron et al. (1981).

pathways. The Tethyan Realm is inclusive of part of the N. Atlantic but it was found necessary to separate the Tethys into 3 regions (west and eastern Tethys and N. Atlantic) for the discussion of nannoconid distribution patterns, although it is recognised that they are of a Tethyan character.

11.1.4 Nannofossil Palaeobiogeography

Knowledge from available literature on the palaeobiogeography of all the provinces is still in its infancy. Foraminifera were one of the first groups to be studied in a palaeobiogeographical context by Gordon (1970), and Grigelis & Gorbachik (1980) used planktonic foraminifera to show migration westward during the Late Jurassic and Early Cretaceous. Calcareous nannoplankton were not used much before the 1980's although their sensitivity as palaeoceanographic indicators had been recognised, although even now there are only a limited number of references available to their use in this field. A summary of some of the palaeobiogeographic literature available concerning *Nannoconus* is given below:

GENERAL: Roth & Bowdler (1981)
Thierstein (1981)
Roth (1989)

ATLANTIC: Roth & Krumbach (1986)

PACIFIC: Roth (1981)

TETHYS: Premoli-Silva *et al.* (1989)

Quantitative data for the pre-Aptian/Albian interval are scarce, thus information on the water-mass distributions and surface water fertility during the Barremian-Berriasian period can only be inferred using floral distribution patterns. However, preservation of nannofossil taxa is important to their distribution. In the Blake Bahama Basin Albian nannofossils are almost completely dissolved and can only be found in thin layers, these were interpreted by Roth (1983) as sediments derived from shallower water by turbidity current action. Similar conditions have been found in the Cape and Angola Basins of the Southern Atlantic (Roth, 1984). Fluctuations in nannofossil taxa and abundance (between individuals or species) may therefore be related to preservation.

This is an important consideration when interpreting the palaeobiogeography of a region using calcareous nannofossils.

During the Aptian/Albian interval cool water assemblages were restricted to high southern latitudes (S. of 50°) in South Atlantic and Indian oceans. In the North and East Atlantic an E-W trend of high floral abundances is recognised, thought to be due to increased surface water fertility in an upwelling zone (Parish, 1982 & Parish *et al.*, 1982). The assemblages show a Tethyan character in response to worldwide circum-equatorial currents during this time interval (Roth, 1989).

A multivariate-statistical approach was used by Roth & Bowdler (1986) to study mid Cretaceous biogeographical distribution patterns. This technique cannot be applied to older time slices with any great reliability. The first biogeographic patterns for *Nannoconus* spp. distribution were plotted as a relative abundance data for the Aptian/Albian interval (Roth & Bowdler, 1986 p. 250, fig. 12). *Nannoconus* and *Broinsonia* are interpreted as inhabiting neritic or shallow-continental margin and epicontinental sea conditions and can reach very high abundances in the Tethys. Due to their overall low abundance in sediments both these genera were determined as unreliable for distribution studies (Roth & Bowdler, 1986). Preservation is known not control the distribution of *Nannoconus* (Noël & Melg uen, 1978; Noël & Manivit, 1978), dissolution and associated overgrowth has a tendency to affect the coherent nature of the wall. This could be responsible for lack of recognition of broken specimens, especially in the SEM and apparent high abundance values of *Nannoconus* in limestone lithologies may be falsified by dissolution of other nannofossil species. *Nannoconus* is found to be rare in high latitudes and in the southern hemisphere (Proto Decima, 1974; Proto Decima *et al*, 1979; Wise & Wind, 1977; Noël & Melg uen, 1978). This is thought to represent ecological limitations on the geographic distribution of this genus with the highest abundances found in the Tethys and margins of the North Atlantic.

11.1.5 Diversification

The rates of species diversification among Cretaceous nannofossils have been summarized by Roth (1989). After a positive rate of diversification (rate of speciation exceeding the rate of extinction) in the early Late Jurassic, the trend is a general increase in the Early Cretaceous. Peak periods were in the early Valanginian, early Aptian and

mid Albian, associated with times of poor ocean ventilation. This is recognised by an increased accumulation of the total organic carbon content of the sediment, slow bottom water exchange, high water mass stability and poor vertical mixing characteristic of periods of high sea level stands and warm climates. Minor fluctuations in the abiotic environment is thought to have caused minor relative abundance patterns but not to be responsible for increased speciation rates. The following data are discussed in an evolutionary manner beginning with the earliest records of *Nannoconus*. Figures are numbered in accordance with the stages, only selected references are given in the key- the reader is referred to appendix III for details of the localities, authors and nannoconid taxa.

11.1 a) Late Tithonian

Bralower *et al.* (1989) recognise a species, similar in structure to *Faviconus multicolumnatus* (=*Nannoconus multicolumnatus* in this work) in the early Late Tithonian. This species has here been tentatively suggested to be an ancestor of nannoconids (refer to Ch.8). The detailed evolutionary model proposed by Bralower *et al.* (1989) suggests the earliest forms evolved in the Western Tethys and are small and compressed individuals with very narrow, irregular central cavities. These taxa rapidly became extinct and assemblages are dominated by the conical and elongate species: *N. steinmanni minor*, *N. kamptneri minor* and *N. dolomiticus*. Species diversification is relatively high during this interval but abundance values are low. Three species become extinct before the Berriasian; *N. infans*, *N. winteri*, and *N. compressus* with five species/grps: *N. bronnimanni*, *N. steinmanni* grp, *N. kamptneri* grp, *N. globulus minor* and *N. dolomiticus* surviving across the Jurassic/Cretaceous boundary. The study of individual taxa distribution is hindered by taxonomic inconsistencies at species level between authors.

Only sporadic occurrences of this genus are recorded from the Western Tethys, North Atlantic, Indian Ocean and E. Pacific (Colombia) which may suggest limited water mass circulation during the latest Tithonian. No marine connections existed between the North and South Atlantic so migration of taxa southward would have been through Western Tethys. The Boreal Realm was isolated by land barriers and the lack of suitable marine facies leaves a gap in the data set.

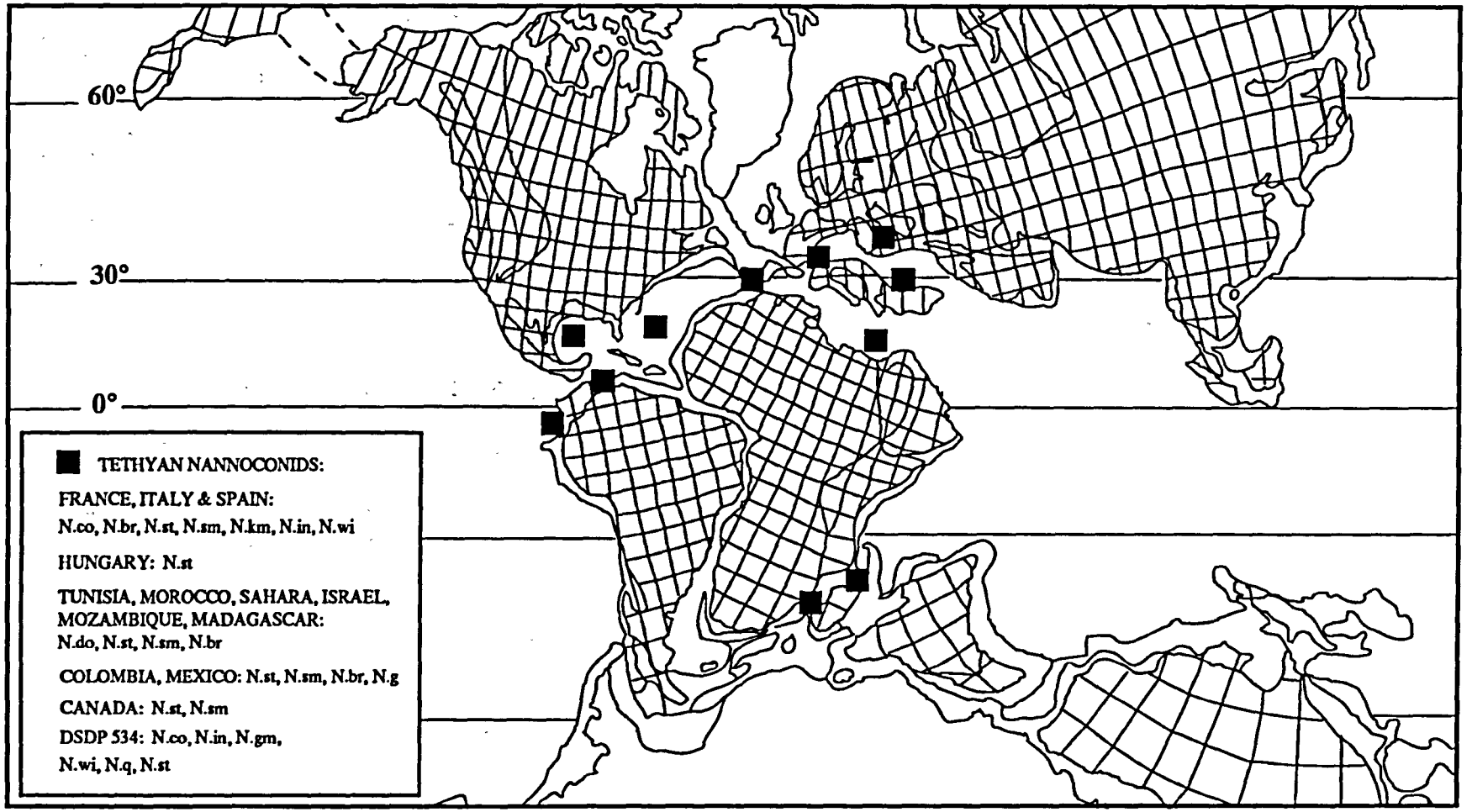


Figure 11.1a) Nannoconid species distribution map for the Late Tithonian (140 my). Please refer to Appendix I for spp. abbreviations.

11.1 b) Berriasian/Ryazanian

Speciation appears to be relatively constant in the Tethys with the larger conical forms continuing to be dominant in the assemblages: *N. steinmanni steinmanni* (syn. *N. colomi*), *N. kamptneri kamptneri* and *N. bermudezi*. An increase in the number of localities which record the presence of nannoconids is evident, which may be due to the lack of material studied/available during the Tithonian but may represent low abundance levels of this genus in the early stages of its evolution. Circulation of warm Tethyan waters is thought to be responsible for the sporadic occurrences of *N. steinmanni steinmanni* in the E. Pacific and Western Tethys and the first recorded occurrence of *N. globulus globulus* in the North Atlantic.

Weak marine connections between the Western Tethys and the Boreal Realm were established by the late Ryazanian. An influx of Tethyan species into the realm is shown by the presence of Tethyan flora, in particular *Nannoconus* spp e.g. *N. steinmanni minor*. The hostile changes in the abiotic environment appear to have increased nannoconid speciation, with several endemic Boreal species recognised in the realm; *N.* sp. (discs), *N. concavus* (syn. *N. alvus*) and *N. sabinae*. Tethyan nannoconids are recorded as far north as Skinnabanken, which suggests that the circulation currents were of a warmer nature.

11.1 c) Valanginian

The early Valanginian has been interpreted as a period of nannofossil speciation by Roth (1989) but this is not evident in the nannoconid assemblages with the appearance of only one new taxon *N. minutus*. *N. globulus globulus* became established in the North Atlantic but there is no major change in the composition of the Tethyan nannoconid assemblages. Slightly higher nannoconid diversity patterns have been observed in Roumania and Hungary but this may be due to problems in taxonomic identifications.

In the Boreal Realm, a minor marine connection with the Western Tethys is suggested by Mutterlose (1991) which is tentatively supported by the presence of Tethyan conical nannoconids, which dominate the nannoconid assemblages worldwide during this period. Valanginian ostracod assemblages show a pattern of migration and diversification from the Tethys to NW Europe, seen as the temperature gradient between the two realms declined.

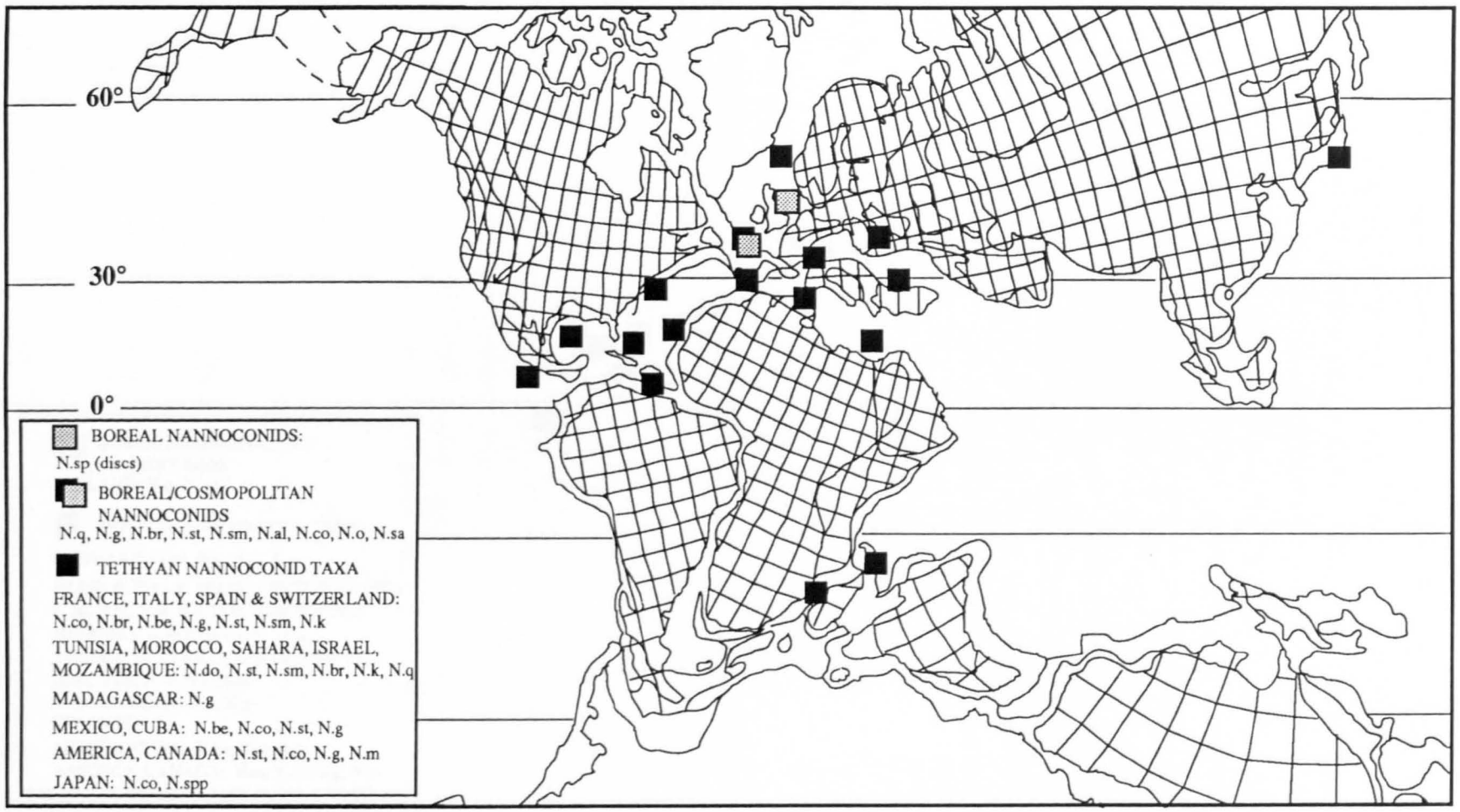


Figure 11.1b) Nannoconid species distribution map for the Berriasian/Ryazanian (140 my).

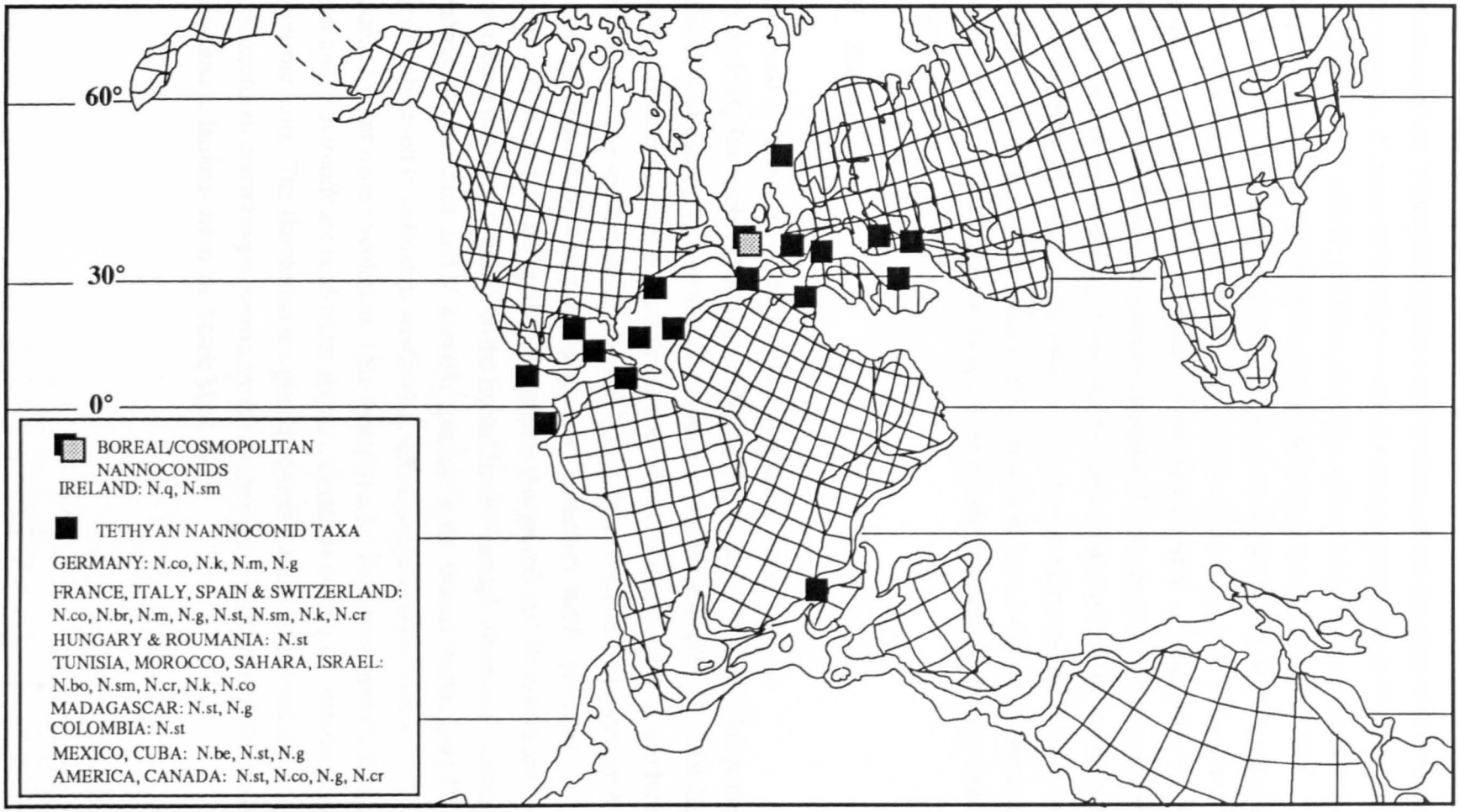


Figure 11.1c) Nannoconid species distribution map for the Valanginian (140 my).

11.1 d) Hauterivian

A continuation of the Valanginian pattern can be shown from the data, with no major speciation events. *N. minutus* became a more dominant component in Western Tethyan assemblages, together with *N. globulus globulus*, and a change from elongate and conical species to the dominance of smaller globular-type species is noted. The stimulus for this change is not fully understood. Data for the North Atlantic are scarce but authors imply the continued dominance of conical species, e.g. *N. steinmanni steinmanni*. The presence of *N. bermudezi* (very elongated *N. steinmanni*) in the North Atlantic may imply localised ideal abiotic conditions for the growth of the nannoconid individuals The true distribution patterns again cannot be interpreted due to the lack of detailed information from the Eastern Pacific. The Boreal realm appears to have been isolated during this time interval although there may have been a marine connection through the Porcupine Basin and the Shetland Basin, the assemblage contains few nannoconids.

11.1 e) Barremian

A major period of species diversification and abundance marks the Late Hauterivian/Early Barremian boundary across the globe. In the Western Tethys the nannoconids dominate the nannofossil assemblage at particular levels in the Maiolica Formation (Apenines), which suggest favourable abiotic conditions for the production of nannoconids. The species which commonly constitute these assemblages are *N. steinmanni steinmanni, N. kamptneri kamptneri, N. bucheri* and *N. globulus*. Speciation of *N. boneti, N. elongatus elongatus* is recognised and these taxa are believed to have migrated rapidly into the Boreal Realm through the marine connection. *N. circularis, N. abundans* and *N. borealis* speciate in the Boreal Realm, only *N. circularis* is observed in sediments worldwide, which suggests there were no restrictions in water mass circulation. One hypothesis for this phenomena is that *N. abundans* and *N. borealis* are cold-water species, unable to survive in Tethyan warm-water environments. The Barremian is a period of high nannoconid abundance values within nannofossil assemblages, shown by the nannoconid limestones of the Maiolica Formation and in laminae from the Munk Marl, etc.

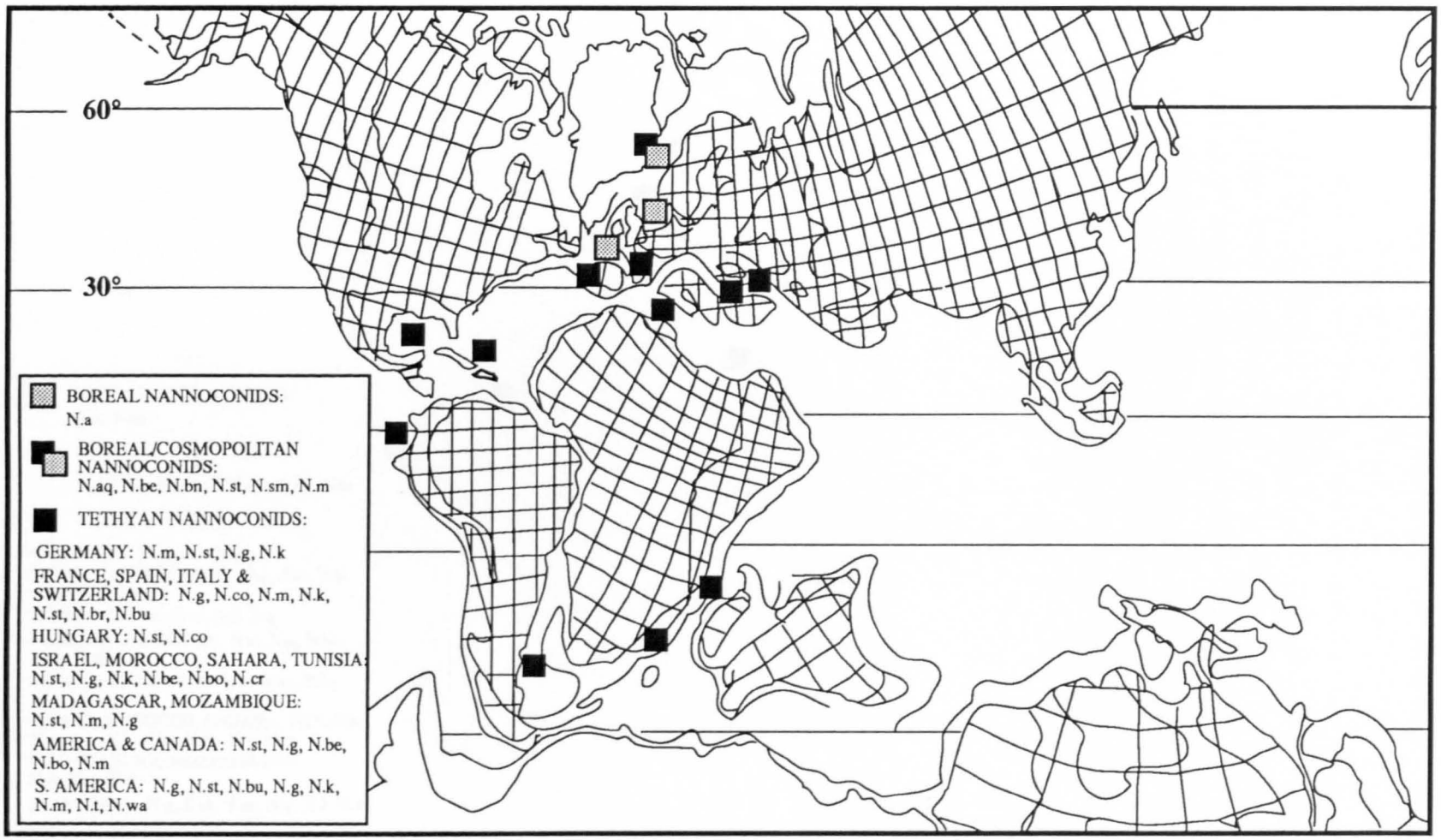


Figure 11.1d) Nannoconid species distribution map for the Hauterivian (120 my).

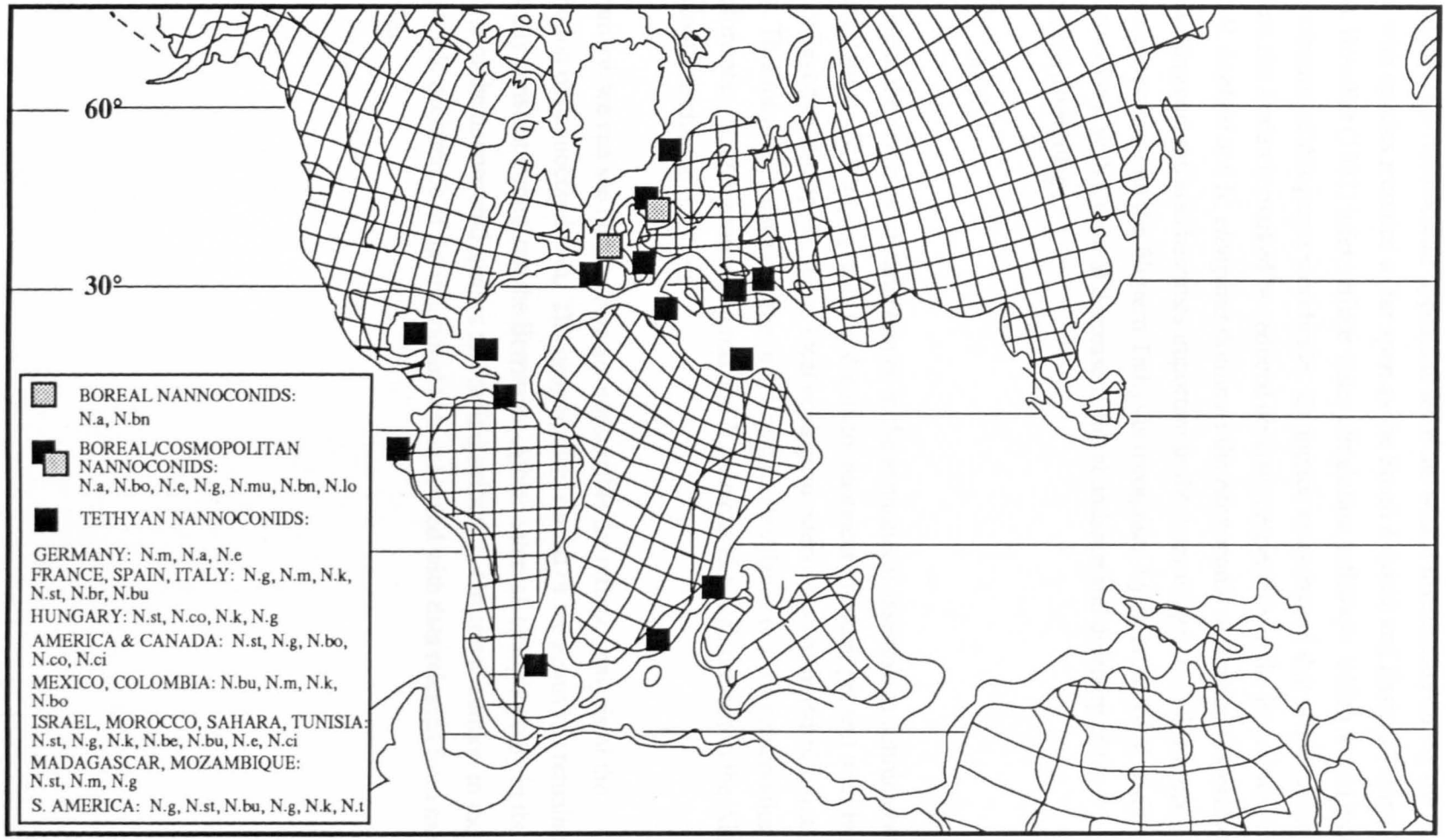


Figure 11.1e) Nannoconid species distribution map for the Barremian (120 my).

11.1 d) Aptian

On a global scale *Nannoconus* appears to have the widest distribution during the early Aptian with species recorded as far apart as the South Atlantic and Eastern Tethys. Roth & Bowdler (1981) infer surface water circulation pathways which would increase the distribution of this genus worldwide. Extinction rates exceed that of speciation and therefore the Aptian is marked by reduced diversity, especially in the Boreal Realm. *N. truitti, N. bucheri* and *N. elongatus* dominate the nannoconid assemblages worldwide, *N. quadriangulus* grp also becomes important in the assemblage. In NW Europe a marine connection with the Western Tethys is recognised by an influx of *N. truitti* group associated with a general decrease in the abundance and diversity of the nannoconid assemblage.

11.1 f) Albian

A decline in the diversity of nannoconids in the nannofossil assemblage culminated in the Late Albian. *N. truitti* grp. is the dominant nannoconid taxon, present worldwide but is believed to 'disappear' due to local ecological phenomena from Brazil (Antunes, 1987). This may represent a decline in the species abundance or poor preservation of the sediments. *N. elongatus elongatus* and *N. minutus* although present in the Albian, also show a decline in numbers.

In summary, we can see that the data are not suitable for refined analysis of the distribution of nannoconid taxa. The geographical spread of the genus has remained essentially constant throughout the Berriasian-Albian interval, changing only in the character of the nannoconid species and their distributon. Greater resolution in the stratigraphic occurrence of the individual taxa is needed with data released from more countries.

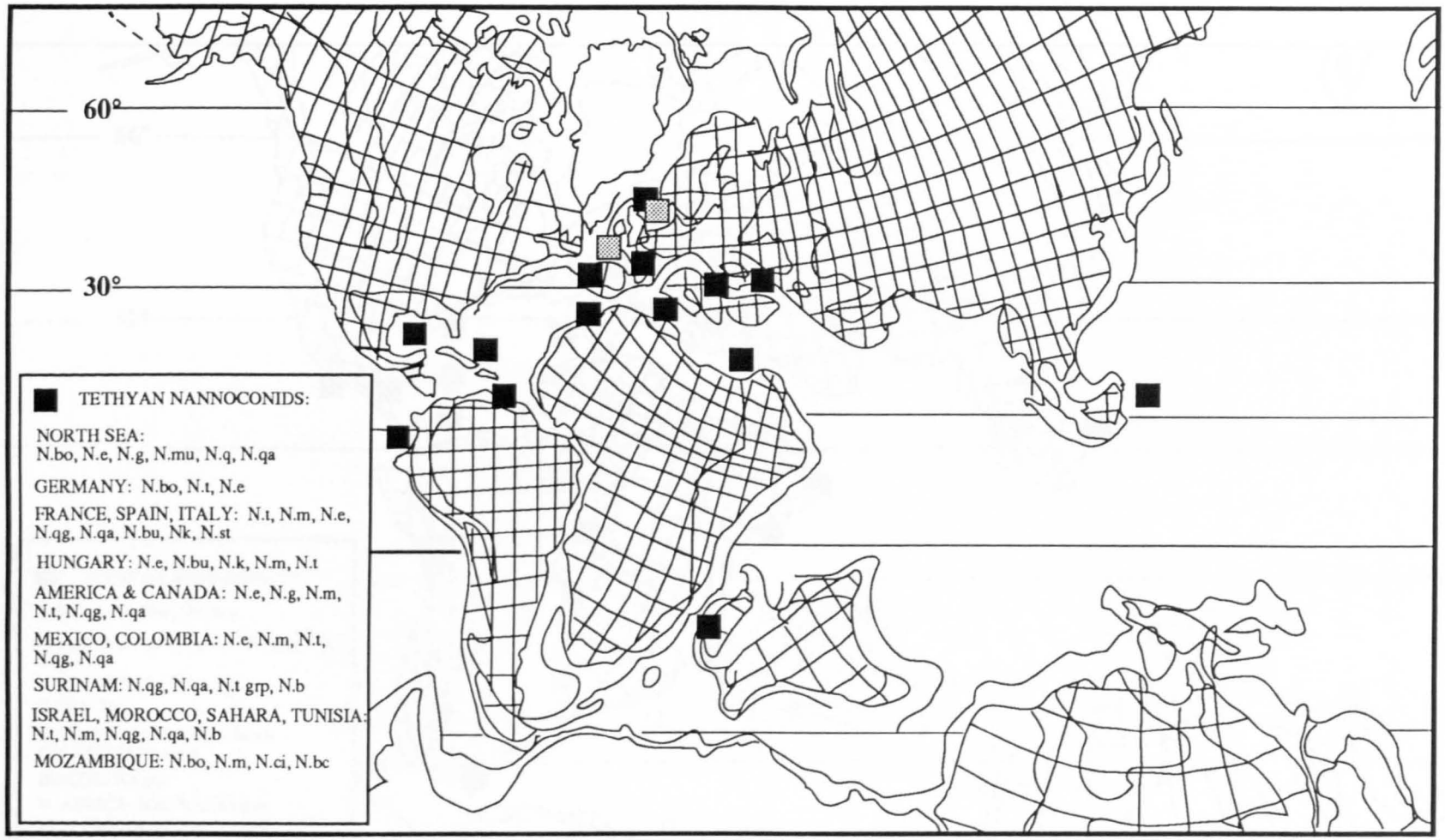


Figure 11.1f) Nannoconid species distribution map for the Aptian (120 my).

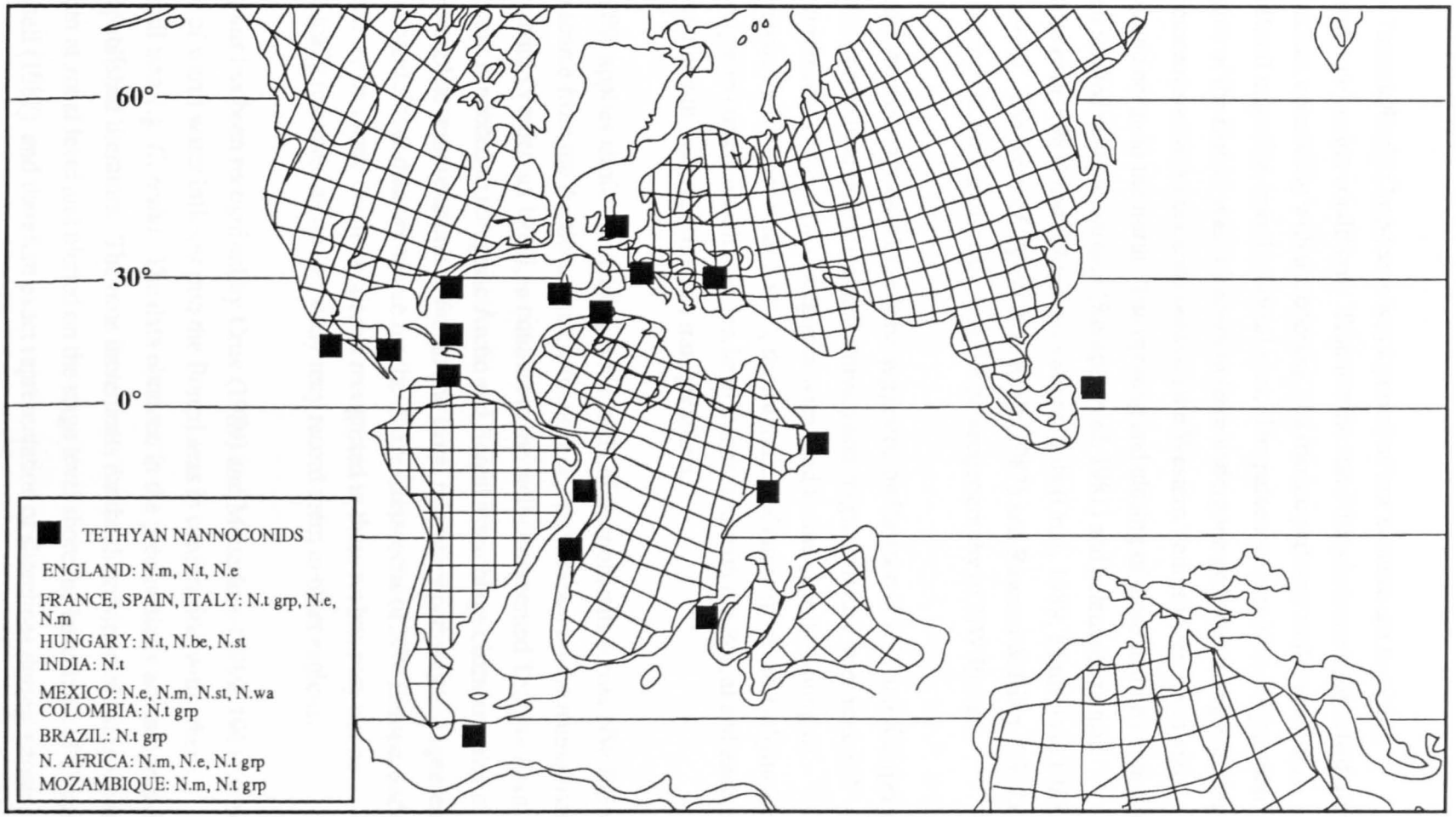


Figure 11.1g) Nannoconid species distribution map for the Albian (100 my).

11.2 Distribution Patterns of *Nannoconus* in NW Europe

The Late Jurassic/Early Cretaceous was a period of low eustatic sea level and widespread non-marine conditions. True marine conditions became established during the Ryazanian, coinciding with the opening of a marine pathway to the south and Tethyan floral migration into the Boreal seas. The palaeogeographic configuration of the margins of the Boreal seas is known to have undergone periodic changes during the Early Cretaceous with connections between the Western Tethys to the south and Boreal-Arctic ocean to the north. The opening and closing of these marine connections have been studied using ammonite (Kemper *et al.* 1981) and belemnite faunas (Mutterlose *et al.* 1983) and calcareous nannofossils (Crux, 1989, Mutterlose 1988, 1989 & 1990). The work of Tyson & Funnell (1987) and Rawson & Riley (1982) are used as a template for the discussion of the palaeogeography of NW Europe.

Three categories of migration have been suggested by Rawson (1973) and Kemper *et al* (1981) using ammonite fauna: isolated strays; mass migrations and inter-regional mass-occurrences. The last two categories were used to interpret the timing of transgressions by Kemper *et al.* (1981), the migration of fauna from the Tethyan Realm being thought to correlate with high sea level stands, and with the Boreal and endemic fauna prevailing in intervals between transgressions.

Crux (1989) applies similar principles in his study of nannofossils across NW Europe. Data are scarce from the Arctic regions, with only one publication on the nannofossils from Svalbard (Verdenius 1978), in contrast to the well-documented Tethyan flora. Further work is needed to recognise Arctic and Boreal assemblage characteristics to obtain a complete representation of faunal and floral migratory pathways. At present published nannofossil data are scarce for the Early Cretaceous of NW Europe, and we must therefore be aware that new species recognised in these realms may not be geographically restricted as further study may record them in other regions.

Nannoconus has been recognised by Crux (1989) and Mutterlose (1989, 1991) to be an indicator of warm water influxes into the Boreal seas in conjunction with other nannofossil taxa e.g. *C. rothii.* The data obtained in the present study are integrated with the published literature. The time increments for the distribution of *Nannoconus* were taken at zonal level and plotted on the stage level shoreline base maps of Tyson and Funnell (1987), and therefore exact representation of shorelines during a zone

could not be shown. The figures indicate which base map was used to represent the zone and the symbols used on the maps are outlined below:

- ● Zone present, *Nannoconus* present
- ▲ Zone present, *Nannoconus* absent
- ? Reliability of data uncertain

A brief synthesis of the palaeogeographic setting during the stage interval is given prior to discussion of the zonal distribution. The figures are numbered in a corresponding manner to the zone they represent, zone name abbreviations are referred to Chapter 9.

Ryazanian

The earliest Cretaceous deposits to blanket NW Europe were laid down during a minor transgressive phase which is represented by the basal Speeton Clay Formation in Yorkshire and the uppermost Kimmeridge Clay Formation in the North Sea. The time-transgressive nature of this regional transgression can be clearly shown by the occurrence of similar facies in Skinnabanken dated as latest Ryazanian-Valanginian (Thomsen 1987). The facies is characterised by fluvio-lacustrine limestone and shale deposits of the Valhall Formation.

The Kimmeridge Clay/Valhall Formation boundary is characterised by an increase in number and diversity of benthonic foraminifera and dinoflagellate cysts at the boundary, associated with a facies change from dark organic-rich shales to carbonate-rich facies (Lott *et al.* 1989). These authors also suggest that foraminiferal assemblages indicate a restricted environment in the Central North Sea during the deposition of the boundary bed (base of Valhall formation). An increase in the faunal and floral content of the Valhall Formation is correlated with a flushing out by oxygenated waters from outside the Central North Sea (Rawson & Riley 1982, Riley & Tyson 1981). The Polish Trough yields a Tethyan ammonite fauna indicating a southern link was present (Sokolowski *et al.* 1976).

Crux (1989) records the earliest nannofossil data from Beds D7D-D6A at Speeton and Core 7B from Skinnabanken with the oldest diverse assemblage present in Bed D7D (Taylor 1978). Crux (1989) compares this data to that of Thierstein (1973) to conclude similar diversity patterns but different assemblage components. Crux (1989) notes the

absence of *N. steinmanni* from the Speeton section and scarcity of Tethyan species *N. bronnimanni* and *N. truitti*. The later species is thought to be misidentified, the evolutionary appearance of this taxon not being until the upper Barremian.

A strong Boreal influence in the nannofossil assemblage is suggested by Crux (1989) due to the abundant *C. salebrosum*, and presence of *S. arcuatus* and *P. fletcheri* associated with the absence of Tethyan taxa. The high abundance levels of *C. margerelii* and *D. lehmanni* are interpreted by Crux (1989) as reflecting a period of transgression. In NW Germany, Mutterlose (1988, 1991) remarks on the appearance of calcareous nannofloras in the latest Ryazanian in Sachsenhagen, at the edge of the Boreal sea. The assemblage is interpreted as Boreal in character with no evidence of a prolonged marine ingression from the Tethys.

11.2 a) *Nannoconus* sp. (discs) Zone (NLKA 27)

The presence of *Nannoconus* sp. (discs) in the Speeton section is interpreted by Crux (1989) as reflecting a migratory pathway from the west of Britain through the Porcupine Basin, offshore Ireland (not shown on the shoreline base maps of Tyson & Funnell 1987). He also suggests only a weak Tethyan influence in the assemblages. Sporadic occurrences of Tethyan *N. globulus, N. bucheri* and endemic Boreal *N. sabinae* are recorded in sections from the Viking Graben, 202/8-1 and the Central Graben with a few specimens of *N. steinmanni* and *N. kamptneri*; abundance is low in these assemblages. The zonal marker was only recognised from the Viking Graben and Speeton (Crux, 1989) which may support the idea of a weak Tethyan migration from the West. No nannoconids are recorded from NW Germany because of non-marine conditions.

The similarities of these large discs to the proximal flange of *N. abundans* is recognised here. Disaggregated flanges and these discs are both low in birefringence, with a very restricted central apertural opening, and the individual plates cannot be seen in the light microscope. These characteristics are used here to assign these taxa to Morphogroup 1. The discs used to date this zone are unlike the Barremian assemblages in which the disaggregated flanges are associated with top views of the central barrel (*N. abundans*). Partial-calcification, due to external environmental stresses in a new environment may be responsible for these morphological features.

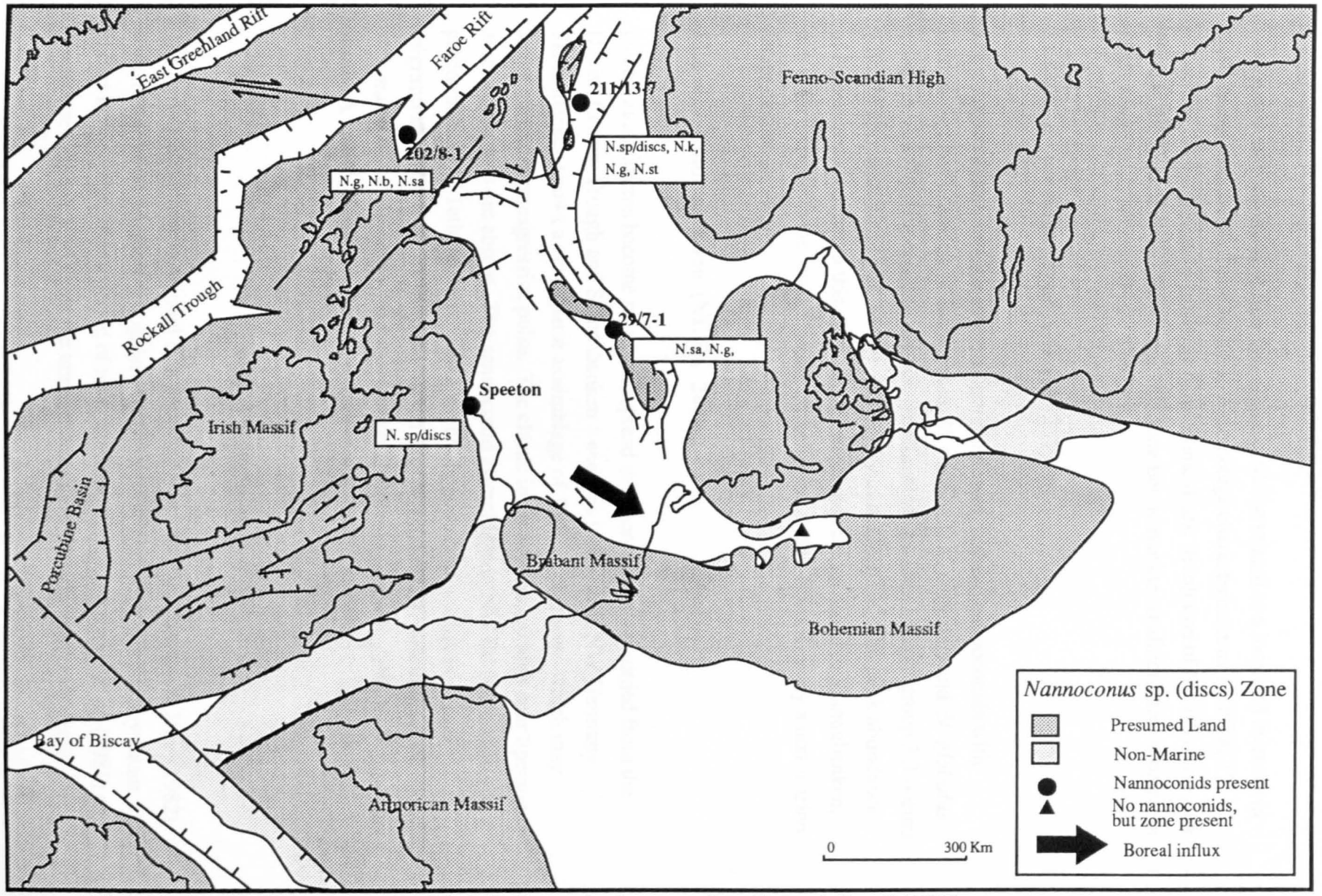


Figure 11.2 a) Distribution of Nannoconus in NLKA 27. Ryazanian base map from Tyson & Funell (1987).

11.2 b) *P. fletcheri* Zone (NLKA 26)

No nannoconids recorded at Speeton, which could be related to a localised increase in clastic input into the surrounding area. Assemblage characteristics as for NLK 27 except for the extinction of the large nannoconid discs. Evolution of *N. concavus* took place in the Central North Sea during this zone but no marine conditions are recorded in NW Germany .

11.2 c) *S. arcuatus* Zone (NLKA 25)

The nannoconid assemblage shows a continuation of Tethyan nannoconids with increasing diversification of Boreal taxa: *N. concavus, N. oviformis* and *N. globulus* subsp. A. Increased speciation of endemic Boreal taxa within Morphogroup 3.3 occurs with the appearance of *N. oviformis* and *N. globulus* subsp. A. The peak abundance of *N. concavus* occurs in this zone. No nannoconids are recorded in Skinnabanken, due to an increase in the clastic nature of the facies, and in NW Germany a non-marine facies occurs.

11.2 d) Unamed Zone (NLKA 24)

Distribution patterns become more widespread with nannoconids recorded from the Danish Central Trough and Skinnabanken and as far south as NW Germany. Skinnabanken shows a very sparse assemblage of Tethyan character, which may suggest a minor transgressive pulse. The clastic input appears too high near Speeton and nannoconids are absent. The nannoconid assemblage in NW Europe consists of predominantly of Tethyan derived taxa which suggests continuation of a minor migrational phase inferred from the presence of *N. minutus, N. dolomiticus, N. steinmanni minor* coupled with the continuing evolution of Boreal species *N. sabinae, N. globulus* subsp. A and *N* cf. *oviformis*.

Early Valanginian

The Early Valanginian is marked by a period of transgression (Rawson & Riley 1982) with marine sedimentation recognised by Crux (1989) in the Lower Saxony Basin and in Bed D5 Speeton, after a period of non-marine conditions. Kemper *et al.* (1981) and Mutterlose (1988 & 1991) note the immigration of the Tethyan ammonite genus

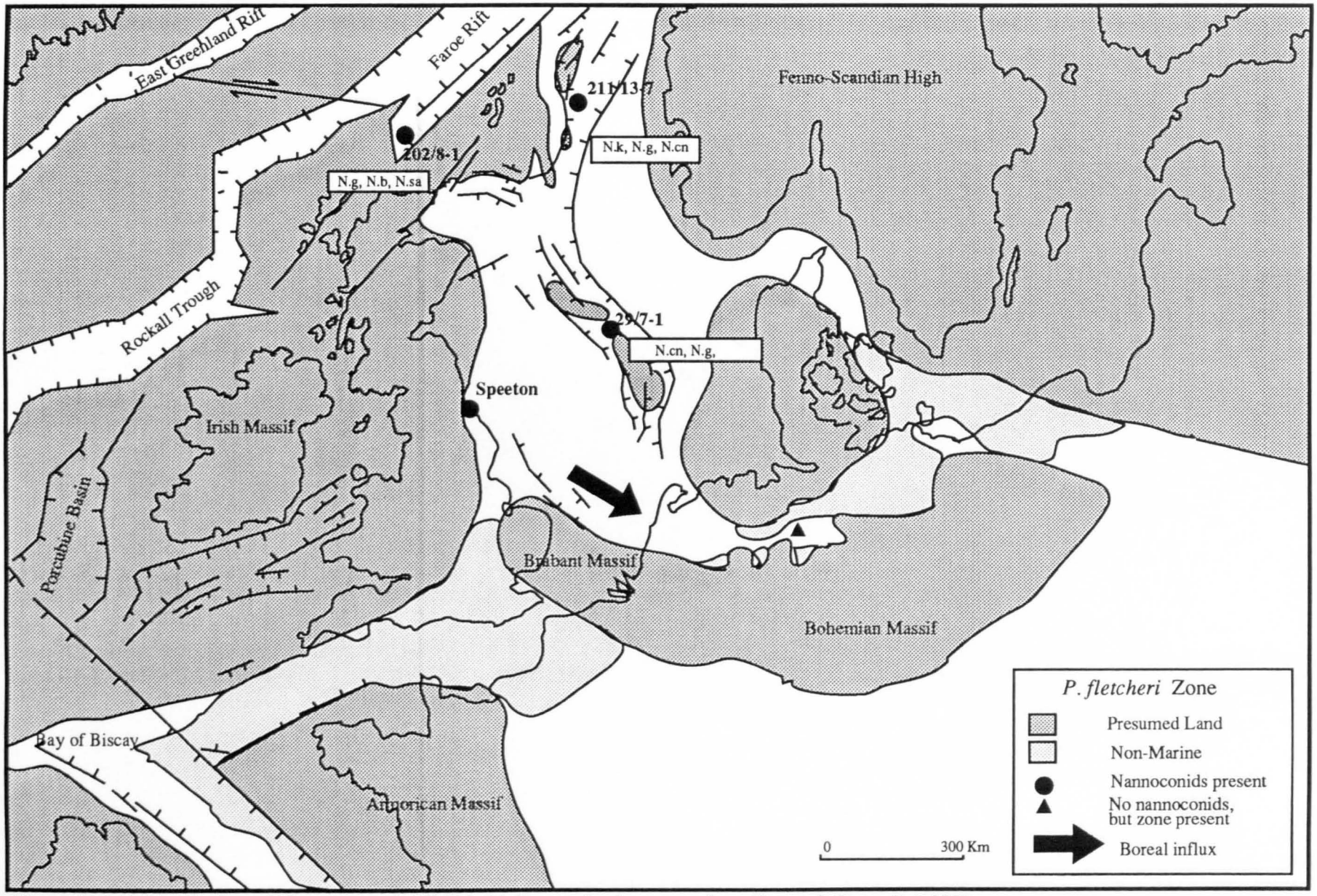


Figure 11.2 b) Distribution of Nannoconus in NLKA 26. Ryazanian base map from Tyson & Funnell (1987).

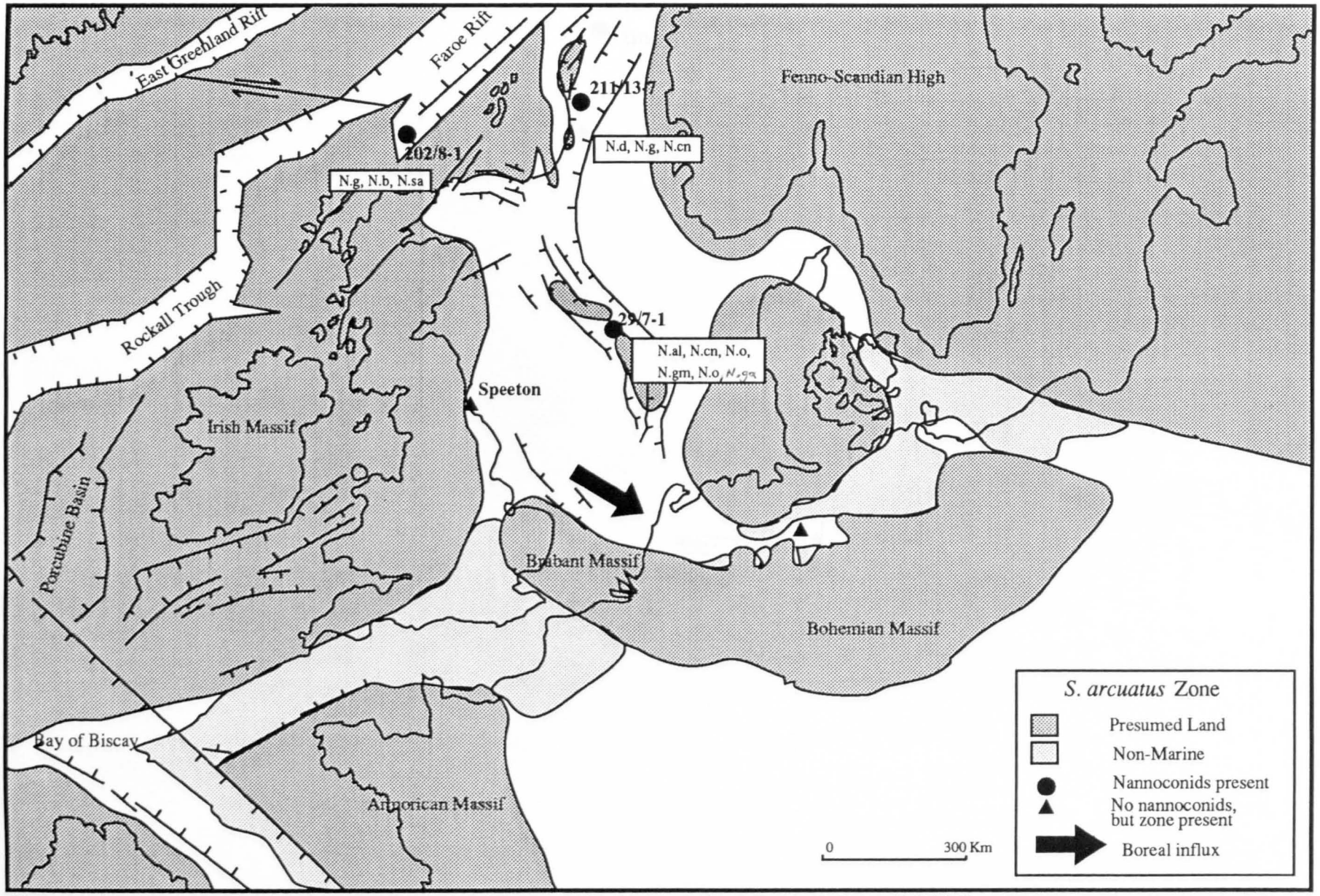


Figure 11.2 c) Distribution of Nannoconus in NLKA 25. Ryazanian base map from Tyson & Funnell (1987).

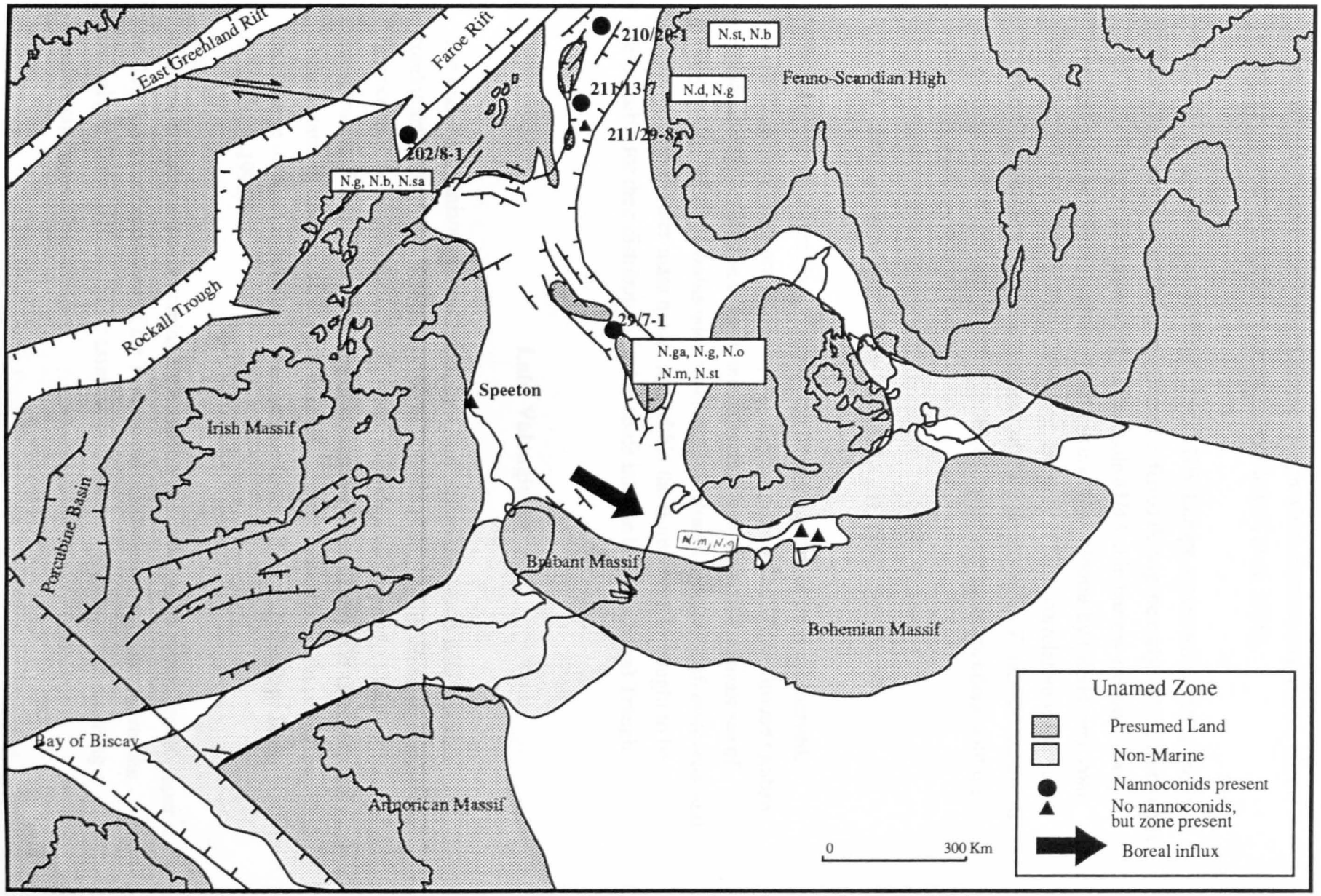


Figure 11.2 d) Distribution of Nannoconus in NLKA 24. Ryazanian base map from Tyson & Funnell (1987).

Platylenticeras, which is recorded from the Lower Saxony Basin and Speeton, through a marine connection in the Polish Central Trough which became established, after a temporary period of brackish conditions (Sokolowski *et al.* 1976).

Very sparse nannofossil assemblages across NW Europe are recorded during this time interval with only a weak Tethyan influence inferred during the early Valanginian (Crux 1989). At Speeton and in an offshore borehole 81/43, thin burrow-mottled, marly limestones are recognised and interpreted as coccolith blooms by (Medd *pers. com.* 1983: in Lott *et al.* 1986). These, however, are only of local correlative value in the Speeton Clay Formation. The appearance of the Boreal species *T. septentrionalis, M. speetonensis* and *Kokia* spp. is also indicative of poor marine connections with the Tethys (Mutterlose 1988 & 1991).

11.2 e) *M. speetonensis* Zone (NLKA 23)

No change in the assemblage composition from the previous zone is observed, however, nannoconids are recognised for the first time in the Witch Ground Graben. ~~Higher diversity is present in the Danish Central Graben with the appearance of Tethyan-derived *N. globulus minor* and endemic Boreal species *N.* cf. *oviformis* and *N.* sp. 1.~~ Minor water-mass movement within the Boreal seas is thought to be responsible for their distribution further south into the Danish Central Trough.

Late Valanginian

The mid-Valanginian is characterised by a short regressive phase with brackish conditions in the Polish Trough (Tyson & Funnell 1987). Nannofossil-rich sediments first occur in the Upper Valanginian, which marks the initiation of a major regional transgressive phase. Crux (1989) records these sediments from NW Germany and notes a hiatus at Speeton during this interval. In the Norwegian Basin and Moray Firth this change in facies is associated with benthic foraminifera and dinoflagellates (Mutterlose 1991).

Endemic ammonite faunas dominate the assemblage in the mid-Valanginian (Kemper *et al.* 1981) and the breakdown of the Tethyan palaeotemperature gradient gives the Boreal and Tethyan flora similar assemblages, although with each still retaining a distinct character (Crux 1989).

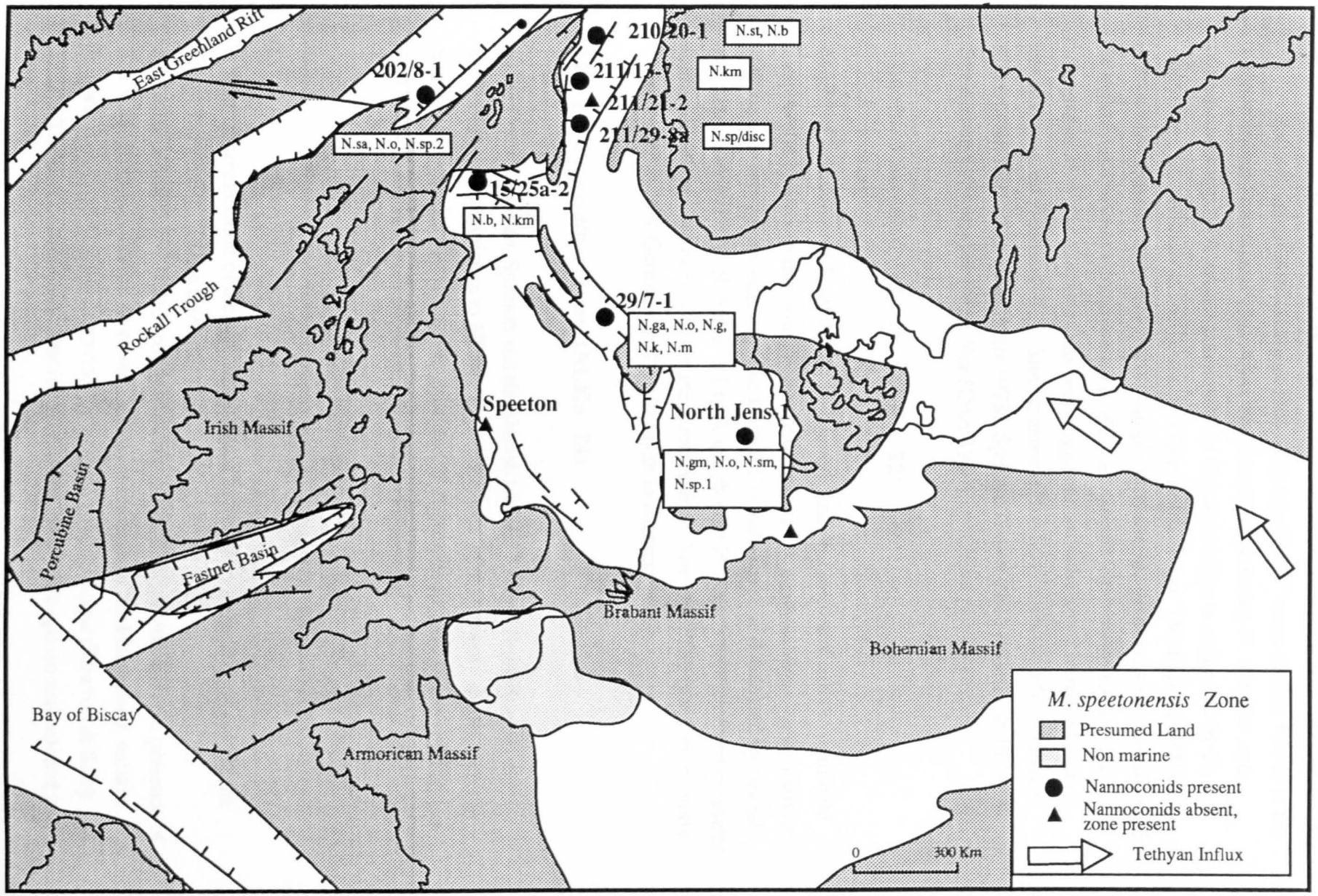


Figure 11.2 e) Distribution of Nannoconus in NLKA 23. Valanginian base map from Tyson & Funnell (1987).

Mutterlose (1988 & 1991) records an increased abundance of *Nannoconus* spp. in the Valanginian of NW Germany indicating a period of warm surface waters in the Dichotomiten-Schichten. This influx consists of *N. globulus, N. minutus* and *Nannoconus* spp. A Tethyan component in the assemblage is suggested by *C. oblongata, C. cuvillieri, S. colligata* and Conusphaera spp. (Mutterlose 1991). *C. salebrosum* remains endemic to NW Europe. *W. barnesae* dominates the assemblage in NW Germany, with a high abundance of *C. margerelii* (Mutterlose 1991). The high abundance of the latter species has been suggested as indicating a restricted basinal environment by Keupp (1978). Similar associations have been recorded from the Norwegian North Sea (Verdenius 1978), Speeton (Perch-Nielsen 1979 & 1978), Speeton and Norwegian North Sea (Crux 1989).

11.2 f) Unstudied Interval (NLKA 22)

Migrated Tethyan taxa *N. globulus, N. bucheri* and *N. kamptneri* are the dominant nannoconid species in this zone. One new taxon, *N. paskentaensis* recognised in NW Europe during this interval. The Danish Central Trough is dominated by Boreal species, *N.* sp 1 and *N. globulus* subsp A which may indicate a restricted environment within the basin. No nannoconids are recorded from Speeton. The first nannoconids are recorded in NW Germany and are Tethyan in character.

11.2 g) *T. striatum* Zone (NLKA 21)

In the Central Graben, Speeton and the Danish Central Trough similarities in the assemblage characteristics to NLKA 22 can be seen. NW Germany shows increasing number of localities that record the presence of *Nannoconus* with species of Tethyan character, *N. globulus, N. kamptneri* and *N. minutus.*

Early Hauterivian

A general continuation of the trend established in the late Valanginian is seen in the Early Hauterivian. In the Lower Saxony Basin sedimentation expanded to the southeast (Kemper 1973) and sedimentation continued at Speeton with the presence of late Valanginian re-worked ammonite faunas at the base of the Hauterivian section. Important early and mid-Hauterivian transgressive pulses occur (Rawson & Riley 1982). The first transgression was initiated in the latest Valanginian and reached its

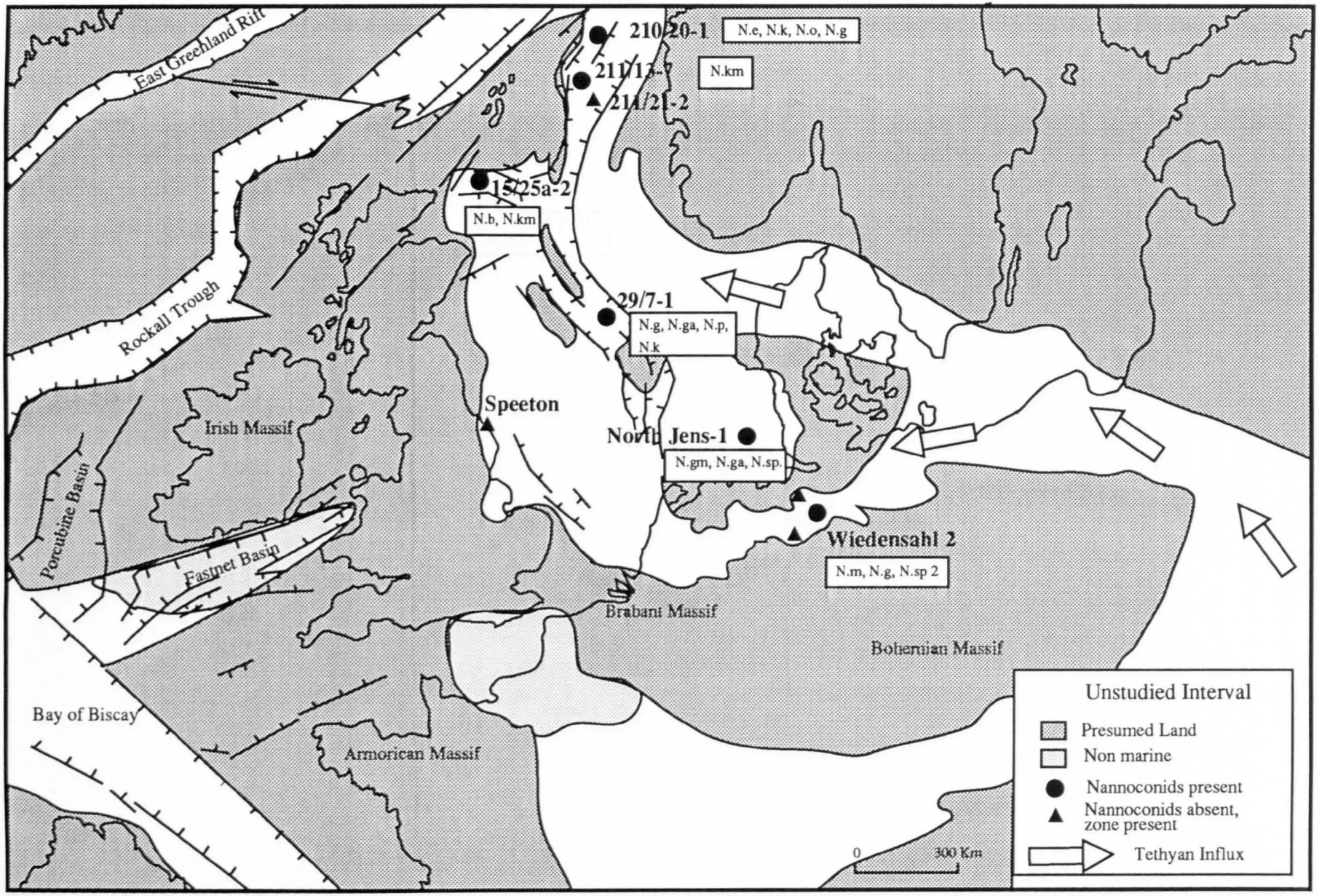


Figure 11.2 f) Distribution of Nannoconus in NLKA 22. Valanginian base map from Tyson & Funnell (1987).

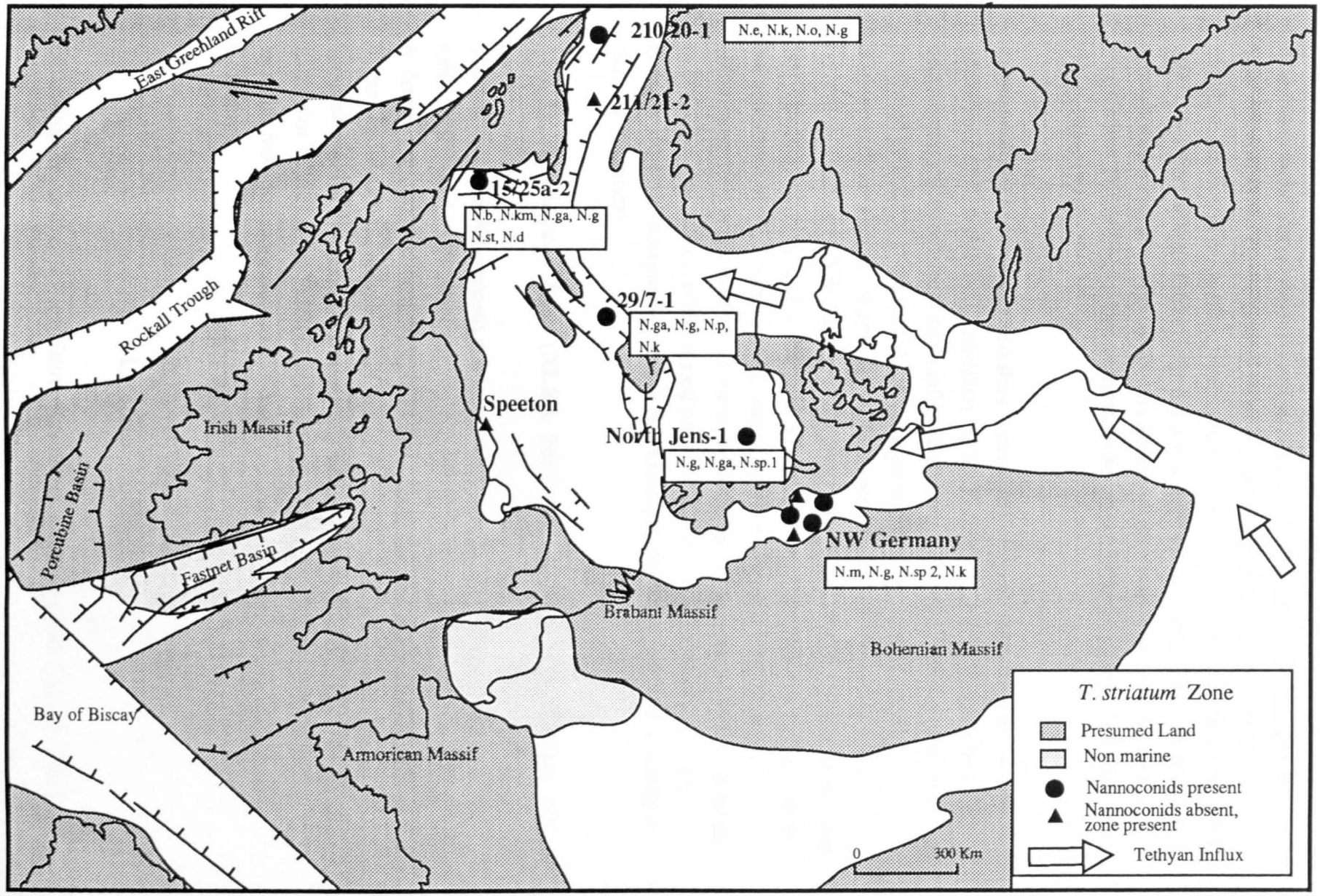


Figure 11.2 g) Distribution of Nannoconus in NLKA 21. Valanginian base map from Tyson & Funnell (1987).

peak in the early Hauterivian *amblygonium* Zone. Tethyan ammonite assemblages are recognised in the Boreal Realm (Kemper, Rawson & Thieuloy 1981, Kemper & Wiedenroth 1987). The belemnite genus *Hibolites* migrated from the Tethys to dominate the Boreal assemblage, replacing *Acroteuthis* in importance (Mutterlose 1988, 1991). Michael & Pape (1971) infer a warm water benthic fauna of bryozoa and crinoids in the east of the Lower Saxony Basin and the presence of the stenothermal foraminifera *Trocholina* indicates migration from the Mediterranean into NW Europe (Mutterlose 1991).

The nannofossil assemblages also show a markedly Tethyan character with the first appearance of *C. rothii* and *C. cuvillieri* in NW Europe (Crux 1989); these first occurrences are associated with an influx of *R. asper.* Thierstein (1971) notes this increased abundance at the Early/Late Valanginian boundary in the Tethys. Nannoconids are also an integral part of the assemblage in NW Europe and in the *amblygonium* Zone of NW Germany (Mutterlose 1988, 1991) with a second influx into NW Germany consisting of *N. bucheri, N. globulus* and *N. kamptneri.* A decrease in the abundance of *W. barnesae* and *C. margerelii* is recorded in NW Germany (Mutterlose 1991). *C. cuvillieri, H. circumradiatus* and *D. lehmannii* are first recorded in NW Germany, margin of the Boreal sea. A small increase in abundance of the endemic Boreal *E. antiquus* is noted in NW Germany, indicating a period of endemic floral development.

11.2 h) *E. antiquus* Zone (NLKA 20)/*C. silvaradion* Zone (NLKA 19)

The first record of *Nannoconus* at Speeton since the Late Ryazanian is mentioned by Crux (1989). In the Central North Sea Tethyan taxa *N. globulus, N. paskentaensis* and *N. kamptneri* dominate the nannoconid assemblage. This Tethyan influx is also present in the Danish Central trough with *N. wassalli, N. globulus, N. steinmanni* and *N. kamptneri* with a few endemic Boreal species *N.* sp 2 and *N.* cf *oviformis* are present. Expansion of the Lower Saxony Basin is recognised by the increase in number of localities from which nannoconids of Tethyan character have been recorded in NW Germany.

Late Hauterivian

Following the peak of the Late Hauterivian transgression Tyson & Funnell (1987)

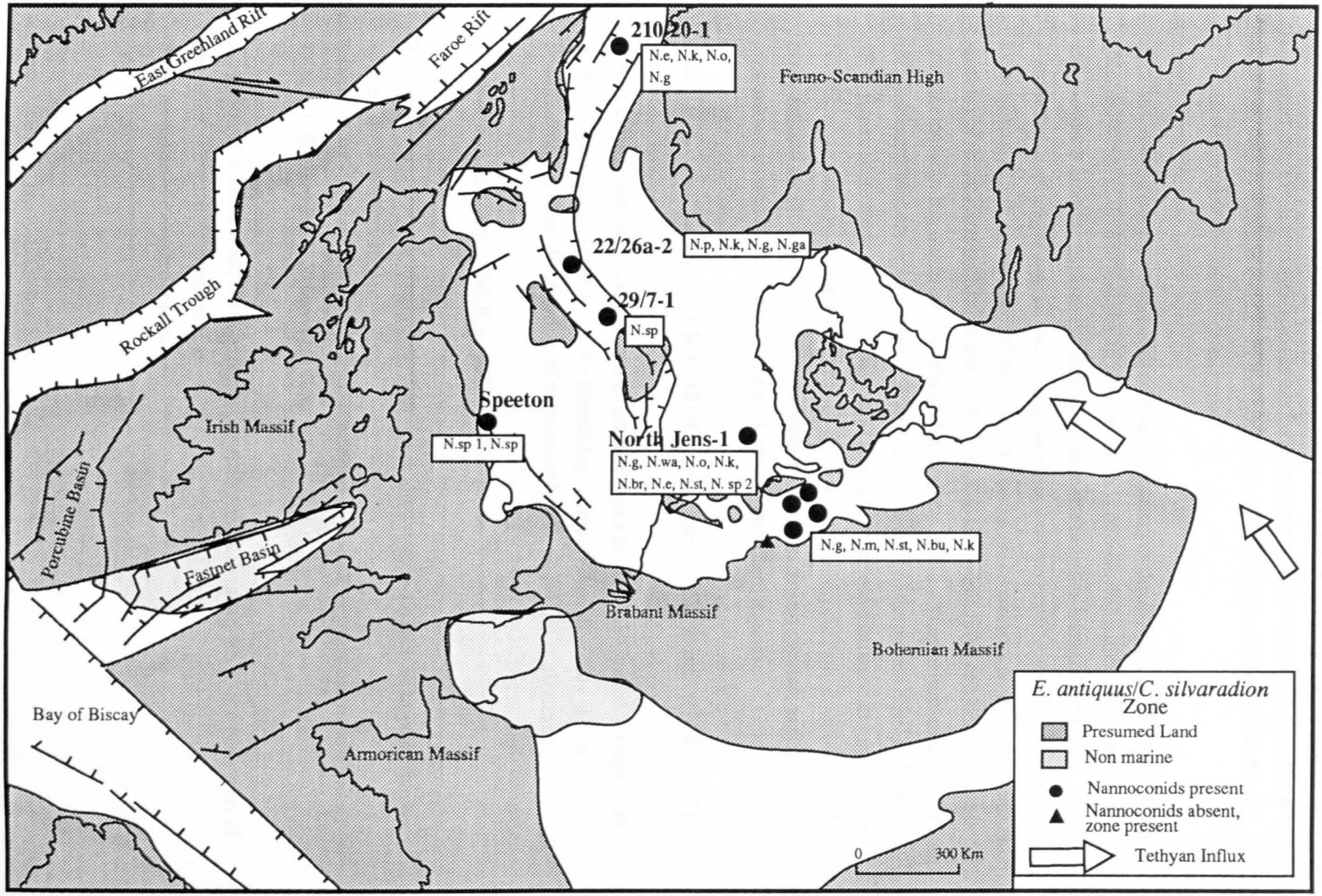


Figure 11.2 h) Distribution of Nannoconus in NLKA 20 & 19. Hauterivian base map from Tyson & Funnell (1987).

suggest that there was a period of regression, at its maximum in the *Aegriocrioceras*-Schichten in NW Germany. The Polish Trough became shallower and the southern link with the Tethys was restricted. In the *staffi* Zone of NW Germany and in the Moray Firth a small transgression is recognised.

The belemnite, *Hibolites* shows differential speciation in the Boreal and Tethyan realms (Mutterlose *et al.* 1983) and the ammonite fauna is of a Boreal nature (Kemper *et al.* 1981) which further suggests the lack of marine connections with the Tethys. Nannoconids, *R. asper* and *C. margerelii* increase in abundance in the *discofalcatus* Zone (Crux 1989). A second influx of nannoconids *N. circularis, N. globulus* and *N. minutus* is recognised by Mutterlose (1991) in NW Germany. This can be correlated with the peak in the transgressive phase (Mutterlose 1991). Other nannofossils in the influx assemblage are *Micrantholithus* spp. and *C. rothii* (Mutterlose 1991). In his 1987 paper Mutterlose discusses this floral change at the mid-Hauterivian boundary in NW Germany and relates this to a change from warm to cold climatic conditions. This is recognised by the appearance and disappearance of coccolith species, and the presence of Boreal and disappearance of Tethyan ammonite species.

11.2 j) *C. margerelii* (NLKA 18)/*T. septentrionalis* Zone (NLKA 17)

A greater diversity of nannoconids are recorded from the Danish Central Trough with *N. boneti* becoming common in the assemblage. In contrast, diversity is low in Speeton but a greater distribution of nannoconids NW Germany is observed.

C. inaequalis Zone (NLKA 16)

This zone was not recognised in the material studied due to the lack of reliable marker species for this interval.

11.2 k) *S. comptus* Zone (NLKA 15)

An influx of nannoconids is recorded at Speeton and Skinnabanken in the early part of this zone. Diversity continues to increase in the Danish Central Trough with a predominance of elongate forms.

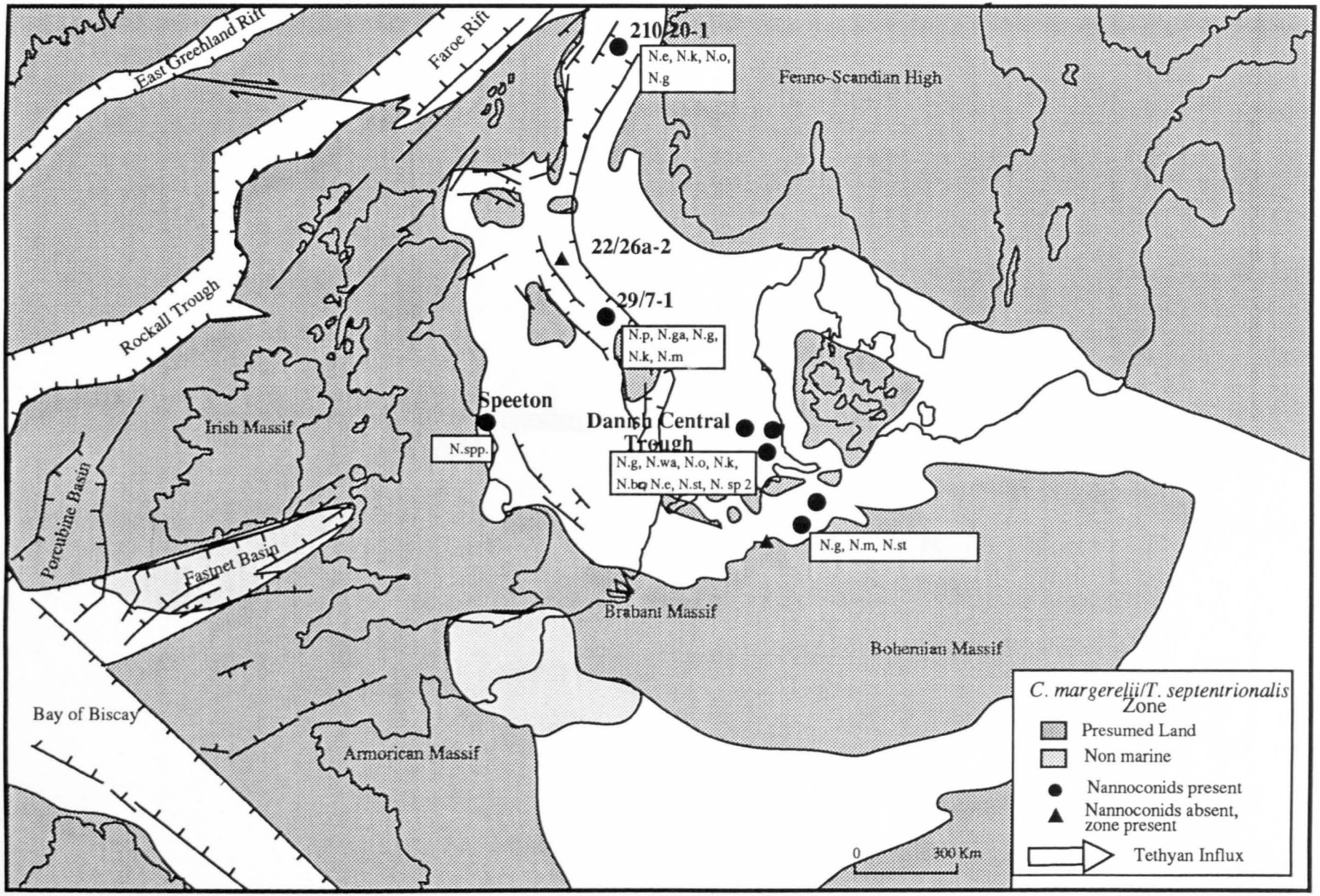


Figure 11.2 j) Distribution of Nannoconus in NLKA 18 & 17. Hauterivian base map from Tyson & Funnell (1987).

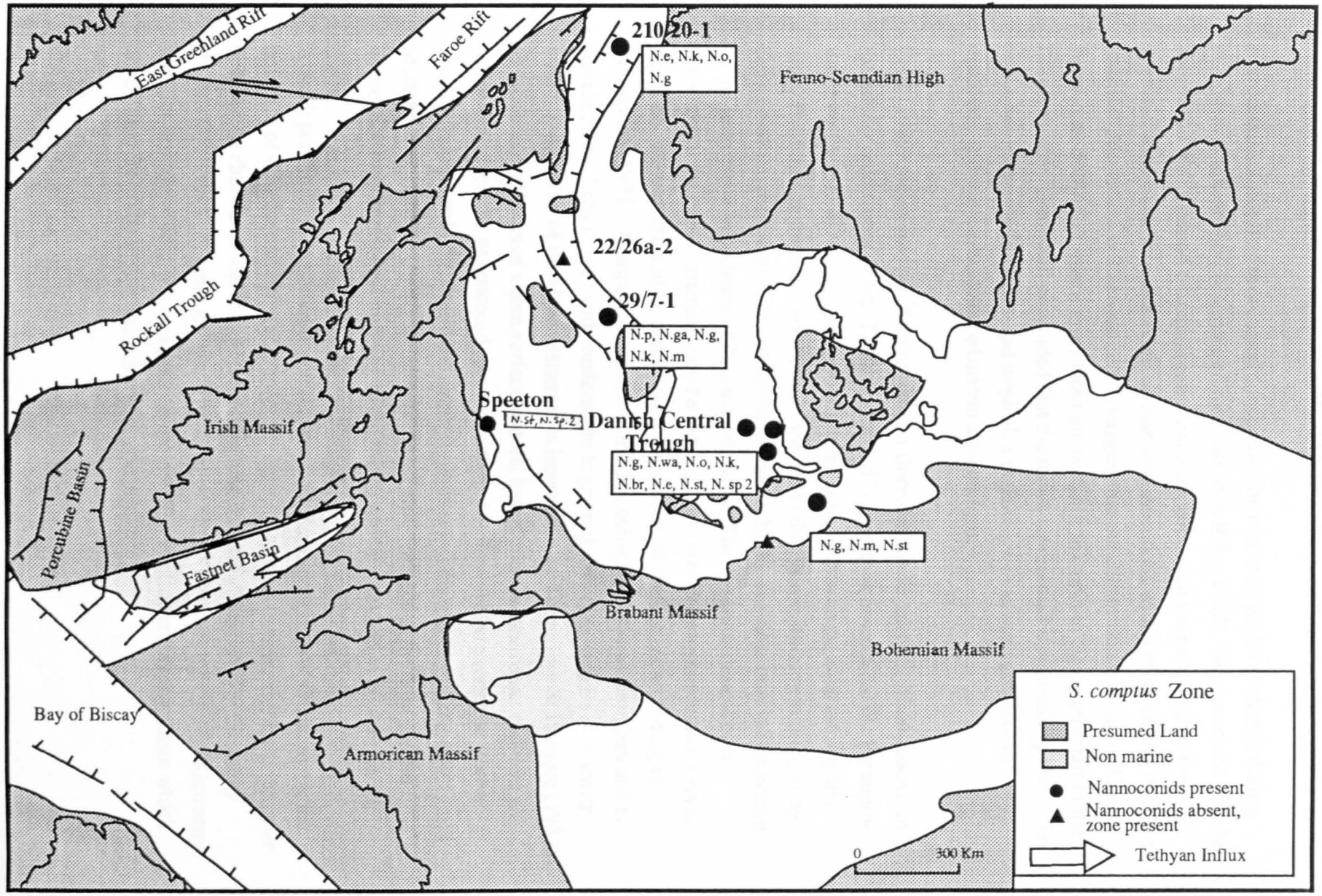


Figure 11.2 k) Distribution of Nannoconus in NLKA 15. Hauterivian base map from Tyson & Funnell (1987).

Barremian

A great deal of debate has occurred concerning the nature of sea level change during this interval (excellently summarised by Rawson & Riley 1982). They conclude that the Barremian was a period of major regression associated with minor transgressive intervals, the Polish Trough having no marine connections with Tethys during this time interval. Mutterlose & Harding (1987) suggest that the Blätterton facies in the Early Barremian occurred furthest away from the northern seaways in the eastern part of the Lower Saxony Basin and concluded that the facies represented a regressive pulse. The climate is interpreted as warm and tropical, a conclusion in accordance with the dinocysts and calcareous nannoplankton assemblages.

Crux (1989) recognises the dominance of a Boreal endemic species, *N. abundans*, in the nannoconid assemblages. The absence of this species is noted from the Porcupine Basin by Crux (1989), suggesting poor marine connections to the west during this time. A decline in the abundance of this species in the Hauptblätterton is thought by Crux (1989) to reflect an influx of northern waters during this time interval, indicated by the increase in abundance of *T. septentrionalis*. The re-establishment of *N. abundans* in the Late Barremian may be indicative of restricted marine connections to the north. *N. wassalli* and *C. oblongata* are restricted to the Tethys according to Mutterlose (1991). *R. asper* is also recognised as being common to abundant and is correlated by Erba (1987) with moderate to high productivity in periods of warmer water. Deposition of the Hauptblätterton is interpreted by Mutterlose & Harding (1987) as reflecting influxes of warm surface waters, based upon *Nannoconus* spp. and *C. rothii*. However, the nannoconid species dominant at this level are endemic Boreal species which would contradict the above hypothesis. This model of Erba (1987) and Mutterlose & Harding (1987) is unlikely on present evidence is the only marine connections are interpreted as being to the north, which would be to cooler waters.

A weak period of immigration is noted in the Late Barremian of NW Germany by the presence of eurythermal belemnite species. Tethyan species *C. margerelii* and *R. asper* decrease in abundance and Boreal flora dominate the assemblage in NW Germany (Mutterlose 1991). *T. septentrionalis* is noted by Crux (1989) as rare in NW Germany. Distinct periods of cold water ingression are noted in the Lower Saxony Basin which are evident from changes in the floral assemblages.

11.2 l) *C. inaequalis* Zone (NLKA 14)

Assemblage characteristics similar to NLKA 15 & 16.

11.2 m) *C. conicus* Zone (NLKA 13)

The endemic Boreal taxon *N. abundans* attains high abundance between zones NLKA 14-NLK 10. The first nannoconids recorded from L/2-2 are dominated by this taxon, with some Tethyan-derived taxa present. In the Danish Central Trough assemblage an elongate morphotype of *N. abundans* is recognised in the laminated facies. Rare monospecific laminae of this taxon have been found. These are discussed in greater detail in chapter 10.2. Blooms of elongate species have not yet been recognised, however faecal pellets containing high abundance values of *N. bucheri* have been found. *N. elongatus minutus* is first recognised in the Danish Central Trough associated with particularly high concentrations of Tethyan taxa.

11.2 n) *Z. sisyphus* Zone (NLKA 12)

N. elongatus minutus first recognised in 22/26a-2, a late record which may suggest non-recognition of the species in the sediment or that it may have taken some time to become established. *N. abundans* with two flanges becomes recognisable in the Central North Sea and Witch Ground Graben. The nannoconid taxa obtain very high abundances in the total nannofossil assemblage. A continuation of the assemblage characteristics established in NLKA 14 can be seen.

11.2 o) *V. matalosa* Zone (NLKA 11)/*N. abundans* Zone (NLK 10)

N. abundans dominates the assemblage with other endemic Boreal species *N. oviformis, N. elongatus minutus, N. globulus* subsp. A present in the assemblage. The first occurrence of the Tethyan taxon, *N. truitti* is recorded from the Danish Central Trough. Only a solitary nannoconid taxon, *N. abundans* is observed in NW Germany.

Aptian

The Aptian-Albian interval is marked by a series of transgressions, with intervals of shallowing and regression between these pulses (Rawson & Riley 1982). In the early

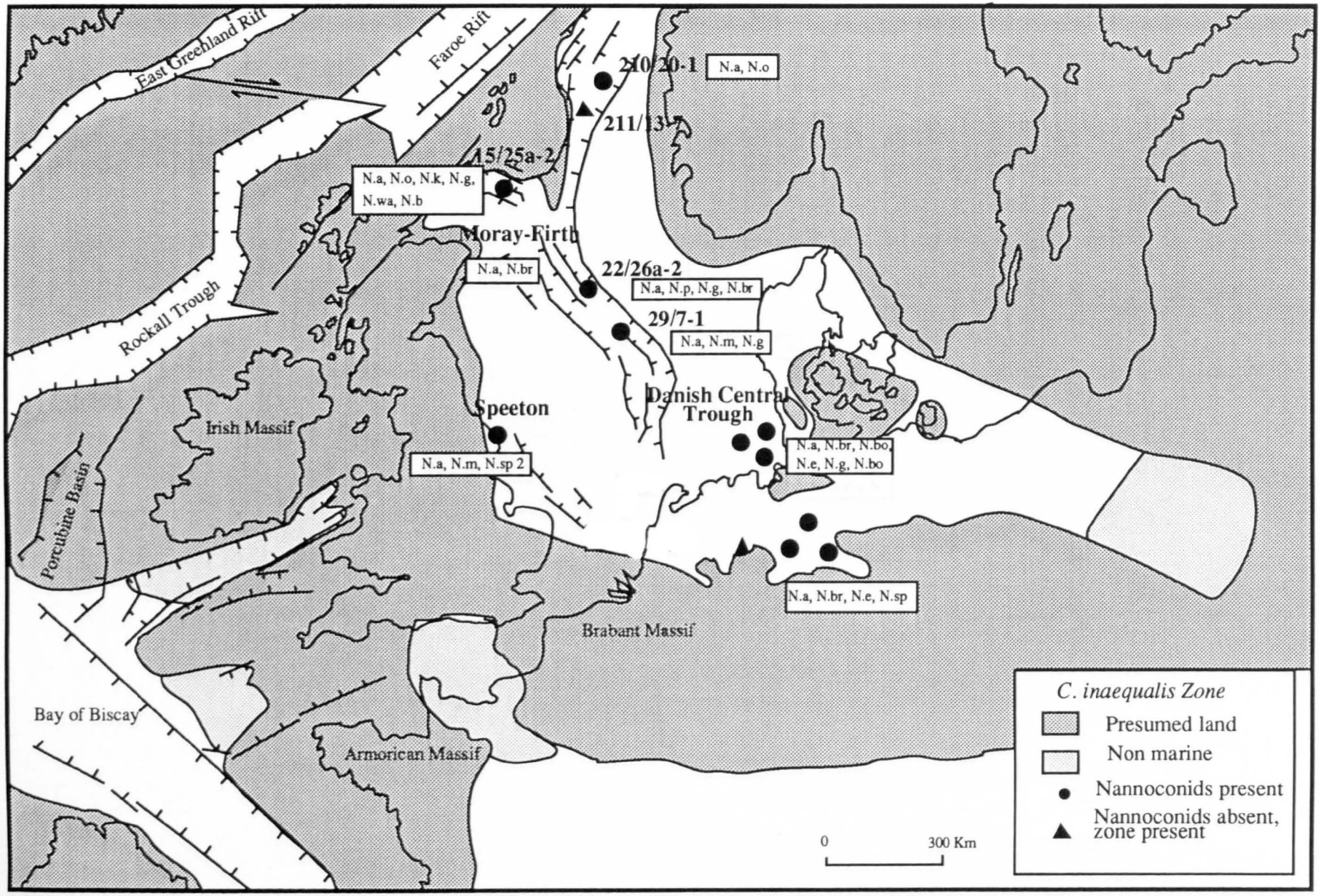


Figure 11.2 l) Distribution of Nannoconus in NLKA 14. Barremian base map from Tyson & Funnell (1987).

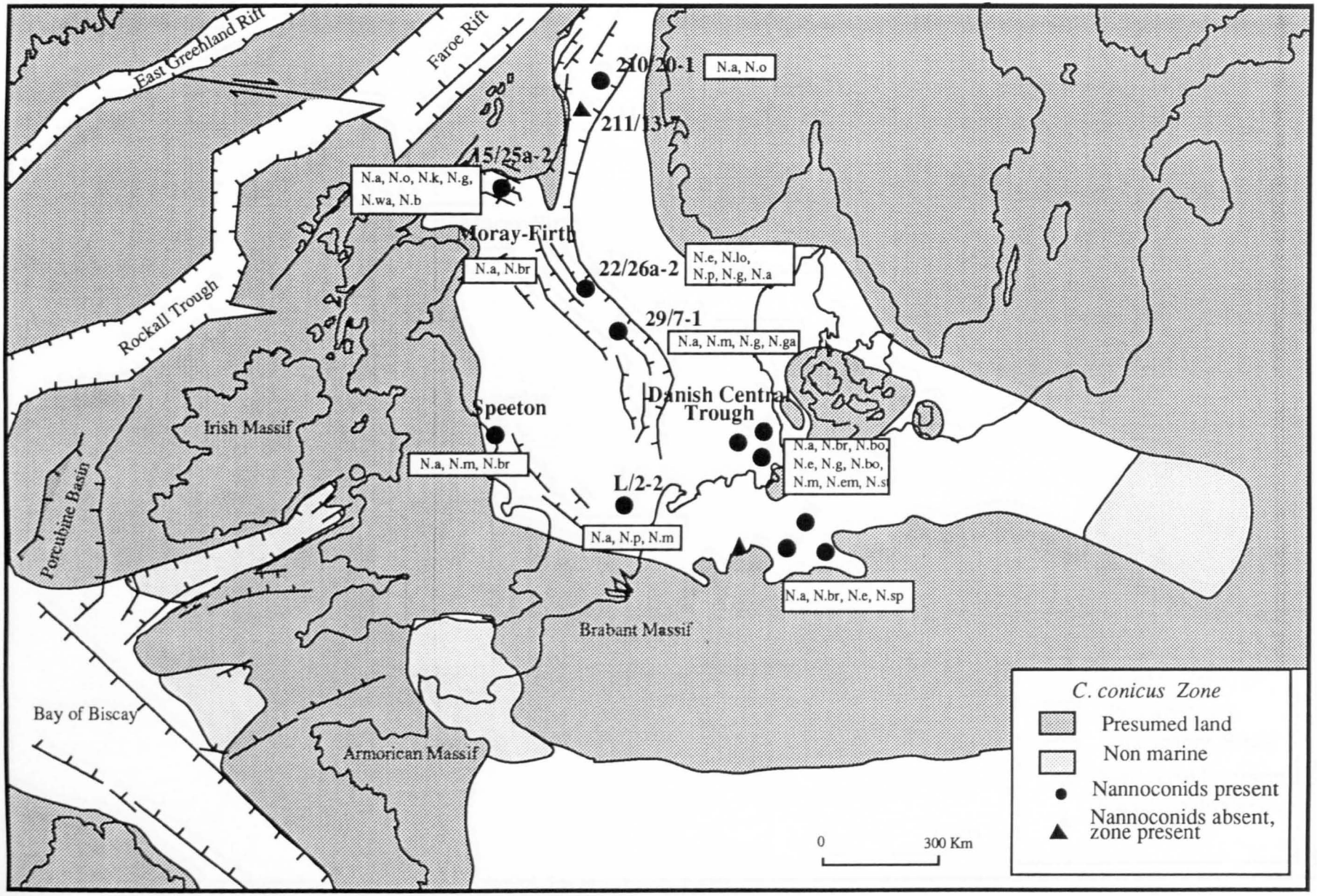


Figure 11.2 m) Distribution of Nannoconus in NLKA 13. Barremian base map from Tyson & Funnell (1987).

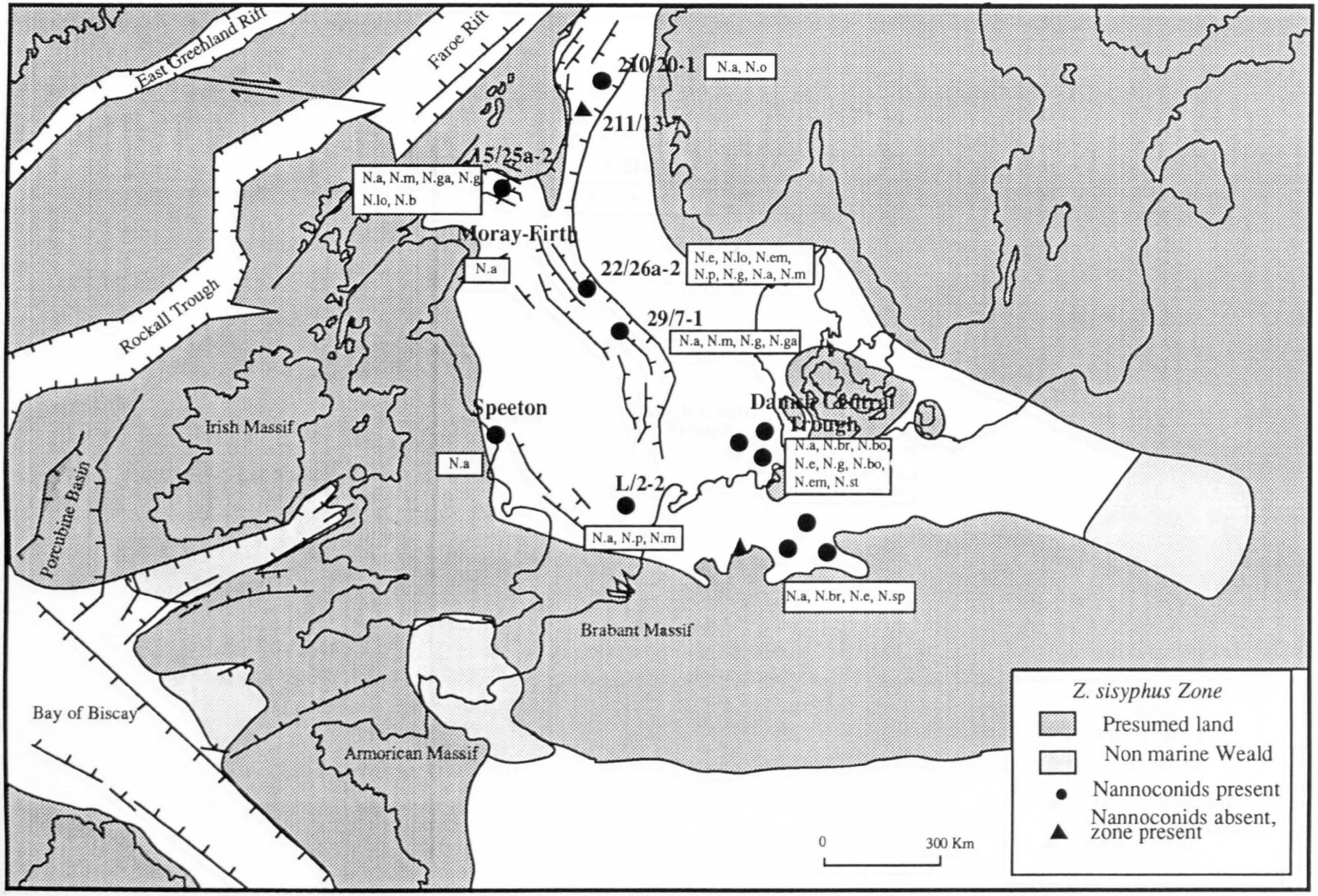


Figure 11.2 n) Distribution of Nannoconus in NLKA 12. Barremian base map from Tyson & Funnell (1987).

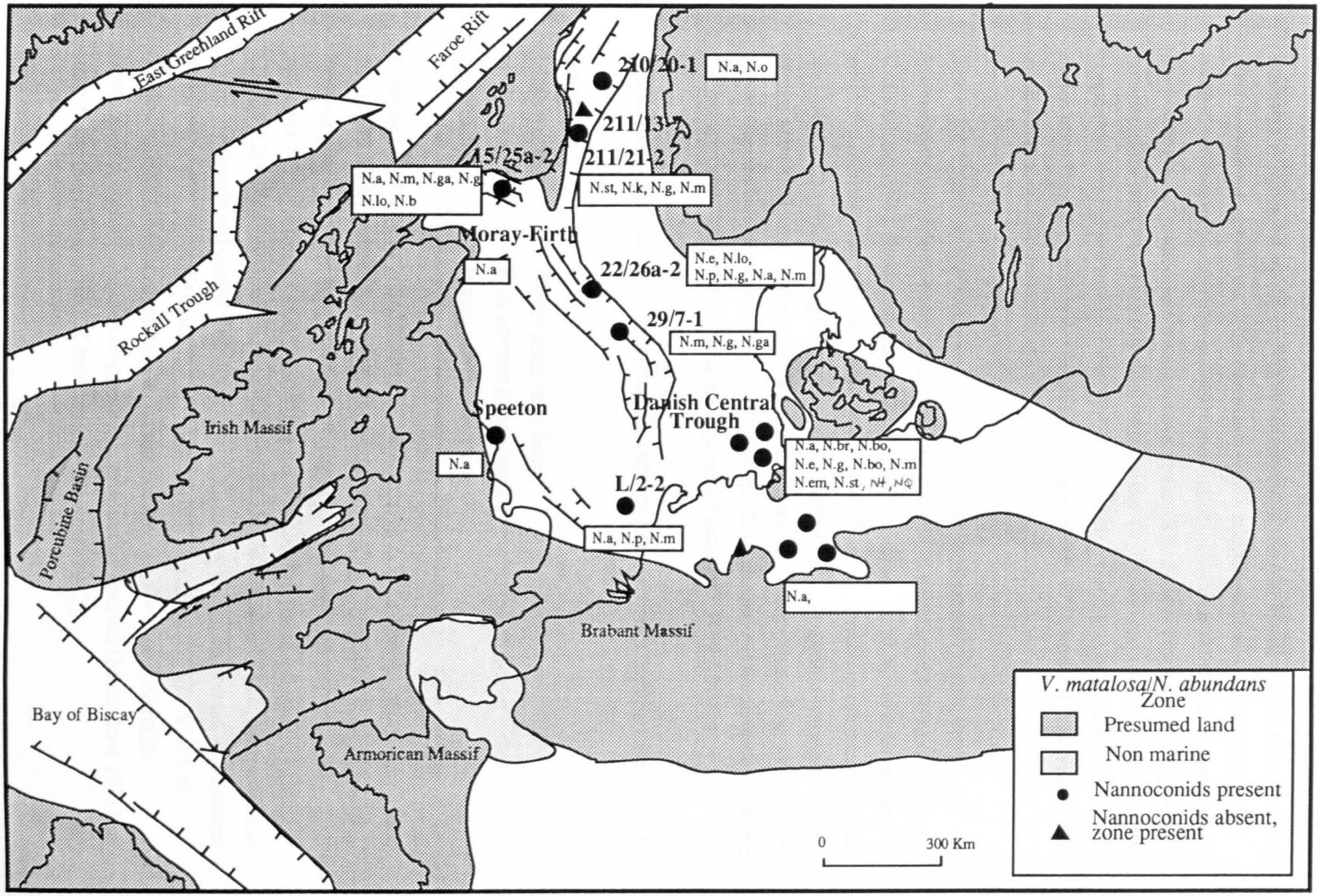


Figure 11.2 o) Distribution of Nannoconus in NLKA 11 & 10. Barremian base map from Tyson & Funnell (1987).

Aptian, microfaunal assemblages show improved circulation in the Central North Sea Basin associated with a transgressive phase (Lott *et al.* 1985). A renewed influx into the basin is indicated by the sudden proliferation of the planktonic foraminifera *Hedbergella infracretacea.* This correlates with a sudden reddening of the calcareous mudstones, interpreted by Jeans (1980) and Gallois & Morter (1982) as oxygenation of the bottom water related to a transgressive phase. The Polish Trough did not have a southern link with Tethys at this time (Raczynska 1979). Widespread volcanic activity is apparent throughout much of the NW Europe during the late Aptian and volcanic facies have been found in NW Germany by Zimmerle (1979), and in England by Jeans *et al.* (1982).

The early Aptian in NW Europe is characterised by a laminated facies, the Fischschiefer, which represents seasonal fluctuations in a transgressive phase (Mutterlose 1991). Endemic nannoconid flora *N. abundans* and *N. borealis* become extinct at the Barremian/Aptian boundary with Tethyan species *N. multicadus, N. truitti* and *N. globulus* dominating the nannoconid assemblage. The general turnover in the faunal and floral assemblages is observed in belemnite faunas (Mutterlose 1990). The Lower Aptian is characterised by an influx of the Tethyan derived *Neohibolites* into the Boreal area and Tethyan ammonite immigrants (Mutterlose 1989, 1991).

Mutterlose (1989) notes the following assemblage characteristics for this time interval:

Substages	
Clansayesian:	Boreal ammonite fauna.
Gargasian:	Rich diverse nannofossil assemblages, *N. truitti* influx.
Bedoulian:	Boreal ammonite fauna.

Abundant *N. truitti* are noted in the middle Aptian of NW Germany (Mutterlose 1989, 1991) and the hypothesis to explain this restricted abundance interval is an influx of Tethyan genera into the Boreal Realm. *R. asper* and *W. barnesae* dominate the assemblages, the former being regarded as a warm surface water indicator by Erba (1987). The distribution of this event is worldwide (Mutterlose 1988). New endemic forms are developed during this interval with *C. litterarius, F. biforamis, R. angustus, E. varolii* and *L. morayfirthensis* in NW Germany (Mutterlose 1991). A lack of nannoconids in the Clansayesian is a distinct feature. The Tethyan belemnite *Neohibolites*, common in the Gargasian is scarce in this interval (Mutterlose 1991), a pattern attributed to a period of coldwater by Kemper (1982).

11.2 p) *L. morayfirthensis* Zone (NLK 9)

Extinction of *N. abundans* occurs in the early part of this zone and *N. truitti* dominates the assemblage in Central and Northern North Sea but not in the abundances of *N. abundans*. A decrease in diversity and abundance of the nannoconid assemblage is characteristic of this zone, and this is most marked in the Danish Central Trough. In NW Germany an increase in the number of Tethyan species is observed in addition to the establishment of *N. truittii*.

11.2 q) *R. asper* Zone (NLK 8)

A very low diversity assemblage with *N. truitti*. as the most common species characterises this zone. North Sea sections: 210/20-1, 211/29-8a, 29-3-1 211/13-7 are barren of nannoconids. In the Danish Central Trough nannoconids decline in abundance and in NW Germany none are recorded.

11.2 r) *M. obtusus* Zone (NLK 7)

A further decline in abundance and distribution can be observed with only 22/26a-2 and 202/8-1 showing the presence of rare specimens of Tethyan-derived *N. truitti* and in NW Germany *N. truitti* is only noted from a solitary section. A slight increase in the diversity of Tethyan-derived taxa can be seen in the Danish Central trough.

Albian

The early Albian transgression is characterised by impoverished micro-faunas and floras in the Central North Sea (Price 1977). BGS: Borehole 81/40, described by Lott *et al.* (1985), shows the absence of ostracods and coccoliths at this interval with only rare agglutinating foraminifera present. The presence of a bentonite horizon indicates volcanism in this area. The onset of mid Albian Red Chalk facies in the Central North Sea indicates a basin-wide mid-Albian transgression. It was not until the late Albian that a connection was re-established with Tethys. In the northern basins the sediments tended to become increasingly calcareous during the course of the Albian transgression (Hesjedal & Hamar 1983).

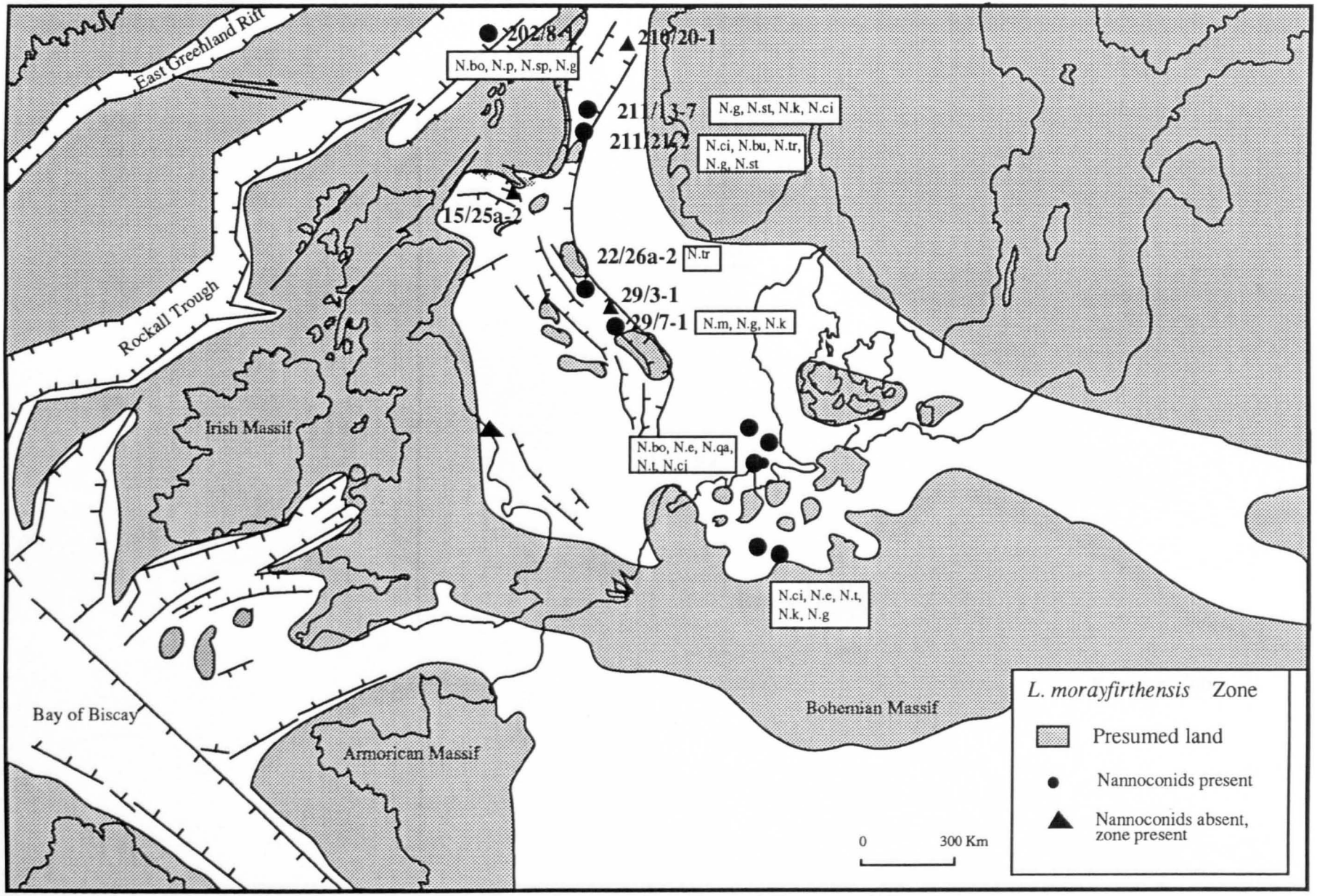


Figure 11.2 p) Distribution of Nannoconus in NLK 9. Aptian base map from Tyson & Funnell (1987).

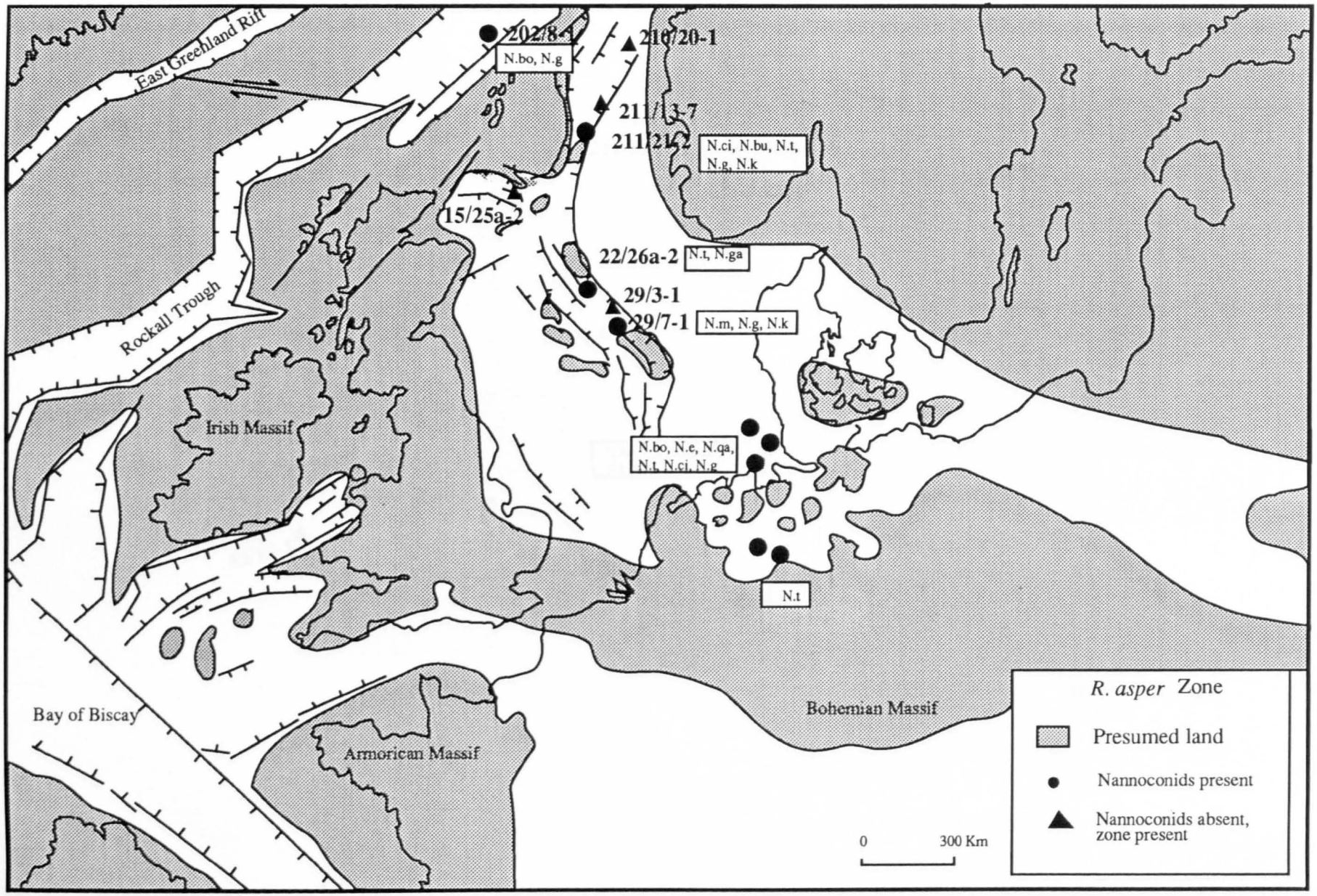


Figure 11.2 q) Distribution of Nannoconus in NLK 8. Aptian base map from Tyson & Funnell (1987).

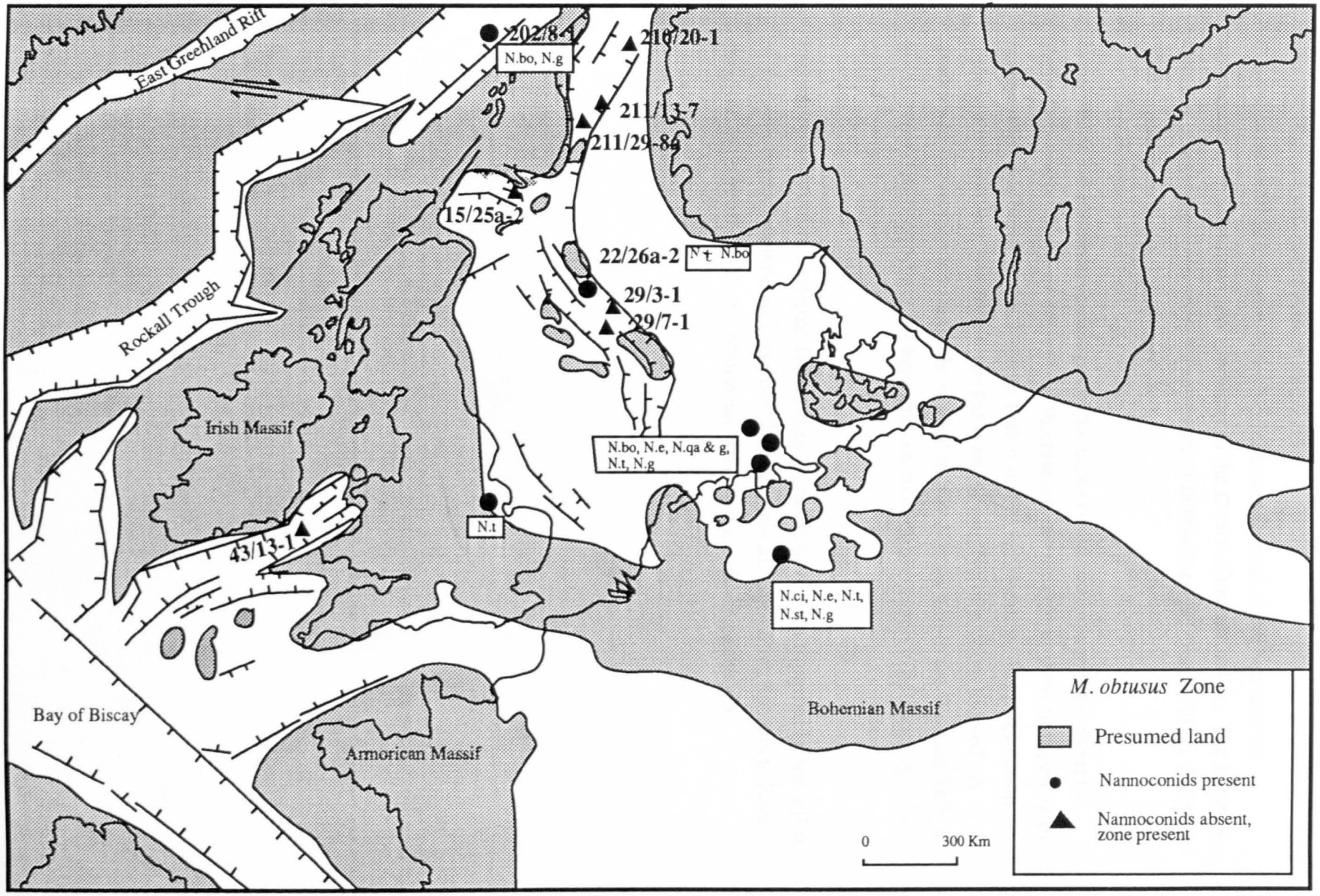


Figure 11.2 r) Distribution of Nannoconus in NLK 7. Aptian base map from Tyson & Funnell (1987).

11.2 s) *B. ambiguus* Zone (NLK 6)-*S. primitivuum* Zone (NLK2)

Continuation of NLK 7 pattern in the Northern and Central North Sea with no nannoconids reported from NW Germany or the Danish Central Graben. The taxon *N. truitti* is observed only as sporadic appearances in this interval, from 43/13-1 during NLK 5 and from 202/8-1 during NLK 2.

In summary, we can observe changes in the nannoconid assemblage throughout the Early Cretaceous. Some of these floral fluctuations are thought to show the opening of marine pathways between the Western Tethys and Boreal Realms. High-resolution timing of these events was found unreliable on the number of sections studied. A greater number of sections should be studied in NW Europe and in the Western Tethys to retrieve in-situ nannoconid phylogenetic information in relation to palaeogeographic events.

Species appearances of Endemic-Boreal taxa appear to have been triggered by the influx of Tethyan-derived nannoconid taxa into this new habitat. Speciation appears to have occurred in response to the environmental stress and a widening gene pool.

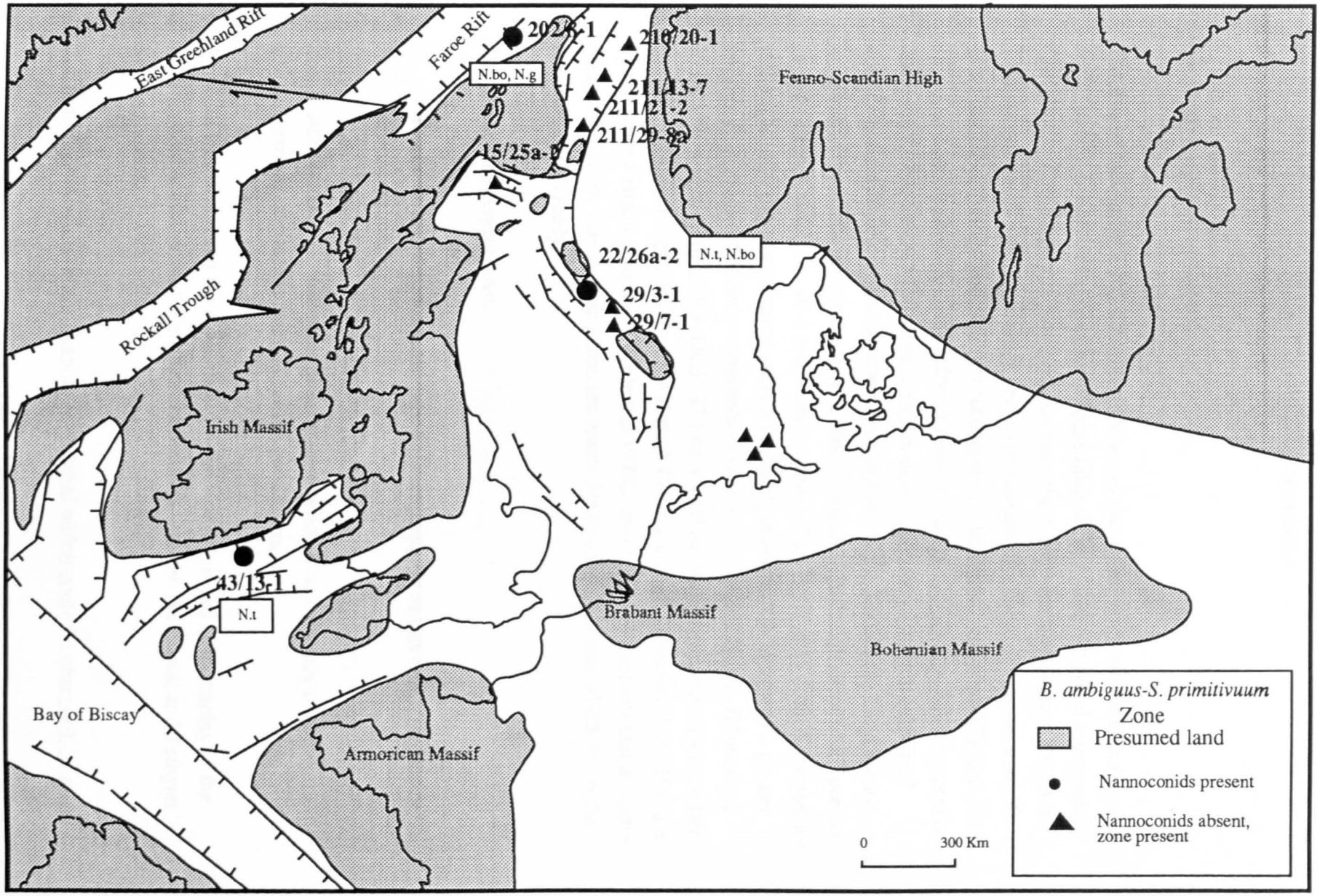


Figure 11.2 s) Distribution of Nannoconus in NLK 6-2. Albian base map from Tyson & Funnell (1987).

Chapter 12.
Concluding Remarks

12.1 Discussion

The title of this thesis 'Early Cretaceous *Nannoconus* (calcareous nannofossil, *incertae sedis*) in NW Europe' encompasses the possibility of inclusion of several interpretive disciplines. This enigmatic nannolith has been the subject for study since 1931 from Tethyan sediments where it obtains very high abundance values. It was not until 30 years later that *Nannoconus* was first recognised in the Boreal sediments (Taylor 1968). Since this date the distribution of *Nannoconus* in NW Europe has been poorly documented in published literature, a pattern directly related to the non-release of confidential information from oil companies drilling in the North Sea. Land section information recording the presence of nannoconid taxa is limited in Britain to: Speeton (Taylor 1968, Crux 1989, etc.) and Mundays Hill (Crux 1992), this limited distribution is thought to be due to ecological controls on this genus. In NW Germany a greater number of sections are directly correlatable to the North Sea and Britain (Mutterlose 1984, 1987a & b, 1988 , 1991, etc.). The only well sections published which contain nannoconid assemblages are from the Danish Central Trough (Thomsen 1987,1989a & b) and Skinnabanken, Norway (Verdenius 1978). It is therefore apparent that available data on the distribution of this genus are scarce for this region, a fact which led to the initiation of this study.

The aims of the project were:

1. To obtain a sound taxonomic base for interpretation of this morphologically diverse genus,

2. Apply this to a biostratigraphic framework in order to elucidate the distribution patterns and controlling parameters,

3. It was hoped that the results would give a proxy record of the timing of the opening and closing of marine connections between the Boreal and Tethyan Realms.

Due to time constraints on the quantity of material which could be observed, it was

decided to obtain data from well sections with a good geographical distribution and to correlate the results with published information from well and land sections. The biostratigraphic control on the occurrence of nannoconids was a combined nannofossil zonation scheme from Jakubowski (1987) and Crux (1989). The age evidence of the general nannofossil assemblage was compared to the nannoconid assemblage where possible. No other faunal or floral biostratigraphic or magnetostratigraphic data was available to provide a tighter biostratigraphic control for the interval studied.

The project was tackled by initially obtaining a comprehensive understanding of the morphological nature of the different nannoconid taxa and applying the new observations to taxonomic species assignments. A database of described nannoconid taxa, with locality and stage occurrence was assembled to aid the interpretation of the phylogenetic and distribution patterns which could be observed in NW Europe.

Methodology:

Taxonomic assignments within the genus were made in the light microscope using partially-polarised and cross-polarised light observation of smear slides. This enabled the external and internal morphology to be studied. The scanning electron microscope provided enhanced detail of the wall ultrastructure and one of the aims of the project was to obtain 'same specimen' light and scanning electron micrographs. The technique used was proposed by Gallagher (1988) and appeared to provide an ideal technique for obtaining strict taxonomic controls. Some of the difficulties which arose were that the nannoconid specimens were not orientated in a perfect longitudinal section (essential for the diagnostic identification purposes), in relation to their 'thick' structure. The scarcity of some of the nannoconid taxa was not conducive to obtaining SEM MICROGRAPHS. Finally the preservation also played an important role in the SEM with the surface structure becoming smooth in appearance which hinders the re-location and observation of the specimen. This technique was found to be time-consuming and non-productive in respect to illustrating the nannoconid taxa during this study.

Nannoconid Ultrastructure:

The initial interpretation of the morphology of *Nannoconus* were made on longitudinal sections in the light microscope. Brönnimann (1955) emended the initial structural

interpretations of Kamptner (1931), describing the test as a construction of wedges orientated perpendicular to the surface with the pointed ends directed towards the axial canal or cavity. The distribution of these wedges in tangential sections was thought to be arranged in a gradually mounting spiral or spirals. This spiral angle was quantified as 30° by Tappan (1980) but Perch-Nielsen (*pers. comm*) observed that differences in this spiral angle were evident. It was decided that it would be interesting to correlate these light microscope observations with detailed scanning electron micrographs of the wall structure. Initially no apparent correlation could be made but careful tracings of small sections were made of a micrograph of *N. boneti*. It was found that two distinct orientation of plates were present, termed Type A and Type B plates for convenience. The two types of plate formed distinct cycles related to the angle of inclination of the component plates and the degree of plate overlap within the cycle. Cycle A was constructed of Type A plates with an angle of 10° to the horizontal intercept angle, overlapping surface of up to 80 %. In contrast Cycle B was constructed of Type B plates which were at a higher horizontal intercept angle 35° and had minimal overlap of about 20 % aligned between zones of Cycle A. When correlated to the spiral feature of Brönnimann (1955) it became apparent that the spiral feature was defined by the extinction of Cycle B and high birefringence of Cycle A. The width of Cycle A was also considerably greater than that of Cycle B which further enhanced the idea of a spiral structure. These new observations show that the nannoconid is not constructed of a simple arrangement of spiralling wedges, however, the structure has not yet been completely clarified and a fuller coverage of nannoconid taxa is needed. Further detailed study of well-preserved specimens in several orientations needs to be done to obtain a more comprehensive idea as to the plate and cycle inter-relationships. A complete coverage of all the known taxa is needed to see the complete variation in wall structure. The application of 3-D modelling of the plate construction in the future may aid this process.

During routine light microscopy it was noted that the inclination of Cycle B to the horizontal taxa was found to vary between taxa but to remain constant within a taxon. The width of Cycle A was also found to be an important variable. An estimate of the inclination was made of individual specimens and at a later date a protractor micrometer was used to correlate some of the estimates to actual values. It was found that all the species observed in NW Europe could be placed in light microscope categories whose parameters were controlled by:

Inclination of Cycle B:		Width of Cycle A:	
1.	$\beta_1 < 20°$,	.1	$< 0.5\mu m$
2.	β_1 20-45°	.2	0.5-1μm
3..	$\beta_1 > 45°$	.3	$> 1\mu m$

These parameters were termed 1.-3. for the inclination and .1-.3 for the variation in width, e.g. a taxon showing the β_1 inclination of $< 20°$ and Width of Cycle A $< 0.5\mu m$ would be placed in Morphogroup 1.1.

A total of 9 morphogroups could be created by a combination of these parameters, however, nannoconid taxa studied here could only be assigned to 5 of these groups, the other groups were not found to be not constructionally viable. The width of Cycle A was found to be directly related to the breadth of the component plates and their degree of overlap. This also affected the inclination of Cycle B to a certain extent although the reason for the differences in inclination is not fully understood. Due to the poor state of preservation of some of the material observed in the SEM only a few taxa were assigned accurate values for the degree of inclination of Type A and B plates. It would be interesting to obtain a range of values for all known the nannoconid taxa, which could help us understand the complexity of these structures.

Systematic Position of *Nannoconus:*

The ambiguous biological nature of *Nannoconus* has been the topic of relatively little discussion, with no modern organisms upon which to propose an analogy to these Tithonian-Campanian enigmatic structures. During observation of a monospecific lamina of *N. abundans* from North Jens-1, 7561'11 an unusual phenomena was observed, amongst the individual specimens a number of double structures were present. These were in perfect contact along the flange and in complete crystallographic continuity, with the ridges and grooves corresponding in both individuals. A biological origin for this feature is here proposed, as the possibility of it being the result of compaction was considered very low. The facies within which they were observed is characterised by blooms forming microscopic laminae, deposited in very quiet water conditions which would enhance the preservation of structures of biological affinity. Similar features in *N. circularis* and *N. truitti* were also observed in material from the

Danish Central Trough, which may lead us to doubt the idea that the individuals were placed in large numbers around a cell, at least not in all taxa. The biological control for the production of this feature needs to be further investigated.

The classification of the individuals is problematic and several authors have attempted to assign *Nannoconus* to the Protozoa or Unicellular Algae. The lack of modern representatives have here been used to suggest that this genus be assigned to *Incertae sedis*. The occurrence of nannoconids in association with other calcareous nannoplankton, size range, and similarities in some of the plate construction mechanisms are here used to suggest an affinity to the Prymnesiophyta. Previous authors concept here included embryonic stages of foraminifera, which show fundamental differences in size and wall construction to the nannoconids. They have also been categorised as Charophyta by Peck (1934), which show a distinct surface impression and are considerably larger in size. The Chlorophyta have a resting cyst in their life cycle which is analogous in outline to some nannoconid species (Cadisch 1934) but differs in wall construction and the presence of only a single opening. Observations of 'spherical' associations of nannoconid individuals have allowed us to assume an affinity to the Prymnesiophyta. However, no convincing illustrations of spheres of nannoconid individuals have yet been observed and in light of the observation of double structures here they are not entirely convincing. The nannoconids show a distinct wall ultrastructure which cannot be related to calcareous dinoflagellate taxa or even directly to prymnesiophyte taxa at present. The botanical nomenclature is used in the text as a standard although the nature of the individuals is under speculation.

Nannoconid Taxonomy:

A total of 33 taxa were observed in the material studied from NW Europe of which 2 new species and 2 new subspecies were recognised but left in open nomenclature until further specimens were observed. These were identified based upon the following characteristics of longitudinal views: wall structure, external and internal features within these morphogroup assignments. The taxonomic assignments of top views were here considered problematic and it was confirmed that no accurate species determinations could be made. However, based upon the distinction of individual plates, birefringence patterns, dimensions of the external and internal diameter, stratigraphic position of the sample and associated nannoconid specimens, a reasonable deduction of the taxonomic

status could be made. Several synonyms were found related to different authors taxonomic concepts and incorrect observation of specimens in oblique views.

Phylogeny:

Once the taxonomic status and morphogroup assignment was established a preliminary interpretation of the phylogeny of nannoconids was made. This involved integrating data from the literature and observations in this study. One of the initial aims of the project was to differentiate phylogenetic speciation (evolution) in-situ as opposed to migrational appearances from Tethys. The biostratigraphic data did not provide the reliability expected due to the absence or non-recognition of some zones in the sections studied. The scarcity of species was also not conducive to an accurate interpretation of their speciation and extinction levels, only their first and last appearance in the sections. The preliminary model discusses the possible precursor to the development of *Nannoconus* , early evolution in the Cretaceous Tethys and a combined model of the evolutionary development during the Early Cretaceous. No material was studied from the Late Cretaceous. The earliest related taxon which shows remarkable similarities in structure is *Faviconus multicolumnatus* which is recorded from the early Late Tithonian of the Western Tethys. Speciation and extinction of several short-bodied nannoconid taxa appears to occur in rapid succession during the early Late Tithonian until the phylogenetic development of conical forms in the late Tithonian which form an abundant component of the nannofossil assemblage in the Tethys. The first nannoconids recognised in the Boreal Realm are endemic *Nannoconus* sp. (discs) which are thought to have been speciated in response to the cooler water environment. Comprehensive lineages are given in chapter 8, only a few salient features of the proposed phylogeny will be discussed here.

In Morphogroup 1.1 ($ß_1 < 20°$ and width of Cycle A $< 0.5\mu m$) a gap in the lineages are very prominent. Due to the thin nature of the plates and short central body it is apparent that the structure contains low $CaCO_3$ values in comparison to some of the more elongate nannoconid bodies. The presence of discs in the assemblage with no central body, comparable to disaggregated flanges of *N. abundans*, may suggest only partial-calcification of the specimen in response to the cool-water environment. This may explain the fine ultrastructure and sporadic occurrences in the stratigraphical record. Only one species from this morphogroup, *N. circularis*, is recognised to migrate from the Boreal to Tethyan seas suggesting a eurythermal nature in this group. Recognition

of sporadic laminae from the Munk Marl are also thought to be related to a particular environmental stimulus. These cannot be intercalated with the seasonality sequence proposed by Thomsen (1989a) which suggests their dominance due to freak conditions i.e. surface water temperature or nutrient availability.

Another interesting feature is that within Morphogroup 3.3 (β_1 >45° and width of Cycle A >1μm) the central cavity remains a prominent feature within the taxa. In all the other morphogroups the central opening varies greatly within species through time.

Distribution Patterns:

Frequent influxes of Tethyan waters into the Boreal realm provided migrational appearances of Tethyan taxa and difficulty arises in interpreting local parallel evolution in different seas from in-situ evolution in one realm and floral migration. Data from published sources is vague and to obtain a more comprehensive outline of phylogeny versus the opening and closing of seaways require greater biostratigraphic refinement and a greater number of sections to be studied in NW Europe.

The biostratigraphic application of this genus to NW Europe was not attempted due to the poor biostratigraphic controls on the data. Two taxa, *N. abundans* and *N. borealis* in addition to *Nannoconus* sp (discs) were used from the combined scheme of Jakubowski (1987) and Crux (1989).

The worldwide distribution patterns of this genus showed it to be well-established in the Tethyan seas from the Late Tithonian and in the Boreal seas from the Late Ryazanian.

12.2 Conclusions

Chapter 4:

1) The optimum method for nannoconid study is by using crossed-nicols and partially-polarised light observation, with the SEM to show greater resolution of wall structure.

2) The study of fracture surfaces is an excellent means of observing seasonal blooms and virtually in-situ deposition in sediments even including faecal pellets e.g. from the

Munk Marl.

3) The 'same-specimen' technique (Gallagher 1987) is a good means of obtaining tight taxonomic control on a specimen, unfortunately, due to the scarcity of nannoconid taxa in the Boreal realm this technique can be time-consuming and inefficient.

4) Careful study of the birefringence patterns of top views can discriminate two types of extinction patterns, parallel-sided and flaring towards the external surface. This is related to the differences in ultrastructure described in this study.

5) In the SEM overgrowth of the exterior can obscure the structural detail of the surface whilst light microscope resolution is not affected for taxonomic purposes.

Chapter 5:
The enigmatic *Nannoconus* is classified as *Incertae sedis* with algal affinities. This is based upon structural, size and occurrence affinities with the Prymnesiophyta.

Chapter 6:
1) Double structures of *N. abundans, N. circularis* and *N. truitti* have been identified in material from the Danish Central Trough, the occurrence of which is attributed to a biological (biomineralisation) origin due to the perfect crystallographic continuity of individuals within the structure.

2) Detailed micrographs on the surface of a specimen of *N. boneti* showed the wall to be constructed of a set of plates in two orientations. Type A plates were at a low inclination to the horizontal axis of the specimen and showed a high degree of overlap of similar individual plates to form Cycle A. In contrast Type B plates showed a higher inclination from the horizontal with minimal plate overlap.

3) Correlation of these SEM observations with the morphological interpretation of the nannoconid structure by Brönniman (1955) showed the spiral described by that author to correspond to the high birefringence of Cycle A bounded by the extinction of Cycle B. The term 'spiral' is here not recommended due to the highly complex nature of the construction.
4) The inclination of Cycle B and the width of Cycle A were found to vary between species but remain constant within a taxon.

5) The variability were attributed to changing dimensions in the breadth of the component plates, degree of overlap of plates in Cycle A and the inclination of Type B plates.

6) The species observed in NW Europe could be assigned to 3 morphogroups in the light microscope based upon three classes of Cycle B inclination (< 20°, 20-45° and >45°). These could be further subdivided based upon the width of Cycle A (< 0.5μm, approximately 0.5-1μm and >1μm).

Chapter 7:

A total of 33 species of *Nannoconus* were identified in NW Europe. The longitudinal section was found to be a diagnostic feature for taxonomy. Taxonomic assignments were based upon categorisation of the specimen into one of the 5 morphogroups observed and then classification according to the external and internal morpho-characteristics. A total of: two new species, *N.* sp 1 and *N.* sp 2; one subspecies, *N. globulus* subsp. λ^{A} and a new combination, *N. wassalli minor* were proposed.

Chapter 8:

1) The earliest analogous structure to *Nannoconus* is *Faviconus* (? syn. *Nannoconus*) in the early Late Tithonian from the Western Tethys.

2) Speciation is recognised to be rapid in the early Late Tithonian with the individuals characterised by a short range, compact structure and poorly developed canal. Conical elongate species became common in the assemblage in the Late Tithonian.

3) The first nannoconids in the Boreal Realm appeared in the Late Tithonian, belonging to Morphogroup 1.1. The speciation of this group is thought to be in response to the harsh external environment. Detailed phylogenetic diagrams are given for the individual morphogroups and figure 8.8 shows a summary of the evolutionary model proposed for the taxa recognised in NW Europe.

Chapter 9:

The combined nannofossil scheme of Jakubowski (1987) and Crux (1989) provided good correlation in general, however, several of the zones were not recognised in the sections due to local and regional hiatuses and non-recognition of the markers

Chapter 10:

1) A few rare nannoconid blooms were observed in material from North Jens-1. These blooms contained an assemblage composed entirely of *N. abundans* although mixed nannoconid and nannofossil lamina were observed. The controls on these monospecific lamina are unknown but may be related to surface water temperature or depletion of a certain element not essential for the construction of this taxa.

2) Six endemic Boreal taxa are identified in the material studied.

3) The genus *Nannoconus* incorporates the cosmopolitan taxa, no comments can be made about endemic Tethyan taxa owing to the restriction of this work to NW Europe.

Chapter 11:

1) An analysis of data for the worldwide occurrence of *Nannoconus* showed this genus to have a wide geographic distribution throughout the Early Cretaceous. There is very little record of new localities recording the presence of nannoconids, partially attributed to the lack of released data from industry. Within the assemblages the taxa show phylogenetic development, however, different taxonomic concepts by authors has also shown this to be unreliable.

2) Nanoconids can theoretically be used to determine the timing and significance of marine connections, however, tighter biostratigraphic control is needed. The Western Tethyan nannoconid flora will also need to be studied to obtain a complete understanding of species migration.

12.3 Further Research

Nannoconid Ultrastructure:

1) To study the Type Collections of Brönimann (1955), Deres & Achériteguy (1980) and other Type Collections to classify all known nannoconid taxa into the morphogroups recognised in this study.

2) To obtain LM and SEM micrographs of all the different morphogroups and respective taxa in addition to all the type reference material as a reference database. The study of all the known morphogroups will also aid in discussing the applicability of

assigning generic status to these morphogroups.

3) To obtain more accurate data on the variations in inclination of the plates and cycles present. and to correlate these to the c-direction of the plates in the light microscope.
4) Determine the structural relationships in a 3-D model by obtaining scanning electron micrographs of well-preserved specimens in several orientations.

Nannoconid Associations:

5) Re-investigate the spherical structures of Trejo (1960) and determine the ecological controls on the occurrence of double structures.

6) Further literature search for possible origins for the unusual double structures observed.

Phylogenetic Development:

7) To review the evolutionary occurrence of these morphogroups and *Faviconus* as a junior synonym of *Nannoconus*. Establish a complete phylogeny for nannoconids.

Worldwide Geographic Distribution of Individual Taxa:

8) Re-study some sections worldwide to obtain a higher resolution framework for the occurrence of this genus.

9) Study distribution of Late Cretaceous nannoconids worldwide.

10) *Nannoconus* as an environmental indicator - try to pinpoint the reason for the sporadic occurrence in seasonal laminae.

11) Increased attention to Eastern Tethyan areas.

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APPENDIX I

Abbreviations List

Species codes

N. abundans	N.a
N. alvus (sen. syn. *N. concavus*)	N.al
N. aquitanicus	N.aq
N. bermudezi	N.be
N. boletus boletus	N.b
N. boletus curtus	N.bc
N. boneti	N.bo
N. borealis	N.bn
N. bronnimanni	N.br
N. bucheri	N.bu
N. calpidomorphous	N.c
N. carniolensis carniolensis	N.ca
N. carniolensis lata	N.cl
N. circularis	N. ci
N. colomi (sen. syn. *N. steinmanni*)	N.co
N. compressus	N.cm
N. concavus	N.cn
N. cornuta	N.cr
N. dauvillieri	N.d
N. dislocatus	N.di
N. dolomiticus	N.do
N. donnatensis	N.dn
N. elongatus elongatus	N.e
N. elongatus minutus subsp. nov.	N.em
N. fragilis	N.f
N. globulus globulus	N.g
N. globulus minor	N.gm
N. globulus A subsp. nov.	N.ga
N. grandis	N.gr
N. inconspicuus	N.i
N. infans	N.in
N. kamptneri kamptneri	N.k
N. kamptneri minor	N.km

N. ligius	N.lo
N. minutus (sen. syn *N. inconspicuus*)	N.m
N. multicolumnatus (jun. syn. *Faviconus)*	N. mc
N. multicadus	N.mu
N. oviformis	N.o
N. paskentensis	N.p
N. quadratus	N.q
N. quadriangulus quadriangulus	N.qg
N. quadriangulus apertus	N.qa
N. regularis	N.r
N. sabinae	N.sa
N. steinmanni steinmanni	N.st
N. steinmanni minor	N.sm
N. truitti truitti	N.tr
N. truitti frequens	N.tf
N. truitti rectangularis	N.tr
N. vocotiensis	N.v
N. wassalli	N.wa
N. winteri	N. wi

Stage Names

TI	Tithonian
BE	Berriasian
Ry	Ryazanian
VA	Valanginian
HT	Hauterivian
BA	Barremian
BR	Barremian (dist charts)
AP	Aptian
AB	Albian
CEN	Cenomanian

Symbols

●	Abundant
O	common
/	few
•	rare
⌐	Top occurrence
⌊	Base occurrence
TO	Acme event
BO	
←	

APPENDIX II

Localities which Record the Global Distribution of *Nannoconus*

REALM	COUNTRY	LOCALITY
BOREAL REALM:	Great Britain	Speeton
		Mundays Hill, Bedfordshire
	Ireland	
	North Sea	Moray Firth Basin
		22/26a-2
		29/7-1
	Denmark	Helgoland Töch
		Adda 1 & 2
		E-1
		I-1
	Norway	Skinnabanken core 7B
	Germany	Aegi
		Konrad 101
		KMS Section
		Leiter
		Moorberg, Sarstedt
		Münchenhagen
		Otto Gott, Sarstedt
		Pollhagen
		Rethmar
		Schacht Konrad 1
		Wiedensahl 2
WESTERN TETHYAN REALM:	France	Basses Alpes
		Berrias, Ardéche
		Broyon, Ardéche
		Carcabuey
		Col de Palluel, Hautes Alpes
		Fozza

	Gargas, Vaucluse
	Ginestous la Garenne, Hérault
	Ginestous les Oliviers, Hérault
	D'Angles, Basses Alpes
	De Vergons
	La Bédoule - Station de Cassis,
	Bouches du Rhône
	La Charce 1, Drôme
	La Charce 11, Drôme
	La Charce 111, Drôme
	Lacicisterne, Hérault
	Lesches en Diois, Drôme
	Lioux Var
	Montslavens, Préalpes externes
	Nazaire-le Désert
	Orpierre, Hautes-Alpes
	Paris Basin
	Pomet
	Valangin, Jura Mountains
Italy	Bellavista ? (Canto Ticino)
	Bosso Valley
	Cismon
	Fonte Giordano
	Frontale
	Gorgo Cerbara
	Lucolena, Rapolena
	Montebibico
	Presale
	Rapdeno
	Santa Anna, Scicily
Spain	Balearic Islands (Ibiza, Majorca)
	Caravaca, Province Murcia
	Focalent (Alicante)
	Mallorca
	Perello Province
Switzerland	Breggia River Section
Yugoslavia	Vrsnik (N Slovenia)

Slovakia	
Israel	Ashqelon 2
	Gevar'am
	Helez 2, 3, 31
	Talmei Yafe 4
Hungary	Aklipuszta Csengöhegy
	Bakonny Mts
	Bakonybél somhegy
	Bocskorhegyi árok
	Borzavár Páskomtetö K 1
	É-Zalai Medence Nagyülaj
	Gerecsehegység Berzsehegy
	Gerecsehegység Felsövadács
	Gerecsehegység ördöggáti Köfejto
	HárskDt Közöskúti árok
	HárskDt Rendkö
	Mecsehegység Zangövárkony
	Lókút L 2 Fúras
	Lókút Futballpálya Mellet
	Lókút Község Kútnál
	Lókút Nagyköfjtö
	Olaszfalu Eperkéshegy
	Sümeg Kövesdomb 7
	Sümeg Mogorósdomb
	Tata Káluáriadomb
	Városlöd
	Villány Mts
	Zirc Alsómajor
	Zirc Bocskorhegy
	Zirc Márvánbánya
Roumania	Szvinyicaánát
	Valley du Minis (Banat)
	Podeni
Algeria	Kef Telrempt
Morocco	

	Tunisia	
	DSDP 41	E North Atlantic
	DSDP 47A	NW African Margin
	DSDP 47B	Vigio Seamount, W Spain
	DSDP 50	Moroccan Basin
EASTERN TETHYAN REALM:	India	Cauvery Basin
	Japan	Sugegadam, Shikoku Island
		Torinosu, Shikoku Island
NORTH ATLANTIC REALM:	Cameroon	Ravin Bleu, Batna
	America	McCarty Creek, California
		Vestal Rd Section, Sacramento Valley
		Stony Creek, Sacramento Valley
	Trinidad	Point á Pierre
	Mexico	Altamira 11
		Anahuac 2
		Carbajal 1
		Chocoy 2
		Escalera 2
		Lajillas 1
		Nato 1
		Noyola 1
		Peyotes 3
		Pozo Barranca 1
		Pozo Bustos
		Pozo Comales 101
		Pozo Garza 1
		Pozo Silozuchil
		San Ambrosio
		Vaquerieas 2
	Cuba	Pinar Del Rio

	Surinam	
	Colombia	
	W North Atlantic	99A 105
	DSDP 1	Blake Bahama Basin
	DSDP 11	N Atlantic
	DSDP 14	Central Atlantic
	DSDP 48	N Atlantic
	DSDP 51	Bermuda Rise, W N.
	DSDP 52	Bermuda Rise, W North Atlantic
	DSDP 76	Blake Bahama Basin, N Atlantic
	DSDP 77	? SE Gulf of Mexico
	DSDP 79	N Atlantic
	DSDP 93	N Atlantic
	DSDP 100	Gulf of Mexico
	DSDP 101A	Bahamas
	DSDP 39	Atlantic
	DSDP 40	
SOUTH ATLANTIC REALM:	Argentina	Nequen Bsin
	Brazil	Ceara Basin
		Espírito Santo Basin
	S America	
	SW Africa	
	Madagascar	
	Mozambique	
	DSDP 36	Falkland Plateau
	DSDP 105	Baffin Bay, Labrador Sea
	DSDP 113	Weddell Sea, E Antartica
	DSDP 71	S Atlantic

PACIFIC REALM:	DSDP 89	Central Pacific
	DSDP 129	Old Pacific Crust

APPENDIX III
Worldwide Distribution of *Nannoconus*

TITHONIAN
(Figure 11.1a)

LOCALITY	REFERENCE	NANNOCONIDS
FRANCE:		
Berrias	Galbrun *et al.* 1986	N.br, N.co, N.st
Berrias	Manivit *et al.* 1986	N.co, N.st
Broyon	Bralower *et al.* 1989	N.in, N.km, N.wi
Carcabuey	Bralower *et al.* 1989	N.cm
Fozza	Bralower *et al.* 1989	N.in, N.wi
Nazaire-le-Désert	Cooper 1985	N.sp 1
Pomet	Thierstein 1975	N. sp
France	Le Hégarat 1973	N.sp
ITALY:		
Montebibico	Dufour & Noël 1959	N.sp
Lucolena	Canuti & Marcucci 1969	N.co
Bosso Section	Bralower *et al.* 1989	N.in, N.do, N.wi, N.sm, N.st
Santa Anna	Manivit *et al.* 1986	N.do, N.sm
SPAIN:		
Spain	Deres & Acheriteguy 1980	N.st
Caravaca	Geel 1966	N.sp
Bellavista, ?	Pasquaré 1960	N.sp
Foncalent	Manivit *et al.* 1986	N.do, N.st, N.qg
Ticino	Grunau & Studer 1956	N.g, N.st, N.sp.
Malta	Deres & Achériteguy 1980	N.br
N AFRICA:		
Tunisia	Deres & Achériteguy 1980	N. do
Sahara	Deres & Achériteguy 1980	N.st, N.sm, N.bn
SW Morocco	Deres & Achériteguy 1980	N. do
MOZAMBIQUE	Deres & Achériteguy 1980	N.do

MADAGASCAR	Deres & Achériteguy 1980	N.st, N.sm
ISRAEL:		
Helez 2	Moshkovitz 1971	N.st
Bakonny Mts	Baldi-Beke 1961	N.do, N.st
Bakonybél, somhegy	Baldi-Beke 1962	N.st
É-Zalai Medence, Nagytilaj	Baldi-Beke 1962	N.st
Hárskút, Közöskúti árok	Baldi-Beke 1962	N.st
Hárskút, Rendkö	Baldi-Beke 1962	N.st
Olaszfalu, Eperkéshegy	Baldi-Beke 1962	N.st
Sümeg, Mogorósdomb	Baldi-Beke 1962	N.st
Tata, Káluáriandomb	Baldi-Beke 1962	N.st
Zirc, Alsómajor	Baldi-Beke 1962	N.st
S AMERICA:		
Colombia	Deres & Achériteguy 1980	N. st
MEXICO:		
Pozo Barranca 1	Trejo 1960	N.st
San Ambrosio 1	Trejo 1960	N.bn, N.g, N.st
Pietrari	Filepscu & Dragastan 1963	N.e, N.st
Pedeni	Filepscu & Dragastan 1963	N.tr, N.ro
CANADA	Deres & Achériteguy 1980	N.st, N.sm
DSDP LEG 11	Wilcoxon 1972	N.sp
DSDP 534 A	Cooper 1985	N.sp 1, N.st
DSDP 534 A	Cooper 1989	N.st
DSDP 534 A	Bralower *et al.* 1989	N.co, N.in, N.gm, N.wi, N.q
DSDP 534 B	Cooper 1985	N.st

BERRIASIAN/RYAZANIAN
(Figure 11.1b)

LOCALITY	REFERENCE	NANNOCONIDS
GREAT BRITAIN:		
Speeton	Crux 1989	N.sp.(discs)

IRELAND	Deres & Achériteguy 1980	N.q, N.g, N.br, N.sm
NORTH SEA:		
29/7-1	Perch-Nielsen 1988	N.al, N.cn, N.o, N.sa
NORWAY:		
Sklinnabanken	Aarhus *et al* 1986	N.co, N.g N.st
FRANCE:		
Berrias	Thierstein 1973	N.co, N.t
Berrias	Galbrun *et al* 1986	N.br, N.co, N.g, N.st, N.q
Berrias	Bralower *et al* 1989	N.g, N.km, N.k, N.sm, N.st, N.wi
Drôme	Deres & Achériteguy 1980	N.st
Suzette	Colom 1952	N.co
Paris Basin	Deres & Achériteguy 1972 1980	N.be, N.co, N.g, N.k, N.st, N.sp 107
Paris Basin	Deres & Achériteguy 1980	
Nazaire-le Desért	Cooper 1985	N.st
Broyon	Bralower *et al* 1989	N.be, N.g, N.in, N.km, N.k, N.st, N.sm, N.wi
Fozza	Thierstein 1973	N.do, N.g, N.in, N.sm, N.st, N.t
Broyon	Thierstein 1973	N.be, N.br, N.co, N.g, N.m, N.t
Ginestous la Garenne	Thierstein 1973	N.co, N.t
Ginestous les Oliviers	Thierstein 1973	N.br, N.co, N.g, N.t
Montsalvens	Thierstein 1973	N.br, N.co, N.m
France	Le Hégarat	N.sp
ITALY:		
Bosso Valley	Bralower *et al* 1989	N.be, N.br, N.do, N.in, N.sm, N.st, N.q, N.t
Montebibico	Dufour & Noël 1959	N.sp
Lucolena, Rapolena	Canuti & Marcucci 1969	N.co
Ticino	Grunau & Studer 1956	N.g, N.st, N.sp.
SPAIN:		
Caravaca	Geel 1966	N.sp
Foncalent	Manivit *et al.* 1986	N. co
Balearic Islands	Colom 1952	N.co
Spain	Deres & Acheriteguy 1980	N.st, N.sm.

SWITZERLAND:		
Breggio River Section	Aita & Okada 1986	N.co, N.spp.
ROUMANIA:		
Podeni	Filepscu & Dragastan 1963	N.ro
HUNGARY:		
Bakonny Mts	Baldi-Beke 1961	N.sp
Bakonybél somhegy	Baldi-Beke 1962	N.co, N.st
Bocskorhegyi árok	Baldi-Beke 1962	N.co, N.st
Gerecshegység Felsövadács	Baldi-Beke 1962	N.co,N.st
Hárskút, Közöskúti árok	Baldi-Beke 1962	N.k, N.st, N.wa
Mecsekhegység Zengövárkony	Baldi-Beke 1962	N.co, N.st
Sümeg, Mogyorósdomb	Baldi-Beke 1962	N.co, N.st
Tata Kálváriadomb	Baldi-Beke 1962	N.co,N.st
Városlöd	Baldi-Beke 1962	N.co, N.st
Zirc,Alsómajor	Baldi-Beke 1962	N.st
ISRAEL:		
1Ashqelon 2	Moshkovitz 1971	N.k, N.st
Gevar'am	Moshkovitz 1971	N.k, N.st
Helez 2	Moshkovitz 1971	N. k, N.st
Helez 31	Moshkovitz 1971	N.k, N.st
Talmei Yafe 4	Moshkovitz 1971	N.k, N.st
N.AFRICA:		
Morocco	Deres & Achériteguy 1980	N. q, N.br, N.st, N.sm
Tunisia	Deres & Achériteguy 1980	N.do, N.st, N.sm, N.br
Sahara	Deres & Achériteguy 1980	N.br, N.st, N.sm
MOZAMBIQUE	Deres & Achériteguy 1980	N.do
MADAGASCAR	Deres & Achériteguy 1980	N.g
CAMEROON:		
Ravin Bleu	Noël 1958	N.sp
AMERICA:		
McCarty Creek	Worsley 1979	N.co
Stony Creek	Bralower 1990	N.m, N.st

CANADA	Deres & Acheriteguy 1980	N.g
MEXICO:		
Pozo Comales	Trejo 1960	N.be, N.co, N.st
Pozo Ghijol 1012	Trejo 1960	N.be, N.g, N.st
San Ambrosio 1	Trejo 1960	N.g, N.st
Pozo Bustos 1	Trejo 1960	N.st
Altamira 11	Trejo 1960	N.st
Chocoy 2	Trejo 1960	N.g, N.st
CUBA:		
Pinar del Rio	Brönnimann 1955	N.sp
JAPAN:		
Torinosu	Aita & Okada 1986	N.co, N.spp.
DSDP LEG 11	Wilcoxon 1972	
DSDP LEG 41, site 367	Cepek 1978	N.co
DSDP 534 A	Cooper 1985	N.st
	Bralower *et al* 1989	N.be, N.bn, N.cm, N.gm, N.g, N.km, N.st, N.m, N.t
DSDP LEG 93, site 603	Covington & Wise 1987	N.sp

VALANGINIAN
(Figure 11.1c)

LOCALITY	REFERENCE	NANNOCONIDS
IRELAND	Deres & Achériteguy 1980	N.q, N.sm
NORWAY:		
Skinnabanken	Aarhus *et al* 1986	N.be, N.k
FRANCE:		
Berrias	Thierstein 1973	N.co, N.g
Ginestous la Garenne	Thierstein 1973	N.br, N.co, N.g, N.m, N.t
Ginestous les oliviers	Thierstein 1973	N.br, N.co, N.g, N.m, N.t
La Charce 1	Thierstein 1973	N.br, N.co, N.g, N.m, N.t

Lacisterne	Thierstein 1973	N.co, N.g
Montsalvens	Thierstein 1973	N.co, N.m
Nazaire-le Desért	Cooper 1985	N.st
Orpierre	Thierstein 1973	N.sp
Paris Basin	Deres & Achériteguy 1972	N.be, N.co, N.g, N.k, N.st, N. sp 107
Paris Basin	Deres & Achériteguy 1980	N.co, N.cr, N.g, N.st, N.sm
France	Le Hégarat 1973	N.sp
GERMANY:		
S.Germany	Kaiser-Wiedich & Wiedich 1985	N.co, N.g, N.sp
Wiedensahl 2	Mutterlose 1988	N.g, N.m, N.k, N.sp
Pollhagen	Mutterlose 1988	N.sp
Münchenhagen	Crux 1989	N.spp, N.m
ITALY:		
Gorgo a cerbara	Bralower 1987	N.g, N.st
Frontale		N.g, N.st
Cismon		N.k, N.st
Fiume Bosso	Bralower *et al* 1989	N.st
Fonte Giordano		N.be, N.sm, N.st
Rapdeno	Canuti & Marcucci 1969	N.co
Ticino	Grunau & Studer 1948	N.g, N.st, N.sp.
SPAIN:		
Caravaca	Geel 1966	N.co, N.g, N.st
Foncalent	Manivit *et al.* 1986	N.be, N.do
Balearic Islands	Colom 1952	N.co
Mer d'Iroise	Deres & Achériteguy 1980	N.g,N.cr, N.be, N.bo, N.k, N.br, N.st, N.sm
NW Spain	Deres & Achériteguy 1980	N.sm
Malta	Deres & Achériteguy 1980	N.st
SWITZERLAND	Deres & Achériteguy 1980	N.br
ROUMANIA:		
Vrsnik	Pavsic & Gorican 1987	N.st
Vallee du Minis (Banat)	Filepscu & Dragastan 1963	N.co, N.do, N.e
HUNGARY:		
Bakonny Mts	Baldi-Beke 1961	N.sp
Sümeg Mogyoródomb	Baldi-Beke 1962	N.st, N.co

Lókút L.2. Fúras	Baldi-Beke 1962	N.st
Hárskút Közöskúti árok	Baldi-Beke 1962	N.bu, N.g, N.wa, N.t
Hárskút Rendkö	Baldi-Beke 1962	N.st
Borzavár Páskomtetö k-1 oldal	Baldi-Beke 1962	N.st
Bakonybél somhegy	Baldi-Beke 1962	N.st
Gerecsehegység ördöggáti Köfejtö	Baldi-Beke 1962	N.st
AMERICA:		
McCarty Creek	Worsley 1979	N.co
McCarty Creek	Bralower 1990	N.st
Stony Creek	Bralower 1990	N.st
CANADA	Deres & Achériteguy 1980	N.cr, N.co, N. g, N.sm, N.st
MEXICO:		
Pozo Garza 1	Trejo 1960	N.be, N.g, N.st
Pozo Barranca 1	Trejo 1960	N.be, N.g, N.st
Pozo Silozuchil 1	Trejo 1960	N.be, N.g, N.st
Pozo Chijol 1012	Trejo 1960	N.g, N.st
Pozo Bustos 1	Trejo 1960	N.be, N.g, N.st
Altamira 11	Trejo 1960	N.be, N.g, N.st
Chocoy 2	Trejo 1960	N.be, N.g, N.st
CUBA:		
Pinar del Rio	Brönnimann 1955	N.sp
N. AFRICA:		
Kef Tahrempt	Nöel 1958 & 1965	N.sp
Tunisia	Deres & Achériteguy 1980	N.st, N.sm, N.co, N.cr, N.bo
Morocco	Deres & Achériteguy 1980	N.bo, N.co, N.cr, N.sm, N.st
Sahara	Deres & Achériteguy 1980	N.st, N.sm, N.co, N. cr, N.bo
MADAGASCAR	Deres & Achériteguy 1980	N.st, N.sm, N.g
COLOMBIA	Deres & Achériteguy 1980	N.st
DSDP 1	Thierstein 1973	N.t
W North Atlantic	Wilcoxon 1972	
DSDP LEG 41, site 370	Cepek 1978	N.co
DSDP LEG 534A	Cooper 1985	N.st
DSDP LEG 77 site 535	Cotillon & Rio 1984	N. sp

DSDP LEG 93, site 603 B	Covington & Wise 1987	N.g, N.k, N.st

HAUTERIVIAN
(Figure 11.1d)

LOCALITY	REFERENCE	NANNOCONIDS
GREAT BRITAIN:		
Speeton	Taylor 1978	N.a
	Perch Nielsen 1979	N.a
	Crux 1989	N.sp 1, N.m
IRELAND	Deres & Achériteguy 1980	N.g
NORWAY:		
Skinnabanken	Aarhus *et al* 1986	N.aq, N.be, N.bn, N.bu,N.g, N.gr, N.k, N.sm, N.st
Skinnabanken	Crux 1989	N.spp, N.mi, N.st
FRANCE:		
Drôme	Deres & Achériteguy 1980	N.st, N.g, N.co, N.cr
D'Angles	Thierstein 1973	N.bu, N.co, N.g, N.m, N.t
La Charce 1	Thierstein 1973	N.br, N.co, N.g, N.m, N.t
La Charce 11	Thierstein 1973	N.br, N.bu, N.co, N.g, N.m, N.t, N.wa
Hauterive	Thierstein 1973	N.br, N.co, N.m, N.t
Lioux Var	Baldi-Beke 1962	N.st
Montsalvens	Thierstein 1973	N.br, N.g
Paris Basin	Deres & Achériteguy 1972	N.be, N.co, N.g, N.k, N.st, N.sp 107
Valangin	Thierstein 1973	N.co, N.g
GERMANY:		
Moorberg	Mutterlose & Wiedenroth 1987	N. sp
Moorberg	Crux 1989	N.sp 1, N.sp 2, N.m, N.st
Konrad 101	Mutterlose & Wiedenroth 1987	N.g
Otto Gott	Crux 1989	N.m, N.st
Niedermehnen 3	Mutterlose 1991	N.bu, N.ci, N.q, N.k, N.sp
Pollhagen	Mutterlose 1988	N.bu, N.g, N.k

Moorberg	Mutterlose 1991	N.co, N.g, N.k, N.m, N.sp
Wiedensahl 2	Mutterlose 1988	N.m, N.st
Wiedensahl 2	Mutterlose 1991	N.m, N.st
S Germany	Kaiser-Wiedich & Wiedich 1985	N.bo, N.k, N.st, N.sp
SPAIN:		
Caravaca	Geel 1966	N.co, N.st
Balearic Islands	Colom 1952	N.co
Spain	Deres & Achériteguy 1980	N.cr, N.co, N.be, N.k, N.m, N.bu, N.st
Malta	Deres & Achériteguy 1980	N.st
ITALY:		
Cismon	Bralower 1987	N.bu, N.k, N.st
Frontale	Bralower 1987	N.br, N.g, N.st
Gorgo a Cerbara	Bralower 1987	N.be, N.bu, N.st
Presale		N.st
Ticino	Grunau & Studer 1956	N.co, N.g, N.st
SWITZERLAND:		
Breggia River Section	Aita & Okada 1986	N.co, N.spp
Switzerland	Deres & Achériteguy 1980	N.st, N.co
HUNGARY:		
Bakonny Mts	Baldi-Beke 1961	N.sp
Gerecsehegység Berzsekhegy	Baldi-Beke 1962	N.co, N.st
lókút nagy Köfejtö	Baldi-Beke 1962	N.st
ISRAEL:		
Ashqelon 2	Moshkovitz 1971	N.be, N.g, N.k, N.st
Gevar'am	Moshkovitz 1971	N.be, N.g, N.k, N.st
Helez 3	Moshkovitz 1971	N.be, N.co, N.g, N.k, N.st
Helez 31	Moshkovitz 1971	N.be, N.k, N.st
Talmei Yafe 4	Moshkovitz 1971	N.be, N.g, N.k, N.st
N.AFRICA:		
Morocco	Deres & Achériteguy 1980	N.st, N.k, N.bo, N.be, N.co, N.cr
Sahara	Deres & Achériteguy 1980	N.bu, N.bo, N.be, N.co, N.st
Tunisia	Deres & Achériteguy 1980	N.k, N. bo, N.cr, N.st

MOZAMBIQUE	Deres & Achériteguy 1980	N.st, N.m
MADAGASCAR	Deres & Achériteguy 1980	N.g, N.st
AMERICA:		
McCarty Creek	Bralower 1990	N.st
CANADA	Deres & Achériteguy 1980	N.st, N.g, N.co, N.be, N.bo, N.m
MEXICO:		
Chocoy 2	Trejo 1960	N.be, N.bo, N.co, N.g, N.k, N.st
Pozo Bustos	Trejo 1960	N.co, N.g, N.st
San Ambrosio, Mexico	Trejo 1960	N.be, N.bo, N.g, N.k, N.st
CUBA:		
Pinar del Rio	Brönnimann 1955	N.sp
S. AMERICA:		
Colombia	Deres & Achériteguy 1980	N.st,
Nequen Basin, Argentina	Angelozzi (in press)	N.g, N.st , N.bu, N.g, N.k, N.st, N.m, N.t, N.wa, N.spp
DSDP LEG 1	Thierstein 1973	N.co
DSDP LEG 11, site 99	Bukry 1972	N.sp
DSDP LEG 41, site 370	Cepek 1978	N.st
DSDP LEG 47A, site 397A	Wind & Cepek 1979	N.bu, N.co, N.g, N.k, N.t, N.wa
DSDP LEG 47B, site 398	Blechschmidt 1979	N. co
W North Atlantic	Wilcoxon 1972	N.sp

BARREMIAN
(Figure 11.6)

LOCALITY	REFERENCE	NANNOCONIDS
GREAT BRITAIN		
Speeton	Taylor 1978	N.a
Speeton	Perch Nielsen 1979	N.a, N.bn

Speeton	Crux 1989	N.a, N.m, N.st
IRELAND	Deres & Achériteguy 1980	N.g
Moray Firth	Jakubowski 1987	N.a, N.bn
22/26a-2	Perch-Nielsen 1988	N.lo
Adda 1	Thomsen 1987	N.a, N.bo, N.bn, N.e
Adda 2	Thomsen 1987	N.a, N.bo, N.e, N.g, N.st
E 1	Thomsen 1987	N.a, N.g, N.mu, N.st, N.qa, N.q, N.t, N.tf
I 1	Thomsen 1987	N.a, N.bo, N.bn, N.g, N.q, N.qa
Danish Central Trough	Thomsen 1989	N.bu, N.bn, N.lo
NORWAY:		
Skinnabanken	Aarhus *et al* 1986	N.aq, N.bu, N.bo, N.e, N.gr, N.t, N.tf, N.qg, N.wa
FRANCE:		
Drôme	Deres & Achériteguy 1980	N.g, N.co, N.st
Basses Alpes	Baldi-Beke 1962	N.bu, N.k, N.st
Angles	Bouche 1965 Noël 1964	N.be, N.bu, N.co, N.e, N.g, N.k, N.m, N.st, N.t, N.sp
D'Angles	Thierstein 1973	N.bu, N.br, N.co, N.g,N.k, N.m, N.t, N.wa
La Charce 111	Thierstein 1973	N.be, N.bu, N.br, N.co, N.g, N.k, N.m, N.t, N.wa
Montsalvens	Thierstein 1973	N.co
Paris Basin	Deres & Achériteguy 1972	N.sp
De Vergons	Bouche 1965	N.be, N.bu, N.e, N.g, N.k, N.st, N.m, N.t, N.wa, N.sp.
SE France:	Deres & Achériteguy 1980	N.be, N.bo, N.st
GERMANY:		
Otto Gott	Mutterlose & Harding 1987	N.a
Otto Gott	Crux 1989	N.a, N.m, N,sp
Moorberg	Mutterlose & Harding 1987	N.a
Moorberg	Mutterlose 1991	N.a, N.m, N.sp
Aegi	Mutterlose 1991	N.a, N.bn, N.e, N.k
KMS Section	Cepek 1982	N.sp
Letter	Mutterlose & Harding 1987	N.a,N.e
Schacht Konrad 1	Stradner & Grün 1973	N.a

S Germany	Kaiser-Wiedich 1985	N.cf a, N.st, N.sp
NW Germany	Cepek & Kemper 1981	N.a
ITALY:		
Gorgo a Cerbara, Italy	Bralower 1987	N.be, N.bu, N.br, N.g, N.st
Presale	Bralower 1987	N.bu, N.br, N.g, N.k, N.st
Frontale	Bralower 1987	N.bu, N.g, N.k, N.st, N.t
Cismon	Bralower 1987	N.bu, N.br, N.k, N.st, N.t
Ticino	Grunau & Studer 1956	N.g, N.st, N.spp.
SPAIN:		
Caravaca, Spain	Geel 1966	N.bu, N.co, N.g, N.k, N.st, N.wa
Balearic Islands	Colom 1952	N.co
Spain	Deres & Achériteguy 1980	N.st, N.k, N.m, N.bu, N.ci
Malta	Deres & Achériteguy 1980	N.st
SWITZERLAND:		
Breggia River Section	Aita & Okada 1986	N.co, N.spp
HUNGARY:		
Bakonny Mts	Baldi-Beke 1961	N.sp
SHmeg Kövesdomb 7	Baldi-Beke 1962	N.co, N.st
Lókút Nagyköfejtö	Baldi-Beke 1962	N.co, N.g, N.k, N.st
Lókút Futballpálya Mellet	Baldi-Beke 1962	N.co, N.k, N.st
Lókút Község Kútnál	Baldi-Beke 1962	N.k, N.st
Aklipuszta Csengöhegy	Baldi-Beke 1962	N.co, N.g, N.k, N.st
Hárskút Közöskúti árok	Baldi-Beke 1962	N.co, N.g, N.st
Hárskút Rendkö	Baldi-Beke 1962	N.co, N.k, N.st
Zirc Márvánbánya	Baldi-Beke 1962	N.co, N.g, N.k, N.st
Zirc Bocskorhegy	Baldi-Beke 1962	N.st
Városlöd	Baldi-Beke 1962	N.co, N.g, N.k, N.st
Gerecsehegység Berzserhegy	Baldi-Beke 1962	N.co, N.g, N.k, N.st
Szvinyicaánát	Baldi-Beke 1962	N.co,N.k, N.st
AMERICA	Deres & Achériteguy 1980	N.g, N.co, N.ci
CANADA	Deres & Achériteguy 1980	N.co, N.g, N.bo, N.ci, N.st
ISRAEL:		
Ashqelon 2	Moshkovitz 1971	N.be, N.bu, N.e, N.g, N.t, N.wa
Talmei Yafe 4	Moshkovitz 1971	N.bu, N.e, N.g, N.t, N.wa

Gevar'am	Moshkovitz 1971	N.be, N.e, N.g, N.k
Helez 2	Moshkovitz 1971	N.be, N.g, N.k, N.st
Helez 3	Moshkovitz 1971	N.be, N.bu, N.co, N.e, N.g, N.k, N.st, N.t
Helez 31	Moshkovitz 1971	N.be, N.bu, N.e, N.k, N.st, N.t, N.wa
N. AFRICA:		
Algeria	Deres & Achériteguy 1980	N.ci
Mozambique	Deres & Achériteguy 1980	N.m, N.ci
Morocco	Deres & Achériteguy 1980	N.bu, N.g, N.co, N.be, N.bo, N.st
Tunisia	Deres & Achériteguy 1980	N.st, N.k, N.bu, N.gr, N.aq, N.wa, N.ci
Sahara	Deres & Achériteguy 1980	N.k, n.bu, N.wa, N.ci
MADAGASCAR	Deres & Achériteguy 1980	N.st, N.g
MEXICO:		
Pozo Garza 1	Trejo 1960	N.bu, N.m, N.t, N.wa
Pozo Comales 101	Trejo 1960	N.bu, N.m, N.t, N.wa
Pozo Barranca 1	Trejo 1960	N. bo, N.bu, N.m, N.t, N.wa
Pozo Chijol 1012	Trejo 1960	N.bu, N.m, N.t, N.wa
Pozo Bustos 1	Trejo 1960	N.bo, N.bu, N.k, N.m, N.t, N.wa
Vaquerieas 2	Cantu-Chapa 1989	N.co, N.e, N.k, N.st, N.wa
CUBA:		
Pinar del Rio	Brönnimann 1955	N.sp
TRINIDAD	Thierstein 1973	N. co
S. AMERICA:		
Nequen Basin	Angelozzi (in press)	N.be, N.bu, N.g, N.k, N.st, N.t
COLUMBIA	Deres & Achériteguy 1980	N.k, N.m, N.bu, N.ci
DSDP LEG 14 site 135	Roth & Thierstein 1972	N.co
DSDP LEG 41 site 367	Cepek 1978	N.co
DSDP LEG 47B site 398	Blechschmidt 1979	N.co, N.t, N.wa
W North Atlantic	Wilcoxon 1972	

APTIAN
(Figure 11.7)

LOCALITY	REFERENCE	NANNOCONIDS
NORTH SEA:		
Adda 2	Thomsen 1987	N.a, N.bo, N.br, N.e, N.g, N.q, N.qa, N.t
E 1	Thomsen 1987	N.e, N.g, N.mu, N.q, N.qa, N.t
I 1	Thomsen 1987	N.a, N.bo, N.g, N.q
FRANCE:		
La Bédoule	Thierstein 1973	N.bu, N.bo, N.g, N.m, N.t, N.wa
Lesches en Dios	Thierstein 1973	N.bu, N.g, N.m, N.t
Paris Basin	Deres, Achériteguy 1972	N.sp
Paris Basin	Deres, Achériteguy 1980	
Gargas	Thierstein 1973	N.bu, N.g, N.m, N.t
Gargas	Barrier 1977	N.ca, N.q, N.qa, N.t
'Angles	Bouché 1965	N.bu, N.co, N.e, N.g, N.k, N.m, N.st, N.t, N.wa
Vergons	Bouché 1965	N.bu, N.e, N.g, N.k, N.st, N.t, N.wa, N.sp
GERMANY:		
Otto Gott	Mutterlose 1987	N.sp
Otto Gott	Mutterlose 1989	N.bo, N.bu, N.t
Rethmar	Mutterlose 1989	N.e, N.g, N.t
KMS Section	Mutterlose 1989	N.sp
Helgoland Töch	Mutterlose 1987	N.e, N.t
SPAIN		
Caravaca	Geel 1966	N.bu, N.co, N.e, N.m, N.t
Perello Province	Moreno de Castro	N.wa
Spain	Deres & Achériteguy 1980	N.qg, Nqa, N.bo, N.k, N.bu, N.gr, N.aq, N.ci, N.v, N.b, N.bc, N.cl, N.ca
ITALY:		
Gorgo Cerbara	Bralower 1987	N.g
Cismon	Bralower 1987	N.bu, N.k, N.t
ISRAEL:		

Ashqelon 2	Moshkovitz 1971	N.bu, N.e, N.k, N.t, N.wa
Talmei Yafe 4	Moshkovitz 1971	N.bu, N.e, N.k, N.t, N.wa
Gevar'am	Moshkovitz 1971	N.st, N.t, N.wa
Helez 2	Moshkovitz 1971	N.be, N.bu, N.e, N.g, N.k, N.t, N.wa
Helez 3	Moshkovitz 1971	N.bu, N.e, N.k, N.t, N.wa
Helez 31	Moshkovitz 1971	N.be, N.bu, N.co, N.k, N.st, N.t, N.wa
SLOVAKIA	Scheibner 1958	N.sp
Slovakia	Misik 1958	N.sp
HUNGARY:		
Bakonny Mts	Baldi-Beke 1961	N.bu, N.e, N.m, N.t
Gerecse Mts	Félegyházy & Nagymarosy 1991	N.be, N.st
Sümeg	Baldi-Beke 1962	N.bu, N.co, N.e, N.g, N.k, N.st, N.t, N.wa
MEXICO:		
Pozo Garza 1	Trejo 1960	N.e, N.m, N.t
Pozo Comales 101	Trejo 1960	N.m, N.t
Pozo Barranca 1	Trejo 1960	N.m, N.t
Pozo Silozuchil 1	Trejo 1960	N.e, N.m, N.t
San Ambrosio 1	Trejo 1960	N.m, N.t
Pozo Bustos	Trejo 1960	N.m, N.t
CUBA:		
Pinar del Rio	Brönnimann 1955	N.sp
COLUMBIA	Deres & Achériteguy 1980	N.qa, N.m, N.bu, N.aq, N.ci, N.tr,N.tf, N.bc, N.ca
SURINAM	Deres & Achériteguy 1980	N.qa, N.qg, N.tr, N.tf, N.b
America:		
McCarty Creek	Worsley 1979	N.bu, N.co
McCarty Creek	Bralower 1990	N.br, N.bu, N.e, N.g, N.gr, N.m, N.st, N.t
Vestal Rd	Bralower 1990	N.e, N.g, N.m, N.sm, N.t
USA	Deres & Achériteguy 1980	N.qg, N.e, N.b, N.bc, N.ca
CANADA	Deres & Achériteguy 1980	N.qg, N.qa, N.bo, N.k, N.wa,

		N.b, N.bc, N.cr
N. AFRICA:		
Algeria	Deres & Achériteguy 1980	N.tr
Libya	Deres & Achériteguy 1980	N.tr
Tunisia	Deres & Achériteguy 1980	N.qa, N.k, N.m, N.b, N.qg
Morocco	Deres & Achériteguy 1980	N.qg, N.qa, N.m, N.b, N.cr, N.cl
MOZAMBIQUE	Deres & Achériteguy 1980	N.bo, N.m, N.ci, N.bc
DSDP LEG 14 site 135	Roth &Thierstein 1972	N.co
DSDP LEG 14 site 136		N.bu, N.co, N.t
DSDP LEG 36 site 327A	Wise & Wind 1977	N.e, N.t, N.mu
DSDP LEG 41 site 367	Cepek 1978	N.bu
DSDP LEG 41 site 670	Cepek 1978	N.co
DSDP LEG 47B site 398	Blechschmidt 1979	N.co, N.wa, N.sp
DSDP LEG 48 site 400A	Müller 1979	N.e, N.k, N.m, N.t
DSDP LEG 48 site 401	Müller 1979	N.e, N.k, N.m, N.t, N.wa
DSDP LEG 51 site 417B	Siesser 1980	N.bu, N.k
DSDP LEG 52 site 417D	Siesser 1980	N.wa
DSDP LEG 79 site 545	Wiegand 1984	N.e, N.qg, N.qa
DSDP LEG 89 site 585	Bergren 1986	N.t
DSDSP LEG 93 site 603B	Covington & Wise 1987	N.co, N.g, N.gr, N.k, N.st
DSDP LEG 71 site 511	Mutterlose 1989	N.ci, N.e, N.mu, N.t, N.v
DSDP LEG 113 site 693A	Mutterlose & Wise 1990	N.g, N.sp
W North Atlantic, 105	Wilcoxon 1987	Ng, N.sp

ALBIAN

(Figure 11.8).

LOCALITY	REFERENCE	NANNOCONIDS
GREAT BRITAIN:		
Mundays hill, Bedfordshire	Crux 1992	N.m, N.t, N.e, N.spp
FRANCE:		
Col de Palleul	Thierstein 1973	N.m, N.t
Lesches en Dios	Thierstein 1973	N.m

Paris Basin	Deres & Achériteguy 1972	N.sp
SE & SW France	Deres & Achériteguy 1980	N.m, Ne, N.tf, N.tr
SPAIN:		
Caravaca	Geel 1966	N.bu, N.e, N.m, N.t
Mallorca	Aguado & Martinez-Gallego 1980	N.t
Spain	Deres & Achériteguy 1980	N.tr, N.tf
HUNGARY:		
Villány Mts, Hungary ?	Baldi-Beke 1961	N.t
Gerecsy Mts	Félegházy & Nagymarosy 1991	N.be, N.st
SLOVAKIA	Scheibner 1958	N.sp
Slovakia	Misik 1958	N.sp
INDIA:		
Cauvery Basin	Jafar & Rai 1989	N.t
MEXICO:		
Peyotes 3	Cantu Chapa 1989	N.e, N.m, N.st, N.wa
Garza z	Cantu Chapa 1989	N.e, N.m, N.st, N.wa
Nato 1	Cantu Chapa 1989	N.e, N.m, N.st, N.wa
Anahuac 2	Cantu Chapa 1989	N.e, N.m, N.st, N.wa
Escalera 2	Cantu Chapa 1989	N.e, N.m, N.st, N.wa
Lajillas 1	Cantu Chapa 1989	N.e, N.m, N.st, N.wa
Carbajal 1	Cantu Chapa 1989	N.e, N.m, N.st, N.wa
Noyola 1	Cantu Chapa 1989	N.e, N.m, N.st, N.wa
CAMEROON	Lambert 1987	N.aff f
CUBA:		
Pinar del Rio	Brönnimann 1955	N.sp
COLUMBIA	Deres & Achériteguy 1980	N.tr, N.tf, N.t
SURINAM	Deres & Achériteguy 1980	N.m, N.e, N.tr, N.tf, N.t
BRAZIL	Troelsen & Quadros 1971	N.sp
Ceara Basin	Cunha 1990	N.t, N.f, N.qa, N.sp
Espírito Santo Basin	Antunes 1987	N.t, N.sp

AMERICA:		
McCarty Creek	Worsley 1979	N.m
McCarty Creek	Bralower 1990	N.bu, N.do, N.m, N.st
USA	Deres & Achériteguy 1980	N.t, N.tf, N.tr
CANADA	Deres & Achériteguy 1980	N.wa, N.e, N.tr, N.t
N. AFRICA:		
Algeria	Deres & Achériteguy 1980	N.m, N.e
Libya	Deres & Achériteguy 1980	N.tr, N.t
Tunisia	Deres & Achériteguy 1980	N.m, N.tf, N. tr
Morocco	Deres & Achériteguy 1980	N.m
Sahara	Deres & Achériteguy 1980	N.tf
MOZAMBIQUE	Deres & Achériteguy 1980	N.m, N.t, N.tr
DSDP 1	Thierstein 1973	N.be, N.co, N.g
DSDP 4-3-2	Thierstein 1973	N.be, N.co, N.g
DSDP LEG 14 site 136	Roth & Thierstein 1972	N.bu, N.co, N.t
DSDP LEG 36 site 327A	Wise & Wind 1977	N.e, N.m, N.t
DSDP LEG 36 site 330		
DSDP LEG 39 site 356	Perch Nielsen 1977	N.sp
DSDP LEG 40 site 361	Proto Decima	N.sp
DSDP LEG 40 site 361	Noël & Melg uen 1978	N.t
DSDP LEG 40 site 364	Proto Decima	N.t
DSDP LEG 40 site 511	Mutterlose 1989	N.t
DSDP LEG 47B site 398	Blechschmidt 1979	N.co, N.sp
DSDP LEG 50 site 415A	Cepek & Gartner & Cool 1980	N.sp
DSDP LEG 51 site 417B	Siesser 1980	N.wa
DSDP LEG 52 site 417D	Siesser 1980	N.wa
DSDP LEG 113 site 693A	Mutterlose & Wise 1990	N.g, N.t, N.sp
DSDP LEG 79 site 545	Wiegand 1984	N.co, N.e, N.q, N.qa
DSDP LEG 79 site 547	Wiegand 1984	N.co, N.t, N.q
DSDP LEG 89 site 585	Bergren 1985	N.t
DSDP LEG 101 site 635B	Watkins & Verbeek 1985	N.e, N.q, N.r, N.t

APPENDIX IV.
Distribution of *Nannoconus* in NW Europe.

The appendix is a compilation of the distribution of *Nannoconus* across NW Europe. The data from available literature and this investigation are divided into zone increments which correspond to the biostratigraphic scheme used in this study.

* Zone present, nannoconids absent
? Zone markers not present/uncertain

Upper Tithonian

Speeton ?	Sissingh 1977	N.st

RYAZANIAN
Nannoconus sp.(discs) Zone (NLKA 27)

ONSHORE U.K:		
Speeton	Crux 1989	N.sp (discs)
Speeton	Sissingh 1977	N.st
OFFSHORE U.K:		
202/8-1	this study	N.g, N.bu, N.sa
211/13-7	this study	N.sp discs, N.k, N.g, N.st
29/7-1	Perch-Nielsen 1988	N.cn, N.sa
29/7-1	this study	N.g, N.o, N. sp 2
NW GERMANY:		
Sachsenhagen	Mutterlose 1988,1991	*

P. fletcheri Zone (NLKA 26)

ONSHORE U.K:		
Speeton	Taylor 1978, Crux 1989	*
OFFSHORE U.K:		

202/8-1	this study	N.g, N.bu, N.sa
211/13-7 ?	this study	N.k, N.g, N.cn
29/7-1	Perch-Nielsen 1988	N.cn
29/7-1	this study	N.g, N.o, N.sp 2.
NW GERMANY:		
Sachsenhagen	Mutterlose 1988, 1991	*

S. arcuatus Zone (NLKA 25)

ONSHORE U.K:		
Speeton	Taylor 1978	*
OFFSHORE U.K:		
202/8-1	this study	N.g, N.bu, N.sa
211/13-7	this study	N.g, N.d, N.cn
29/7-1	Perch-Nielsen 1988	N.al, N.cn, N.o
29/7-1	this study	N. ga , N.o
NORWAY:		
Skinnabanken	Crux 1989	*
NW GERMANY:		
Sachsenhagen	Mutterlose 1988, 1991	*

VALANGINIAN

Unamed Zone (NLKA 24)

ONSHORE U.K:		
Speeton	Taylor 1978, Crux 1989	*
OFFSHORE U.K:		
202/8-1	this study	N.bu, N.sa, N.g
210/20-1 ?	this study	N.st, N. cf bu, N. sp (3.3)
211/13-7 ?	this study	N.g, N.d
211/29-8a ?	this study	*
29/7-1	this study	N.g, N.ga , N.st,

29/7-1	this study	N.sp 2, N.m, N.cf o

DANISH CENTRAL TROUGH:

North Jens-1 ?	this study	N.sm, N.do

NORWAY:

Sklinnabanken	Thomsen 1987	N.st, N.sp 2

NW GERMANY:

Sachsenhagen	Mutterlose 1988, 1991	*
Wiedensahl 2	Mutterlose 1988, 1991	*

M. speetonensis Zone (NLKA 23)

ONSHORE U.K:

Speeton	Taylor 1978, Crux 1989	

OFFSHORE U.K:

202/8-1	this study	N.sa, N.cf o, N.g, N.sp 2
210/20-1	this study	N.st, N cf bu
211/13-7	this study	N.km
211/21-2 ?	this study	*
211/29-8a	this study	N. sp/disc
29/7-1	this study	N.ga N cf o, N.g, N.k, N.m
15/25a-2 ?	this study	N.bu, N.km

DANISH CENTRAL TROUGH:

North Jens-1	this study	N.gm, N.cf o, N.sm, N.do, N. sp, N.sp/discs (Crux), N.sp 1.

NW GERMANY:

Wiedensahl 2	Mutterlose 1988, 1991	*

Unstudied Interval (NLKA 22)

ONSHORE U.K:		
Speeton	Taylor 1978	*
OFFSHORE U.K:		
210/20-1	this study	N.e, N.k, N.o, N.g
211/21-2	this study	?
29/7-1 ?	this study	N.g, N.ga, N.p, N.k
15/25a-2 ?	this study	N.km, N.bu
DANISH CENTRAL TROUGH:		
North Jens-1	this study	N.g, N.ga, N.sp 1
NW GERMANY:		
Wiedensahl 2	Mutterlose 1991	N.m, N.sp 2
Wiedensahl 2	Mutterlose 1988	N.m, N.g, N.sp, N.k
Pollhagen	Mutterlose 1988, 1991	*
Münchenhagen	Mutterlose 1991	*

HAUTERIVIAN

***T. striatum* Zone (NLKA 21)**

ONSHORE U.K:		
Speeton	Taylor 1978	*
OFFSHORE U.K:		
210/20-1	this study	N.e, N.k, N.o, N.g
211/21-2	this study	?
29/7-1 ?	this study	N.p, N.k, N.g, N.ga
15/25a-2	this study	N cf o, N.bu, N.gm, N.g, N.ga, N.l, N.st, N.d
DANISH CENTRAL TROUGH:		
North Jens-1	this study	N.g, N.ga, N.sp 1
NW GERMANY:		
Münchenhagen	Mutterlose 1991	N.m, N.sp
Wiedensahl 2	Mutterlose 1991	N.g, N.m, N.sp 2

Wiedensahl 2	Mutterlose 1988	N.m, N.g, N.sp, N.k
Pollhagen	Mutterlose 1991	N.sp
Pollhagen	Mutterlose 1988	N.sp
Konrad 101	Kemper *et al.* 1987	*
Diepenau	Mutterlose 1991	*
Ottensen	Mutterlose 1991	*

***E. antiquus* Zone (NLKA 20)**

ONSHORE U.K:		
Speeton	Crux 1989	N.sp 1, N.spp
OFFSHORE U.K:		
210/20-1	this study	N.e, N.k, N.o, N.g
22/26a-2	this study	
29/7-1	this study	N.p, N.k, N.g, N.ga
DANISH CENTRAL GRABEN:		
North Jens-1	this study	N.g, N.gm, N.wa, N. cf o, N.k, N.br, N. e, N.st, N.sp 2
NW GERMANY:		
Moorberg	Crux 1989	N.sp.2, N.spp
Wiedensahl 2	Mutterlose 1991	N.g, N.m, N.st, N.sp 2
Wiedensahl 2	Mutterlose 1988	N.m, N.st
Pollhagen	Mutterlose 1991	N.bu, N.cf g, N.k, N.sp
Pollhagen	Mutterlose 1988	N.bu, N.cf g, N.k, N.sp
Niedermehnen	Mutterlose 1991	N.bu, N.ci, N.k, N.m, N.q
Moorberg	Mutterlose 1991	N.co, N.m, N.sp
Engelbostel	Mutterlose 1991	N. cf e, N. cf bu,
Engelbostel	Mutterlose 1991	N.ci, N.sp 1
Heisterholz 2	Mutterlose 1991	N.cf bu, N.sp 1
Konrad 101	Kemper *et al.* 1987	*

C. silvaradion Zone (NLKA 19)

ONSHORE U.K:		
Speeton	Crux 1989	N.spp
OFFSHORE U.K:		
210/20-1 ?	this study	N.e, N.g, N.o, N.k
211/29-8	Perch-Nielsen 1988	N.di
22/26a-2 ?	this study	
29/7-1 ?	this study	N.p, N.g, N.k, N.ga
DANISH CENTRAL GRABEN:		
North Jens-1 ?	this study	N.g, N.gm, N.wa, N.cf o, N. k, N. br, N.e, N.st, N.sp 2, N.wa
NW GERMANY:		
Moorberg	Crux 1989	N.m, N.sp 1, N.sp 2, N.spp
Konrad 101	Kemper *et al.* 1987	N.g
Moorberg	Mutterlose 1991	N.co, N.m, N.sp
Wiedensahl 2	Mutterlose 1991	N.g, N.st, N.sp 2

C. margerelii Zone (NLKA 18)

ONSHORE U.K:		
Speeton	Crux 1989	N.spp
OFFSHORE U.K:		
210/20-1	this study	N.e, N.g, N.k, N.o
22/26a-2 ?	this study	
29/7-1 ?	this study	N.p, N.g, N. ga N.k, N.m
DANISH CENTRAL TROUGH:		
E-1	this study	N.p, N. sp (2.3), N.bo

Adda-1	Thomsen 1987	N.e, N.g
Adda-2	this study	N cf ci
I-1	Thomsen 1987	*
North Jens-1	this study	N.g, N.gm, N.wa, N. cf o, N.st, N.e, N.br, N.k, N.sp 2
NW GERMANY:		
Moorberg	Mutterlose 1987	N.sp
Niederwöhren	Mutterlose 1991	N.m, N.sp
Konrad 101	Kemper *et al.* 1987	*

***T. septentrionalis* Zone (NLKA 17)**

ONSHORE U.K:		
Speeton	Crux 1989	*
OFFSHORE U.K:		
210/20-1 ?	this study	N.e, N.g, N.o, N.k
22/26a-2 ?	this study	
29/7-1 ?	this study	N.k, N.p, N.g, N.ga
DANISH CENTRAL TROUGH:		
E-1	this study	N.e, N.br, N.bo N.sp (2.2), N. cf.o
Adda-1	Thomsen 1987	N.e, N.g
Adda-2	this study	N.cf ci ?
I-1	Thomsen 1987	*
North Jens-1 ?	this study	N.g, N.gm, N.cf o, N.k, N.br, N.e, N.st, N.sp 2, N.wa
NW GERMANY:		
Moorberg	Mutterlose 1991	N.co, N.g, N.k, N.sp
Otto Gott	Crux 1989 & Mutterlose 1991	*
Konrad 101	Kemper *et al.* 1987	*

BARREMIAN

S. comptus Zone\C. *inaequalis* Zone (NLKA 15/16)

ONSHORE U.K:		
Speeton	Crux 1989	N.st, N.sp 2
Speeton	Taylor 1978	N.a
OFFSHORE U.K:		
210/20-1	this study	N.e, N.g, N.o, N.k
Moray-Firth	Jakubowski 1987	N.br
22/26a-2	this study	
29/7-1 ?	this study	N.p, N.k, N.g, N.ga
NORWAY:		
Sklinnabanken	Crux 1989	N.m, N.sp 2, N.sp.
DANISH CENTRAL TROUGH:		
Adda-1	Thomsen 1987	N.e, N.g
E-1	Thomsen 1987	N.a, N.e, N.g, N.st, N.t
E-1 ?	this study	N.e, N.br, N.bo, N. cf.o, N. sp (2.2), N.g
I-1	Thomsen 1987	N.a, N.bo, N.br, N.qg
North Jens-1 ?	this study	N.g, N.gm, N.wa, N.cf o, N.k, N.br, N.e, N.st, N.sp 2 N. wa
NW GERMANY:		
Moorberg	Mutterlose 1991	N.a, N.m, N.sp 2, N.sp
Moorberg	Köthe 1981	N.a
Frielingen	Mutterlose 1991	N.a, N.ci, N.aff ci, N.bu, N.g, N.k
Otto Gott	Mutterlose 1991	N.m, N.sp
Otto Gott	Crux 1989	N.m, N.st
Leiter	Mutterlose & Harding 1987	*

R. pseudoangustus Zone (NLKA 14)

ONSHORE U.K:		
Speeton	Crux 1989	N.a, N.m, N.sp 2
Speeton	Taylor 1978	N.a
OFFSHORE U.K:		
210/20-1 ?	this study	N.a, N.o
211/13-7	this study	?
Moray-Firth	Jakubowski 1987	N.a, N.br
22/26a-2	this study	N.a, N.p, N.g, N.br, N.em
29/7-1 ?	this study	N.a, N.m, N.g
15/25a-2	this study	N.a, N. cf o, N.k, N.qa, N.sp.1, N.g, N.wa, N.bu
NETHERLANDS BASIN:		
L/2-2	this study	N.a, N.p, N.m
DANISH CENTRAL TROUGH:		
Adda-1	Thomsen 1987	N.a, N.br
Adda-2	Thomsen 1987	N.a, N.bo, N.br, N.qg, N.e, N.g
Adda-2	this study	N.a
E-1	Mutterlose 1991	N.a, N.e, N.g, N.st, N.t
E-1 ?	this study	N.e, N.br, N.bo, N. cf.o, N.g, N.sp (2.2), N.a
I-1	Mutterlose 1991	N.a, N.br, N.bo, N.qg
I-1 ?	this study	N.a, N.m, N. sp 2
North Jens-1 ?	this study	N.a, N.g, N.br, N.cf o, N. em, N.e, N.p, N.bo, N.st, N.bu, N.d, N.tr
NW GERMANY:		
Aegi	Mutterlose & Harding 1987	N.a, N.br, N.e, N.sp,

		N.k
Leiter	Mutterlose & Harding 1987	N.a, N.e
Otto Gott	Mutterlose 1991	N.a, N.sp
Otto Gott	Crux 1989	N.m, N.sp 2, N.spp
Otto Gott	Mutterlose & Harding 1987	N.a
Moorberg	Mutterlose 1991	N.a, N.sp
Moorberg	Köthe 1981	N.a
Moorberg	Mutterlose & Harding 1987	N.a
Schacht Konrad 1	Stradner & Grün 1973	N.a
NW Germany	Cepek & Kemper 1981	N.a

C. conicus Zone (NLKA 13)

ONSHORE U.K:		
Speeton	Crux 1989	N.a, N.br, N.m, N.spp
Speeton	Taylor 1978	N.a
OFFSHORE U.K:		
210/20-1 ?	this study	N.a, N.o
211/13-7 ?	this study	?
Moray-Firth	Jakubowski 1987	N.a, N.br
22/26a-2	Perch-Nielsen 1988	N.lo
22/26a-2	this study	N.em, N.br, N.p, N.g N.a
29/7-1 ?	this study	N.a, N.m, N.g, N.ga
15/25a-2 ?	this study	N.g, N.wa, N.a, N.m, N.bu, N.sp
NETHERLANDS BASIN:		
L/2-2	this study	N.a, N.p, N.m, N.sp
DANISH CENTRAL TROUGH:		
Adda-1	Thomsen 1987	N.a
Adda-2	Thomsen 1987	N.a, N.bo, N.br, N.qg, N.e, N.g
Adda-2	this study	N.o, N.a, N.bo, N.p, N.m, N. cf ci
E-1	Thomsen 1987	N.a, N.e, N.g, N.st, N.t

E-1 ?	this study	N.a, N.t
I-1	Thomsen 1987	N.a, N.e, N.g, N.st,
I-1	this study	N.a, N.m, N. sp 2
North Jens-1	this study	N.a, N.g, N. cf o, N. br, N. em, N. e, N.p, N. bo, N. st, N.tr, N. bu, N. d
NW GERMANY:		
Aegi	Mutterlose & Harding 1987	N.a, N.br, N.e, N.sp, N.k
Leiter	Mutterlose & Harding 1987	N.a, N.e
Otto Gott	Crux 1989	N.a, N.sp 3
Otto Gott	Mutterlose & Harding 1987	N.a
Moorberg	Köthe 1981	N.a
Moorberg	Mutterlose & Harding 1987	N.a
Schacht Konrad 1	Stradner, Grün 1973	N.a
NW Germany	Cepek & Kemper 1981	N.a N.t, N.q

***Z. sisyphus* Zone (NLKA 12)**

ONSHORE U.K:		
Speeton	Taylor 1978	N.a
OFFSHORE U.K:		
2 10/20-1 ?	this study	N.a, N.o
211/13-7 ?	this study	?
Moray-Firth	Jakubowski 1987	N.a
22/26a-2	this study	N.a, N.em, N.g, N.p
29/7-1 ?	this study	N.a, N.m, N.g, N.ga
15/25a-2 ?	this study	N.g, N. sp, N.m, N.l, N.ga, N.e, N.d, N.bu, N.a
NETHERLANDS BASIN:		
L/2-2	this study	N.a, N. p, N.m

DANISH CENTRAL TROUGH:		
Adda-1	Thomsen 1987	N.a, N.e, N.g, N.st, N.t
Adda-2	Thomsen 1987	N.e, N.g, N.st, N.t
Adda-2	this study	N.m, N.a, N.o, N.bo, N.k
E-1 ?	this study	N.a, N.t
I-1	this study	N.a, N. sp 2
North Jens-1	this study	N.a, N.g, N.cf o, N.br, N.em, N.e, N.p, N.bo, N.st, N.tr, N.bu, N.d
NW GERMANY:		
Aegi	Mutterlose & Harding 1987	N.a, N.e, N.sp, N.k
Leiter ?	Mutterlose & Harding 1987	N.a, N.e
Moorberg ?	Mutterlose & Harding 1987	N.a
Moorberg	Köthe 1981	N.a
Otto Gott	Mutterlose 1991	N.a, N.sp
Otto Gott	Crux 1989	N.a
Otto Gott ?	Mutterlose & Harding 1987	N.a
Schacht Konrad 1 ?	Stradner & Grün 1973	N.a
Hoheneggelsen	Mutterlose 1991	N.a, N.br, N.e
NW Germany ?	Cepek & Kemper 1981	N.a N.bo, N.br, N.qg

V. matalosa Zone (NLKA 11)

ONSHORE U.K:		
Speeton	Taylor 1978	N.a
OFFSHORE U.K:		
210/20-1 ?	this study	N.a, N.o
211/13-7 ?	this study	?
Moray-Firth	Jakubowski 1987	N.a
22/26a-2	this study	N.a, N.p, N.em, N.g, N.sp 2
29/7-1 ?	this study	N.ga, N.m, N.m, N. bu

15/25a-2 ?	this study	N.m, N.g, N.sp, N.l, N.e, N.em, N.q, N.bu, N.a
NETHERLANDS BASIN:		
L/2-2	this study	N.a, N.p, N.m, N. sp
DANISH CENTRAL TROUGH:		
Adda-2	this study	N.a, N.m, N.o, N.g
E-1 ?	this study	N.a, N.t
I-1	this study	N.a
North Jens-1	this study	N.a, N.g, N. cf o, N.br, N.em, N.e, N.p, N.bo, N.st, N.tr, N.bu, N.d
NW GERMANY:		
Aegi	Mutterlose & Harding 1987	N.a, N.e, N.sp, N.k
Moorberg ?	Mutterlose & Harding 1987	N.a
Moorberg	Köthe 1981	N.a
Otto Gott ?	Mutterlose & Harding 1987	N.a
Schacht Konrad 1 ?	Stradner & Grün 1973	N.a
NW Germany ?	Cepek & Kemper 1981	N.a

***N.abundans* (Nlk 10) Zone**

ONSHORE U.K:		
Speeton	Taylor 1978	N.a
OFFSHORE U.K:		
202/8-1	this study	N.bo, N.p, N. sp 2, N.e, N.k
210/20-1 ?	this study	N.a, N.o
211/13-7 ?	this study	?
Moray-Firth	Jakubowski 1987	N.a
211/21-2 ?	this study	N.st, N. k, N. g, N.m, N.sp (2.3), N.sp (3.3)
22/26a-2	this study	N.a, N.p, N.em, N.g,

22/26a-2	this study	N. sp 2
29/3-1	this study	N.a
29/7-1	this study	N.a, N.m, N.bu, N.g, N. ga
15/25a-2	this study	N.a, N.sp, N.qa, N.m, N.em, N.sp 2, N.p, N.bo, N.br
NETHERLANDS BASIN:		
L/2-2	this study	N.a, N.p, N.m, N.sp
DANISH CENTRAL TROUGH:		
Adda-1	Thomsen 1987	N.a, N.e, N.g, N.st, N.t
Adda-2	Thomsen 1987	N.a, N.br, N.bo, N.e,
E-1	this study	N.a, N.t
I-1 ?	this study	N.a
North Jens-1	this study	N.a, N.cf o, N. ga, N.l, N. em, N.p, N.e, N.tr, N.d, N.sp
NW GERMANY:		
Aegi	Mutterlose & Harding 1987	N.a, N.e, N.sp, N.k
Moorberg ?	Mutterlose & Harding 1987	N.a
Moorberg	Köthe 1981	N.a
Otto Gott ?	Mutterlose & Harding 1987	N.a
Otto Gott	Mutterlose 1991	N.st
Schacht Konrad 1 ?	Stradner & Grün 1973	N.a
Hoheneggelsen	Mutterlose 1991	N.e, N.aff br, N.aff e, N.sp 1
NW Germany ?	Cepek & Kemper 1981	N.a N.g, N.qg

***N. abundans* Zone (NLK 10)**

OFFSHORE U.K:		
Moray-Firth	Jakubowski 1987	N.a
211/21-2 ?	this study	N. st, N. k, N. m, N.

		g, N.sp (2.3), N. sp. (3.3)
DANISH CENTRAL TROUGH:		
E-1	this study	N.a, N.t
NW GERMANY:		
Gott	Mutterlose & Harding 1987	N.a

***L. moray-firthensis* Zone (NLK 9)**

OFFSHORE U.K:		
202/8-1	this study	N.bo, N.p, N.sp 2, N.g
210/20-1 ?	this study	*
211/13-7 ?	this study	N.g, N.st, N.k, N.cf ci
211/21-2 ?	this study	N.ci, N. bu, N.tr N.g, N.st
22/26a-2 ?	this study	N.tr
29/3-1 ?	this study	*
29/7-1 ?	this study	N.m, N.g, N.k
15/25a-2 ?	this study	*
DANISH CENTRAL TROUGH:		
Adda-2	Thomsen 1987	N.bo, N.e, N.g, N.qg, N.qa, N.sp 1
E-1	Thomsen 1987	N.e, N.g, N.st, N.t
E-1	this study	N.g, N.t, N. sp 2, N. sp
I-1	Thomsen 1987	N.bo, N.e, N.g, N.qg
North Jens-1	this study	N.st, N.bo, N.bu, N.tr, N.sp
NW GERMANY:		
Hoheneggelsen	Mutterlose 1991	N.ci, N.e, N.t, N.k, N.st, N.sp
Rethmar	Mutterlose 1991	N.e, N.g, N.t, N.v, N.sp

APTIAN

E. varolii Sub-zone (NLK 8B)

DANISH CENTRAL TROUGH:		
Adda-2	Thomsen 1987	N.e, N.g, N.bo, N.qa, N.qg, N.sp 1
E-1	Thomsen 1987	N.e, N.g, N.t
I-1	Thomsen 1987	N.bo, N.e, N.g, N.qg
NW GERMANY:		
Hoheneggelsen	Mutterlose 1991	N.ci, N.e, N.st, N.t, N.sp, N.k

E. apertior Sub-zone (NLK 8A)

OFFSHORE U.K:		
29/7-1	this study	*
DANISH CENTRAL TROUGH:		
Adda-2	Thomsen 1987	N.bo, N.e, N.g, N.qa, N.qg, N.sp
E-1	Thomsen 1987	N.e, N.g, N.t
I-1	Thomsen 1987	N.bo, N.e, N.g, N.qg
NW GERMANY:		
Otto Gott	Mutterlose 1991	N.b, N.bu, N.t, N.sp

R. asper Zone (NLK 8)

OFFSHORE U.K:		
202/8-1 ?	this study	N.g, N.bo
210/20-1 ?	this study	*
211/13-7 ?	this study	*
211/21-2 ?	this study	N.tr, N.ci, N.bu, N.g, N.k
211/29-8a ?	this study	*
22/26a-2	this study	N. ga, N.tr, N. q
29/3-1 ?	this study	*
29/7-1 ?	this study	N.m, N.g, N.k

15/25a-2 ?	this study	*

DANISH CENTRAL TROUGH:

E-1	this study	N.t
North Jens-1	this study	N.bo

M. obtusus Zone (NLK 7)

OFFSHORE U.K:

202/8-1	this study	N.bo, N.g
210/20-1 ?	this study	*
211/13-7 ?	this study	*
211/29-8a ?	this study	*
22/26a-2 ?	this study	N.bo, N.tr
29/3-1	this study	*
29/7-1 ?	this study	*
15/25a-2 ?	this study	*
43/13-1 ?	this study	*

DANISH CENTRAL TROUGH:

Adda-2	Thomsen 1987	N.bo, N.e, N.g, N.qa, N.qg, N.sp
E-1	Thomsen 1987	N.e, N.g, N.t
I-1	Thomsen 1987	N.bo, N.e, N.g, N.qg
North Jens-1	this study	N.tr, N.e, N.bo, N.sp

NW GERMANY:

Arpeke 2	Mutterlose 1991	N.t

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B. ambiguus Zone (NLK 6)

OFFSHORE U.K:

202/8-1	this study	N.bo, N.g
210/201-1 ?	this study	*
211/13-7 ?	this study	*
211/21-2 ?	this study	*
22/26a-2 ?	this study	? N. bo, N.tr
29/3-1 ?	this study	*

29/7-1 ?	this study	*
15/25a-2 ?	this study	*
43/13-1 ?	this study	*

DANISH CENTRAL TROUGH:

Adda 2	Thomsen 1987	*
I-1	Thomsen 1987	*
North Jens-1 ?	this study	*

B. constans Sub-zone (NLK 5B)

OFFSHORE U.K:

211/29-8a	this study	*

P. columnata Sub-zone (NLK 5A)

No data

R. parvidentatum Zone (NLK 5)

OFFSHORE U.K:

202/8-1 ?	this study	*
210/20-1 ?	this study	*
211/13-7 ?	this study	*
211/21-2 ?	this study	*
211/29-8a ?	this study	*
22/26a-2	this study	*
29/7-1	this study	*
15/25a-2 ?	this study	*
43/13-1 ?	this study	N.tr

DANISH CENTRAL TROUGH:

North Jens-1 ?	this study	*

W. barnesae Sub-zone (NLK 4B)

No data

E. turriseiffeli Sub-zone (NLK 4A)

OFFSHORE U.K:		
211/29-8a	this study	N.tr
22/26a-2	this study	N.tr
29/7-1	this study	*

G. praeobliquum Zone (NLK 4)

ONSHORE U.K:		
Mundays Hill	Crux 1992	N.e, N.t, N.m, N.spp
OFFSHORE U.K:		
202/8-1	this study	*
210/20-1 ?	this study	*
211/13-7 ?	this study	*
15/25a-2 ?	this study	*
43/13-1 ?	this study	N.tr, N.m, ? N.g
DANISH CENTRAL TROUGH:		
North Jens-1 ?	this study	*

H. gorkae Zone (NLK 3)

ONSHORE U.K:		
Mundays Hill	Crux 1992	N.e, N.t, N.m, N.spp
OFFSHORE U.K:		
202/8-1 ?	this study	*
210/20-1 ?	this study	*
15/25a-2 ?	this study	*
43/13-1 ?	this study	N.sp

S. primitivuum Zone (NLK 2)

ONSHORE U.K:		
Mundays Hill	Crux 1992	N.e, N.t, N.m, N.spp

OFFSHORE U.K:		
202/8-1 ?	this study	N.bo, N.g
210/20-1 ?	this study	*
15/25a-2 ?	this study	*
43/13-1 ?	this study	N.sp

CENOMANIAN

***P. anfractus* Zone (NLK 1)**

No data

210/20-1

SYMBOL LEGEND

- . 1 SPECIMEN
- / 2-5 SPECIMENS
- o 6-20 "
- ● 21-100 "

? UNCERTAIN TAXONOMIC IDENTIFICATION

SAMPLE TYPES (ST): SW SIDEWALL

A/B	SCIENTIFIC NAME		REG NO.
A	SERIBISCUTUM	PRIMITIVUM (LARGE)	1
A	MANIVITELLA	PEMMATOIDEA	2
A	WATZNAUERIA	FOSSACINCTA	3
A	WATZNAUERIA	BARNESAE	4
A	GLAUKOLITHUS	COMPACTUS	5
A	GRANTARHABDUS	MEDDII	6
A	SOLLASITES	HAYI	7
A	VAGALAPILLA	MATALOSA	8
A	LITHRAPHIDITES	CARNIOLENSIS	9
A	NANNOCONUS	SP./DISC (FLORAL)	10
A	ZEUGRHABDOTUS	EMBERGERI	11
A	BISCUTUM	ELLIPTICUM(WIDE RIM)	12
A	DISCORHABDUS	IGNOTUS	13
A	BISCUTUM	ELLIPTICUM	14
A	CRETARHABDUS	CONICUS	15
A	PERISSOCYCLUS	FLETCHERI	16
A	RHAGODISCUS	ASPER	17
A	WATZNAUERIA	OVATA	18
A	AXOPODORHABDUS	DIETZMANNII	19
A	MICROSTAURUS	CHIASTIUS	20
A	RHAGODISCUS	ANGUSTUS	21
A	VAGALAPILLA	MATALOSA (SMALL)	22
A	ZEUGRHABDOTUS	SISYPHUS	23
A	STAUROLITHITES	SP.1	24
A	ZEUGRHABDOTUS	ERECTUS	25
A	ASSIPETRA	INFRACRETACEA	26
A	COROLLITHION	LAFFITTEI	27
A	CRUCIBISCUTUM	SALEBROSUM	28
A	MICRANTHOLITHUS	OBTUSUS	29
A	MICRANTHOLITHUS	SP.	30
A	KOKIA	SP.	31
A	NANNOCONUS	SP.	32
A	CRETARHABDUS	ANGUSTIFORATUS	33
A	NANNOCONUS	SP./DISC MGRP 3	34
A	TEGUMENTUM	STRIATUM	35
A	CONUSPHAERA	ROTHII	36
A	CYCLAGELOSPHAERA	MARGERELII	37
A	TEGULALITHUS	SEPTENTRIONALIS	38
A	LITHRAPHIDITES	MORAYFIRTHENSIS	39
A	MICRANTHOLITHUS	SPEETONENSIS	40
A	SPEETONIA	COLLIGATA	41
A	WATZNAUERIA	MANIVITAE	42
A	MICRANTHOLITHUS	HOSCHULZII	43
A	BUKRYLITHUS	AMBIGUUS	44
A	CAVED UPPER CRET.	NANNOFOSSILS	45
A	SOLLASITES	HORTICUS	46
A	SOLLASITES	SP.	47
A	TRANOLITHUS	GABALUS	48
A	NANNOCONUS	ABUNDANS	49
A	NANNOCONUS	ABUNDANS (BARREL)	50
A	NANNOCONUS	ABUNDANS (FLANGE)	51
A	NANNOCONUS	CF. CIRCULARIS	52
A	NANNOCONUS	MINUTUS	53
A	NANNOCONUS	CF. BUCHERI	54
A	NANNOCONUS	ELONGATUS	55
A	NANNOCONUS	KAMPTNERI KAMPTNERI	56
A	NANNOCONUS	STEINMANNI STEINMANNI	57
A	NANNOCONUS	CF. OVIFORMIS	58
A	NANNOCONUS	GLOBULUS	59
A	NANNOCONUS	SP. (OBLIQUE) 3.3	60

NANNOFOSSILS

MGRP 1.1

MGRP 2.2

MGRP 2.3

MGRP 3.3

INDEX	REG NO.
ASSIPETRA. INFRACRETACEA	26
AXOPODORH. DIETZMANNII	19
BISCUTUM . ELLIPTICUM	14
BISCUTUM . ELLIPTICUM(WIDE RIM)	12
BUKRYLITH. AMBIGUUS	44
CAVED UPP. NANNOFOSSILS	45
CONUSPHAE. ROTHII	36
COROLLITH. LAFFITTEI	27
CRETARHAB. ANGUSTIFORATUS	33
CRETARHAB. CONICUS	15
CRUCIBISC. SALEBROSUM	28
CYCLAGELO. MARGERELII	37
DISCORHAB. IGNOTUS	13
GLAUKOLIT. COMPACTUS	5
GRANTARHA. MEDDII	6
KOKIA . SP.	31
LITHRAPHI. CARNIOLENSIS	9
LITHRAPHI. MORAYFIRTHENSIS	39
MANIVITEL. PEMMATOIDEA	2
MICRANTHO. HOSCHULZII	43
MICRANTHO. OBTUSUS	29
MICRANTHO. SP.	30
MICRANTHO. SPEETONENSIS	40
MICROSTAU. CHIASTIUS	20
NANNOCONU. SP.	32
NANNOCONU. SP./DISC (FLORAL)	10
NANNOCONU. SP./DISC MGRP 3	34
PERISSOCY. FLETCHERI	16
RHAGODISC. ANGUSTUS	21
RHAGODISC. ASPER	17
SERIBISCU. PRIMITIVUM (LARGE)	1
SOLLASITE. HAYI	7
SOLLASITE. HORTICUS	46
SOLLASITE. SP.	47
SPEETONIA. COLLIGATA	41
STAUROLIT. SP. 1	24
TEGULALIT. SEPTENTRIONALIS	38
TEGUMENTU. STRIATUM	35
TRANOLITH. GABALUS	48
VAGALAPIL. MATALOSA	8
VAGALAPIL. MATALOSA (SMALL)	22
WATZNAUER. BARNESAE	4
WATZNAUER. FOSSACINCTA	3
WATZNAUER. MANIVITAE	42
WATZNAUER. OVATA	18
ZEUGRHABD. EMBERGERI	11
ZEUGRHABD. ERECTUS	25
ZEUGRHABD. SISYPHUS	23
NANNOCONU. ABUNDANS	49
NANNOCONU. ABUNDANS (BARREL)	50
NANNOCONU. ABUNDANS (FLANGE)	51
NANNOCONU. CF. CIRCULARIS	52
NANNOCONU. CF. BUCHERI	54
NANNOCONU. MINUTUS	53
NANNOCONU. ELONGATUS	55
NANNOCONU. KAMPTNERI KAMPTNERI	56
NANNOCONU. STEINMANNI STEINMANNI	57
NANNOCONU. CF. OVIFORMIS	58
NANNOCONU. GLOBULUS	59
NANNOCONU. SP. (OBLIQUE) 3.3	60

STNF

6721.00 6738.00 6748.00 6768.00 6778.00 6772.00 6782.00 6786.00 6794.00 6793.00 6800.00 6805.00 6925.00

DEPTH IN FEET BELOW DERRICK FLOOR

6721.00 6738.00 6748.00 6768.00 6778.00 6772.00 6782.00 6786.00 6794.00 6793.00 6800.00 6805.00 6925.00

NANNO-PLANKTON ZONATION

NN6 10-14

BIOSTRATIGRAPHIC SUBDIVISION

TIME-STRATIGRAPHIC SUBDIVISION

AP/AB

BA

HT? - VA

ACT?

SHELL U.K. EXPLORATION & PRODUCTION

SHETLAND BASIN
LOWER CRETACEOUS
CALCAREOUS NANNOFOSSILS
SHELL/ESSO WELL: 210/20-1

CONFIDENTIAL

Author : B.VAN NIEL | Date : 1991 | Rev.

Encl. 1 | Drawing No.

211/13-7

DEPTH IN FEET BELOW DERRICK FLOOR

A/B	SCIENTIFIC NAME		REG NO.		INDEX	REG NO.
A	GARTNERAGO	PRAEOBLIQUUM	1		ASSIPETRA. INFRACRETACEA	9
A	PREDISCOSPHAERA	COLUMNATA	2		AXOPODORH. DIETZMANNII	11
A	EPROLITHUS	ORBICULATUS	3		BISCUTUM . ELLIPTICUM	12
A	SERIBISCUTUM	PRIMITIVUM (LARGE)	4		BISCUTUM . ELLIPTICUM(WIDE RIM)	44
A	EIFFELLITHUS	TURRISEIFFELII	5		BUKRYLITH. AMBIGUUS	29
A	ZEUGRHABDOTUS	SISYPHUS	6		CAVED UPP. NANNOFOSSILS	7
A	CAVED UPPER CRET.	NANNOFOSSILS	7		CERATOLIT. SP.	27
A	STAUROLITHITES	CRUX	8		CHIASTOZY. CEPEKII	48
A	ASSIPETRA	INFRACRETACEA	9		COCCOSPHE. SP.	59
A	WATZNAUERIA	OVATA	10		CONUSPHAE. ROTHII	50
A	AXOPODORHABDUS	DIETZMANNII	11		COROLLITH. LAFFITT EI	30
A	BISCUTUM	ELLIPTICUM	12		CRETARHAB. ANGUSTIFORATUS	42
A	CYCLAGELOSPHAERA	MARGERELII	13		CRETARHAB. CONICUS	19
A	DISCORHABDUS	IGNOTUS	14		CRETARHAB. SP.	64
A	RHAGODISCUS	ASPER	15		CRUCIBISC. SALEBROSUM	24
A	WATZNAUERIA	BARNESAE	16		CRUCIELLI. CUVILLIERI	33
A	TEGUMENTUM	STRADNERI	17		CYCLAGELO. MARGERELII	13
A	EPROLITHUS	VAROLII	18		DIAZOMATO. LEHMANII	37
A	CRETARHABDUS	CONICUS	19		DISCORHAB. IGNOTUS	14
A	MICROSTAURUS	CHIASTIUS	20		EIFFELLIT. TURRISEIFFELII	5
A	WATZNAUERIA	FOSSACINCTA	21		EPROLITHU. ORBICULATUS	3
A	VAGALAPILLA	MATALOSA	22		EPROLITHU. SP.	53
A	RHAGODISCUS	ANGUSTUS	23		EPROLITHU. VAROLII	18
A	CRUCIBISCUTUM	SALEBROSUM	24		GARTNERAG. PRAEOBLIQUUM	1
A	PERISSOCYCLUS	NOELIAE	25		GRANTARHA. MEDDII	32
A	SOLLASITES	HAYI	26		HEMIPODOR. GORKAE	56
A	CERATOLITHINA	SP.	27		HOLOCOCCO. SP.	62
A	ZEUGRHABDOTUS	ERECTUS	28		KOKIA . BOREALIS	60
A	BUKRYLITHUS	AMBIGUUS	29		KOKIA . CURVATUS	45
A	COROLLITHION	LAFFITTEI	30		LITHRAPHI. CARNIOLENSIS	31
A	LITHRAPHIDITES	CARNIOLENSIS	31		MANIVITEL. PEMMATOIDEA	38
A	GRANTARHABDUS	MEDDII	32		MICRANTHO. HOSCHULZII	39
A	CRUCIELLIPSIS	CUVILLIERI	33		MICRANTHO. LAMBERTII	46
A	RHAGODISCUS	PSEUDOANGUSTUS	34		MICRANTHO. OBTUSUS	40
A	SPEETONIA	COLLIGATA	35		MICRANTHO. SPEETONENSIS	52
A	STAUROLITHITES	SP. 1	36		MICROSTAU. CHIASTIUS	20
A	DIAZOMATOLITHUS	LEHMANII	37		NANNOCONU. SP.	47
A	MANIVITELLA	PEMMATOIDEA	38		NANNOCONU. SP./DISC (FLORAL)	55
A	MICRANTHOLITHUS	HOSCHULZII	39		NANNOCONU. SP./DISC (SMOOTH)	54
A	MICRANTHOLITHUS	OBTUSUS	40		NANNOCONU. SP./DISC MGRP 3	63
A	ZEUGRHABDOTUS	EMBERGERI	41		PERISSOCY. NOELIAE	25
A	CRETARHABDUS	ANGUSTIFORATUS	42		PREDISCOS. COLUMNATA	2
A	TRIQUETORHABDULUS	SHETLANDENSIS	43		RHAGODISC. ANGUSTUS	23
A	BISCUTUM	ELLIPTICUM(WIDE RIM)	44		RHAGODISC. ASPER	15
A	KOKIA	CURVATUS	45		RHAGODISC. PSEUDOANGUSTUS	34
A	MICRANTHOLITHUS	LAMBERTII	46		SERIBISCU. PRIMITIVUM (LARGE)	4
A	NANNOCONUS	SP.	47		SOLLASITE. ARCUATUS	61
A	CHIASTOZYGOUS	CEPEKII	48		SOLLASITE. HAYI	26
A	TEGULALITHUS	SEPTENTRIONALIS	49		SOLLASITE. HORTICUS	57
A	CONUSPHAERA	ROTHII	50		SOLLASITE. SP.	65
A	TRANOLITHUS	GABALUS	51		SPEETONIA. COLLIGATA	35
A	MICRANTHOLITHUS	SPEETONENSIS	52		STAUROLIT. CRUX	8
A	EPROLITHUS	SP.	53		STAUROLIT. MUTTERLOSEI	58
A	NANNOCONUS	SP./DISC (SMOOTH)	54		STAUROLIT. SP. 1	36
A	NANNOCONUS	SP./DISC (FLORAL)	55		TEGULALIT. SEPTENTRIONALIS	49
A	HEMIPODORHABDUS	GORKAE	56		TEGUMENTU. STRADNERI	17
A	SOLLASITES	HORTICUS	57		TRANOLITH. GABALUS	51
A	STAUROLITHITES	MUTTERLOSEI	58		TRIQUETOR. SHETLANDENSIS	43
A	COCCOSPHERES	SP.	59		VAGALAPIL. MATALOSA	22
A	KOKIA	BOREALIS	60		WATZNAUER. BARNESAE	16
A	SOLLASITES	ARCUATUS	61		WATZNAUER. FOSSACINCTA	21
A	HOLOCOCCOLITH	SP.	62		WATZNAUER. OVATA	10
A	NANNOCONUS	SP./DISC MGRP 3	63		ZEUGRHABD. EMBERGERI	41
A	CRETARHABDUS	SP.	64		ZEUGRHABD. ERECTUS	28
A	SOLLASITES	SP.	65		ZEUGRHABD. SISYPHUS	6
A	NANNOCONUS	CF. CIRCULARIS	66	MGRP 1.1	NANNOCONU. CF. CIRCULARIS	66
A	NANNOCONUS	SP. (LARGE DISC)	67		NANNOCONU. SP. (LARGE DISC)	67
A	NANNOCONUS	CONCAVUS	68		NANNOCONU. CONCAVUS	68
A	NANNOCONUS	DAUVILLIERI	69	MGRP 2.2	NANNOCONU. DAUVILLIERI	69
A	NANNOCONUS	KAMPTNERI KAMPTNERI	70	MGRP 2.3	NANNOCONU. KAMPTNERI KAMPTNERI	70
A	NANNOCONUS	STEINMANNI STEINMANNI	71		NANNOCONU. KAMPTNERI MINOR	72
A	NANNOCONUS	KAMPTNERI MINOR	72		NANNOCONU. STEINMANNI STEINMANNI	71
A	NANNOCONUS	GLOBULUS GLOBULUS	73	MGRP 3.3	NANNOCONU. GLOBULUS GLOBULUS	73
A	NANNOCONUS	OVIFORMIS	74		NANNOCONU. OVIFORMIS	74

NANNOFOSSILS

SYMBOL LEGEND

■ BARREN SAMPLE (NF)
• 1 SPECIMEN
/ 2-5 SPECIMENS
o 6-20 .
● 21-100 .
? UNCERTAIN TAXONOMIC IDENTIFICATION

SAMPLE TYPES (ST): SIDEWALL

STNF

1164.5M 1163.0M 1162.5M 1162.0M 1161.5M 1161.0M 1160.5M 1160.0M 1159.5M 1159.0M 1158.5M 1158.0M 1157.5M 1157.0M 1156.5M 1156.0M 1155.5M 1155.0M 1154.5M 1154.0M 1153.5M 1153.0M 1152.5M 1152.0M 1151.5M 1151.0M 1150.5M 1150.0M 1149.5M 1149.0M 1148.5M 1148.0M 1147.5M 1147.0M 1146.5M 1146.0M 1145.5M 1145.0M 1144.5M 1144.0M 1143.5M 1143.0M 1142.5M 1142.0M 1141.5M 1141.0M 1140.5M 1140.0M 1139.5M 1139.0M 1138.5M 1138.0M 1137.5M 1137.0M 1136.5M 1136.0M 1135.5M 1135.0M 1134.5M 1134.0M 1133.5M 1133.0M 1132.5M 1132.0M 1131.5M 1131.0M 1130.5M 1130.0M 1129.5M 1129.0M 1128.5M 1128.0M 1127.5M 1127.0M 1126.5M 1126.0M 1125.5M 1125.0M 1124.5M 1124.0M 1123.5M 1123.0M 1122.5M 1122.0M 1121.5M 1121.0M 1120.5M 1120.0M 1119.5M 1119.0M 1118.5M 1118.0M 1117.5M 1117.0M 1116.5M 1116.0M 1115.5M 1115.0M 1114.5M 1114.0M 1113.5M 1113.0M 1112.5M 1112.0M 1111.5M 1111.0M 1110.5M 1110.0M 1109.5M 1109.0M 1108.5M 1108.0M 1107.5M 1107.0M 1106.5M 1106.0M 1105.5M 1105.0M 1104.5M 1104.0M 1103.5M 1103.0M 1102.5M 1102.0M 1101.5M 1101.0M 1100.5M 1100.0M 1099.5M 1099.0M 1098.5M 1098.0M 1097.5M 1097.0M 1096.5M 1096.0M 1095.5M 1095.0M 1094.5M 1094.0M 1093.5M 1093.0M 1092.5M 1092.0M 1091.5M 1091.0M 1090.5M 1090.0M 1089.5M 1089.0M 1088.5M 1088.0M 1087.5M 1087.0M 1086.5M 1086.0M 1085.5M 1085.0M 1084.5M 1084.0M 1083.5M 1083.0M 1082.5M 1082.0M 1081.5M 1081.0M 1080.5M 1080.0M 1079.5M 1079.0M 1078.5M 1078.0M 1077.5M 1077.0M 1076.5M 1076.0M 1075.5M 1075.0M 1074.5M 1074.0M 1073.5M 1073.0M 1072.5M 1072.0M 1071.5M 1071.0M 1070.5M 1070.0M 1069.5M 1069.0M 1068.5M 1068.0M 1067.5M 1067.0M 1066.5M 1066.0M 1065.5M 1065.0M 1064.5M 1064.0M 1063.5M 1063.0M 1062.5M 1062.0M 1061.5M 1061.0M 1060.5M 1060.0M 1059.5M 1059.0M 1058.5M 1058.0M 1057.5M 1057.0M 1056.5M 1056.0M 1055.5M 1055.0M 1054.5M 1054.0M 1053.5M 1053.0M 1052.5M 1052.0M 1051.5M 1051.0M 1050.5M 1050.0M 1049.5M 1049.0M 1048.5M 1048.0M 1047.5M 1047.0M 1046.5M 1046.0M 1045.5M 1045.0M 1044.5M 1044.0M 1043.5M 1043.0M 1042.5M 1042.0M 1041.5M 1041.0M 1040.5M 1040.0M 1039.5M 1039.0M 1038.5M 1038.0M 1037.5M 1037.0M 1036.5M 1036.0M 1035.5M 1035.0M 1034.5M 1034.0M 1033.5M 1033.0M 1032.5M 1032.0M 1031.5M 1031.0M 1030.5M 1030.0M 1029.5M 1029.0M 1028.5M 1028.0M 1027.5M 1027.0M 1026.5M 1026.0M 1025.5M 1025.0M 1024.5M 1024.0M 1023.5M 1023.0M 1022.5M 1022.0M 1021.5M 1021.0M 1020.5M 1020.0M 1019.5M 1019.0M 1018.5M 1018.0M 1017.5M 1017.0M 1016.5M 1016.0M 1015.5M 1015.0M 1014.5M 1014.0M 1013.5M 1013.0M 1012.5M 1012.0M 1011.5M 1011.0M 1010.5M 1010.0M 1009.5M 1009.0M 1008.5M 1008.0M 1007.5M 1007.0M 1006.5M 1006.0M 1005.5M 1005.0M 1004.5M 1004.0M 1003.5M 1003.0M 1002.5M 1002.0M 1001.5M 1001.0M 1000.5M 1000.0M 999.5M 999.0M 998.5M 998.0M 997.5M 997.0M 996.5M 996.0M 995.5M 995.0M 994.5M 994.0M 993.5M 993.0M 992.5M 992.0M 991.5M 991.0M 990.5M 990.0M 989.5M 989.0M 988.5M 988.0M 987.5M 987.0M 986.5M 986.0M 985.5M 985.0M 984.5M 984.0M 983.5M 983.0M 982.5M 982.0M 981.5M 981.0M 980.5M 980.0M 979.5M 979.0M 978.5M 978.0M 977.5M 977.0M 976.5M 976.0M 975.5M 975.0M 974.5M 974.0M 973.5M 973.0M 972.5M 972.0M 971.5M 971.0M 970.5M 970.0M 969.5M 969.0M 968.5M 968.0M 967.5M 967.0M 966.5M 966.0M 965.5M 965.0M 964.5M 964.0M 963.5M 963.0M 962.5M 962.0M 961.5M 961.0M 960.5M 960.0M 959.5M 959.0M 958.5M 958.0M 957.5M 957.0M 956.5M 956.0M 955.5M 955.0M 954.5M 954.0M 953.5M 953.0M 952.5M 952.0M 951.5M 951.0M 950.5M 950.0M 949.5M 949.0M 948.5M 948.0M 947.5M 947.0M 946.5M 946.0M 945.5M 945.0M 944.5M 944.0M 943.5M 943.0M 942.5M 942.0M 941.5M 941.0M 940.5M 940.0M 939.5M 939.0M 938.5M 938.0M 937.5M 937.0M 936.5M 936.0M 935.5M 935.0M 934.5M 934.0M 933.5M 933.0M 932.5M 932.0M 931.5M 931.0M 930.5M 930.0M 929.5M 929.0M 928.5M 928.0M 927.5M 927.0M 926.5M 926.0M 925.5M 925.0M 924.5M 924.0M 923.5M 923.0M 922.5M 922.0M 921.5M 921.0M 920.5M 920.0M 919.5M 919.0M 918.5M 918.0M 917.5M 917.0M 916.5M 916.0M 915.5M 915.0M 914.5M 914.0M 913.5M 913.0M 912.5M 912.0M 911.5M 911.0M 910.5M 910.0M 909.5M 909.0M 908.5M 908.0M 907.5M 907.0M 906.5M 906.0M 905.5M 905.0M 904.5M 904.0M 903.5M 903.0M 902.5M 902.0M 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186.5M 186.0M 185.5M 185.0M 184.5M 184.0M 183.5M 183.0M 182.5M 182.0M 181.5M 181.0M 180.5M 180.0M 179.5M 179.0M 178.5M 178.0M 177.5M 177.0M 176.5M 176.0M 175.5M 175.0M 174.5M 174.0M 173.5M 173.0M 172.5M 172.0M 171.5M 171.0M 170.5M 170.0M 169.5M 169.0M 168.5M 168.0M 167.5M 167.0M 166.5M 166.0M 165.5M 165.0M 164.5M 164.0M 163.5M 163.0M 162.5M 162.0M 161.5M 161.0M 160.5M 160.0M 159.5M 159.0M 158.5M 158.0M 157.5M 157.0M 156.5M 156.0M 155.5M 155.0M 154.5M 154.0M 153.5M 153.0M 152.5M 152.0M 151.5M 151.0M 150.5M 150.0M 149.5M 149.0M 148.5M 148.0M 147.5M 147.0M 146.5M 146.0M 145.5M 145.0M 144.5M 144.0M 143.5M 143.0M 142.5M 142.0M 141.5M 141.0M 140.5M 140.0M 139.5M 139.0M 138.5M 138.0M 137.5M 137.0M 136.5M 136.0M 135.5M 135.0M 134.5M 134.0M 133.5M 133.0M 132.5M 132.0M 131.5M 131.0M 130.5M 130.0M 129.5M 129.0M 128.5M 128.0M 127.5M 127.0M 126.5M 126.0M 125.5M 125.0M 124.5M 124.0M 123.5M 123.0M 122.5M 122.0M 121.5M 121.0M 120.5M 120.0M 119.5M 119.0M 118.5M 118.0M 117.5M 117.0M 116.5M 116.0M 115.5M 115.0M 114.5M 114.0M 113.5M 113.0M 112.5M 112.0M 111.5M 111.0M 110.5M 110.0M 109.5M 109.0M 108.5M 108.0M 107.5M 107.0M 106.5M 106.0M 105.5M 105.0M 104.5M 104.0M 103.5M 103.0M 102.5M 102.0M 101.5M 101.0M 100.5M 100.0M 99.5M 99.0M 98.5M 98.0M 97.5M 97.0M 96.5M 96.0M 95.5M 95.0M 94.5M 94.0M 93.5M 93.0M 92.5M 92.0M 91.5M 91.0M 90.5M 90.0M 89.5M 89.0M 88.5M 88.0M 87.5M 87.0M 86.5M 86.0M 85.5M 85.0M 84.5M 84.0M 83.5M 83.0M 82.5M 82.0M 81.5M 81.0M 80.5M 80.0M 79.5M 79.0M 78.5M 78.0M 77.5M 77.0M 76.5M 76.0M 75.5M 75.0M 74.5M 74.0M 73.5M 73.0M 72.5M 72.0M 71.5M 71.0M 70.5M 70.0M 69.5M 69.0M 68.5M 68.0M 67.5M 67.0M 66.5M 66.0M 65.5M 65.0M 64.5M 64.0M 63.5M 63.0M 62.5M 62.0M 61.5M 61.0M 60.5M 60.0M 59.5M 59.0M 58.5M 58.0M 57.5M 57.0M 56.5M 56.0M 55.5M 55.0M 54.5M 54.0M 53.5M 53.0M 52.5M 52.0M 51.5M 51.0M 50.5M 50.0M 49.5M 49.0M 48.5M 48.0M 47.5M 47.0M 46.5M 46.0M 45.5M 45.0M 44.5M 44.0M 43.5M 43.0M 42.5M 42.0M 41.5M 41.0M 40.5M 40.0M 39.5M 39.0M 38.5M 38.0M 37.5M 37.0M 36.5M 36.0M 35.5M 35.0M 34.5M 34.0M 33.5M 33.0M 32.5M 32.0M 31.5M 31.0M 30.5M 30.0M 29.5M 29.0M 28.5M 28.0M 27.5M 27.0M 26.5M 26.0M 25.5M 25.0M 24.5M 24.0M 23.5M 23.0M 22.5M 22.0M 21.5M 21.0M 20.5M 20.0M 19.5M 19.0M 18.5M 18.0M 17.5M 17.0M 16.5M 16.0M 15.5M 15.0M 14.5M 14.0M 13.5M 13.0M 12.5M 12.0M 11.5M 11.0M 10.5M 10.0M 9.5M 9.0M 8.5M 8.0M 7.5M 7.0M 6.5M 6.0M 5.5M 5.0M 4.5M 4.0M 3.5M 3.0M 2.5M 2.0M 1.5M 1.0M 0.5M 0.0M

DEPTH IN FEET BELOW DERRICK FLOOR

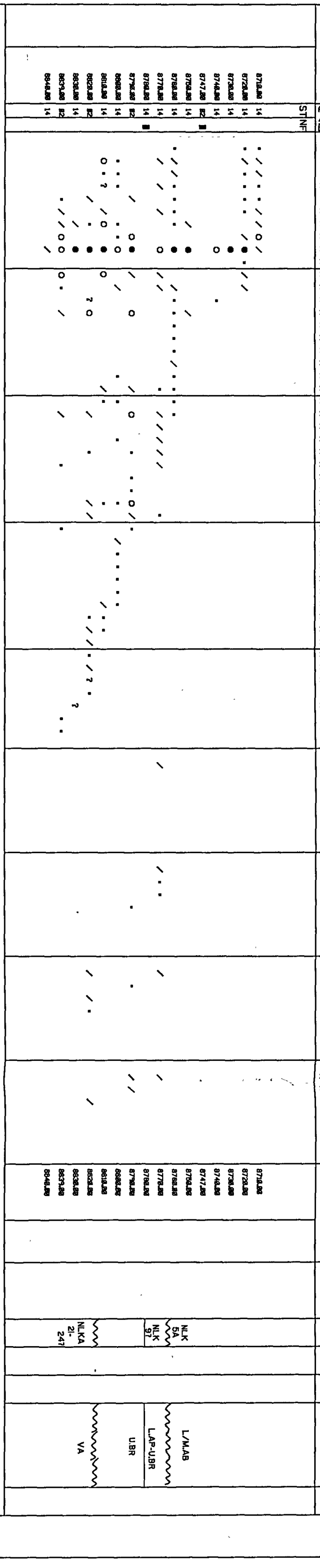
NANNO-PLANKTON ZONATION

BIOSTRATIGRAPHIC SUBDIVISION

TIME-STRATIGRAPHIC SUBDIVISION

NLK 4/5 | NLK 3b-NLKA 1b /

211/21-2



A/B	SCIENTIFIC NAME		REG NO.		INDEX	REG NO.
A	VAGALAPILLA	MATALOSA	1		AXOPODORH. DIETZMANNII	38
A	GARTNERAGO	PRAEOBLIQUUM	2		BISCUTUM . ELLIPTICUM	22
A	PREDISCOSPHAERA	COLUMNATA	3		BRAARUDOS. STENORHETHA	15
A	VAGALAPILLA	MATALOSA (SMALL)	4		BUKRYLITH. AMBIGUUS	20
A	CRETARHABDUS	CONICUS	5		CAVED UPP. NANNOFOSSILS	11
A	EPROLITHUS	FLORALIS	6		COCCOSPHE. SP.	24
A	RHAGODISCUS	ASPER	7		CONUSPHAE. ROTHII	26
A	WATZNAUERIA	FOSSACINCTA	8		COROLLITH. LAFFITTEI	25
A	WATZNAUERIA	BARNESAE	9		CRETARHAB. CONICUS	5
A	TEGUMENTUM	SALILLUM	10		CRETARHAB. SP.	37
A	CAVED UPPER CRET.	NANNOFOSSILS	11		CRUCIBISC. SALEBROSUM	29
A	ZEUGRHABDOTUS	SISYPHUS	12		CYCLAGELO. MARGERELII	14
A	GRANTARHABDUS	MEDDII	13		DISCORHAB. IGNOTUS	39
A	CYCLAGELOSPHAERA	MARGERELII	14		EIFFELLIT. TURRISEIFFELII	32
A	BRAARUDOSPHAERA	STENORHETHA	15		EIFFELLIT. TURRISEIFFELLI	16
A	EIFFELLITHUS	TURRISEIFFELLI	16		EPROLITHU. FLORALIS	6
A	EPROLITHUS	ORBICULATUS	17		EPROLITHU. ORBICULATUS	17
A	PREDISCOSPHAERA	SP.	18		EPROLITHU. SP.	21
A	TEGUMENTUM	STRADNERI	19		GARTNERAG. OBLIQUUM	23
A	BUKRYLITHUS	AMBIGUUS	20		GARTNERAG. PRAEOBLIQUUM	2
A	EPROLITHUS	SP.	21		GRANTARHA. MEDDII	13
A	BISCUTUM	ELLIPTICUM	22		KOKIA . BOREALIS	40
A	GARTNERAGO	OBLIQUUM	23		KOKIA . CURVATUS	41
A	COCCOSPHERES	SP.	24		LITHRAPHI. CARNIOLENSIS	27
A	COROLLITHION	LAFFITTEI	25		MANIVITEL. PEMMATOIDEA	46
A	CONUSPHAERA	ROTHII	26		MICRANTHO. HOSCHULZII	30
A	LITHRAPHIDITES	CARNIOLENSIS	27		MICRANTHO. OBTUSUS	42
A	ZEUGRHABDOTUS	EMBERGERI	28		NANNOCONU. SP.	31
A	CRUCIBISCUTUM	SALEBROSUM	29		PREDISCOS. COLUMNATA	3
A	MICRANTHOLITHUS	HOSCHULZII	30		PREDISCOS. SP.	18
A	NANNOCONUS	SP.	31		RHAGODISC. ANGUSTUS	33
A	EIFFELLITHUS	TURRISEIFFELII	32		RHAGODISC. ASPER	7
A	RHAGODISCUS	ANGUSTUS	33		SERIBISCU. PRIMITIVUM (LARGE)	43
A	STAUROLITHITES	CRUX	34		SOLLASITE. ARCUATUS	44
A	WATZNAUERIA	OVATA	35		SPEETONIA. COLLIGATA	45
A	ZEUGRHABDOTUS	ERECTUS	36		STAUROLIT. CRUX	34
A	CRETARHABDUS	SP.	37		TEGUMENTU. SALILLUM	10
A	AXOPODORHABDUS	DIETZMANNII	38		TEGUMENTU. STRADNERI	19
A	DISCORHABDUS	IGNOTUS	39		VAGALAPIL. MATALOSA	1
A	KOKIA	BOREALIS	40		VAGALAPIL. MATALOSA (SMALL)	4
A	KOKIA	CURVATUS	41		WATZNAUER. BARNESAE	9
A	MICRANTHOLITHUS	OBTUSUS	42		WATZNAUER. FOSSACINCTA	8
A	SERIBISCUTUM	PRIMITIVUM (LARGE)	43		WATZNAUER. MANIVITAE	47
A	SOLLASITES	ARCUATUS	44		WATZNAUER. OVATA	35
A	SPEETONIA	COLLIGATA	45		ZEUGRHABD. EMBERGERI	28
A	MANIVITELLA	PEMMATOIDEA	46		ZEUGRHABD. ERECTUS	36
A	WATZNAUERIA	MANIVITAE	47		ZEUGRHABD. SISYPHUS	12
A	NANNOCONUS	CIRCULARIS	48	MGRP 1.1	NANNOCONU. CIRCULARIS	48
A	NANNOCONUS	BUCHERI	49	MGRP 2.2	NANNOCONU. BUCHERI	49
A	NANNOCONUS	SP. (OBLIQUE) 2.2	50		NANNOCONU. MINUTUS	52
A	NANNOCONUS	TRUITTI TRUITTI	51		NANNOCONU. SP. (OBLIQUE) 2.2	50
A	NANNOCONUS	MINUTUS	52		NANNOCONU. TRUITTI TRUITTI	51
A	NANNOCONUS	STEINMANNI STEINMANNI	53	MGRP 2.3	NANNOCONU. KAMPTNERI KAMPTNERI	54
A	NANNOCONUS	KAMPTNERI KAMPTNERI	54		NANNOCONU. SP. (FRAGMENTS) 2.3	55
A	NANNOCONUS	SP. (FRAGMENTS) 2.3	55		NANNOCONU. SP. (OBLIQUE) 2.3	56
A	NANNOCONUS	SP. (OBLIQUE) 2.3	56		NANNOCONU. STEINMANNI STEINMANNI	53
A	NANNOCONUS	GLOBULUS GLOBULUS	57	MGRP 3.3	NANNOCONU. GLOBULUS	57
A	NANNOCONUS	SP. (OBLIQUE) 3.3	58		NANNOCONU. GLOBULUS SUBSP NOV.A	59
A	NANNOCONUS	GLOBULUS SUBSP NOV.A	59		NANNOCONU. SP. (OBLIQUE) 3.3	58

DEPTH IN FEET BELOW DERRICK FLOOR

BIOSTRATIGRAPHIC SUBDIVISION

NANNO-PLANKTON ZONATION

NLK 5A
NLK 97
NLKA 21-247

TIME-STRATIGRAPHIC SUBDIVISION

L/M.AB
L.AP-U.BR
U.BR
VA

SYMBOL LEGEND

■ BARREN SAMPLE (NF)
• 1 SPECIMEN
/ 2-5 SPECIMENS
○ 6-20 "
● 21-100 "
? UNCERTAIN TAXONOMIC IDENTIFICATION

SAMPLE TYPES (ST):

SW SIDEWALL
DC DRIED DITCH CTG

SHELL U.K. EXPLORATION & PRODUCTION

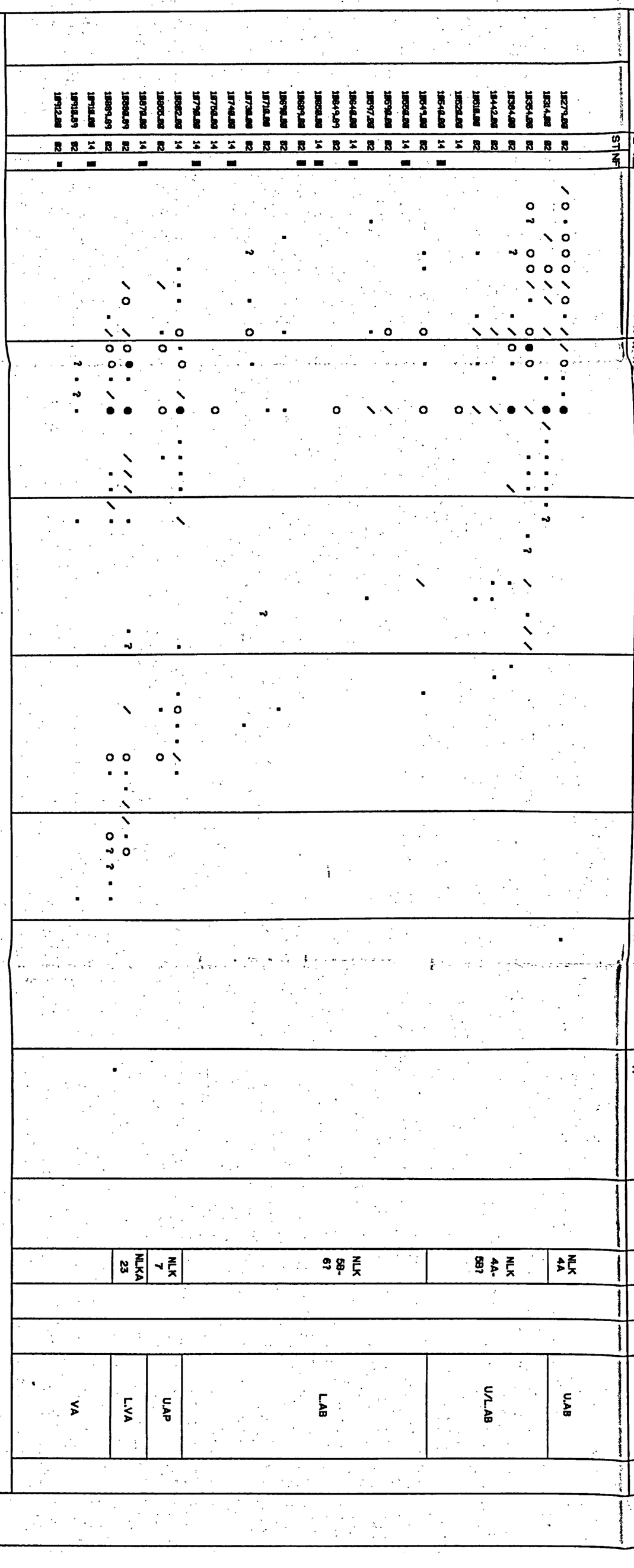
SHETLAND BASIN
LOWER CRETACEOUS
CALCAREOUS NANNOFOSSILS
SHELL/ESSO WELL:211/21-2

CONFIDENTIAL

Author : B.VAN NIEL | Date : 1991 | Rev.
Encl. 3 | Drawing No.

211/29-8A

DEPTH IN FEET BELOW DERRICK FLOOR



A/B	SCIENTIFIC NAME		REG NO.
A	TEGUMENTUM	SALIUM	1
A	SERIBISCUTUM	PRIMITIVUM (LARGE)	2
A	EPROLITHUS	FLORALIS	3
A	EIFFELLITHUS	TURRISEIFFELII	4
A	PREDISCOSPHAERA	COLUMNATA	5
A	ZEUGRHABDOTUS	SISYPHUS	6
A	CAVED UPPER CRET.	NANNOFOSSILS	7
A	DISCORHABDUS	IGNOTUS	8
A	MANIVITELLA	PEMMATOIDEA	9
A	RHAGODISCUS	ASPER	10
A	WATZNAUERIA	FOSSACINCTA	11
A	BISCUTUM	ELLIPTICUM	12
A	BISCUTUM	ELLIPTICUM(WIDE RIM)	13
A	MICRANTHOLITHUS	SP.	14
A	WATZNAUERIA	BARNESAE	15
A	TRANOLITHUS	GABALUS	16
A	STAUROLITHITES	SP.1	17
A	WATZNAUERIA	OVATA	18
A	BUKRYLITHUS	AMBIGUUS	19
A	CRETARHABDUS	CONICUS	20
A	WATZNAUERIA	MANIVITAE	21
A	AXOPODORHABDUS	DIETZMANNII	22
A	CRETARHABDUS	SP.	23
A	TEGUMENTUM	STRIATUM	24
A	EPROLITHUS	ORBICULATUS	26
A	EPROLITHUS	VAROLII	27
A	EPROLITHUS	SP.11	28
A	COROLLITHION	LAFFITTTEI	29
A	GLAUKOLITHUS	COMPACTUS	30
A	NANNOCONUS	SP./DISC MGRP 2.	31
A	REPAGULUM	PARVIDENTATUM	32
A	HOLOCOCCOLITH	SP.	33
A	CYCLAGELOSPHAERA	MARGERELII	34
A	EPROLITHUS	SP.	35
A	PERISSOCYCLUS	PLETHOTRETUS	36
A	CRUCIBISCUTUM	SALEBROSUM	37
A	MICRANTHOLITHUS	HOSCHULZII	38
A	COROLLITHION	SILVARADION	39
A	KOKIA	SP.	40
A	STAUROLITHITES	CRUX	41
A	MICRANTHOLITHUS	SPEETONENSIS	42
A	SOLLASITES	HORTICUS	43
A	COROLLITHION	RHOMBICUM	44
A	NANNOCONUS	SP./DISC (SMOOTH)	45
A	CONUSPHAERA	ROTHII	46
A	NANNOCONUS	TRUITTI GROUP	47
A	NANNOCONUS	STEINMANNI MINOR	48

NANNOFOSSILS

MGRP 2.2

MGRP 2.3

INDEX	REG NO.
AXOPODORH. DIETZMANNII	22
BISCUTUM . ELLIPTICUM	12
BISCUTUM . ELLIPTICUM(WIDE RIM)	13
BUKRYLITH. AMBIGUUS	19
CAVED UPP. NANNOFOSSILS	7
CONUSPHAE. ROTHII	46
COROLLITH. LAFFITEI	29
COROLLITH. RHOMBICUM	44
COROLLITH. SILVARADION	39
CRETARHAB. CONICUS	20
CRETARHAB. SP.	23
CRUCIBISC. SALEBROSUM	37
CYCLAGELO. MARGERELII	34
DISCORHAB. IGNOTUS	8
EIFFELLIT. TURRISEIFFELII	4
EPROLITHU. FLORALIS	3
EPROLITHU. ORBICULATUS	26
EPROLITHU. SP.	35
EPROLITHU. SP. 11	28
EPROLITHU. VAROLII	27
GLAUKOLIT. COMPACTUS	30
HOLOCOCCO. SP.	33
KOKIA . SP.	40
MANIVITEL. PEMMATOIDEA	9
MICRANTHO. HOSCHULZII	38
MICRANTHO. SP.	14
MICRANTHO. SPEETONENSIS	42
NANNOCONU. SP./DISC (SMOOTH)	45
NANNOCONU. SP./DISC MGRP 2.	31
PERISSOCY. PLETHOTRETUS	36
PREDISCOS. COLUMNATA	5
REPAGULUM. PARVIDENTATUM	32
RHAGODISC. ASPER	10
SERIBISCU. PRIMITIVUM (LARGE)	2
SOLLASITE. HORTICUS	43
STAUROLIT. CRUX	41
STAUROLIT. SP. 1	17
TEGUMENTU. SALIUM	1
TEGUMENTU. STRIATUM	24
TRANOLITH. GABALUS	16
WATZNAUER. BARNESAE	15
WATZNAUER. FOSSACINCTA	11
WATZNAUER. MANIVITAE	21
WATZNAUER. OVATA	18
ZEUGRHABD. SISYPHUS	6
NANNOCONU. TRUITTI GROUP	47
NANNOCONU. STEINMANNI MINOR	48

SYMBOL LEGEND

- ▮ BARREN SAMPLE (NF)
- . 1 SPECIMEN
- / 2-5 SPECIMENS
- o 6-20 .
- ● 21-100 .
- ? UNCERTAIN TAXONOMIC IDENTIFICATION

SAMPLE TYPES (ST):

B2 SIDEWALL

14 DRIED DITCH CTG

BIOSTRATIGRAPHIC SUBDIVISION	NANNO-PLANKTON ZONATION	TIME-STRATIGRAPHIC SUBDIVISION
	NLK 4A	U.AB
	NLK 4A-58?	U/L.AB
	NLK 58-61	L.AB
	NLK 7	U.AP
	NLKA 23	L.VA
		VA

SHELL U.K. EXPLORATION & PRODUCTION

NORTHERN NORTH SEA
LOWER CRETACEOUS
CALCAREOUS NANNOFOSSILS
SHELL/ESSO WELL:211/29-8A

CONFIDENTIAL

Author : B.VAN NIEL | Date : 1991 | Rev.

Encl. 4 | Drawing No.

202/8-1

SYMBOL LEGEND

. 1 SPECIMEN
/ 2-6 SPECIMENS
o 8-20 .
● 21-UBE .

? UNCERTAIN TAXONOMIC IDENTIFICATION

SAMPLE TYPES (ST):

02 SIDEWALL
14 DRILL CUTTINGS

STNF	A/B	SCIENTIFIC NAME		REG NO.		INDEX	REG NO.
	A	EPROLITHUS	ORBICULATUS	1		ASSIPETRA. INFRACRETACEA	33
	A	MANIVITELLA	PEMMATOIDEA	2		AXOPODORH. CF. DIETZMANNI	50
	A	LITHRAPHIDITES	CARNIOLENSIS	3		AXOPODORH. DIETZMANNII	25
	A	CERATOLITHINA	SP.	4		BISCUTUM . ELLIPTICUM	7
	A	PREDISCOSPHAERA	COLUMNATA	5		BISCUTUM . ELLIPTICUM(WIDE RIM)	12
	A	ZEUGRHABDOTUS	SISYPHUS	6		BRAARUDOS. BATILLIFORMIS	58
	A	BISCUTUM	ELLIPTICUM	7		BRAARUDOS. HOCKWOLDENISIS	30
	A	STAUROLITHITES	CRUX	8		BUKRYLITH. AMBIGUUS	52
	A	WATZNAUERIA	BARNESAE	9		CAVED UPP. NANNOFOSSILS	17
	A	WATZNAUERIA	FOSSACINCTA	10		CERATOLIT. SP.	4
	A	ZEUGRHABDOTUS	ERECTUS	11		CONUSPHAE. MEXICANA	56
	A	BISCUTUM	ELLIPTICUM(WIDE RIM)	12		CONUSPHAE. ROTHII	45
	A	EIFFELLITHUS	TURRISEIFFELII	13		COROLLITH. LAFFITTTEI	34
	A	HEMIPODORHABDUS	GORKAE	14		CRETARHAB. ANGUSTIFORATUS	32
	A	TEGUMENTUM	SALIUM	15		CRETARHAB. CONICUS	16
	A	CRETARHABDUS	CONICUS	16		CRETARHAB. MADINGLEYENSIS	48
	A	CAVED UPPER CRET.	NANNOFOSSILS	17		CRETARHAB. SP.	43
	A	RHAGODISCUS	ASPER	18		CRUCIBISC. SALEBROSUM	42
	A	TEGUMENTUM	STRADNERI	19		CYCLAGELD. MARGERELII	37
	A	WATZNAUERIA	OVATA	20		DIAZOMATO. LEHMANII	36
	A	EPROLITHUS	SP.	21		DISCORHAB. IGNOTUS	31
	A	VAGALAPILLA	MATALOSA	22		EIFFELLIT. TURRISEIFFELII	13
	A	RHAGODISCUS	ANGUSTUS	23		EPROLITHU. ORBICULATUS	1
	A	SERIBISCUTUM	PRIMITIVUM (LARGE)	24		EPROLITHU. SP.	21
	A	AXOPODORHABDUS	DIETZMANNII	25		GARTNERAG. PRAEOBLIQUUM	28
	A	SPEETONIA	COLLIGATA	26		HEMIPODOR. GORKAE	14
	A	TRANOLITHUS	GABALUS	27		KOKIA . BOREALIS	59
	A	GARTNERAGO	PRAEOBLIQUUM	28		KOKIA . CURVATUS	53
	A	SCAPHOLITHUS	FOSILIS	29		LITHRAPHI. CARNIOLENSIS	3
	A	BRAARUDOSPHAERA	HOCKWOLDENISIS	30		LITHRAPHI. SP.	39
	A	DISCORHABDUS	IGNOTUS	31		MANIVITEL. PEMMATOIDEA	2
	A	CRETARHABDUS	ANGUSTIFORATUS	32		MICRANTHO. HOSCHULZII	46
	A	ASSIPETRA	INFRACRETACEA	33		MICRANTHO. OBTUSUS	57
	A	COROLLITHION	LAFFITTEI	34		MICRANTHO. OBTUSUS(INCIS.PLAT)	55
	A	MICRANTHOLITHUS	SPEETONENSIS	35		MICRANTHO. SP.	47
	A	DIAZOMATOLITHUS	LEHMANII	36		MICRANTHO. SPEETONENSIS	35
	A	CYCLAGELOSPHAERA	MARGERELII	37		MICROSTAU. CHIASTIUS	41
	A	ZEUGRHABDOTUS	EMBERGERI	38		NANNOCONU. SP./DISC (SMOOTH)	40
	A	LITHRAPHIDITES	SP.	39		NANNOCONU. SP./DISC MGRP 1.	60
	A	NANNOCONUS	SP./DISC (SMOOTH)	40		NANNOCONU. SP./DISC MGRP 3..	44
	A	MICROSTAURUS	CHIASTIUS	41		PREDISCOS. COLUMNATA	5
	A	CRUCIBISCUTUM	SALEBROSUM	42		RHAGODISC. ANGUSTUS	23
	A	CRETARHABDUS	SP.	43		RHAGODISC. ASPER	18
	A	NANNOCONUS	SP./DISC MGRP 3.	44		SCAPHOLIT. FOSILIS	29
	A	CONUSPHAERA	ROTHII	45		SERIBISCU. PRIMITIVUM (LARGE)	24
	A	MICRANTHOLITHUS	HOSCHULZII	46		SOLLASITE. HORTICUS	54
	A	MICRANTHOLITHUS	SP.	47		SOLLASITE. SP.	51
	A	CRETARHABDUS	MADINGLEYENSIS	48		SPEETONIA. COLLIGATA	26
	A	WATZNAUERIA	MANIVITAE	49		STAUROLIT. CRUX	8
	A	AXOPODORHABDUS	CF. DIETZMANNI	50		TEGUMENTU. SALIUM	15
	A	SOLLASITES	SP.	51		TEGUMENTU. STRADNERI	19
	A	BUKRYLITHUS	AMBIGUUS	52		TRANOLITH. GABALUS	27
	A	KOKIA	CURVATUS	53		VAGALAPIL. MATALOSA	22
	A	SOLLASITES	HORTICUS	54		WATZNAUER. BARNESAE	9
	A	MICRANTHOLITHUS	OBTUSUS(INCIS.PLAT)	55		WATZNAUER. FOSSACINCTA	10
	A	CONUSPHAERA	MEXICANA	56		WATZNAUER. MANIVITAE	49
	A	MICRANTHOLITHUS	OBTUSUS	57		WATZNAUER. OVATA	20
	A	BRAARUDOSPHAERA	BATILLIFORMIS	58		ZEUGRHABD. EMBERGERI	38
	A	KOKIA	BOREALIS	59		ZEUGRHABD. ERECTUS	11
	A	NANNOCONUS	SP./DISC MGRP 1.	60		ZEUGRHABD. SISYPHUS	6
	A	NANNOCONUS	CONCAVUS	61	MGRP 1.1	NANNOCONU. CONCAVUS	61
	A	NANNOCONUS	SP. (LARGE DISC)	62		NANNOCONU. SP. (LARGE DISC)	62
	A	NANNOCONUS	BUCHERI	64	MGRP 2.2	NANNOCONU. BUCHERI	64
	A	NANNOCONUS	BONETI	65	MGRP 2.3	NANNOCONU. BONETI	65
	A	NANNOCONUS	SP. (OBLIQUE) 2.3	66		NANNOCONU. BONETI (BROKEN)	71
	A	NANNOCONUS	ELONGATUS ELONGATUS	67		NANNOCONU. ELONGATUS ELONGATUS	67
	A	NANNOCONUS	KAMPTNERI KAMPTNERI	68		NANNOCONU. KAMPTNERI KAMPTNERI	68
	A	NANNOCONUS	PASKENTIENSIS	69		NANNOCONU. PASKENTIENSIS	69
	A	NANNOCONUS	SP. 2.	70		NANNOCONU. SP. 2.	70
	A	NANNOCONUS	BONETI (BROKEN)	71		NANNOCONU. SP. (OBLIQUE) 2.3	66
	A	NANNOCONUS	GLOBULUS GLOBULUS	72	MGRP 3.3	NANNOCONU. CF. OVIFORMIS	75
	A	NANNOCONUS	SP. (OBLIQUE) 3.3	73		NANNOCONU. GLOBULUS GLOBULUS	72
	A	NANNOCONUS	GLOBULUS SUBSP.NOV. A	74		NANNOCONU. GLOBULUS SUBSP.NOV. A	74
	A	NANNOCONUS	CF. OVIFORMIS	75		NANNOCONU. SP. (OBLIQUE) 3.3	73
	A	NANNOCONUS	SP. (FRAGMENTS) 1.3	76	OTHER FOSSILS	NANNOCONU. SP. (FRAGMENTS) 1.3	76

NANNOFOSSILS

DEPTH IN FEET BELOW DERRICK FLOOR

4768.00 4769.00 4788.00 4818.00 4848.00 4863.00 4885.00 4908.00 4924.00 4938.00 4958.00 4982.00 4998.00 5018.00 5029.00 5058.00 5083.00 5098.00 5128.00 5138.00 5148.00

NANNO-PLANKTON ZONATION

NLK 2-5? | NLK 9-10? | NLKA 23 | NLKA 23-27

BIOSTRATIGRAPHIC SUBDIVISION

TIME-STRATIGRAPHIC SUBDIVISION

U.AB? | AB | AP? | U.BR? | L.VA | L.VA-U.RY

SHELL U.K. EXPLORATION & PRODUCTION

SHETLAND BASIN
LOWER CRETACEOUS
CALCAREOUS NANNOFOSSILS
SHELL/ESSO WELL:202/8-1

CONFIDENTIAL

Author : B.VAN NIEL | Date : 1991 | Rev.

Encl. 5 | Drawing No.

15/25A-2

DEPTH IN FEET BELOW DERRICK FLOOR

SYMBOL LEGEND

BARREN SAMPLE (NP)

. 1 SPECIMEN

/ 2-5 SPECIMENS

O 6-20 .

● 21-100 .

SAMPLE TYPES (ST):

82 SIDEWALL

83 WET DITCH CTG

14 DRIED DITCH CTG

15 CORE CHIP

A/B	SCIENTIFIC NAME		REG NO.
A	WATZNAUERIA	BARNESAE	1
A	PREDISCOSPHAERA	COLUMNATA	2
A	EIFFELLITHUS	TURRISEIFFELII	3
A	SERIBISCUTUM	PRIMITIVUM (LARGE)	4
A	TRANOLITHUS	CF. PHACELOSUS	5
A	VAGALAPILLA	MATALOSA	6
A	CAVED UPPER CRET.	NANNOFOSSILS	7
A	CRETARHABDUS	ANGUSTIFORATUS	8
A	TEGUMENTUM	STRADNERI	9
A	CRETARHABDUS	CONICUS	10
A	BISCUTUM	ELLIPTICUM	11
A	CYCLAGELOSPHAERA	MARGERELII	12
A	WATZNAUERIA	FOSSACINCTA	13
A	EPROLITHUS	APERTIOR	14
A	MANIVITELLA	PEMMATOIDEA	15
A	EPROLITHUS	SP.	16
A	STAUROLITHITES	CRUX	17
A	RHAGODISCUS	ASPER	18
A	GARTNERAGO	PRAEOBLIQUUM	19
A	EPROLITHUS	VAROLII	20
A	TRANOLITHUS	GABALUS	21
A	WATZNAUERIA	OVATA	22
A	HEMIPODORHABDUS	GORKAE	23
A	ZEUGRHABDOTUS	ERECTUS	24
A	ZEUGRHABDOTUS	SISYPHUS	25
A	CRETARHABDUS	SP.	26
A	DISCORHABDUS	IGNOTUS	27
A	TEGUMENTUM	STRIATUM	28
A	SOLLASITES	SP.	29
A	TEGUMENTUM	SALIUM	30
A	RHAGODISCUS	PSEUDOANGUSTUS	31
A	SCAPHOLITHUS	FOSILIS	32
A	NANNOCONUS	SP./DISC (FLORAL)	33
A	BISCUTUM	ELLIPTICUM(WIDE RIM)	34
A	REPAGULUM	PARVIDENTATUM	35
A	RHAGODISCUS	ANGUSTUS	36
A	GLAUKOLITHUS	COMPACTUS	37
A	CHIASTOZYGOUS	SP.	38
A	CRUCIBISCUTUM	SALEBROSUM	39
A	SOLLASITES	HAYI	40
A	CERATOLITHINA	SP.	41
A	COROLLITHION	LAFFITTEI	42
A	MICRANTHOLITHUS	SP.	43
A	EPROLITHUS	SP.11	44
A	STAUROLITHITES	SP.1	45
A	LITHRAPHIDITES	CARNIOLENSIS	46
A	EPROLITHUS	ORBICULATUS	47
A	CONUSPHAERA	ROTHII	48
A	GRANTARHABDUS	MEDDII	49
A	ASSIPETRA	INFRACRETACEA	50
A	AXOPODORHABDUS	DIETZMANNII	51
A	BUKRYLITHUS	AMBIGUUS	52
A	NANNOCONUS	SP.(OBLIQUE)	53
A	COCCOSPHERES	SP.	54
A	AXOPODORHABDUS	CF. DIETZMANNI	55
A	MICRANTHOLITHUS	HOSCHULZII	56
A	ZEUGRHABDOTUS	EMBERGERI	57
A	WATZNAUERIA	MANIVITAE	58
A	NANNOCONUS	SP./DISC (SMOOTH)	59
A	MICRANTHOLITHUS	OBTUSUS	60
A	CHIASTOZYGOUS	CEPEKII	61
A	STAUROLITHITES	MUTTERLOSEI	62
A	MICROSTAURUS	CHIASTIUS	63
A	TEGULALITHUS	SEPTENTRIONALIS	64
A	SOLLASITES	HORTICUS	65
A	SPEETONIA	COLLIGATA	66
A	VAGALAPILLA	SWINNERTONII	67
A	HOLOCOCCOLITH	SP.	68
A	LITHRAPHIDITES	SP.	69
A	DIAZOMATOLITHUS	LEHMANII	70
A	MICRANTHOLITHUS	LAMBERTII	71
A	KOKIA	BOREALIS	72
A	STRADNERLITHUS	COMPTUS	73
A	NANNOCONUS	SP.	74
A	NANNOCONUS	ABUNDANS	75
A	NANNOCONUS	ABUNDANS (BARREL)	76
A	NANNOCONUS	CF. CIRCULARIS	77
A	NANNOCONUS	ABUNDANS (FLANGE)	78
A	NANNOCONUS	'SP.1	79
A	NANNOCONUS	SP. MGRP 1	80
A	NANNOCONUS	ABUNDANS (ELONGATE)	81
A	NANNOCONUS	TRUITTI GROUP	82
A	NANNOCONUS	QUAD.. APERTUS	83
A	NANNOCONUS	MINUTUS	84
A	NANNOCONUS	TRUITTI TRUITTI	85
A	NANNOCONUS	DAUVILLIERI	86
A	NANNOCONUS	BUCHERI	87
A	NANNOCONUS	QUADRIANGULUS GROUP	88
A	NANNOCONUS	ELONGATUS MINUTUS	89
A	NANNOCONUS	SP. MGRP 2.3	90
A	NANNOCONUS	PASKENTIENSIS	91
A	NANNOCONUS	BONETI	92
A	NANNOCONUS	BOREALIS	93
A	NANNOCONUS	ELONGATUS ELONGATUS	94
A	NANNOCONUS	LONGUS	95
A	NANNOCONUS	KAMPTNERI KAMPTNERI	96
A	NANNOCONUS	KAMPTNERI MINOR	97
A	NANNOCONUS	STEINMANNI STEINMANNI	98
A	NANNOCONUS	GLOBULUS SUBSP.NOV.A	99
A	NANNOCONUS	SP. (OBLIQUE) 3.3	100
A	NANNOCONUS	GLOBULUS GLOBULUS	101
A	NANNOCONUS	SP. 3	102
A	NANNOCONUS	WASSALII WASSALII	103
A	NANNOCONUS	CF. OVIFORMIS	104
A	NANNOCONUS	GLOBULUS MINOR	105

NANNOFOSSILS

MGRP 1.1

MGRP 1.2

MGRP 2.2

MGRP 2.3

MGRP 3.3

INDEX	REG NO.
ASSIPETRA. INFRACRETACEA	50
AXOPODORH. CF. DIETZMANNI	55
AXOPODORH. DIETZMANNII	51
BISCUTUM . ELLIPTICUM	11
BISCUTUM . ELLIPTICUM(WIDE RIM)	34
BUKRYLITH. AMBIGUUS	52
CAVED UPP. NANNOFOSSILS	7
CERATOLIT. SP.	41
CHIASTOZY. CEPEKII	61
CHIASTOZY. SP.	38
COCCOSPHE. SP.	54
CONUSPHAE. ROTHII	48
COROLLITH. LAFFITTTEI	42
CRETARHAB. ANGUSTIFORATUS	8
CRETARHAB. CONICUS	10
CRETARHAB. SP.	26
CRUCIBISC. SALEBROSUM	39
CYCLAGELO. MARGERELII	12
DIAZOMATO. LEHMANII	70
DISCORHAB. IGNOTUS	27
EIFFELLIT. TURRISEIFFELII	3
EPROLITHU. APERTIOR	14
EPROLITHU. ORBICULATUS	47
EPROLITHU. SP.	16
EPROLITHU. SP. 11	44
EPROLITHU. VAROLII	20
GARTNERAG. PRAEOBLIQUUM	19
GLAUKOLIT. COMPACTUS	37
GRANTARHA. MEDDII	49
HEMIPODOR. GORKAE	23
HOLOCOCCO. SP.	68
KOKIA . BOREALIS	72
LITHRAPHI. CARNIOLENSIS	46
LITHRAPHI. SP.	69
MANIVITEL. PEMMATOIDEA	15
MICRANTHO. HOSCHULZII	56
MICRANTHO. LAMBERTII	71
MICRANTHO. OBTUSUS	60
MICRANTHO. SP.	43
MICROSTAU. CHIASTIUS	63
NANNOCONU. SP.	74
NANNOCONU. SP. (OBLIQUE)	53
NANNOCONU. SP./DISC (FLORAL)	33
NANNOCONU. SP./DISC (SMOOTH)	59
PREDISCOS. COLUMNATA	2
REPAGULUM. PARVIDENTATUM	35
RHAGODISC. ANGUSTUS	36
RHAGODISC. ASPER	18
RHAGODISC. PSEUDOANGUSTUS	31
SCAPHOLIT. FOSILIS	32
SERIBISCU. PRIMITIVUM (LARGE)	4
SOLLASITE. HAYI	40
SOLLASITE. HORTICUS	65
SOLLASITE. SP.	29
SPEETONIA. COLLIGATA	66
STAUROLIT. CRUX	17
STAUROLIT. MUTTERLOSEI	62
STAUROLIT. SP.1	45
STRADNERL. COMPTUS	73
TEGULALIT. SEPTENTRIONALIS	64
TEGUMENTU. SALIUM	30
TEGUMENTU. STRADNERI	9
TEGUMENTU. STRIATUM	28
TRANOLITH. CF. PHACELOSUS	5
TRANOLITH. GABALUS	21
VAGALAPIL. MATALOSA	6
VAGALAPIL. SWINNERTONII	67
WATZNAUER. BARNESAE	1
WATZNAUER. FOSSACINCTA	13
WATZNAUER. MANIVITAE	58
WATZNAUER. OVATA	22
ZEUGRHABD. EMBERGERI	57
ZEUGRHABD. ERECTUS	24
ZEUGRHABD. SISYPHUS	25
NANNOCONU. 'SP.1	79
NANNOCONU. ABUNDANS	75
NANNOCONU. ABUNDANS (BARREL)	76
NANNOCONU. ABUNDANS (FLANGE)	78
NANNOCONU. CF. CIRCULARIS	77
NANNOCONU. SP. MGRP 1	80
NANNOCONU. ABUNDANS (ELONGATE)	81
NANNOCONU. BUCHERI	87
NANNOCONU. DAUVILLIERI	86
NANNOCONU. MINUTUS	84
NANNOCONU. QUAD. APERTUS	83
NANNOCONU. QUADRIANGULUS GROUP	88
NANNOCONU. TRUITTI GROUP	82
NANNOCONU. TRUITTI TRUITTI	85
NANNOCONU. BONETI	92
NANNOCONU. BOREALIS	93
NANNOCONU. ELONGATUS ELONGATUS	94
NANNOCONU. ELONGATUS MINUTUS	89
NANNOCONU. KAMPTNERI KAMPTNERI	96
NANNOCONU. KAMPTNERI MINOR	97
NANNOCONU. LONGUS	95
NANNOCONU. PASKENTIENSIS	91
NANNOCONU. SP. MGRP 2.3	90
NANNOCONU. STEINMANNI STEINMANN	98
NANNOCONU. CF. OVIFORMIS	104
NANNOCONU. GLOBULUS GLOBULUS	101
NANNOCONU. GLOBULUS SUBSP.NOV.A	99
NANNOCONU. GLOBULUS MINOR	105
NANNOCONU. SP. 3	102
NANNOCONU. SP. (OBLIQUE) 3.3	100
NANNOCONU. WASSALII WASSALII	103

DEPTH IN FEET BELOW DERRICK FLOOR

NANNO-PLANKTON ZONATION	BIOSTRATIGRAPHIC SUBDIVISION	TIME-STRATIGRAPHIC SUBDIVISION
NLK 4A		A8?
NLK 4B		U.AB
NLK 5A		U/M.AB
NLK 5-7		M/L.AB
NLK 8A		M/L.AB-U.AP
NLK 10		U.AP
		U.AP-U.BR?
NLKA 11-13		U.BR
NLKA 14		U/L.BR
NLK 21		L.BR
		7L.HT/VA
		VA?

SHELL U.K. EXPLORATION & PRODUCTION

WITCH GROUND GRABEN
LOWER CRETACEOUS
CALCAREOUS NANNOFOSSILS
SHELL/ESSO WELL: 15/25A-2

CONFIDENTIAL

Author: B.VAN NIEL | Date: 1991 | Rev.

Encl. 6 | Drawing No.

SYMBOL LEGEND

SAMPLE TYPES (ST):

1 SPECIMEN
2-5 SPECIMENS
6-20 "
21-100 "
SIDEWALL
SIDED DITCH CTG
CORE CHIP

DEPTH IN FEET BELOW DERRICK FLOOR

STINF

A/B	SCIENTIFIC NAME		REG NO.		INDEX	REG NO.
A	TEGUMENTUM	SALIUM	1		ASSIPETRA. INFRACRETACEA	43
A	VAGALAPILLA	MATALOSA	2		AXOPODORH. DIETZMANNII	30
A	BISCUTUM	ELLIPTICUM	3		BISCUTUM . ELLIPTICUM	3
A	EIFFELLITHUS	TURRISEIFFELII	4		BISCUTUM . ELLIPTICUM(WIDE RIM)	21
A	EPROLITHUS	SP.	5		BUKRYLITH. AMBIGUUS	18
A	RHAGODISCUS	ASPER	6		CAVED UPP. NANNOFOSSILS	49
A	WATZNAUERIA	BARNESAE	7		CHIASTOZY. CEPEKII	60
A	EPROLITHUS	SP. 11	8		CONUSPHAE. ROTHII	62
A	WATZNAUERIA	MANIVITAE	9		COROLLITH. GEOMETRICUM	57
A	PREDISCOSPHAERA	COLUMNATA	10		COROLLITH. LAFFITTTEI	28
A	CRETARHABDUS	CONICUS	11		CRETARHAB. ANGUSTIFORATUS	50
A	RHAGODISCUS	ANGUSTUS	12		CRETARHAB. CONICUS	11
A	ZEUGRHABDOTUS	ERECTUS	13		CRETARHAB. SP.	36
A	WATZNAUERIA	FOSSACINCTA	14		CRUCIBISC. SALEBROSUM	39
A	ZEUGRHABDOTUS	SISYPHUS	15		CRUCIELLI. CUVILLIERI	52
A	EPROLITHUS	SP. 16	16		CYCLAGELO. MARGERELII	38
A	NANNOCONUS	SP./DISC (FLORAL)	17		DISCORHAB. IGNOTUS	26
A	BUKRYLITHUS	AMBIGUUS	18		EIFFELLIT. TURRISEIFFELII	4
A	PHANULITES	CF. ANFRACTUS	19		EPROLITHU. APERTIOR	35
A	ZEUGRHABDOTUS	EMBERGERI	20		EPROLITHU. FLORALIS	48
A	BISCUTUM	ELLIPTICUM(WIDE RIM)	21		EPROLITHU. ORBICULATUS	29
A	WATZNAUERIA	OVATA	22		EPROLITHU. SP.	5
A	SERIBISCUTUM	PRIMITIVUM (LARGE)	23		EPROLITHU. SP. 11	8
A	STAUROLITHITES	CRUX	24		EPROLITHU. SP. 16	16
A	TEGUMENTUM	STRADNERI	25		GLAUKOLIT. COMPACTUS	61
A	DISCORHABDUS	IGNOTUS	26		GRANTARHA. MEDDII	32
A	TRANOLITHUS	GABALUS	27		HOLOCOCCO. SP.	33
A	COROLLITHION	LAFFITTEI	28		LITHRAPHI. CARNIOLENSIS	41
A	EPROLITHUS	ORBICULATUS	29		LITHRAPHI. MORAYFIRTHENSIS	47
A	AXOPODORHABDUS	DIETZMANNII	30		LITHRAPHI. SP.	51
A	RHAGODISCUS	SPLENDENS	31		MANIVITEL. PEMMATOIDEA	34
A	GRANTARHABDUS	MEDDII	32		MICRANTHO. HOSCHULZII	45
A	HOLOCOCCOLITH	SP.	33		MICRANTHO. OBTUSUS	59
A	MANIVITELLA	PEMMATOIDEA	34		MICRANTHO. OBTUSUS(INCIS.PLATE)	54
A	EPROLITHUS	APERTIOR	35		MICRANTHO. SP.	46
A	CRETARHABDUS	SP.	36		MICROSTAU. CHIASTIUS	42
A	REPAGULUM	PARVIDENTATUM	37		NANNOCONU. SP.	40
A	CYCLAGELOSPHAERA	MARGERELII	38		NANNOCONU. SP. (OBLIQUE)	65
A	CRUCIBISCUTUM	SALEBROSUM	39		NANNOCONU. SP./DISC (FLORAL)	17
A	NANNOCONUS	SP.	40		NANNOCONU. SP./DISC (SMOOTH)	58
A	LITHRAPHIDITES	CARNIOLENSIS	41		PHANULITE. CF. ANFRACTUS	19
A	MICROSTAURUS	CHIASTIUS	42		PREDISCOS. COLUMNATA	10
A	ASSIPETRA	INFRACRETACEA	43		REPAGULUM. PARVIDENTATUM	37
A	TEGULALITHUS	SEPTENTRIONALIS	44		RHAGODISC. ANGUSTUS	12
A	MICRANTHOLITHUS	HOSCHULZII	45		RHAGODISC. ASPER	6
A	MICRANTHOLITHUS	SP.	46		RHAGODISC. SPLENDENS	31
A	LITHRAPHIDITES	MORAYFIRTHENSIS	47		SERIBISCU. PRIMITIVUM (LARGE)	23
A	EPROLITHUS	FLORALIS	48		SOLLASITE. HAYI	63
A	CAVED UPPER CRET.	NANNOFOSSILS	49		SOLLASITE. SP.	64
A	CRETARHABDUS	ANGUSTIFORATUS	50		SPEETONIA. COLLIGATA	56
A	LITHRAPHIDITES	SP.	51		STAUROLIT. CRUX	24
A	CRUCIELLIPSIS	CUVILLIERI	52		STAUROLIT. SP. 1	53
A	STAUROLITHITES	SP. 1	53		TEGULALIT. SEPTENTRIONALIS	44
A	MICRANTHOLITHUS	OBTUSUS(INCIS.PLATE)	54		TEGUMENTU. SALIUM	1
A	VAGALAPILLA	MATALOSA (SMALL)	55		TEGUMENTU. STRADNERI	25
A	SPEETONIA	COLLIGATA	56		TEGUMENTU. STRIATUM	67
A	COROLLITHION	GEOMETRICUM	57		TEGUMENTU. STRIATUM (LARGE)	66
A	NANNOCONUS	SP./DISC (SMOOTH)	58		TRANOLITH. GABALUS	27
A	MICRANTHOLITHUS	OBTUSUS	59		VAGALAPIL. MATALOSA	2
A	CHIASTOZYGOUS	CEPEKII	60		VAGALAPIL. MATALOSA (SMALL)	55
A	GLAUKOLITHUS	COMPACTUS	61		WATZNAUER. BARNESAE	7
A	CONUSPHAERA	ROTHII	62		WATZNAUER. FOSSACINCTA	14
A	SOLLASITES	HAYI	63		WATZNAUER. MANIVITAE	9
A	SOLLASITES	SP.	64		WATZNAUER. OVATA	22
A	NANNOCONUS	SP. (OBLIQUE)	65		ZEUGRHABD. EMBERGERI	20
A	*TEGUMENTUM*	*STRIATUM (LARGE)*	66		*ZEUGRHABD. ERECTUS*	13
A	TEGUMENTUM	STRIATUM	67		ZEUGRHABD. SISYPHUS	15
A	NANNOCONUS	ABUNDANS	68	MGRP 1.1	NANNOCONU. ABUNDANS	68
A	NANNOCONUS	SP. MGRP 1.2	69	MGRP 1.2	NANNOCONU. SP. MGRP 1.2	69
A	NANNOCONUS	SP. (OBLIQUE) 2.2	70	MGRP 2.2	NANNOCONU. BUCHERI	75
A	NANNOCONUS	TRUITTI GROUP	71		NANNOCONU. QUADRIANGULUS GROUP	72
A	NANNOCONUS	QUADRIANGULUS GROUP	72		NANNOCONU. SP. (FRAGMENTS) 2.2	73
A	NANNOCONUS	SP. (FRAGMENTS) 2.2	73		NANNOCONU. SP. (OBLIQUE) 2.2	70
A	NANNOCONUS	TRUITTI FREQUENS	74		NANNOCONU. TRUITTI FREQUENS	74
A	NANNOCONUS	BUCHERI	75		NANNOCONU. TRUITTI GROUP	71
A	NANNOCONUS	BONETI	76	MGRP 2.3	NANNOCONU. BONETI	76
A	NANNOCONUS	BOREALIS	77		NANNOCONU. BOREALIS	77
A	NANNOCONUS	ELONGATUS MINUTUS	78		NANNOCONU. ELONGATUS ELONGATUS	82
A	NANNOCONUS	SP. 2	79		NANNOCONU. ELONGATUS MINUTUS	78
A	NANNOCONUS	KAMPTNERI MINOR	80		NANNOCONU. KAMPTNERI MINOR	80
A	NANNOCONUS	PASKENTIENSIS	81		NANNOCONU. PASKENTIENSIS	81
A	NANNOCONUS	ELONGATUS ELONGATUS	82		NANNOCONU. SP. 2	79
A	NANNOCONUS	GLOBULUS SUBSP.NOV.A	83	MGRP 3.3	NANNOCONU. CF. OVIFORMIS	84
A	NANNOCONUS	CF. OVIFORMIS	84		NANNOCONU. GLOBULUS GLOBULUS	85
A	NANNOCONUS	GLOBULUS GLOBULUS	85		NANNOCONU. GLOBULUS SUBSP.NOV.A	83
A	NANNOCONUS	GLOBULUS MINOR	86		NANNOCONU. GLOBULUS MINOR	86

NANNOFOSSILS

DEPTH IN FEET BELOW DERRICK FLOOR

NANNO-PLANKTON ZONATION

BIOSTRATIGRAPHIC SUBDIVISION

TIME-STRATIGRAPHIC SUBDIVISION

NLKA 4A?
NLK 5
NLK 6-8
NLK 8
NLK 10 NLKA II
NLKA II-14
NLKA 17

U/M.LAB
L.LAB
LAB-U.AP
U/L.AP
L.AP
U.BR
L.BR
L.BR-U.HT
U.HT
HTT

SHELL U.K. EXPLORATION & PRODUCTION

SHETLAND BASIN
LOWER CRETACEOUS
CALCAREOUS NANNOFOSSILS
SHELL/ESSO WELL: 22/26A-2

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Encl. 7 | Drawing No.

29/3-1

DEPTH IN FEET BELOW DERRICK FLOOR

STNF	A/B	SCIENTIFIC NAME		REG NO.		INDEX	REG NO.
1113865.00 S2	A	WATZNAUERIA	BARNESAE	1	NANNOFOSSILS	BISCUTUM . ELLIPTICUM	8
1113925.00 S2	A	MICRANTHOLITHUS	HOSCHULZII	2		COROLLITH. LAFFITTTEI	7
1122365.00 S2	A	RHAGODISCUS	ASPER	3		CRETARHAB. MADINGLEYENSIS	22
1121485.00 S2	A	CRUCIBISCUTUM	SALEBROSUM	4		CRETARHAB. SP.	23
1111485.00 S2	A	RHAGODISCUS	PSEUDOANGUSTUS	5		CRUCIBISC. SALEBROSUM	4
1093635.00 S2	A	WATZNAUERIA	OVATA	6		DIAZOMATO. LEHMANII	24
1092625.00 S2	A	COROLLITHION	LAFFITTEI	7		DISCORHAB. IGNOTUS	9
1082845.00 S2	A	BISCUTUM	ELLIPTICUM	8		EPROLITHU. APERTIOR	12
	A	DISCORHABDUS	IGNOTUS	9		LITHRAPHI. CARNIOLENSIS	15
	A	WATZNAUERIA	FOSSACINCTA	10		MICRANTHO. HOSCHULZII	2
	A	ZEUGRHABDOTUS	SISYPHUS	11		MICRANTHO. SP.	16
	A	EPROLITHUS	APERTIOR	12		MICROSTAU. CHIASTIUS	17
	A	RHAGODISCUS	ANGUSTUS	13		NANNOCONU. SP. (OBLIQUE)	18
	A	STAUROLITHITES	CRUX	14		NANNOCONU. SP./DISC (FLORAL)	25
	A	LITHRAPHIDITES	CARNIOLENSIS	15		NANNOCONU. SP./DISC (SMOOTH)	20
	A	MICRANTHOLITHUS	SP.	16		NANNOCONU. SP./DISC MGRP 1.	19
	A	MICROSTAURUS	CHIASTIUS	17		RHAGODISC. ANGUSTUS	13
	A	NANNOCONUS	SP. (OBLIQUE)	18		RHAGODISC. ASPER	3
	A	NANNOCONUS	SP./DISC MGRP 1.	19		RHAGODISC. PSEUDOANGUSTUS	5
	A	NANNOCONUS	SP./DISC (SMOOTH)	20		STAUROLIT. CRUX	14
	A	VAGALAPILLA	MATALOSA	21		VAGALAPIL. MATALOSA	21
	A	CRETARHABDUS	MADINGLEYENSIS	22		WATZNAUER. BARNESAE	1
	A	CRETARHABDUS	SP.	23		WATZNAUER. FOSSACINCTA	10
	A	DIAZOMATOLITHUS	LEHMANII	24		WATZNAUER. OVATA	6
	A	NANNOCONUS	SP./DISC (FLORAL)	25		ZEUGRHABD. EMBERGERI	26
	A	ZEUGRHABDOTUS	EMBERGERI	26		ZEUGRHABD. SISYPHUS	11
	A	NANNOCONUS	ABUNDANS (BARREL)	27	MGRP 1.1	NANNOCONU. ABUNDANS	28
	A	NANNOCONUS	ABUNDANS	28		NANNOCONU. ABUNDANS (BARREL)	27

SYMBOL LEGEND

■ BARREN SAMPLE (NF)
• 1 SPECIMEN
/ 2 -5 SPECIMENS
o 6 -20 .
● 21-100 .

SAMPLE TYPES (ST):

S2 SIDEWALL

NLK 10	NLK 7
U.BR	U.AP-U.BR?
	U.AP

NANNO-PLANKTON ZONATION

BIOSTRATIGRAPHIC SUBDIVISION

TIME-STRATIGRAPHIC SUBDIVISION

SHELL U.K. EXPLORATION & PRODUCTION

WEST CENTRAL GRABEN
LOWER CRETACEOUS
CALCAREOUS NANNOFOSSILS
SHELL/ESSO WELL:29/3-1

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Author : B.VAN NIEL | Date : 1991 | Rev.

Encl. 8 | Drawing No.

29/7-1

SYMBOL LEGEND

BARREN SAMPLE (NF)
1 SPECIMEN
2-5 SPECIMENS
6-20
21-100

SAMPLE TYPES (ST):

SIDEWALL

DEPTH IN FEET BELOW DERRICK FLOOR	A/B	SCIENTIFIC NAME		REG NO.		INDEX	REG NO.
9988.00	A	EIFFELLITHUS	TURRISEIFFELII	1		ASSIPETRA. INFRACRETACEA	27
9932.00	A	GARTNERAGO	PRAEOBLIQUUM	2		AXOPODORH. CF. DIETZMANNI	53
9954.00	A	STRADNERLITHUS	COMPTUS	3		AXOPODORH. DIETZMANNII	43
10023.00	A	MICRANTHOLITHUS	SP.	4		BISCUTUM . ELLIPTICUM	17
10078.00	A	HEMIPODORHABDUS	GORKAE	5		BISCUTUM . ELLIPTICUM(WIDE RIM)	26
10094.00	A	MICRANTHOLITHUS	HOSCHULZII	6		BRAARUDOS. HOCKWOLDENISIS	49
10116.00	A	CRETARHABDUS	CONICUS	7		BUKRYLITH. AMBIGUUS	34
10158.00	A	DISCORHABDUS	IGNOTUS	8		CAVED UPP. NANNOFOSSILS	36
10178.00	A	MANIVITELLA	PEMMATOIDEA	9		CERATOLIT. SP.	20
10198.00	A	MICRANTHOLITHUS	OBTUSUS	10		COCCOSPHE. SP.	19
10218.00	A	WATZNAUERIA	OVATA	11		CONUSPHAE. ROTHII	40
10238.00	A	RHAGODISCUS	ASPER	12		COROLLITH. LAFFITTTEI	33
10282.00	A	WATZNAUERIA	BARNESAE	13		CRETARHAB. ANGUSTIFORATUS	38
10298.00	A	WATZNAUERIA	FOSSACINCTA	14		CRETARHAB. CONICUS	7
10318.00	A	RHAGODISCUS	ANGUSTUS	15		CRETARHAB. MADINGLEYENSIS	29
10328.00	A	CRETARHABDUS	SP.	16		CRETARHAB. SP.	16
10338.00	A	BISCUTUM	ELLIPTICUM	17		CRUCIBISC. SALEBROSUM	28
10368.00	A	CYCLAGELOSPHAERA	MARGERELII	18		CRUCIELLI. CUVILLIERI	30
10394.00	A	COCCOSPHERES	SP.	19		CYCLAGELO. MARGERELII	18
10423.00	A	CERATOLITHINA	SP.	20		DIAZOMATO. LEHMANII	21
10439.00	A	DIAZOMATOLITHUS	LEHMANII	21		DISCORHAB. IGNOTUS	8
10468.00	A	ZEUGRHABDOTUS	SISYPHUS	22		EIFFELLIT. TURRISEIFFELII	1
10488.00	A	WATZNAUERIA	MANIVITAE	23		EPROLITHU. ANTIQUUS	44
10518.00	A	SPEETONIA	COLLIGATA	24		EPROLITHU. SP.	31
10544.00	A	MICROSTAURUS	CHIASTIUS	25		GARTNERAG. PRAEOBLIQUUM	2
10574.00	A	BISCUTUM	ELLIPTICUM(WIDE RIM)	26		GRANTARHA. MEDDII	32
10596.00	A	ASSIPETRA	INFRACRETACEA	27		HEMIPODOR. GORKAE	5
10622.00	A	CRUCIBISCUTUM	SALEBROSUM	28		HOLOCOCCO. SP.	58
10650.00	A	CRETARHABDUS	MADINGLEYENSIS	29		KOKIA . BOREALIS	48
10695.00	A	CRUCIELLIPSIS	CUVILLIERI	30		KOKIA . CURVATUS	57
10713.00	A	EPROLITHUS	SP.	31		KOKIA . SP.	46
10738.00	A	GRANTARHABDUS	MEDDII	32		LITHRAPHI. CARNIOLENSIS	51
10755.00	A	COROLLITHION	LAFFITTEI	33		MANIVITEL. PEMMATOIDEA	9
10773.00	A	BUKRYLITHUS	AMBIGUUS	34		MICRANTHO. HOSCHULZII	6
10782.00	A	STAUROLITHITES	CRUX	35		MICRANTHO. OBTUSUS	10
10808.00	A	CAVED UPPER CRET.	NANNOFOSSILS	36		MICRANTHO. SP.	4
10819.00	A	TEGUMENTUM	STRADNERI	37		MICRANTHO. SPEETONENSIS	45
	A	CRETARHABDUS	ANGUSTIFORATUS	38		MICROSTAU. CHIASTIUS	25
	A	TRIQUETORHABDULUS	SHETLANDENSIS	39		NANNOCONU. SP.	61
	A	CONUSPHAERA	ROTHII	40		NANNOCONU. SP./DISC (SMOOTH)	62
	A	ZEUGRHABDOTUS	EMBERGERI	41		NANNOCONU. SP./DISC MGRP 1.	63
	A	STAUROLITHITES	SP. 1.	42		NANNOCONU. SP./DISC MGRP 3..	54
	A	AXOPODORHABDUS	DIETZMANNII	43		RHAGODISC. ANGUSTUS	15
	A	EPROLITHUS	ANTIQUUS	44		RHAGODISC. ASPER	12
	A	MICRANTHOLITHUS	SPEETONENSIS	45		SOLLASITE. ARCUATUS	56
	A	KOKIA	SP.	46		SOLLASITE. HAYI	55
	A	ZEUGRHABDOTUS	ERECTUS	47		SOLLASITE. HORTICUS	59
	A	KOKIA	BOREALIS	48		SOLLASITE. SP.	60
	A	BRAARUDOSPHAERA	HOCKWOLDENISIS	49		SPEETONIA. COLLIGATA	24
	A	STAUROLITHITES	MUTTERLOSEI	50		STAUROLIT. CRUX	35
	A	LITHRAPHIDITES	CARNIOLENSIS	51		STAUROLIT. MUTTERLOSEI	50
	A	TRANOLITHUS	GABALUS	52		STAUROLIT. SP. 1.	42
	A	AXOPODORHABDUS	CF. DIETZMANNI	53		STRADNERL. COMPTUS	3
	A	NANNOCONUS	SP./DISC MGRP 3.	54		TEGUMENTU. STRADNERI	37
	A	SOLLASITES	HAYI	55		TRANOLITH. GABALUS	52
	A	SOLLASITES	ARCUATUS	56		TRIQUETOR. SHETLANDENSIS	39
	A	KOKIA	CURVATUS	57		WATZNAUER. BARNESAE	13
	A	HOLOCOCCOLITH	SP.	58		WATZNAUER. FOSSACINCTA	14
	A	SOLLASITES	HORTICUS	59		WATZNAUER. MANIVITAE	23
	A	SOLLASITES	SP.	60		WATZNAUER. OVATA	11
	A	NANNOCONUS	SP.	61		ZEUGRHABD. EMBERGERI	41
	A	NANNOCONUS	SP./DISC (SMOOTH)	62		ZEUGRHABD. ERECTUS	47
	A	NANNOCONUS	SP./DISC MGRP 1.	63		ZEUGRHABD. SISYPHUS	22
	A	NANNOCONUS	ABUNDANS	66	MGRP 1.1	NANNOCONU. ABUNDANS	66
	A	NANNOCONUS	SP. MGRP 1.2	67	MGRP 1.2	NANNOCONU. SP. MGRP 1.2	67
	A	NANNOCONUS	CONCAVUS	64		NANNOCONU. CONCAVUS	64
	A	NANNOCONUS	SP.3	65		NANNOCONU. SP.3	65
	A	NANNOCONUS	MINUTUS	68	MGRP 2.2	NANNOCONU. BUCHERI	69
	A	NANNOCONUS	BUCHERI	69		NANNOCONU. MINUTUS	68
	A	NANNOCONUS	TRUITTI GROUP	70		NANNOCONU. TRUITTI GROUP	70
	A	NANNOCONUS	SP. MGRP 2.3	71	MGRP 2.3	NANNOCONU. KAMPTNERI KAMPTNERI	72
	A	NANNOCONUS	KAMPTNERI KAMPTNERI	72		NANNOCONU. PASKENTIENSIS	73
	A	NANNOCONUS	PASKENTIENSIS	73		NANNOCONU. SP. (DOUB.SPEC)2.3	74
	A	NANNOCONUS	SP. (DOUB.SPEC)2.3	74		NANNOCONU. SP. 2	76
	A	NANNOCONUS	STEINMANNI STEINMANNI	75		NANNOCONU. SP. MGRP 2.3	71
	A	NANNOCONUS	SP. 2	76		NANNOCONU. STEINMANNI STEINMANNI	75
	A	NANNOCONUS	GLOBULUS SUBSP.NOV.A	77	MGRP 3.3	NANNOCONU. CF. OVIFORMIS	79
	A	NANNOCONUS	GLOBULUS GLOBULUS	78		NANNOCONU. GLOBULUS GLOBULUS	78
	A	NANNOCONUS	CF. OVIFORMIS	79		NANNOCONU. GLOBULUS SUBSP.NOV.A	77
	A	NANNOCONUS	OVIFORMIS	80		NANNOCONU. OVIFORMIS	80

NANNOFOSSILS

DEPTH IN FEET BELOW DERRICK FLOOR

NANNO-PLANKTON ZONATION	BIOSTRATIGRAPHIC SUBDIVISION	TIME-STRATIGRAPHIC SUBDIVISION
NLK 4A		U.AB
NLK 8A		?
NLK 8/9		U.AP
NLK 10-NLKA 14		U.AP-L.BR
		U/L.BR
		H7/BR?
NLKA 23		L.VA
NLK 24		L.VA?-U.RY
NLKA 25		U.RY
		U.RY?

SHELL U.K.EXPLORATION & PRODUCTION

CENTRAL GRABEN
LOWER CRETACEOUS
CALCAREOUS NANNOFOSSILS
SHELL/ESSO WELL: 29/7-1

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Author : B.VAN NIEL	Date : 1991	Rev.
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DEPTH IN FEET BELOW DERRICK FLOOR	A/B	SCIENTIFIC NAME		REG NO.		INDEX	REG NO.
1633.00 02	A	COROLLITHION	SILVARADION	1	NANNOFOSSILS	ASSIPETRA. INFRACRETACEA	30
1640.00 02	A	CHIASTOZYGOUS	SP.	2		AXOPODORH. DIETZMANNII	8
1650.00 02	A	PERISSOCYCLUS	PLETHOTRETUS	3		BISCUTUM . ELLIPTICUM	10
1672.00 02	A	TEGULALITHUS	SEPTENTRIONALIS	4		BISCUTUM . ELLIPTICUM(WIDE RIM)	44
1693.00 02	A	CRETARHABDUS	ANGUSTIFORATUS	5		BUKRYLITH. AMBIGUUS	38
1713.50 02	A	MANIVITELLA	PEMMATOIDEA	6		CAVED UPP. NANNOFOSSILS	45
1727.50 02	A	STAUROLITHITES	MUTTERLOSEI	7		CHIASTOZY. CEPEKII	32
1740.00 02	A	AXOPODORHABDUS	DIETZMANNII	8		CHIASTOZY. SP.	2
1998.50 02	A	TRANOLITHUS	GABALUS	9		COROLLITH. GEOMETRICUM	21
2077.00 02	A	BISCUTUM	ELLIPTICUM	10		COROLLITH. LAFFITTEI	26
2080.00 02	A	CRETARHABDUS	CONICUS	11		COROLLITH. SILVARADION	1
2083.00 02	A	CYCLAGELOSPHAERA	MARGERELII	12		CRETARHAB. ANGUSTIFORATUS	5
2089.00 02	A	LITHRAPHIDITES	CARNIOLENSIS	13		CRETARHAB. CONICUS	11
2091.00 02	A	RHAGODISCUS	ASPER	14		CRETARHAB. MADINGLEYENSIS	42
2093.00 02	A	STAUROLITHITES	CRUX	15		CRUCIBISC. SALEBROSUM	33
2102.00 02	A	WATZNAUERIA	BARNESAE	16		CYCLAGELO. MARGERELII	12
2105.00 02	A	WATZNAUERIA	FOSSACINCTA	17		DISCORHAB. IGNOTUS	27
2112.00 02	A	WATZNAUERIA	OVATA	18		EIFFELLIT. TURRISEIFFELII	34
2123.00 02	A	ZEUGRHABDOTUS	ERECTUS	19		EPROLITHU. FLORALIS	39
2138.00 02	A	MICROSTAURUS	CHIASTIUS	20		EPROLITHU. SP.	41
2148.00 02	A	COROLLITHION	GEOMETRICUM	21		EPROLITHU. SP. 16	46
2149.50 02	A	MICRANTHOLITHUS	OBTUSUS	22		GRANTARHA. MEDDII	28
2150.00 02	A	ZEUGRHABDOTUS	SISYPHUS	23		HEMIPODOR. GORKAE	24
2153.50 02	A	HEMIPODORHABDUS	GORKAE	24		LITHRAPHI. CARNIOLENSIS	13
STNF	A	TEGUMENTUM	STRIATUM	25		MANIVITEL. PEMMATOIDEA	6
	A	COROLLITHION	LAFFITTEI	26		MICRANTHO. HOSCHULZII	37
	A	DISCORHABDUS	IGNOTUS	27		MICRANTHO. OBTUSUS	22
	A	GRANTARHABDUS	MEDDII	28		MICRANTHO. SP.	29
	A	MICRANTHOLITHUS	SP.	29		MICROSTAU CHIASTIUS	20
	A	ASSIPETRA	INFRACRETACEA	30		NANNOCONU. SP./DISC (FLORAL)	35
	A	PERISSOCYCLUS	FLETCHERI	31		NANNOCONU. SP./DISC (SMOOTH)	36
	A	CHIASTOZYGOUS	CEPEKII	32		PERISSOCY. FLETCHERI	31
	A	CRUCIBISCUTUM	SALEBROSUM	33		PERISSOCY. PLETHOTRETUS	3
	A	EIFFELLITHUS	TURRISEIFFELII	34		RHAGODISC. ASPER	14
	A	NANNOCONUS	SP./DISC (FLORAL)	35		SERIBISCU. PRIMITIVUM (LARGE)	43
	A	NANNOCONUS	SP./DISC (SMOOTH)	36		STAUROLIT. CRUX	15
	A	MICRANTHOLITHUS	HOSCHULZII	37		STAUROLIT. MUTTERLOSEI	7
	A	BUKRYLITHUS	AMBIGUUS	38		TEGULALIT. SEPTENTRIONALIS	4
	A	EPROLITHUS	FLORALIS	39		TEGUMENTU. STRIATUM	25
	A	ZEUGRHABDOTUS	EMBERGERI	40		TRANOLITH. GABALUS	9
	A	EPROLITHUS	SP.	41		WATZNAUER. BARNESAE	16
	A	CRETARHABDUS	MADINGLEYENSIS	42		WATZNAUER. FOSSACINCTA	17
	A	SERIBISCUTUM	PRIMITIVUM (LARGE)	43		WATZNAUER. OVATA	18
	A	BISCUTUM	ELLIPTICUM(WIDE RIM)	44		ZEUGRHABD. EMBERGERI	40
	A	CAVED UPPER CRET.	NANNOFOSSILS	45		ZEUGRHABD. ERECTUS	19
	A	EPROLITHUS	SP. 16	46		ZEUGRHABD. SISYPHUS	23
	A	NANNOCONUS	ABUNDANS	47	MGRP 1.1	NANNOCONU. ABUNDANS	47
	A	NANNOCONUS	SP. MGRP 1 2	48	MGRP 1.2	NANNOCONU. SP MGRP 1 2	48
	A	NANNOCONUS	MINUTUS	49	MGRP 2.2	NANNOCONU. MINUTUS	49
	A	NANNOCONUS	PASKENTIENSIS	50	MGRP 2.3	NANNOCONU. PASKENTIENSIS	50

SYMBOL LEGEND

C CAVED
? UNCERTAIN TAXONOMIC IDENTIFICATION
BARREN SAMPLE (NF)
. 1 SPECIMEN
/ 2 -5 SPECIMENS
o 6 -20 "
● 21-100 "

SAMPLE TYPE (ST) :
02 SIDEWALL

DEPTH IN FEET BELOW DERRICK FLOOR	NANNO-PLANKTON ZONATION	BIOSTRATIGRAPHIC SUBDIVISION	TIME-STRATIGRAPHIC SUBDIVISION
1633.00	NLK10		
1640.00	NLKA 13 / NLKA 13?		
1650.00	NLKA 13? / NLKA 20		
1672.00			
1693.00			
1713.50			
1727.50			L BR-U VA
1740.00			U/L BR
1998.50			
2077.00			? U VA
2080.00			
2083.00			
2089.00			
2091.00			HIATUS
2093.00			
2102.00			
2105.00			
2112.00			
2123.00			
2138.00			
2148.00			
2149.50			
2150.00			
2153.50			

SHELL U.K. EXPLORATION & PRODUCTION

DUTCH SECTOR

LOWER CRETACEOUS CALCAREOUS NANNOFOSSILS

WELL: L/2-2

INTERVAL: 1633'-2153'

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Author : B. VAN NIEL | Date : 1991 | Rev.

Encl. 10 | Drawing No. 62025c

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SYMBOL LEGEND

SAMPLE TYPE (ST) :

- • 1 SPECIMEN
- / 2-5 SPECIMENS
- o 6-20 "
- ● 21-100 "
- ? UNCERTAIN TAXONOMIC IDENTIFICATION

16 CORE CHIP

DEPTH IN FEET BELOW DERRICK FLOOR	ST	NF
8190.00	16	
8190.60	16	
8191.00	16	
8191.10	16	
8193.00	16	
8193.10	16	
8195.00	16	
8200.00	16	
8207.60	16	
8208.50	16	
8209.00	16	
8210.11	16	
8211.30	16	
8211.40	16	
8219.00	16	
8234.00	16	

A/B	SCIENTIFIC NAME		REG NO.
A	NANNOCONUS	SP.	1
A	TEGUMENTUM	STRIATUM	2
A	RHAGODISCUS	ANGUSTUS	3
A	AXOPODORHABDUS	DIETZMANNII	4
A	BUKRYLITHUS	AMBIGUUS	5
A	CRETARHABDUS	ANGUSTIFORATUS	6
A	COROLLITHION	GEOMETRICUM	7
A	TRANOLITHUS	GABALUS	8
A	ZEUGRHABDOTUS	ERECTUS	9
A	ZEUGRHABDOTUS	SISYPHUS	10
A	BISCUTUM	ELLIPTICUM	11
A	CRETARHABDUS	CONICUS	12
A	DISCORHABDUS	IGNOTUS	13
A	RHAGODISCUS	ASPER	14
A	STAUROLITHITES	CRUX	15
A	WATZNAUERIA	BARNESAE	16
A	WATZNAUERIA	FOSSACINCTA	17
A	WATZNAUERIA	OVATA	18
A	VAGALAPILLA	MATALOSA (SMALL)	19
A	HEMIPODORHABDUS	GORKAE	20
A	NANNOCONUS	SP /DISC (FLORAL)	21
A	TEGUMENTUM	STRADNERI	22
A	WATZNAUERIA	MANIVITAE	23
A	MICRANTHOLITHUS	SP	24
A	NANNOCONUS	SP /DISC MGRP 3	25
A	COROLLITHION	LAFFITTEI	26
A	CYCLAGELOSPHAERA	MARGERELII	27
A	CRETARHABDUS	SP	28
A	MICRANTHOLITHUS	OBTUSUS(INCIS.PLAT)	29
A	CRUCIBISCUTUM	SALEBROSUM	30
A	SERIBISCUTUM	PRIMITIVUM (LARGE)	31
A	MICROSTAURUS	CHIASTIUS	32
A	VAGALAPILLA	SWINNERTONII	33
A	CHIASTOZYGOUS	CEPEKII	34
A	STAUROLITHITES	MUTTERLOSEI	35
A	MICRANTHOLITHUS	OBTUSUS	36
A	LITHRAPHIDITES	MORAYFIRTHENSIS	37
A	VAGALAPILLA	MATALOSA	38
A	STAUROLITHITES	SP I	39
A	TEGULALITHUS	SEPTENTRIONALIS	40
A	GRANTARHABDUS	MEDDII	41
A	CHIASTOZYGOUS	SP	42
A	LITHRAPHIDITES	SP	43
A	SOLLASITES	HORTICUS	44
A	NANNOCONUS	SP /DISC MGRP 2	45
A	ASSIPETRA	INFRACRETACEA	46
A	CONUSPHAERA	ROTHII	47
A	COROLLITHION	SILVARADION	48
A	MANIVITELLA	PEMMATOIDEA	49
A	MICRANTHOLITHUS	HOSCHULZII	50
A	NANNOCONUS	SP MGRP 1.2	51
A	NANNOCONUS	TRUITTI TRUITTI	52
A	NANNOCONUS	TRUITTI GROUP	53
A	NANNOCONUS	SP (FRAGMENTS) 2.2	54
A	NANNOCONUS	SP MGRP 2 3	55
A	NANNOCONUS	BONETI	56
A	NANNOCONUS	BOREALIS	57
A	NANNOCONUS	ELONGATUS ELONGATUS	58
A	NANNOCONUS	SP (FRAGMENTS) 2.3	59
A	NANNOCONUS	PASKENTIENSIS	60
A	NANNOCONUS	GLOBULUS GLOBULUS	61
A	NANNOCONUS	CF OVIFORMIS	62

NANNOFOSSILS

INDEX	REG NO
ASSIPETRA. INFRACRETACEA	46
AXOPODORH DIETZMANNII	4
BISCUTUM . ELLIPTICUM	11
BUKRYLITH. AMBIGUUS	5
CHIASTOZY. CEPEKII	34
CHIASTOZY. SP	42
CONUSPHAE ROTHII	47
COROLLITH. GEOMETRICUM	7
COROLLITH LAFFITTEI	26
COROLLITH. SILVARADION	48
CRETARHAB. ANGUSTIFORATUS	6
CRETARHAB. CONICUS	12
CRETARHAB. SP	28
CRUCIBISC SALEBROSUM	30
CYCLAGELO. MARGERELII	27
DISCORHAB. IGNOTUS	13
GRANTARHA. MEDDII	41
HEMIPODOR. GORKAE	20
LITHRAPHI. MORAYFIRTHENSIS	37
LITHRAPHI. SP	43
MANIVITEL. PEMMATOIDEA	49
MICRANTHO. HOSCHULZII	50
MICRANTHO. OBTUSUS	36
MICRANTHO. OBTUSUS(INCIS.PLAT)	29
MICRANTHO SP.	24
MICROSTAU. CHIASTIUS	32
NANNOCONU. SP	1
NANNOCONU SP /DISC (FLORAL)	21
NANNOCONU. SP /DISC MGRP 2	45
NANNOCONU. SP./DISC MGRP 3	25
RHAGODISC. ANGUSTUS	3
RHAGODISC. ASPER	14
SERIBISCU. PRIMITIVUM (LARGE)	31
SOLLASITE. HORTICUS	44
STAUROLIT CRUX	15
STAUROLIT. MUTTERLOSEI	35
STAUROLIT. SP. 1	39
TEGULALIT. SEPTENTRIONALIS	40
TEGUMENTU. STRADNERI	22
TEGUMENTU STRIATUM	2
TRANOLITH. GABALUS	8
VAGALAPIL MATALOSA	38
VAGALAPIL. MATALOSA (SMALL)	19
VAGALAPIL. SWINNERTONII	33
WATZNAUER BARNESAE	16
WATZNAUER. FOSSACINCTA	17
WATZNAUER MANIVITAE	23
WATZNAUER. OVATA	18
ZEUGRHABD. ERECTUS	9
ZEUGRHABD. SISYPHUS	10

MGRP 1.2

INDEX	REG NO
NANNOCONU. SP. MGRP 1.2	51

MGRP 2.2

INDEX	REG NO
NANNOCONU SP. (FRAGMENTS) 2.2	54
NANNOCONU. TRUITTI GROUP	53
NANNOCONU. TRUITTI TRUITTI	52

MGRP 2.3

INDEX	REG NO
NANNOCONU. BONETI	56
NANNOCONU. BOREALIS	57
NANNOCONU. ELONGATUS ELONGATUS	58
NANNOCONU. PASKENTIENSIS	60
NANNOCONU SP. MGRP 2 3	55
NANNOCONU. SP. (FRAGMENTS) 2.3	59

MGRP 3.3

INDEX	REG NO
NANNOCONU. CF. OVIFORMIS	62
NANNOCONU GLOBULUS GLOBULUS	61

DEPTH IN FEET BELOW DERRICK FLOOR

DEPTH IN FEET BELOW DERRICK FLOOR
8190.00
8190.60
8191.00
8191.10
8193.00
8193.10
8195.00
8200.00
8207.60
8208.50
8209.00
8210.11
8211.30
8211.40
8219.00
8234.00

BIOSTRATIGRAPHIC SUBDIVISION

NANNO-PLANKTON ZONATION

NANNO-PLANKTON ZONATION
?NLKB
NLK9
NLKA 18
NLKA 13
NLKK10
NLKA 13
NLKA 18

TIME-STRATIGRAPHIC SUBDIVISION

TIME-STRATIGRAPHIC SUBDIVISION
? U AP
U/L AP
LAP/UBR
U/L BR
LBR-LHT
U/L HT

"SHELL U.K. EXPLORATION & PRODUCTION

DANISH CENTRAL TROUGH

LOWER CRETACEOUS

CALCAREOUS NANNOFOSSILS

WELL: E-1

INTERVAL: 8190'-8234'

CONFIDENTIAL

Author : B. VAN NIEL	Date : 1991	Rev.
Encl. II	Drawing No. 62020c	

I-1

DEPTH IN FEET BELOW DERRICK FLOOR

ST	NF	A/B	SCIENTIFIC NAME		REG NO.		INDEX	REG NO.
	16	A	TEGUMENTUM	STRADNERI	1	NANNOFOSSILS	AXOPODORH. DIETZMANNII	3
	16	A	NANNOCONUS	SP./DISC (FLORAL)	2		BISCUTUM . ELLIPTICUM	6
	15	A	AXOPODORHABDUS	DIETZMANNII	3		BISCUTUM ELLIPTICUM(WIDE RIM)	7
	16	A	COROLLITHION	LAFFITTEI	4		BUKRYLITH. AMBIGUUS	24
	16	A	ZEUGRHABDOTUS	ERECTUS	5		CAVED UPP. NANNOFOSSILS	27
	16	A	BISCUTUM	ELLIPTICUM	6		COROLLITH. LAFFITTEI	4
		A	BISCUTUM	ELLIPTICUM(WIDE RIM)	7		CRETARHAB. CONICUS	8
		A	CRETARHABDUS	CONICUS	8		CRETARHAB. MADINGLEYENSIS	21
		A	CYCLAGELOSPHAERA	MARGERELII	9		CRUCIBISC. SALEBROSUM	22
		A	DISCORHABDUS	IGNOTUS	10		CYCLAGELO MARGERELII	9
		A	MICROSTAURUS	CHIASTIUS	11		DISCORHAB. IGNOTUS	10
		A	NANNOCONUS	SP /DISC (SMOOTH)	12		GLAUKOLIT. COMPACTUS	28
		A	RHAGODISCUS	ASPER	13		GRANTARHA. MEDDII	25
		A	STAUROLITHITES	CRUX	14		MICRANTHO. SP.	29
		A	WATZNAUERIA	BARNESAE	15		MICROSTAU CHIASTIUS	11
		A	WATZNAUERIA	FOSSACINCTA	16		NANNOCONU. SP /DISC (FLORAL)	2
		A	WATZNAUERIA	OVATA	17		NANNOCONU. SP /DISC (SMOOTH)	12
		A	STAUROLITHITES	SP. 1	18		RHAGODISC. ASPER	13
		A	WATZNAUERIA	MANIVITAE	19		STAUROLIT CRUX	14
		A	ZEUGRHABDOTUS	EMBERGERI	20		STAUROLIT. MUTTERLOSEI	26
		A	CRETARHABDUS	MADINGLEYENSIS	21		STAUROLIT. SP 1	18
		A	CRUCIBISCUTUM	SALEBROSUM	22		TEGUMENTU STRADNERI	1
		A	TEGUMENTUM	STRIATUM	23		TEGUMENTU. STRIATUM	23
		A	BUKRYLITHUS	AMBIGUUS	24		WATZNAUER. BARNESAE	15
		A	GRANTARHABDUS	MEDDII	25		WATZNAUER. FOSSACINCTA	16
		A	STAUROLITHITES	MUTTERLOSEI	26		WATZNAUER MANIVITAE	19
		A	CAVED UPPER CRET.	NANNOFOSSILS	27		WATZNAUER. OVATA	17
		A	GLAUKOLITHUS	COMPACTUS	28		ZEUGRHABD. EMBERGERI	20
		A	MICRANTHOLITHUS	SP	29		ZEUGRHABD. ERECTUS	5
		A	NANNOCONUS	ABUNDANS (BARREL)	30	MGRP 1.1	NANNOCONU. ABUNDANS (BARREL)	30
		A	NANNOCONUS	SP. MGRP 1.1	31		NANNOCONU SP. MGRP 1.1	31
		A	NANNOCONUS	ELONGATUS MINUTUS	32	MGRP 2.3	NANNOCONU. ELONGATUS MINUTUS	32
		A	NANNOCONUS	SP. 2	33		NANNOCONU. SP. 2	33

NLKA 13	NLKIO	NANNO-PLANKTON ZONATION	BIOSTRATIGRAPHIC SUBDIVISION
U BR			TIME-STRATIGRAPHIC SUBDIVISION

SYMBOL LEGEND

SAMPLE TYPE (ST) :

- 1 SPECIMEN
- / 2 - 5 SPECIMENS
- O 6 - 20 "
- ● 21-100 "
- ? UNCERTAIN TAXONOMIC IDENTIFICATION

15 CORE CHIP

SHELL U.K. EXPLORATION & PRODUCTION

DANISH CENTRAL NORTH SEA

LOWER CRETACEOUS CALCAREOUS NANNOFOSSILS

WELL: I-1

INTERVAL: 9493'-9539'

CONFIDENTIAL

Author : B. VAN NIEL | Date : 1991 | Rev.

Encl. 12 | Drawing No. 62023c

ADDA-2

SYMBOL LEGEND

SAMPLE TYPE (ST) :

- ▪ 1 SPECIMEN
- / 2 - 5 SPECIMENS
- o 6 - 20 "
- ● 21 - 100 "
- ? UNCERTAIN TAXONOMIC IDENTIFICATION.

15 CORE CHIP

DEPTH IN FEET BELOW DERRICK FLOOR	ST	NF	A/B	SCIENTIFIC NAME		REG NO.		INDEX	REG NO.
7750.00	15		A	COROLLITHION	GEOMETRICUM	1		ASSIPETRA. INFRACRETACEA	29
7756.00	15		A	GLAUKOLITHUS	COMPACTUS	2		AXOPODORH DIETZMANNII	10
7768.00	15		A	ZEUGRHABDOTUS	SISYPHUS	3		BISCUTUM . ELLIPTICUM	11
7774.00	15		A	TEGUMENTUM	STRIATUM	4		CAVED UPP. NANNOFOSSILS	27
7778.00	15		A	COROLLITHION	LAFFITTEI	5		CONUSPHAE. ROTHII	37
7811.00	15		A	RHAGODISCUS	ANGUSTUS	6		COROLLITH. GEOMETRICUM	1
7820.00	15		A	CRETARHABDUS	CONICUS	7		COROLLITH. LAFFITTEI	5
7841.00	15		A	MICROSTAURUS	CHIASTIUS	8		CRETARHAB. CONICUS	7
7849.11	15		A	WATZNAUERIA	OVATA	9		CRETARHAB. MADINGLEYENSIS	43
			A	AXOPODORHABDUS	DIETZMANNII	10		CRETARHAB. SP	28
			A	BISCUTUM	ELLIPTICUM	11		CRUCIBISC. SALEBROSUM	24
			A	DISCORHABDUS	IGNOTUS	12		CYCLAGELO. MARGERELII	25
			A	LITHRAPHIDITES	CARNIOLENSIS	13		DISCORHAB. IGNOTUS	12
			A	MICRANTHOLITHUS	HOSCHULZII	14		EPROLITHU SP. II	20
			A	MICRANTHOLITHUS	OBTUSUS	15		GLAUKOLIT. COMPACTUS	2
			A	RHAGODISCUS	ASPER	16		GRANTARHA. MEDDII	34
			A	STAUROLITHITES	CRUX	17		LITHRAPHI CARNIOLENSIS	13
			A	WATZNAUERIA	BARNESAE	18		MANIVITEL. PEMMATOIDEA	30
			A	WATZNAUERIA	FOSSACINCTA	19		MICRANTHO. HOSCHULZII	14
			A	EPROLITHUS	SP II	20		MICRANTHO. OBTUSUS	15
			A	NANNOCONUS	SP./DISC MGRP 1.	21		MICRANTHO. SP.	33
			A	STAUROLITHITES	MUTTERLOSEI	22		MICROSTAU. CHIASTIUS	8
			A	TRANOLITHUS	GABALUS	23		NANNOCONU. SP./DISC (FLORAL)	39
			A	CRUCIBISCUTUM	SALEBROSUM	24		NANNOCONU SP /DISC MGRP 1.	21
			A	CYCLAGELOSPHAERA	MARGERELII	25		NANNOCONU. SP./DISC MGRP 2.	31
			A	TEGULALITHUS	SEPTENTRIONALIS	26		RHAGODISC. ANGUSTUS	6
			A	CAVED UPPER CRET.	NANNOFOSSILS	27		RHAGODISC. ASPER	16
			A	CRETARHABDUS	SP	28		RHAGODISC. PSEUDOANGUSTUS	40
			A	ASSIPETRA	INFRACRETACEA	29		STAUROLIT. CRUX	17
			A	MANIVITELLA	PEMMATOIDEA	30		STAUROLIT. MUTTERLOSEI	22
			A	NANNOCONUS	SP /DISC MGRP 2.	31		STAUROLIT. SP. I	41
			A	VAGALAPILLA	MATALOSA	32		TEGULALIT. SEPTENTRIONALIS	26
			A	MICRANTHOLITHUS	SP	33		TEGUMENTU. STRADNERI	42
			A	GRANTARHABDUS	MEDDII	34		TEGUMENTU. STRIATUM	4
			A	ZEUGRHABDOTUS	EMBERGERI	35		TRANOLITH. GABALUS	23
			A	WATZNAUERIA	MANIVITAE	36		VAGALAPIL. MATALOSA	32
			A	CONUSPHAERA	ROTHII	37		WATZNAUER. BARNESAE	18
			A	ZEUGRHABDOTUS	ERECTUS	38		WATZNAUER. FOSSACINCTA	19
			A	NANNOCONUS	SP./DISC (FLORAL)	39		WATZNAUER. MANIVITAE	36
			A	RHAGODISCUS	PSEUDOANGUSTUS	40		WATZNAUER. OVATA	9
			A	STAUROLITHITES	SP. I	41		ZEUGRHABD. EMBERGERI	35
			A	TEGUMENTUM	STRADNERI	42		ZEUGRHABD. ERECTUS	38
			A	CRETARHABDUS	MADINGLEYENSIS	43		ZEUGRHABD. SISYPHUS	3
			A	NANNOCONUS	ABUNDANS	44	MGRP 1.1	NANNOCONU. ABUNDANS	44
			A	NANNOCONUS	CF CIRCULARIS	45	MGRP 1.1	NANNOCONU. CF CIRCULARIS	45
			A	NANNOCONUS	MINUTUS	46	MGRP 2.2	NANNOCONU. MINUTUS	46
			A	NANNOCONUS	KAMPTNERI KAMPTNERI	47	MGRP 2.3	NANNOCONU BONETII	49
			A	NANNOCONUS	PASKENTIENSIS	48	MGRP 2.3	NANNOCONU. KAMPTNERI KAMPTNERI	47
			A	NANNOCONUS	BONETII	49	MGRP 2.3	NANNOCONU. PASKENTIENSIS	48
			A	NANNOCONUS	OVIFORMIS	50	MGRP 3.3	NANNOCONU. OVIFORMIS	50
			A	NANNOCONUS	SP. (FRAGMENTS) 3.3	51	MGRP 3.3	NANNOCONU. SP. (FRAGMENTS) 3.3	51
			A	NANNOCONUS	SP. (OBLIQUE) 3.3	52	MGRP 3.3	NANNOCONU. SP. (OBLIQUE) 3.3	52

DEPTH IN FEET BELOW DERRICK FLOOR

BIOSTRATIGRAPHIC SUBDIVISION			
NANNO-PLANKTON ZONATION	NLK10		
	NLK10 NLKA13		
	NLKA 13		
TIME-STRATIGRAPHIC SUBDIVISION	U BR		
	U/L BR		
	L BR		

SHELL U.K. EXPLORATION & PRODUCTION

DANISH CENTRAL TROUGH

LOWER CRETACEOUS CALCAREOUS NANNOFOSSILS

WELL: ADDA-2

INTERVAL: 7750'-7849'

CONFIDENTIAL

Author : B. VAN NIEL	Date : 1991	Rev.
Encl. 13	Drawing No. 62021c	

NORTH JENS-I

DEPTH IN FEET BELOW DERRICK FLOOR

ST = SAMPLE TYPE (ST) : 14 DRIED DITCH CTG; 15 CORE CHIP; 02 SIDEWALL

NF = BARREN SAMPLE (NF)

A/B = A: UNCERTAIN TAXONOMIC IDENTIFICATION; B: SCIENTIFIC NAME

REG NO. = REGISTRATION NUMBER

INDEX = NANNOFOSSILS

ST	NF	A/B	SCIENTIFIC NAME	REG NO.	INDEX
		A	EPROLITHUS APERTIOR	1	ASSIPETRA. INFRACRETACEA
		A	MICROSTAURUS CHIASTIUS	2	AXOPODORH. CF. DIETZMANNI
		A	LITHRAPHIDITES SP.	3	AXOPODORH. DIETZMANNI
		A	TEGUMENTUM STRIATUM	4	BISCUTUM. ELLIPTICUM
		A	WATZNAUERIA MANIVITAE	5	BISCUTUM. ELLIPTICUM(WIDE RIM)
		A	CYCLAGELOSPHAERA MARGERELII	6	BISCUTUM. SP.
		A	CRETAHABDUS SP.	7	BRAARUDOS. STENORHETHA
		A	HEMIPODORHABDUS GORKAE	8	BUKRYLITH. AMBIGUUS
		A	WATZNAUERIA BARNESAE	9	CAVED UPP. NANNOFOSSILS
		A	WATZNAUERIA FOSSACINCTA	10	CHIASTOZY. CEPEKII
		A	COROLLITHION SILVARADIAN	11	CHIASTOZY. SP.
		A	BISCUTUM ELLIPTICUM	12	CONIASPHAE. ROTHII
		A	DISCORHABDUS IGNOTUS	13	COROLLITH. GEOMETRICUM
		A	RHAGODISCUS ASPER	14	COROLLITH. LAFFITTEI
		A	HOLOCOCCOLITH SP.	15	COROLLITH. SILVARADIAN
		A	KOKIA MANIVITELLA	16	CRETARHAB. ANGUSTIFORATUS
		A	RHAGODISCUS ANGUSTUS	17	CRETARHAB. CONICUS
		A	RHAGODISCUS EMBERGERI	18	CRETARHAB. MADINGLEYENSIS
		A	ZEUGRHABDOTUS SISYPHUS	19	CRUCIBISC. SP.
		A	CRETARHABDUS CONICUS	20	CRUCIBISC. SALEBROSUM
		A	SPLENDENS PRAEOBLIQUUM	21	CRUCIELLI. CUVILLIERI
		A	RHAGODISCUS SP.	22	CYCLAGELO. MARGERELII
		A	GARTNERAGO PRAEOBLIQUUM	23	DIAZOMATO. LEHMANII
		A	EPROLITHUS SP.	24	DISCORHAB. IGNOTUS
		A	MADINGLEYENSIS MADINGLEYENSIS	25	EPROLITHU. ANTIQUUS
		A	TRANOLITHUS GABALUS	26	EPROLITHU. APERTOIR
		A	AXOPODORHABDUS DIETZMANNII	27	EPROLITHU. SP.
		A	ELLIPTICUM(WIDE RIM) ELLIPTICUM(WIDE RIM)	28	EPROLITHU. SP. II
		A	BISCUTUM PLETHOTRETUS	29	EPROLITHU. VAROLII
		A	PERISSOCYCLUS MEDDII	30	GARTNERAG. PRAEOBLIQUUM
		A	GRANTARHABDUS CRUX	31	GLAUKOLIT. COMPACTUS
		A	STAUROLITHITES VAROLII	32	GRANTARHA. MEDDII
		A	EPROLITHUS OBTUSUS	33	HEMIPODOR. GORKAE
		A	MICRANTHOLITHUS STENORHETHA	34	HOLOCOCCO. SP.
		A	BRAARUDOSPHAERA SP.	35	KOKIA. BOREALIS
		A	CHIASTOZYGUS PSEUDOANGUSTUS	36	KOKIA. CURVATUS
		A	RHAGODISCUS LAFFITTEI	37	KOKIA. SP.
		A	COROLLITHION GEOMETRICUM	38	LITHRAPHI. CARNIOLENSIS
		A	NANNOCONUS SP./DISC (FLORAL)	39	LITHRAPHI. CF. MORAYFIRTHENSIS
		A	MICRANTHOLITHUS OBTUSUS(INCIS.PLAT)	40	LITHRAPHI. SP.
		A	ZEUGRHABDOTUS ERECTUS	41	MANIVITEL. PEMMATOIDEA
		A	SOLLASITES HORTICUS	42	MICRANTHO. HOSCHULZII
		A	LITHRAPHIDITES CF. MORAYFIRTHENSIS	43	MICRANTHO. OBTUSUS
		A	TEGUMENTUM STRIATUM (LARGE)	44	MICRANTHO. OBTUSUS(INCIS.PLAT)
		A	STAUROLITHITES SP. I.	45	MICRANTHO. SP.
		A	LITHRAPHIDITES CARNIOLENSIS	46	MICRANTHO. SPEETONENSIS
		A	NANNOCONUS SP.	47	MICROSTAU. CHIASTIUS
		A	STAUROLITHITES MUTTERLOSEI	48	NANNOCONU. SP.
		A	CRETARHABDUS ANGUSTIFORATUS	49	NANNOCONU. SP. (OBLIQUE)
		A	CRUCIELLIPSIS CUVILLIERI	50	NANNOCONU. SP./DISC (FLORAL)
		A	NANNOCONUS SP./DISC (SMOOTH)	51	NANNOCONU. SP./DISC (SMOOTH)
		A	MICRANTHOLITHUS SPEETONENSIS	52	NANNOCONU. SP./DISC MGRP 1.
		A	AXOPODORHABDUS CF. DIETZMANNI	53	NANNOCONU. SP./DISC MGRP 2.
		A	MICRANTHOLITHUS SP.	54	NANNOCONU. SP./DISC MGRP 3.
		A	GLAUKOLITHUS COMPACTUS	55	PEMISSOCY. SP.
		A	PERISSOCYCLUS NOELIAE	56	PERISSOCY. FLETCHERI
		A	NANNOCONUS SP./DISC MGRP 3	57	PERISSOCY. NOELIAE
		A	MICRANTHOLITHUS HOSCHULZII	58	PERISSOCY. PLETHOTRETUS
		A	VAGALAPILLA MATALOSA	59	RHAGODISC. ASPER
		A	TEGULALITHUS SEPTENTRIONALIS	60	RHAGODISC. PSEUDOANGUSTUS
		A	PEMISSOCYCLUS SP.	61	RHAGODISC. SPLENDENS
		A	ASSIPETRA INFRACRETACEA	62	SERIBISCU. PRIMITIVUM (LARGE)
		A	CONUSPHAERA ROTHII	63	SOLLASITE. HORTICUS
		A	CRUCIBISCUTUM SALEBROSUM	64	SOLLASITE. SP.
		A	BUKRYLITHUS AMBIGUUS	65	SPEETONIA. COLLIGATA
		A	DIAZOMATOLITHUS LEHMANII	66	STAUROLIT. CRUX
		A	SPEETONIA COLLIGATA	67	STAUROLIT. MUTTERLOSEI
		A	SOLLASITES SP.	68	STAUROLIT. SP. I
		A	TEGUMENTUM OCTIFORMIS	69	TEGULALIT. SEPTENTRIONALIS
		A	NANNOCONUS SP. (OBLIQUE)	70	TEGUMENTU. OCTIFORMIS
		A	CAVED UPPER CRET. NANNOFOSSILS	71	TEGUMENTU. STRIATUM
		A	NANNOCONUS SP./DISC MGRP 2.	72	TEGUMENTU. STRIATUM (LARGE)
		A	CHIASTOZYGUS CEPEKII	73	TEGUMENTU. SP.
		A	EPROLITHUS ANTIQUUS	74	TRANOLITH. GABALUS
		A	EPROLITHUS SP. II	75	TRIQUETOR. SHETLANDENSIS
		A	PERISSOCYCLUS FLETCHERI	76	VAGALAPIL. MATALOSA
		A	KOKIA BOREALIS	77	WATZNAUER. BARNESAE
		A	TRIQUETORHABDULUS SHETLANDENSIS	78	WATZNAUER. FOSSACINCTA
		A	KOKIA CURVATUS	79	WATZNAUER. MANIVITAE
		A	SERIBISCUTUM PRIMITIVUM (LARGE)	80	ZEUGRHABD. EMBERGERI
		A	BISCUTUM SP.	81	ZEUGRHABD. ERECTUS
		A	NANNOCONUS SP./DISC MGRP 1.	82	ZEUGRHABD. SISYPHUS
		A	NANNOCONUS ABUNDANS (BARREL)	83	NANNOCONU. SP. I
		A	NANNOCONUS ABUNDANS	84	NANNOCONU. ABUNDANS
		A	NANNOCONUS CIRCULARIS	85	NANNOCONU. ABUNDANS (BARREL)
		A	NANNOCONUS SP. MGRP 1.1	86	NANNOCONU. ABUNDANS (FLANGE)
		A	NANNOCONUS ABUNDANS (FLANGE)	87	NANNOCONU. CIRCULARIS
		A	NANNOCONUS SP. I.	88	NANNOCONU. SP. (LARGE DISC)
		A	NANNOCONUS SP. (LARGE DISC)	89	NANNOCONU. SP. MGRP 1.1
		A	NANNOCONUS SP. MGRP1.1	90	NANNOCONU. SP. MGRP1.1
		A	NANNOCONUS SP. (OBLIQUE) 1.2	91	NANNOCONU. SP. (OBLIQUE) 1.2
		A	NANNOCONUS TRUITTI TRUITTI	92	NANNOCONU. BUCHERI
		A	NANNOCONUS TRUITTI FREQUENS	93	NANNOCONU. DAUVILLIERI
		A	NANNOCONUS BUCHERI	94	NANNOCONU. MINUTUS
		A	NANNOCONUS DAUVILLIERI	95	NANNOCONU. QUADRIANGULUS GROUP
		A	NANNOCONUS QUADRIANGULUS GROUP	96	NANNOCONU. SP. (OBLIQUE) 2.2
		A	NANNOCONUS MINUTUS	97	NANNOCONU. TRUITTI FREQUENS
		A	NANNOCONUS TRUITTI GROUP	98	NANNOCONU. TRUITTI GROUP
		A	NANNOCONUS SP. (OBLIQUE) 2.2	99	NANNOCONU. TRUITTI TRUITTI
		A	NANNOCONUS BONETI	100	NANNOCONU. BONETI
		A	NANNOCONUS ELONGATUS ELONGATUS	101	NANNOCONU. BOREALIS
		A	NANNOCONUS SP. MGRP2.3	102	NANNOCONU. CF. ELONGATUS
		A	NANNOCONUS STEINMANNI STEINMANNI	103	NANNOCONU. DOLOMITICUS
		A	NANNOCONUS PASKENTIENSIS	104	NANNOCONU. ELONGATUS ELONGATUS
		A	NANNOCONUS ELONGATUS MINUTUS	105	NANNOCONU. ELONGATUS MINUTUS
		A	NANNOCONUS LONGUS	106	NANNOCONU. KAMPTNERI KAMPTNERI
		A	NANNOCONUS SP.2.	107	NANNOCONU. LONGUS
		A	NANNOCONUS CF ELONGATUS	108	NANNOCONU. PASKENTIENSIS
		A	NANNOCONUS BOREALIS	109	NANNOCONU. SP. (DOUB.SPECI2.3
		A	NANNOCONUS KAMPTNERI KAMPTNERI	110	NANNOCONU. SP.2.
		A	NANNOCONUS DOLOMITICUS	111	NANNOCONU. STEINMANNI MINOR
		A	NANNOCONUS STEINMANNI MINOR	112	NANNOCONU. STEINMANNI STEINMANNI
		A	NANNOCONUS GLOBULUS SUBSP.NOV A	113	NANNOCONU. CF GLOBULUS
		A	NANNOCONUS CF. OVIFORMIS	114	NANNOCONU. CF. OVIFORMIS
		A	NANNOCONUS GLOBULUS GRP	115	NANNOCONU. GLOBULUS GLOBULUS
		A	NANNOCONUS GLOBULUS SUBSP.NOV A	116	NANNOCONU. GLOBULUS SUBSP.NOV A
		A	NANNOCONUS SP. (FRAGMENTS) 3.3	117	NANNOCONU. GLOBULUS GROUP
		A	NANNOCONUS CF. GLOBULUS	118	NANNOCONU. GLOBULUS GRP
		A	NANNOCONUS SP 3.	119	NANNOCONU. GLOBULUS MINOR
		A	NANNOCONUS GLOBULUS GROUP	120	NANNOCONU. SP. 3.
		A	NANNOCONUS WASSALII WASSALII	121	NANNOCONU. SP. (FRAGMENTS) 3.3
		A	NANNOCONUS GLOBULUS MINOR	122	NANNOCONU. WASSALII WASSALII

DEPTH IN FEET BELOW DERRICK FLOOR

BIOSTRATIGRAPHIC SUBDIVISION

NANNO-PLANKTON ZONATION: NLK4 | NLK7 | NLK8 | NLK9 | NLK10 | NLKA 11-13 | NLKA 22 | NLKA 11

TIME-STRATIGRAPHIC SUBDIVISION: U/M AB-UAP | U AP | U/L AP | LAP/UBR | U BR | HIATUS ON LOG | U BR | U/L BR | ? LBR/LHT | ? L HT/UVA | U/L VA | ? L VA | KIMMERIDGE CLAY

SYMBOL LEGEND

- BARREN SAMPLE (NF)
- • 1 SPECIMEN
- / 2 -5 SPECIMENS
- ○ 6 -20 "
- ● 21-100 "
- ? UNCERTAIN TAXONOMIC IDENTIFICATION

SAMPLE TYPES (ST) :
14 DRIED DITCH CTG
15 CORE CHIP
02 SIDEWALL

SHELL U.K. EXPLORATION & PRODUCTION

DANISH CENTRAL TROUGH

LOWER CRETACEOUS
CALCAREOUS NANNOFOSSILS
WELL: NORTH JENS-I
INTERVAL: 7312'-8100'

CONFIDENTIAL

Author : B. VAN NIEL	Date : 1991	Rev.
	Encl. 14	Drawing No. 62019c

63/10-1

DEPTH IN FEET BELOW DERRICK FLOOR

A/B	SCIENTIFIC NAME		REG NO.
A	LITHRAPHIDITES	CARNIOLENSIS	1
A	WATZNAUERIA	MANIVITAE	2
A	CAVED UPPER CRET.	NANNOFOSSILS	3
A	ZEUGRHABDOTUS	ERECTUS	4
A	WATZNAUERIA	BARNESAE	5
A	EIFFELLITHUS	TURRISEIFFELII	6
A	BRAARUDOSPHAERA	STENORHETHA	7
A	DISCORHABDUS	IGNOTUS	8
A	WATZNAUERIA	FOSSACINCTA	9
A	MICRANTHOLITHUS	OBTUSUS	10
A	BISCUTUM	ELLIPTICUM	11
A	GRANTARHABDUS	MEDDII	12
A	MANIVITELLA	PEMMATOIDEA	13
A	MICRANTHOLITHUS	SPEETONENSIS	14
A	TRANOLITHUS	GABALUS	15
A	RHAGODISCUS	ANGUSTUS	16
A	STAUROLITHITES	CRUX	17
A	RHAGODISCUS	ASPER	18
A	COROLLITHION	SILVARADION	19
A	LITHRAPHIDITES	CF. MORAYFIRTHENSIS	20
A	NANNOCONUS	SP./DISC MGRP 2.	21
A	ZEUGRHABDOTUS	SISYPHUS	22
A	CRETARHABDUS	CONICUS	23
A	CYCLAGELOSPHAERA	MARGERELII	24
A	CRETARHABDUS	SP.	25
A	HEMIPODORHABDUS	GORKAE	26
A	COROLLITHION	LAFFITTEI	27
A	GLAUKOLITHUS	COMPACTUS	28
A	ASSIPETRA	INFRACRETACEA	29
A	EPROLITHUS	ORBICULATUS	30
A	VAGALAPILLA	MATALOSA	31
A	MICRANTHOLITHUS	SP	32
A	NANNOCONUS	SP.	33
A	WATZNAUERIA	OVATA	34
A	NANNOCONUS	ABUNDANS	35
A	NANNOCONUS	CF. CIRCULARIS	36
A	NANNOCONUS	TRUITTI GROUP	37
A	NANNOCONUS	CF. OVIFORMIS	38

NANNOFOSSILS

MGRP 1.1

MGRP 2.2

MGRP 3.3

REG NO	INDEX
29	ASSIPETRA. INFRACRETACEA
11	BISCUTUM ELLIPTICUM
7	BRAARUDOS. STENORHETHA
3	CAVED UPP NANNOFOSSILS
27	COROLLITH LAFFITTEI
19	COROLLITH SILVARADION
23	CRETARHAB. CONICUS
25	CRETARHAB SP.
24	CYCLAGELO MARGERELII
8	DISCORHAB. IGNOTUS
6	EIFFELLIT TURRISEIFFELII
30	EPROLITHU ORBICULATUS
28	GLAUKOLIT COMPACTUS
12	GRANTARHA MEDDII
26	HEMIPODOR GORKAE
1	LITHRAPHI. CARNIOLENSIS
20	LITHRAPHI. CF. MORAYFIRTHENSIS
13	MANIVITEL PEMMATOIDEA
10	MICRANTHO. OBTUSUS
32	MICRANTHO SP.
14	MICRANTHO SPEETONENSIS
33	NANNOCONU SP.
21	NANNOCONU SP./DISC MGRP 2.
16	RHAGODISC ANGUSTUS
18	RHAGODISC ASPER
17	STAUROLIT CRUX
15	TRANOLITH. GABALUS
31	VAGALAPIL MATALOSA
5	WATZNAUER. BARNESAE
9	WATZNAUER. FOSSACINCTA
2	WATZNAUER. MANIVITAE
34	WATZNAUER. OVATA
4	ZEUGRHABD ERECTUS
22	ZEUGRHABD. SISYPHUS
35	NANNOCONU ABUNDANS
36	NANNOCONU CF. CIRCULARIS
37	NANNOCONU TRUITTI GROUP
38	NANNOCONU CF OVIFORMIS

ST NF

1170.00 1191.00 1209.00 1224.00 1245.00 1250.00 1255.00 1260.00 1269.00 1320.00 1341.00 1350.00

BIOSTRATIGRAPHIC MARKERS

NANNO-PLANKTON ZONATION	BIOSTRATIGRAPHIC SUBDIVISION	TIME-STRATIGRAPHIC SUBDIVISION
NLK4 — NLK7		U AB/U AP
NLK8		U AP
NLK9		L AP
NLK10		U BR

SYMBOL LEGEND

C CAVED

? UNCERTAIN TAXONOMIC IDENTIFICATION

• 1 SPECIMEN

/ 2 - 5 SPECIMENS

O 6 - 20 "

● 21 - 100 "

SAMPLE TYPE (ST) :

14 DRIED DITCH CTG

SHELL U.K. EXPLORATION & PRODUCTION

FASTNET BASIN

LOWER CRETACEOUS CALCAREOUS NANNOFOSSILS

WELL: 63/10-1

INTERVAL: 1170'-1350'

CONFIDENTIAL

Author : B. VAN NIEL | Date : 1991 | Rev.

Encl. 15 | Drawing No. 620226

43/13-1

DEPTH IN FEET BELOW DERRICK FLOOR

ST	NF	2720.00	2730.00	2750.00	2770.00	2800.00	2830.00
	14						

A/B	SCIENTIFIC NAME		REG NO.
A	RHAGODISCUS	ASPER	1
A	SPEETONIA	COLLIGATA	2
A	BISCUTUM	ELLIPTICUM	3
A	CAVED UPPER CRET.	NANNOFOSSILS	4
A	TEGUMENTUM	SALIUM	5
A	WATZNAUERIA	BARNESAE	6
A	EPROLITHUS	FLORALIS	7
A	SERIBISCUTUM	PRIMITIVUM (LARGE)	8
A	NANNOCONUS	SP /DISC MGRP 1.	9
A	DISCORHABDUS	IGNOTUS	10
A	ZEUGRHABDOTUS	SISYPHUS	11
A	BRAARUDOSPHAERA	BATILLIFORMIS	12
A	BRAARUDOSPHAERA	STENORHETHA	13
A	LITHRAPHIDITES	SP	14
A	NANNOCONUS	SP./DISC MGRP 3.	15
A	RHAGODISCUS	ANGUSTUS	16
A	STAUROLITHITES	SP. 1.	17
A	MANIVITELLA	PEMMATOIDEA	18
A	PREDISCOSPHAERA	COLUMNATA	19
A	WATZNAUERIA	FOSSACINCTA	20
A	ZEUGRHABDOTUS	ERECTUS	21
A	CRETARHABDUS	CONICUS	22
A	CRETARHABDUS	SP.	23
A	HOLOCOCCOLITH	SP.	24
A	TRANOLITHUS	GABALUS	25
A	BRAARUDOSPHAERA	HOCKWOLDENISIS	26
A	EPROLITHUS	SP.	27
A	GARTNERAGO	PRAEOBLIQUUM	28
A	LITHRAPHIDITES	CARNIOLENSIS	29
A	NANNOCONUS	ABUNDANS (FLANGE)	30
A	NANNOCONUS	MINUTUS	31
A	NANNOCONUS	TRUITTI GROUP	32
A	NANNOCONUS	SP. (OBLIQUE) 3.3	33

NANNOFOSSILS

MGRP 1.1

MGRP 2.2

MGRP 3.3

INDEX	REG NO.
BISCUTUM . ELLIPTICUM	3
BRAARUDOS BATILLIFORMIS	12
BRAARUDOS. HOCKWOLDENISIS	26
BRAARUDOS. STENORHETHA	13
CAVED UPP NANNOFOSSILS	4
CRETARHAB. CONICUS	22
CRETARHAB SP.	23
DISCORHAB. IGNOTUS	10
EPROLITHU FLORALIS	7
EPROLITHU. SP.	27
GARTNERAG. PRAEOBLIQUUM	28
HOLOCOCCO SP	24
LITHRAPHI. CARNIOLENSIS	29
LITHRAPHI. SP	14
MANIVITEL. PEMMATOIDEA	18
NANNOCONU. SP./DISC MGRP 1	9
NANNOCONU. SP./DISC MGRP 3	15
PREDISCOS. COLUMNATA	19
RHAGODISC ANGUSTUS	16
RHAGODISC. ASPER	1
SERIBISCU. PRIMITIVUM (LARGE)	8
SPEETONIA. COLLIGATA	2
STAUROLIT. SP. 1	17
TEGUMENTU. SALIUM	5
TRANOLITH. GABALUS	25
WATZNAUER. BARNESAE	6
WATZNAUER. FOSSACINCTA	20
ZEUGRHABD. ERECTUS	21
ZEUGRHABD. SISYPHUS	11
NANNOCONU. ABUNDANS (FLANGE)	30
NANNOCONU MINUTUS	31
NANNOCONU. TRUITTI GROUP	32
NANNOCONU. SP. (OBLIQUE) 3.3	33

BIOSTRATIGRAPHIC SUBDIVISION

NANNO-PLANKTON ZONATION

NLK2

NLK4

TIME-STRATIGRAPHIC SUBDIVISION

7AP/U AB

U AB

U/M AB

SYMBOL LEGEND

R REWORKED

? UNCERTAIN TAXONOMIC IDENTIFICATION

BARREN SAMPLE (NF)

• 1 SPECIMEN

/ 2-5 SPECIMENS

O 6-20 "

● 21-100 "

SAMPLE TYPE (ST) :

14 DRIED DITCH CTG

BRITISH PETROLEUM EXPLORATION LTD

PORCUBINE BASIN

LOWER CRETACEOUS CALCAREOUS NANNOFOSSILS

WELL: 43/13-1

INTERVAL: 2720'-2830'

CONFIDENTIAL

Author : B. VAN NIEL	Date : 1991	Rev.
Encl. 16	Drawing No. 62024c	