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Foraminiferal biostratigraphy and palaeoecology of the Albian to Santonian (Cretaceous) of Bornholm, Denmark

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University of Plymouth

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**Foraminiferal biostratigraphy and palaeoecology of the Albian to Santonian
(Cretaceous) of Bornholm, Denmark.**

by

Stephen Ronald Packer BSc., MSc.

Thesis submitted in partial fulfilment for the Degree of Doctor of Philosophy to the Council for
National Academic Awards.

Research conducted at Polytechnic South West.

July 1991

**CONTAINS
PULLOUTS**

Abstract

Foraminiferal biostratigraphy and palaeoecology of the Albian to Santonian (Cretaceous) of Bornholm, Denmark.

S.R. Packer

The foraminiferal fauna recorded from the Arnager Greensand, Arnager Limestone and Bavnodde Greensand formations of Bornholm, Denmark are described herein. These formations range in age from Early Albian to Middle Santonian. The succession contains major breaks in deposition.

A new foraminiferal biozonal scheme is presented, comprising six local assemblage biozones. These are compared to foraminiferal zonal schemes proposed for other areas of Northwest Europe. This data is then integrated with published data from macrofossil groups.

Palaeoecological data is presented utilising foraminiferal group composition through the succession. An event synthesis is proposed for the study interval combining palaeoecology, biostratigraphy, lithostratigraphy and basin events.

Transgressive phases are recognised in the Early Albian, Early Cenomanian and Late Cenomanian-Early Turonian. The Coniacian interval overall shows stable outer shelf water depths, whilst the Late Coniacian-Santonian is probably characterised by an initial phase of increasing water depth followed by a probably tectonically influenced water depth reduction.

Acknowledgements

Many people have contributed to the production of this thesis, in particular staff at Polytechnic South West. I am grateful to the technicians in the Department of Geological Sciences for assistance and sorting out various problems whilst I was at Plymouth and afterwards. Roy Moate and Brian Lakey are thanked for their patient help when using the SEM facilities as are Media services for providing invaluable technical support.

I should also like to thank the other members of the postgraduate group at Plymouth (1986-1988) for their friendship and inspiration.

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Whilst at Paleoservices several people contributed some thought provoking discussion on taxonomic and sedimentological aspects of this work, for which I am grateful.

I am indebted to my fellow directors at Millennia for agreeing to let me use the computing and reproduction facilities and for their encouragement. Jamie Powell kindly read large parts of the text for me, as did my father, both of whom deserve thanks.

Finally, thanks to Katherine for her continued support and encouragement, and for helping me to keep things in perspective.

Declaration

This is to certify that the work submitted for the Degree of Doctor of Philosophy under the title "Foraminiferal biostratigraphy and palaeoecology of the Albian to Santonian (Cretaceous) of Bornholm, Denmark" is the result of original work.

All authors and works consulted are fully acknowledged. No part of this work has been accepted in substance for any other degrees and is not being concurrently submitted in candidature for any other degree.

During the tenure of this thesis, one paper has been published:

S. Packer, M.B. Hart, B.A. Tocher and S. Braley 1989 "Upper Cretaceous microbiostratigraphy of Bornholm, Denmark" *In*: Batten D.J. and Keen, M.C. "Northwest European micropalaeontology and palynology" , pp.236-247. Ellis Horwood.

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Appendix

Lists of Foraminifera previously recorded from the Arnager Greensand, Arnager Limestone and Bavnodde Greensand.

Chapter One

1.1. Introduction.

This work comprises a detailed study of the microfaunas (principally foraminifera) of Albian-Santonian (Cretaceous) sediments from the Danish island of Bornholm. This study forms part of a wider project on the succession being carried out by Danish and German geologists working on the macrofaunas (Dr.W.K.Christensen, Geological Museum and University of Copenhagen), and the sedimentology (Dr. R.Bromley, University of Copenhagen, Dr. N. Nøe-Nygaard, Geological Museum of Copenhagen and Dr. F. Surlyk, University of Copenhagen). Work on the pollen and spores from the succession is being carried out by Dr.D.J.Batten (University College, Aberystwyth) and work on the dinoflagellates by Dr.B.Tocher (University College, Aberystwyth).

The aims of this work are:

- The systematic description and cataloguing of the foraminiferal fauna.
- To define a working foraminiferal biozonation for the succession.
- To provide an overall palaeoenvironmental interpretation for the Albian to Santonian interval based upon the foraminiferal data generated and published work on the macrofauna and sedimentology.
- To outline evidence for sea level changes during Albian to Santonian times.

The importance of this study lies in its contribution to the understanding of the Danish sub-basin during the mid-Cretaceous and the provision of a biostratigraphic framework for the interval.

1.2. The Geology of Bornholm : Introduction.

The Danish island of Bornholm lies in the southern Baltic (55 degrees N, 15 degrees E), approximately 65 km from Ystad, on the Swedish coast (See Figure 1.1.). The island lies within the structurally complex Fennoscandian Border Zone which trends NW-SE through Scania and into Bornholm. The greater part of the island is formed of Precambrian granites, migmatites and gneisses. Palaeozoic sediments are generally found within the southern part

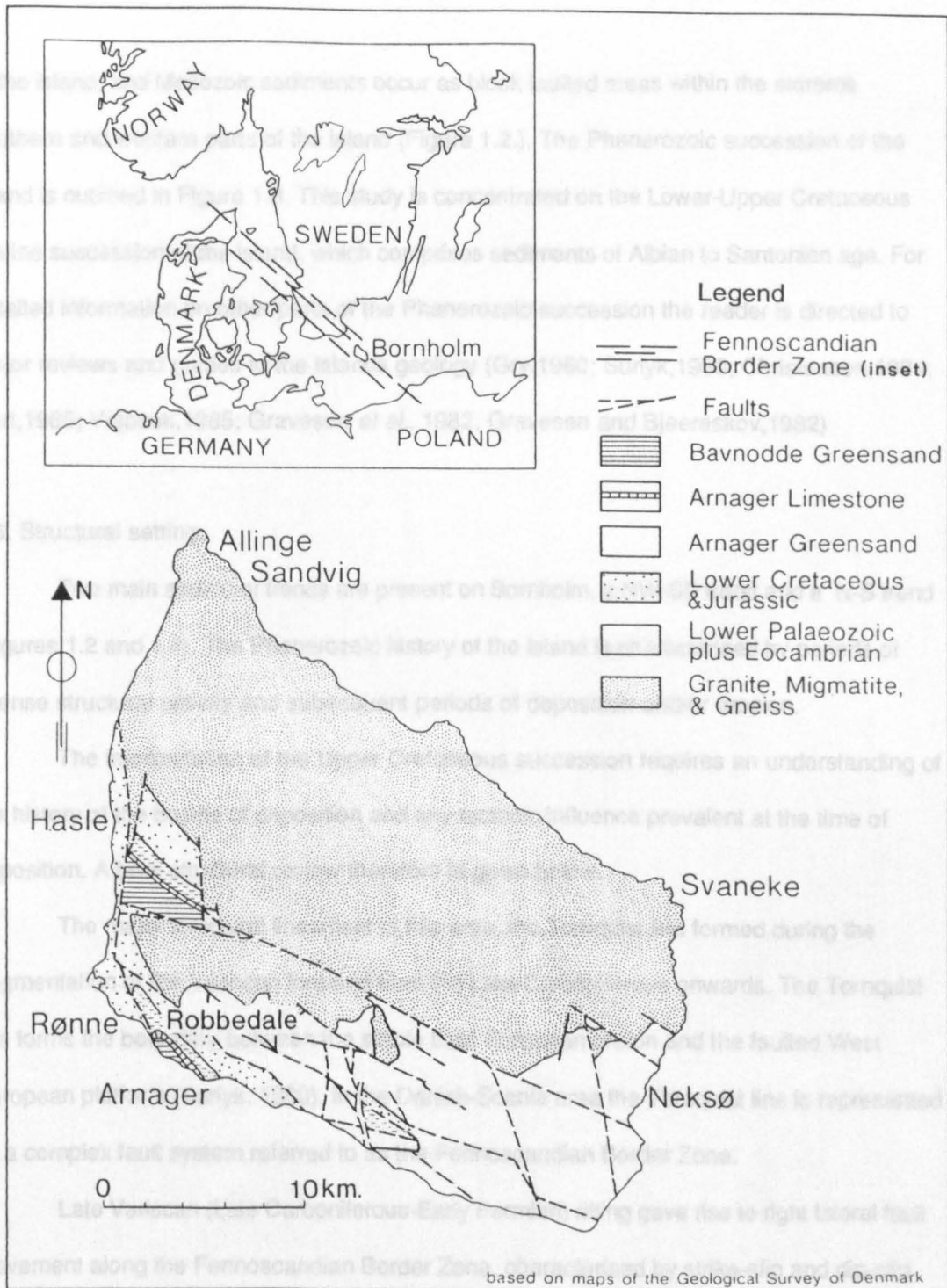


Figure 1.1 Location map of Bornholm Island (inset) and outline geological map

of the island, and Mesozoic sediments occur as block faulted areas within the extreme southern and western parts of the island (Figure 1.2.). The Phanerozoic succession of the island is outlined in Figure 1.3. This study is concentrated on the Lower-Upper Cretaceous marine succession of the island, which comprises sediments of Albian to Santonian age. For detailed information on other parts of the Phanerozoic succession the reader is directed to major reviews and guides to the islands geology (Gry,1960; Surlyk,1980; Christensen,1984; Hart,1985; Vejbaek,1985; Gravesen *et al.*, 1982; Gravesen and Bjeereskov,1982)

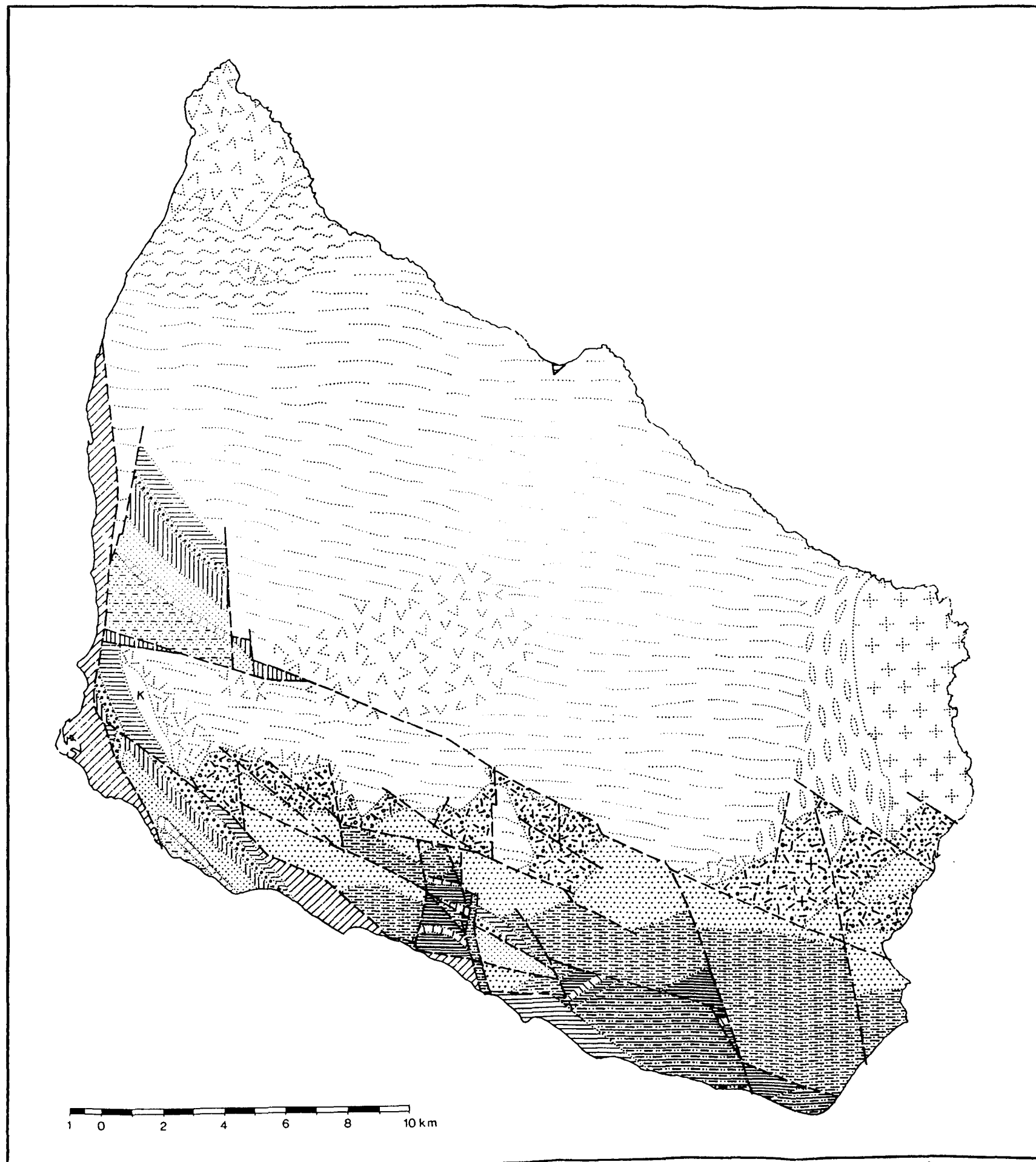
1.3. Structural setting.

Two main structural trends are present on Bornholm, a NW-SE trend and a N-S trend (Figures 1.2 and 1.4). The Phanerozoic history of the island is characterised by periods of intense structural activity and subsequent periods of deposition and/or erosion.








The interpretation of the Upper Cretaceous succession requires an understanding of the history of the basins of deposition and any tectonic influence prevalent at the time of deposition. A brief structural review therefore is given below.

The major structural lineament of this area, the Tornquist line formed during the fragmentation of the Variscan foreland from the Late Carboniferous onwards. The Tornquist line forms the boundary between the stable East European craton and the faulted West European platform (Surlyk, 1980). In the Danish-Scania area the Tornquist line is represented by a complex fault system referred to as the Fennoscandian Border Zone.








Late Variscan (Late Carboniferous-Early Permian) rifting gave rise to right lateral fault movement along the Fennoscandian Border Zone, characterised by strike-slip and dip-slip movements (Surlyk,1980; Ziegler,1981; Vejbaek,1985). During Triassic times regional crustal extension caused rapid subsidence of new troughs both within and neighbouring the Danish area. Triassic faulting and subsidence characterise the Rønne Graben west of Bornholm, (Surlyk, 1980). The Triassic rifting continued into the Jurassic and is referred to as the Cimmerian (Kimmerian) phases, during which the characteristic horst structures of Scania were initiated (Bergstrom *et al.*, 1982; Norling and Bergstrom, 1987). The Early Cimmerian phase is seen on Bornholm with the Lower Jurassic resting on both Keuper and Palaeozoic











MESOZOIC

-  Bavnodde Greensand
Lower-Middle Santonian
-  Arnager Limestone
Middle-Upper Coniacian
-  Arnager Greensand
Middle Cenomanian
-  Jydegård Formation
Upper Berriasian-Valanginian
-  Robberdale Formation
Upper Berriasian
-  Rabekke Formation
Tithonian? – Lower Berriasian
-  Risebæk Member and Bornholm Group
Upper Ladinian-Carnian –
Lower and Middle Jurassic

PALAEOZOIC

-  Rastrites Shale and
Cyrtograptus Shale
Lower Silurian
-  Dicellograptus Shale and
Jerrestad Formation
Middle-Upper Ordovician
-  Komstad Limestone
Skelbro Limestone
Lower Ordovician
-  Alum Shale, Dictyonema Shale
Middle and Upper Cambrian
Lower Ordovician
-  Læså Formation
Lower Cambrian
-  Balka Sandstone
Lower Cambrian
-  Nexø Sandstone
Lower Cambrian

PRECAMBRIAN

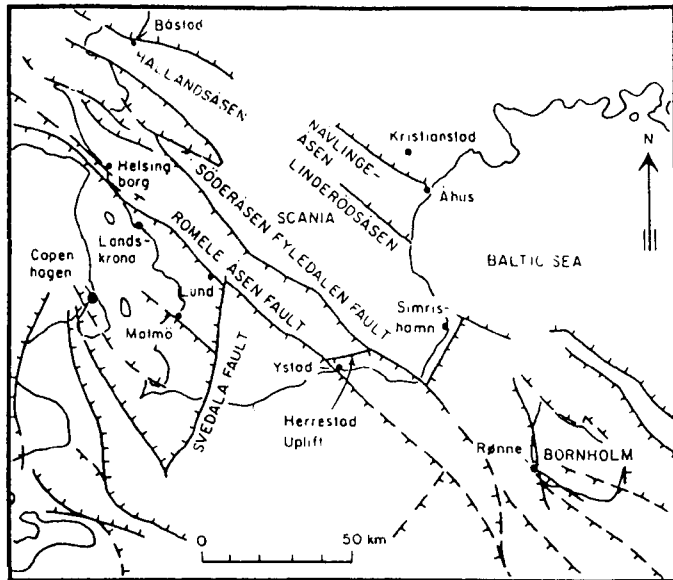
-  Svaneke Granite
-  Hammer Granite
-  Gneiss
-  Vang Gneiss
-  Paradisbakke Migmatite
-  Rønne Granite
-  K Kaolin
-  Faults

1.2 Geological map of Bornholm. Geological map of Denmark 1:50 000 map sheet 1812 III and IV Bornholm. Geological basic data map. Gravesen, P. and Rasmussen, L.A. (Geological Survey of Denmark, map series no. 4).

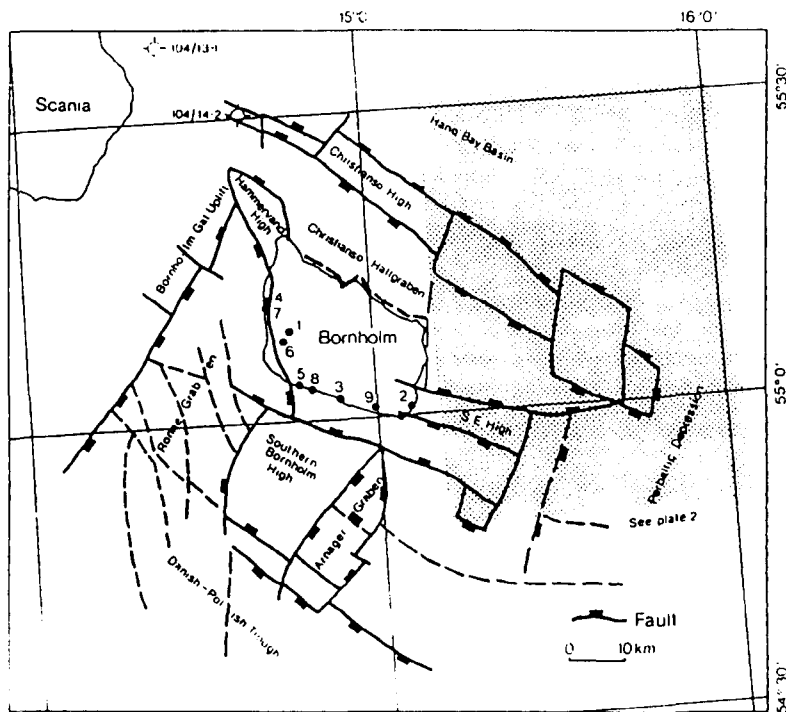
Udarbejdet af H. Gry 1960
 Nyere tilføjelser til legenden
 © DANMARKS GEOLOGISKE UNDERSØGELSE
 1988

Chronostratigraphy			Danish Subbasin	Bornholm			
Mesozoic	Cretaceous	Maastrichtian	Chalk	Bavnodde Greensand Fm			
		Campanian					
		Santonian					
		Coniacian			Arnager Lst. Fm		
		Turonian	dark mudstone				
		Cenomanian			marl & sand		
		Albian	Rodby Fm	Arnager Greensand Fm			
		Aptian	Vedsted Fm				
		Barremian					
		Hauterivian					
		Valanginian			Jydegård Fm		
		Berrias, Ryazan			Robbedale Fm		
		Jurassic	U	Tithon, Volgian	Bream Fm	Frederikshavn Mb	
				Kimmeridgian		Borglum Mb	
	Oxfordian				Flyvbjerg Mb		
	Callovian			Haldager Fm			
	M		Bathonian			Sand Mb	
			Bajocian				
			Aalenian			Mb F-IV	
	L		Toarcian			Mb F-III	
			Pliensbachian	Fjerritslev Fm		Mb F-II	
			Sinemurian			Mb F-I	
			Hettangian				
					Gassum Fm		Sose beds
	Triassic	Keuper	Rhaetian	Vinding Fm	Skagerrak Fm		
			Norian	Oddesund Fm			
Carnian							
Musch Kalk		Ladinian	Marl, limestone, evaporites, redbeds		Redbeds		
		Anisian					
Bunter		Skythian	Red sandstone & mudstone				
Permian		Zechstein	Carbonates & evaporites				
	Rotliegendes	Redbeds					
Carboniferous	U	Stephanian	?				
		Westphalian					
L	Namurian						
	Viséan	Mud-, lime- & marl stone					
Paleozoic	Devonian						
	Silurian	Ludlowian	Sandstone				
		Wenlockian	Claystone				
		Llandoveryian	Mudstone		Cyrtograptus Graptolite Shale Rastrites		
	Ordovician	Ashgillian	?		Dalmanitina beds		
		Caradocian		Jerrestad Fm			
		Llandeilian		Dicellograptus Shale			
		Llanvirnian					
		Arenigian		Komstad Fm			
		Tremadocian		Skelbro Lst. Fm			
	Cambrian	Upper	Alum Shale		Alum Shale		
		Middle	Alum Shale		Andrarum Limestone Fm		
		Lower	Mudstone Quartzite		Alum Shale Exsulans Limestone Fm Læså Fm Balka Sandstone Fm Nekse Sandstone Fm		
	Precambrian				Gneiss, granite & dolerite		

Figure 1.3 Phanerozoic succession of Denmark, including Bornholm (Surllyk, 1980)



Main structural trends in southern Scandinavia (Christensen, 1984)



Major structural elements of the Bornholm area (Vejbaek, 1985).

Figure 1.4 Structural setting.

(Gry, 1969). The mid-Cimmerian in Scania produced NW-SE trending block faulting, including horst and graben formation and volcanism (Norling and Bergstrom, 1987). On Bornholm this phase is indicated by the pre-Toarcian-Bajocian hiatus and the succeeding Middle Jurassic basal conglomerate (Gry, 1969). During the Late Jurassic - Early Cretaceous, a major rifting phase occurred, known as the Late Cimmerian event. This is demonstrated in Scania by occurrences of Jurassic - Lower Cretaceous strata angularly truncated by Upper Cretaceous deposits (Bergstrom *et al.*, 1982), and on Bornholm where the Lower Cretaceous is seen resting unconformably on older deposits, representing basin expansion facilitated by block faulting (Rolle *et al.*, 1979). The subsidence caused by this event, and the consequent relative sea level rise influenced the facies associations on Bornholm at this time (Gravesen, 1981).

Following the Late Cimmerian event, the Scania - Bornholm area was virtually unaffected by major tectonic events until the Late Cretaceous (Santonian). However, Gravesen (1982) suggests that minor tectonic phases may have occurred e.g. the Aptian-Austrian phase (Ziegler, 1981). It has to be assumed from existing evidence (e.g. Vejbaek, 1985) that tectonic influence was negligible during the Aptian - Coniacian period. Tectonic quiescence is demonstrated by Norling and Bergstrom (1987) for Scania during this period. Upper Cretaceous sediments deposited over the horst and graben topography in the Bornholm area formed a uniform sheet, tapering in a northeast direction (Vejbaek, 1985).

In Late Cretaceous - Early Tertiary times Bornholm and much of Scania were situated along an inversion axis and were uplifted along faults (Gravesen, 1981; Ziegler, 1981, 1982; Norling and Bergstrom, 1987). In the Bornholm area Vejbaek (1985) recorded some minor discordancies in the Upper Cretaceous succession, which he states, " must be of a Late Cretaceous age and probably reflect sub Hercynian tectonism " He proposed that major inversion events in the Rønne and Arnager Grabens took place during the Tertiary. Ziegler (1982) places Bornholm within the major inversion axis associated with the Polish - Danish trough from the Santonian onwards. Norling and Bergstrom (1987), suggested that inversion took place from the Santonian onwards in Scania. Conversely Jensen and Hamann (1988)

suggest that transpressional movements took place after deposition of the Bavnodde Greensand.

1.4. The Albian - Santonian (Cretaceous) succession of Bornholm.

Albian - Santonian marine sediments are found in three downfaulted areas in the South and West of the island, Gry (1960). These areas are shown in figures 1.2. and 1.5.

- The Arnager - Rønne airport area on the South coast (Figure 1.6.)
- The Nyker area near the Western coast
- The Grødby Å and Laeså area.

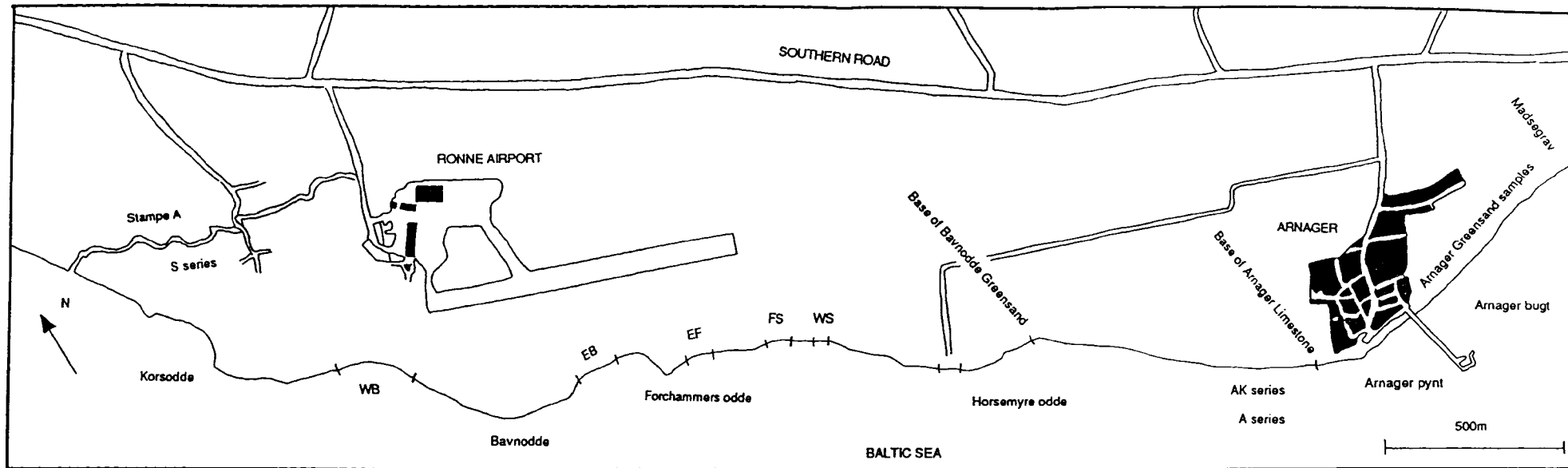
The succession consists of, from bottom to top: the Arnager Greensand Formation, the Arnager Limestone Formation and the Bavnodde Greensand Formation, Christensen (1984). The best exposures of the succession are found on the South coast in the Arnager-Rønne airport area. The general dip of the local fault block is 6 degrees towards the southwest. Near or at the coast, the dip is greater (Kennedy *et al.*, 1981). Nøe-Nygaard and Surlyk (1985) give a 5 degree dip towards the southwest for the Arnager Limestone in this area.

1.4.1. The Arnager Greensand Formation.

This formation consists of poorly sorted quartz-glaucanite sand which rests with a slight angular unconformity on the Jydegaard Formation (Lower Cretaceous); the junction is exposed on the coast at Madsegrav. The Jydegaard Formation has been ascribed to the Valanginian by Christensen (1972), however a younger age is possible (for discussion see Surlyk, 1980; Kennedy *et al.*, 1981; Gravesen *et al.*, 1982; Christensen, 1984).

The junction between the Jydegaard and the overlying Arnager Greensand has been described by Bromley (1979) and Kennedy *et al.*, (1981). Bromley (1979) found that the basal Greensand was rich in sharks teeth, and lacks phosphatic pebbles. Burrowing activity across the junction caused considerable mixing, with the resultant obliteration of the original junction. Thalassinoidian boxwork systems were found to have introduced greensand over a metre into the underlying Jydegaard Formation.

Figure 1.5 Amager-Ronne airport locality map, source W.K. Christensen (unpublished)



The most detailed description of the boundary between the two formations is given in Kennedy *et al.*, (1981), following work by W.K.Christensen (see *op. cit.*, fig.3, p.205). The succession consists of cross bedded white sand which is topped by clay. This is in turn overlain by a 30cm bed of burrowed white sand, infilled by Greensand, the "spotted sand " of Ravn (1916). The boundary between the two formations was drawn at the top of this bed by Kennedy *et al.*, (1981). The Arnager Greensand Formation starts with 30cm of glauconitic quartz sand (without phosphate pebbles). This is succeeded by a conglomerate consisting of phosphatised pebbles and cobbles. It consists mainly of phosphatic nodules (1cm - 30cm in size), Lower Cambrian sandstones, quartzite and probable Jurassic or Early Cretaceous aged lignite. This bed is described in detail by Ravn (1925), who termed it the "basalkonglomerat". Ravn (*op. cit.*) recognised two generations of phosphatic nodules. Firstly primary nodules of phosphatised glauconitic sandstone and secondary nodules consisting of primary nodules cemented by a matrix of brownish phosphatised glauconitic sand. This "basalkonglomerat" has been found to vary between 18-55cm thick, with a reported mean thickness of 37cm Ravn (1925).

The overlying Arnager Greensand is unconsolidated and appears to be totally bioturbated; the whole formation is about 85m thick (Christensen,1984). Generally poor exposure has resulted in a lack of detailed sedimentological information for this unit.

In the Stampen Å river area the basal Arnager Greensand can be observed in the river section where it is overturned, with the dip shallowing to the east as one moves upriver. Scattered river sections have been sampled both in 1986 and 1988, by MBH and the author; these are recorded in Table 1.

1.4.2. The age of the Arnager Greensand Formation.

Ravn (1916,1925) examined the macrofauna of the Arnager Greensand Formation and ascribed the primary nodules of the conglomerate to the Lower Albian (*Tardefurcata- Regularis* Zones) and the fauna from the matrix of the secondary nodules to the Upper Albian and Lower Cenomanian. The main thickness of the Arnager Greensand was thought to be

younger in age. These ages were subsequently confirmed by Rozenkrantz (1945), Birkelund (1957) and Douglas and Rankin (1969).

Hart (1979) ascribed the lower 5m of greensand above the basal conglomerate to the Lower Cenomanian on the basis of the presence of *Lingulogavelinella jarzvevae* (Vasilenko, 1961) and *Plectina cenomana* Carter and Hart (1977) suggesting equivalence to Zone 10 of the latter authors. The main thickness of the Arnager Greensand is of early Middle Cenomanian age, based principally on the occurrence of *Rotalipora reicheli* (Mornod, 1950).

Kennedy *et al.*, (1981) revised the ammonite faunas of the Arnager Greensand Formation including the work of Ravn (1916,1925) and Rozenkrantz (1945). Ammonites from the primary nodules were found to represent two time intervals in the Early Albian (*Leymeriella tardefurcata* and *Douvilleiceras mammillatum* Zones). Ammonites from the phosphatised matrix of the secondary nodules were ascribed to the *Mantelliceras saxbii* and *Mantelliceras dixoni* Zones. The Arnager Greensand Formation above the conglomerate was found to be early Middle Cenomanian (*Turrilites costatus* Zone). It is important to note that unphosphatised ammonites from the main thickness of the Arnager Greensand, (which give *Turrilites costatus* Zone age) do not have their exact horizons recorded, though preservation indicates hard bands near the base of the greensand. The presence of two *Schloenbachia* spp. may indicate an Early Cenomanian age, but since most of the ammonites probably came from the hard beds, very little of the Greensand can be older than Middle Cenomanian. There is a slight discrepancy in ages between the foraminifera (Hart, 1979) and the ammonites (Kennedy *et al.*, 1981); foraminifera indicating Lower Cenomanian for the basal 5m above the conglomerate, ammonites indicating Lower Middle Cenomanian for the whole greensand above the conglomerate.

Christensen (1984) notes the occurrence of *Inoceramus tenuistriatus* Nagao and Matsumoto, which occurring above the conglomerate suggests a Middle to Late Cenomanian age. The presence of the belemnite *Actinocamax primus* (Arkhangelsky) in the Greensand gives an Early to Middle Cenomanian age.

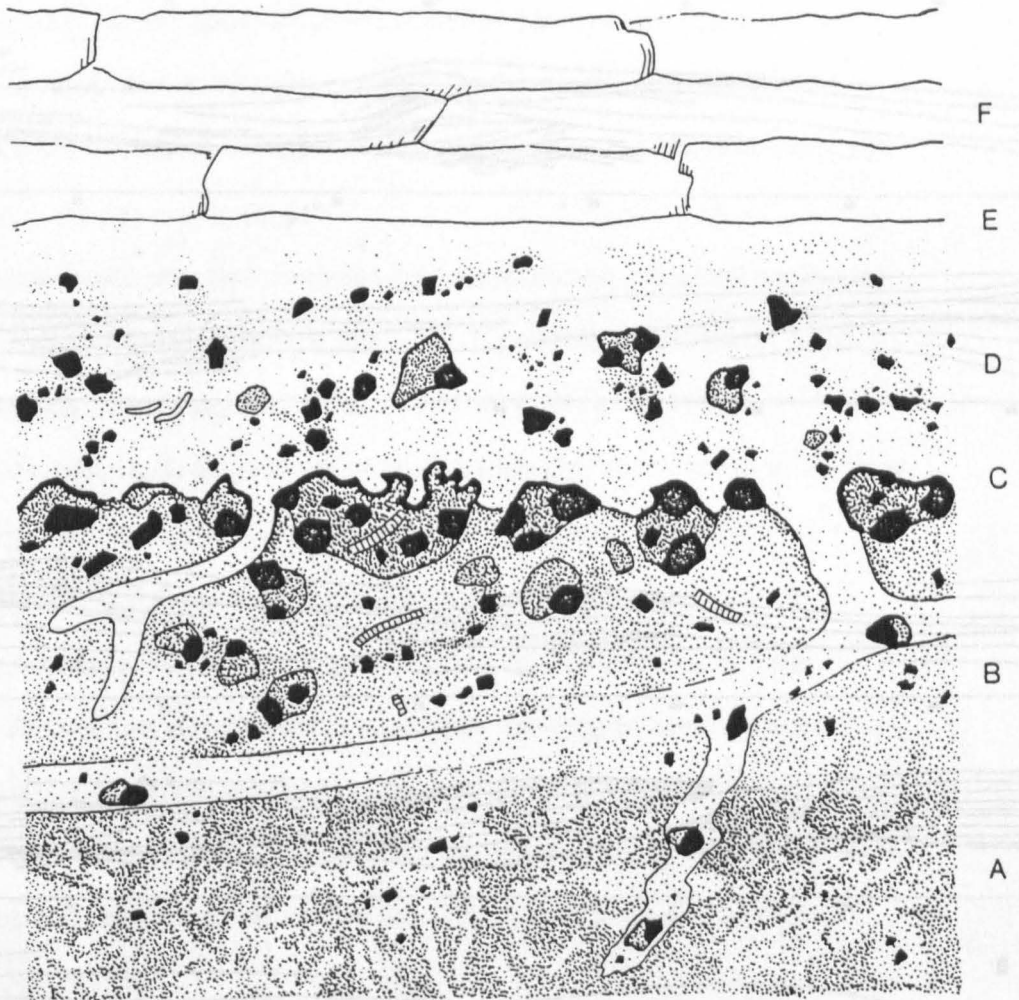
1.4.3 The Arnager Limestone Formation.

The Arnager Limestone Formation is a marly, silica-rich chalk, which is approximately 12-20m thick (Christensen, 1984; Nøe-Nygaard and Surlyk, 1985). The contact between the Arnager Greensand Formation and overlying Arnager Limestone Formation is complex, consisting of several generations of phosphatised and glauconitised pebbles. The contact is exposed on the coast just west of Arnager Pynt. This boundary has been described in some detail by Bromley (1979). (See Figure 1.6). The alphabetic notation and description of the boundary given below are based on the work of Bromley (1979).

The top of the Arnager Greensand Formation is richly glauconitic and highly bioturbated, containing phosphatic clasts (Unit A), which have been piped downwards by burrowing organisms. This is followed by the basal bed of the Limestone, Unit B, which consists of richly glauconitic limestone, containing phosphatised clasts of limestone less rich in glauconite. This passes up into Unit C which forms a sharp green tinted junction, impregnated with glauconite, thought to represent a hardground surface. Unit C is overlain by hard pale grey limestone (Unit D) which contains irregularly distributed glauconite grains and phosphatic compound intraclasts. From the base of Unit D, large, (upto 8cm in diameter) *Thalassinoides suevicus* and smaller *Thalassinoides paradoxicus* can be seen to penetrate down through Units C, B, and A. Above Unit D, a well defined parting plane occurs, (Unit E) and this is in turn overlain by slabby limestone, which is virtually free of glauconite, (Unit F). The presence of compound phosphatised intraclasts in units A-E, indicates repeated periods of sedimentation, cementation, erosion and phosphatisation.

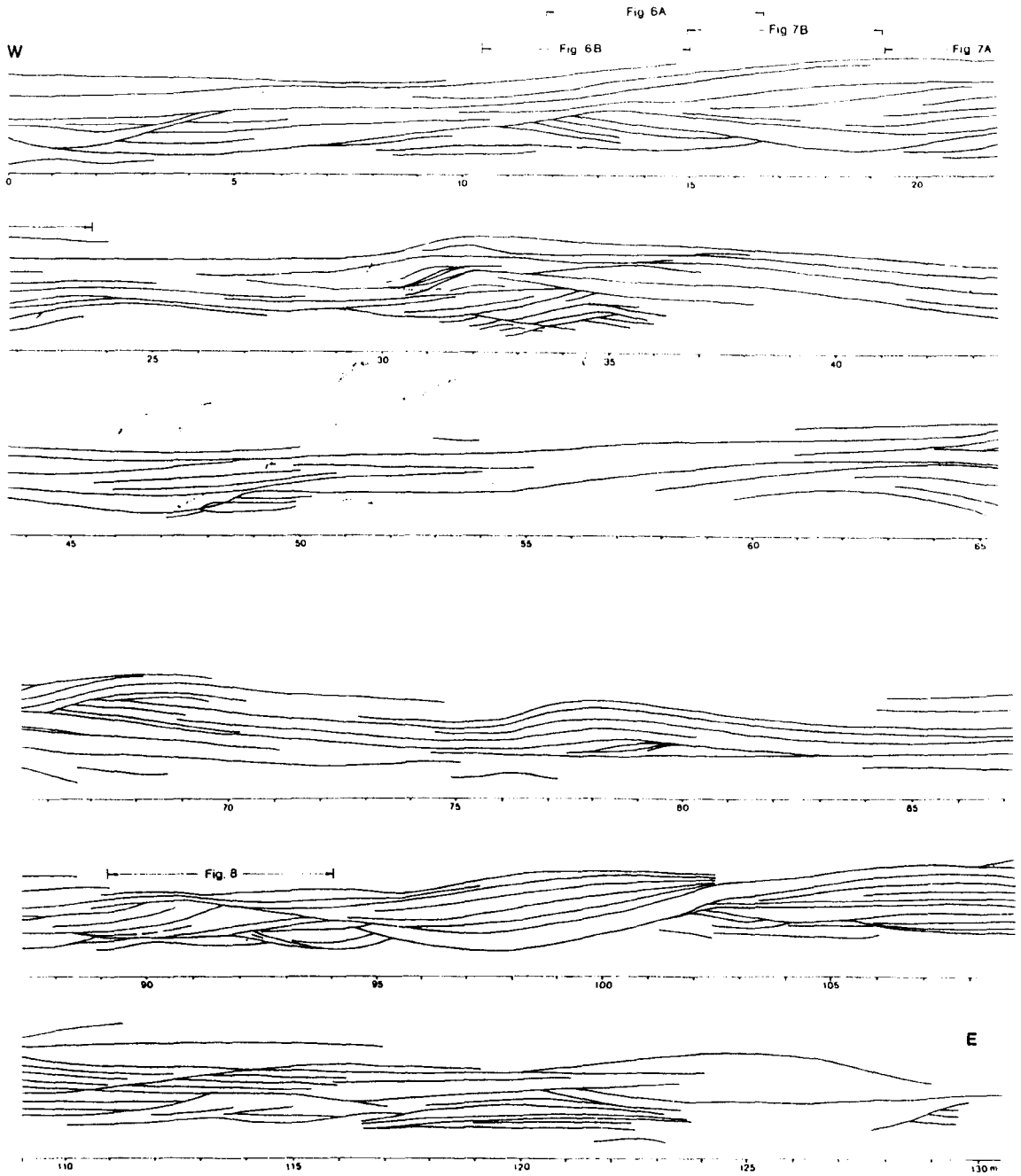
This boundary can also be observed in the Stampen Å river bed just below Ørsteds Kilde. The phosphatised conglomerate unit can be observed by excavation of the river bed, during conditions of low water. The dip is difficult to determine, but is probably regionally consistent at around 8-15 degrees. Limestone exposures can also be recognised along the river further to the east, although the exposure is generally very poor.

It is important to note that geophysical investigations suggest that offshore, the boundary between the Arnager Greensand Formation and Arnager Limestone Formation does not appear to be discordant, Jensen and Hamann (1989).



Lithology of the bottom bed of the Arnager Limestone, overlying the Arnager Greensand. A: Arnager Greensand, a highly bioturbated greensand, richly glauconitic, containing no phosphatic clasts except those piped down from the overlying beds by burrowers. Top junction not very sharp. B: richly glauconitic limestone, the basal bed of the Arnager Limestone, containing dark brown, phosphatized clasts of a limestone less rich in glauconite grains than the surrounding matrix (clasts indicated in black). Chiefly towards the top of unit B, these clasts are incorporated within compound intraclasts of richly glauconitic limestone. Sediment (with clasts) of unit B is extensively piped down into the topmost levels of Unit A within numerous burrows. C: sharp junction tinted dark green with impregnated glauconite; the impregnation most strongly affects the compound intraclasts where these are in contact with the junction. Although encrusting organisms and organic borings are not in evidence, this glauconitised surface is clearly a hardground. D: fairly hard limestone, pale grey, containing irregularly distributed glauconite grains together with phosphatic and compound intraclasts, chiefly in burrow fills. From the base, large *Thalassinoides suevicus* up to 8 cm in diameter, and much smaller *T. paradoxicus* penetrate the underlying unit B. Some of the *T. suevicus* continue down into the uppermost metre of unit A. E: well defined parting plane. F: slabby, hard Arnager Limestone of normal lithofacies, almost free of glauconite grains.

Figure 1.6 Boundary between Arnager Greensand and Arnager Limestone (Bromley, 1979).



Section of the Arnager Limestone in the cliff west of Arnager Harbour, showing the nature of low, overlapping mounds. The section has not been corrected for dip. The right end of the section starts approximately 1 m above the basal conglomerate. In many cases the apparently truncated beds actually pass over the top of the mounds and continue for a short distance down the other flank of the mound. Note that the section only shows the basal 2-3 m of the cliff. The SW dip of the strata means, however, that most of the sequence exposed in the cliff is represented in the cliff transect. It is thus biased towards the smaller structures while the shapes of the larger mounds as seen from the beach are too distorted to allow drawing.

Figure 1.7 Diagram of mound bedding structures in the Arnager Limestone, proposed by Noe-Nygaard and Surtyk, (1985).

The main part of the Arnager Limestone Formation (exposed on the coast) is lithologically uniform and consists of marly, silica rich chalk. Estimates of the carbonate content of the lower part of the limestone, above the level of Unit E are given as 55-65% (Nøe-Nygaard and Surlyk, 1985) and 45-70% (Christensen, 1984), who also suggests that the carbonate content declines towards the top of the limestone to around 30%. Non carbonates present include clays, sand as well as silica.

Nøe-Nygaard and Surlyk (1985) reviewed the macropalaeontological associations of the Arnager Limestone Formation. Burrowing activity is recognisable at most levels. Trace fossils recorded include *Zoophycos*, *Chondrites*, *Planolites*, *Teichichnus*(?) and *Thalassinoides*. The shelly fauna of the formation is of very low abundance and diversity. Ravn (1918) described twenty six species of which most were represented by only a few specimens. Inoceramids and rhynchonellid brachiopods are the most common forms. Siliceous sponges and spicules are found in great abundance, characterised by large numbers of vase shaped, low, conical and branched forms reaching 10-20cm in height. Sponges are found throughout the limestone, as are abundant radiolaria.

Mapping of irregular bedding within the limestone reveals that deposition was associated with low mud mounds. Nøe-Nygaard and Surlyk (1985) attributed these to formation by sponge baffling.

1.4.4 The age of the Arnager Limestone Formation.

There has been considerable confusion over the biostratigraphic age for this formation. This problem has been reviewed by Christensen (1976, 1983 and 1984). It has been assigned to the Upper Turonian, Ravn (1918, 1946); Birkelund (1957). These conclusions were opposed by Stolley (1930) and Jeletzky (1958). Kauffman (see Christensen, 1983 and 1984) has assigned the formation to the Upper Turonian / Lower Coniacian on the basis of inoceramids, whilst Kennedy (see Christensen, 1984) has identified both Coniacian and Campanian ammonites from the formation. Specimens of the echinoid

Echinocorys ex. gr. *gravesi* Desor from the hardground indicate a Middle to Early Coniacian age. (See Christensen, 1984).

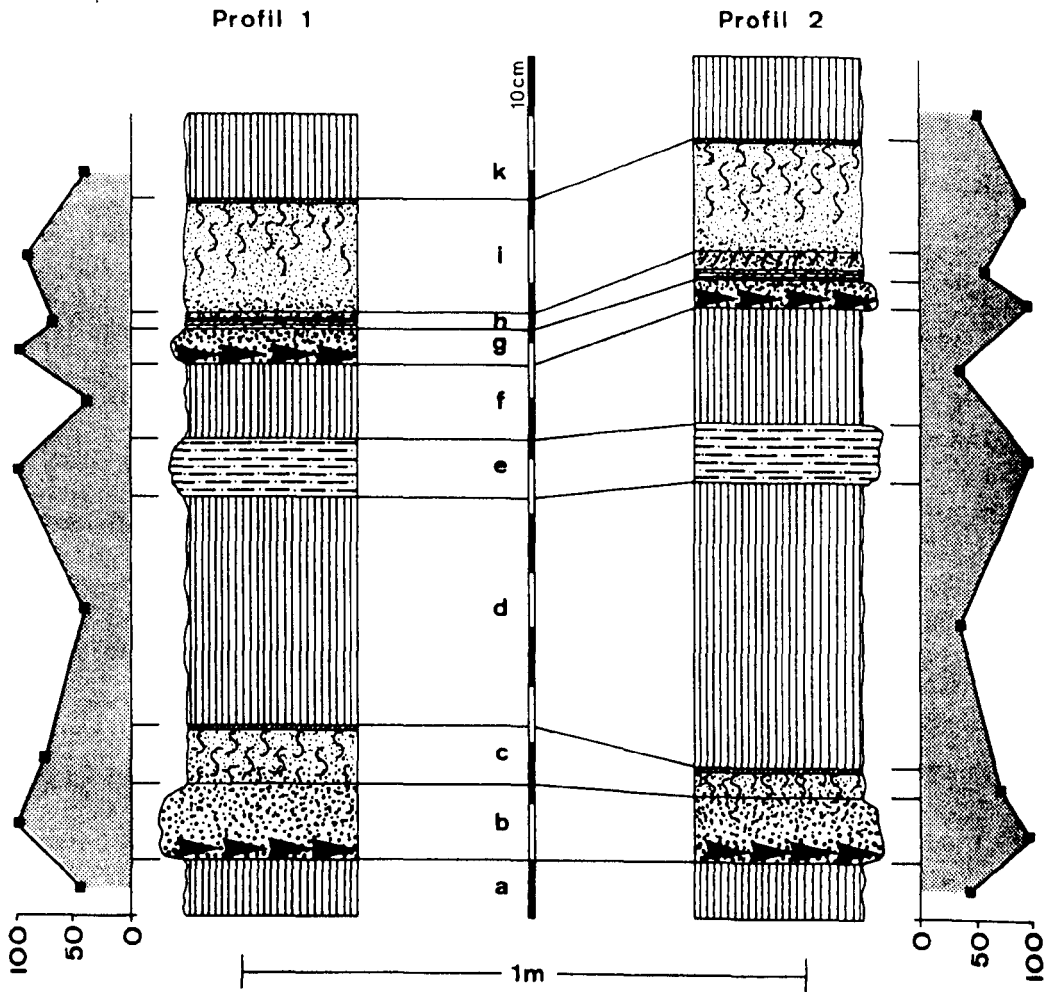
The formation has been assigned to the Upper Coniacian on the basis of the foraminifera (Douglas and Rankin, 1969; Stenestad, 1972; Hart, 1980) and on belemnite evidence (Christensen, 1973). A Coniacian age is given by Bailey and Hart (1979) and Solakius and Larsson (1985). Hart (in: Bromley, 1979) and Packer *et al.*, (1989) recognised a major hiatus between the Middle Cenomanian Arnager Greensand Formation and the Coniacian Arnager Limestone Formation at the level of Unit C. The generally accepted age for this Formation is Coniacian (Christensen, 1984).






1.4.5 The Bavnodde Greensand Formation.

The Bavnodde Greensand Formation is a poorly sorted, glauconitic, fine grained, silty, quartz sand, approximately 180m thick (Christensen, 1985). The contact between the Arnager Limestone Formation and overlying Bavnodde Greensand Formation has been studied by Ravn (1929) who found that the Greensand rests upon the eroded surface of the limestone, an observation confirmed by Christensen (1984), who states ".....the basal greensand follows directly upon the top bed of the limestone without any development of conglomerate or phosphatic nodules at the base of the greensand".

This boundary is now best exposed in the Stampen Å river, close to the airport. Passing upriver to the east (from the stone bridge on the road to Kørsodde), exposures of the Arnager Limestone Formation can be seen in the river bed. The boundary with the Bavnodde Greensand can be observed around the small stone bridge (Localities 10-12, See figure 1.12). At locality 12, the limestone is seen to be faintly glauconitic, and becomes gradually more glauconitic up-river, until true Bavnodde Greensand Formation is observed at locality 9. At locality 10 the limestone/ greensand boundary may be observed, represented by increasing glaucony and reworked clasts (up to 2cm) of pure Arnager Limestone Formation. This confirms Ravn's original observations.

There is very little sedimentological information available on the Bavnodde Greensand Formation. Packer *et al.*, (1989) suggest that coarse levels within this formation



-  non-cemented glauconitic sandy marl (clay, silt, fine sand)
 -  less cemented sandstone nodule layer (fine gravel to medium sand)
 -  non-cemented medium to fine sand with hardened limonitic clay on top (unit c)
 -  lamellar and cross bedded medium to fine sand, non cemented (unit b)
 -  fine gravel to coarse sand with orientated belemnites at base, partially biotubated (unit a), commonly silicified
- } bioturb

Studied section of the Bavnodde Grønsand. Diagrams show grain size of washed-residue >0.1 mm in weight percent for samples a-k. Classification of grain size follows DIN 4188(57)

Figure 1.8 Schmidt (1982). Sedimentological logs of the Bavnodde Greensand, showing proposed turbiditic sequences.

may represent storm events. Schmidt (1992; Einsele and Seilacher, 1982) suggested that graded sandstone units within the Bavnodde Greensand Formation could be accounted for by shallow water turbidite events. Graded sequences were observed (from bottom to top) to consist of:

a) Fine gravel and coarse sand with sponges, pelecypods and belemnites, with pelecypod valves embedded in vertical position, with rostra showing unimodal azimuth orientation.

Passing into:

b) Medium to fine sand with planar lamination in the lower part and ripple cross lamination in the upper part. Passing into:

c) Medium to fine sand similar to b) but bioturbated and covered by limonitic clay. (See Figure 1.8)

A turbiditic origin is assumed because of, unimodal belemnite orientation, the high concentration of belemnites, and the current direction (perpendicular to the strike of the local fault system). Active faulting could provide the necessary palaeoslope to have generated turbidites. Clearly more detailed sedimentological work is required in this area, as the Schmidt (1992) paper is only a short summary, lacking in detail.

1.4.6 The age of the Bavnodde Greensand Formation.

The Bavnodde Greensand has been assigned to the lower-Middle Santonian by Christensen (1971) on belemnite evidence, and by inoceramids, Ravn (1921). Solakius and Larsson (1985) proposed a Santonian age on the basis of the foraminifera, whilst Bailey and Hart (1979) and Packer *et al.*, (1989) proposed a Late Coniacian-Santonian age.

Kaufmann (1992; Christensen, 1984) records inoceramids that indicate a Late Santonian-Early Campanian age, whilst Kennedy (see Christensen, 1984) has identified Santonian ammonites from the formation.

Solakius (1989) recognises a hiatus between the Amager Limestone Formation and the overlying Bavnodde Greensand Formation, with the Upper Coniacian and Lower Santonian absent, on the basis of the foraminifera.

Text Plates

1.1. Contact of the Jydegaard Formation and overlying Arnager Greensand Formation at Madsegrav. (Top of page)

1.2. Typical Arnager Greensand exposure on Arnager beach. (Bottom of page)



Text Plates

1.3. Contact of the Arnager Greensand and Arnager Limestone at Arnager Pynt. (Top of page)

1.4. Exposure of the Bavnodde Greensand at Bavnodde. (Bottom of page)



Text Plates

1.5. The Arnager Limestone, Arnager Greensand boundary at Arnager Pynt, showing trench dug to sample boundary. (Top of page)

1.6. Arnager Limestone, Arnager Greensand boundary showing phosphatised conglomerate. (Bottom of page)



Text Plate.

1.7. The Arnager Limestone, Bavnodde Greensand boundary on the coast. (Presently not exposed, photograph taken by M.B. Hart in 1975)



Fig. 1.9

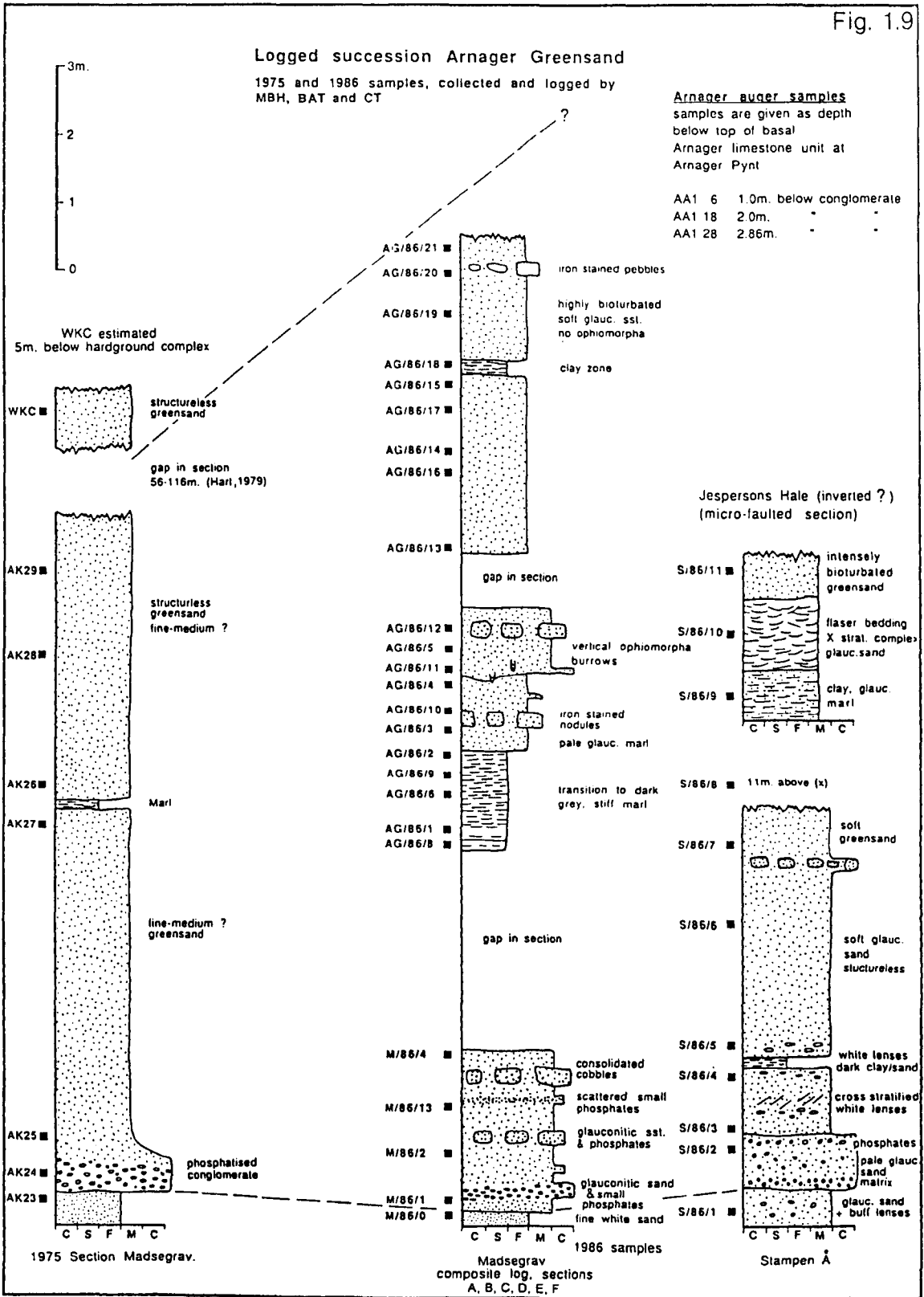
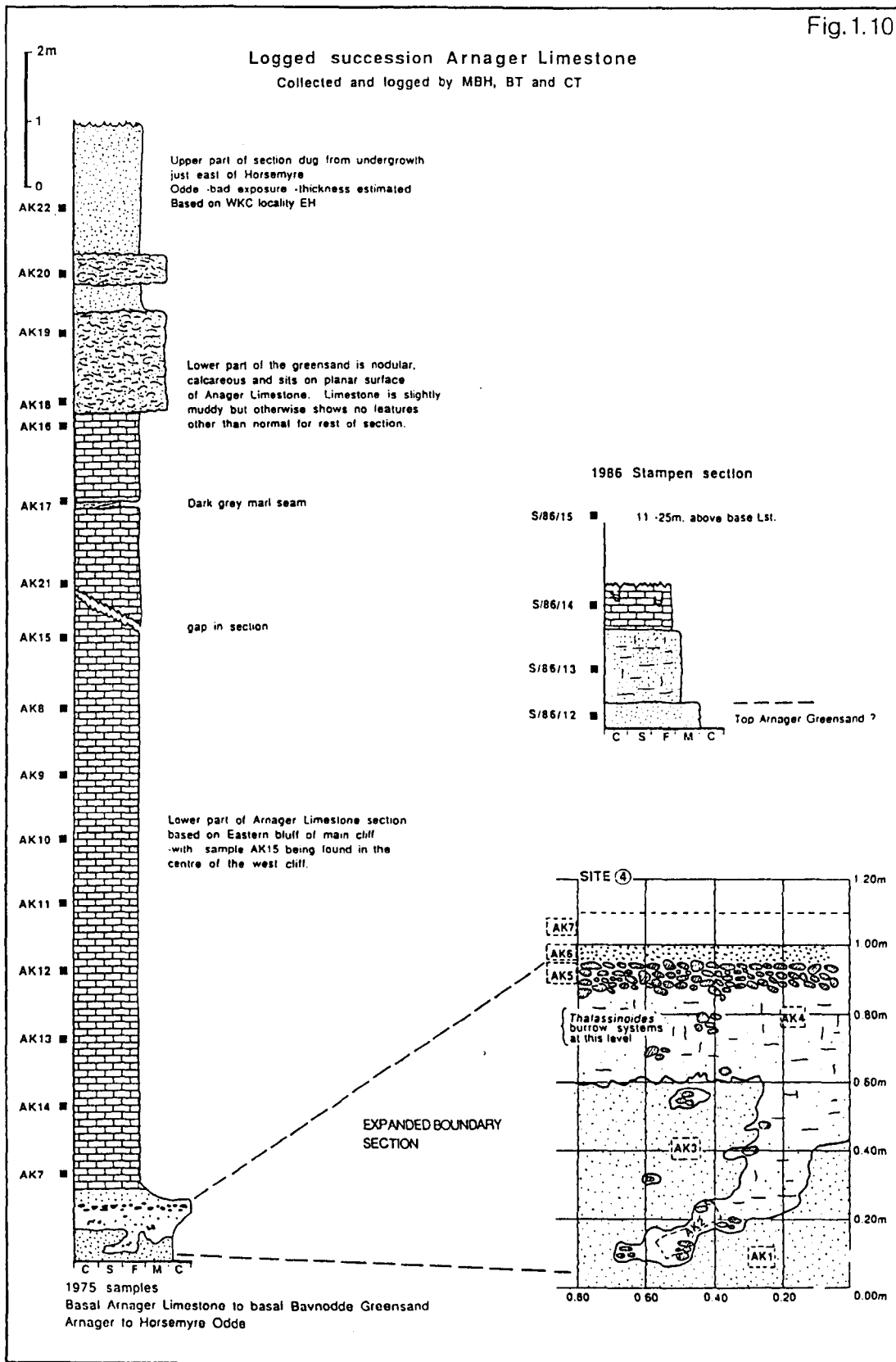


Fig. 1.10



Logged succession Bavnodde Greensand

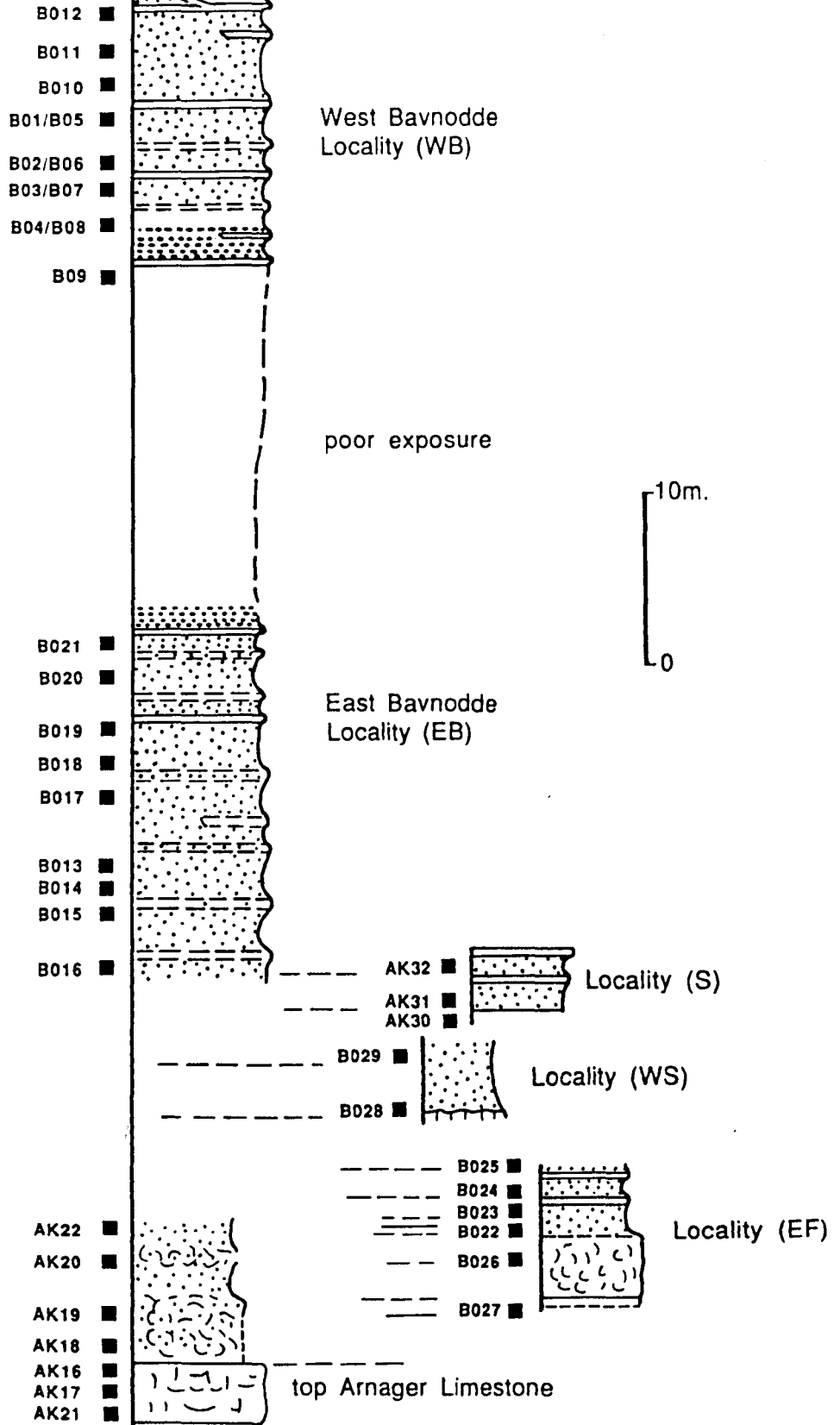



Fig. 1.12

Locality map of Stampen River area, Bornholm
(mapped August 1988 SRP, MBH)

 strike and dip measurement
 S/88/10 sample no. and location

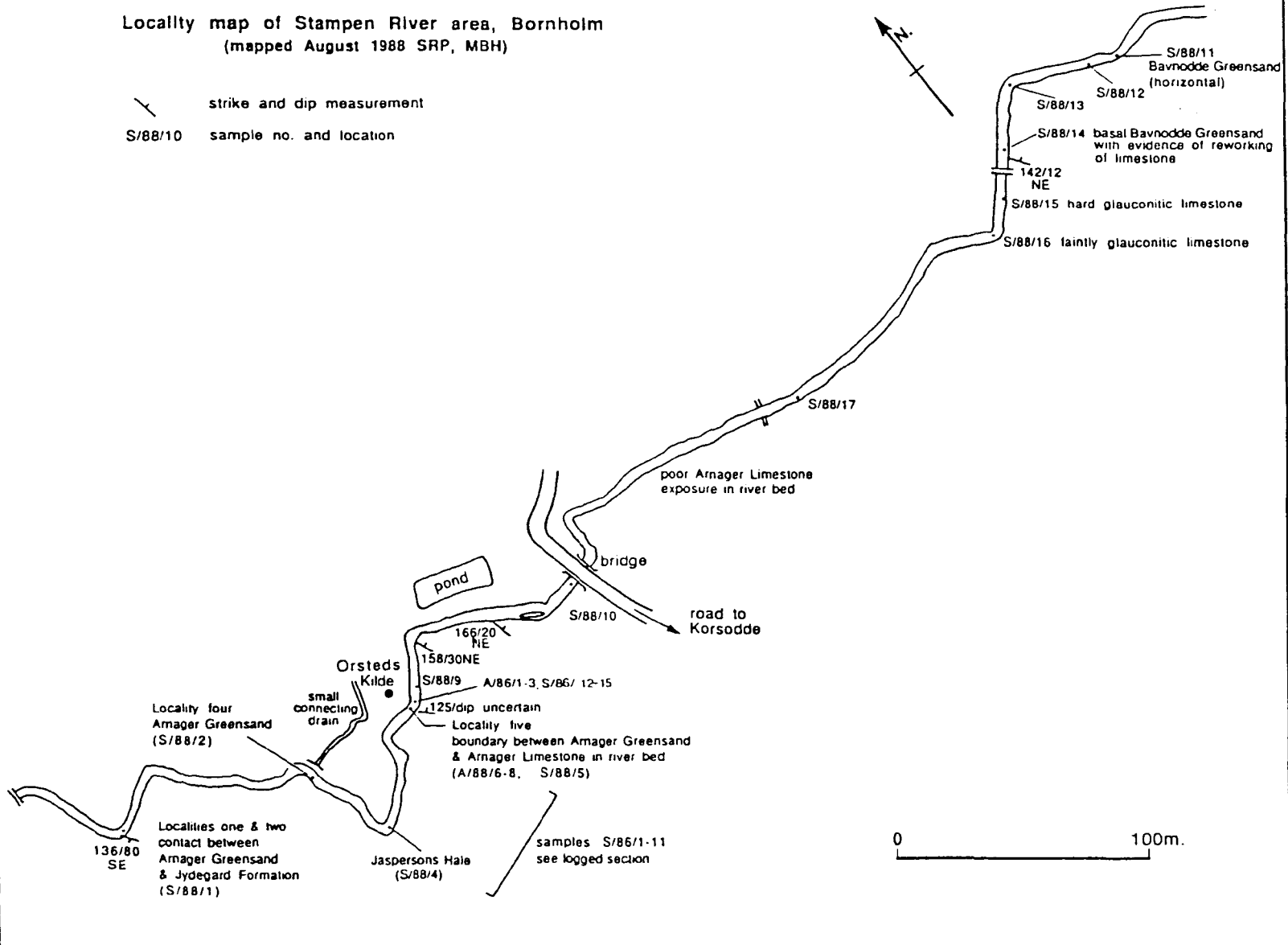


Table 1.1

Sample name	Year	location	Sample numbers
Arnager Greensand			
Madsegrav	1975	Madsegrav	AK24-29
M series	1986	Madsegrav	M/86/0-4
S series	1986	Stampe Å	S/86/1-11
Section B	1986	65m west of M	AG/86/1-5
Section C	1986	102m west of M	AG/86/6-7
Section D	1986	115m west of M	AG/86/8-15
Section E	1986	142m west of M	AG/86/16-20
Section F	1986	175m west of M	AG/86/21
WKC	1975	Sewerage works	WKC
S series	1988	Stampe Å	S/88/1-8
Arnager Limestone			
Lst basal section	1975	Arnager Pynt	AK1-AK15
Lst/basal Bavnodde	1975	Horsemyre ødde	AK16-22
A series	1986	Stampe Å	A/86/1-3
S series	1986	Stampe Å	S/86/12-15
S series	1988	Stampe Å	S/88/9-10,15-17
Bavnodde Greensand			
BO	1975	Forchammers ødde(EF)	BO27-25
BO	1975	Horsemyre ødde(FS/WS)	BO28-29
AK	1975	Horsemyre ødde(S)	AK30-32
BO	1975	East Bavnodde(EB)	BO16-21
BO	1975	West Bavnodde(WB)	BO1-12
FO	1986	Forchammers ødde(FO)	FO/86/1-10
S series	1988	Stampe Å	S/88/11-14

1.4.7 Sample collection and logging

Sections of the succession were logged and sampled, principally in 1975 by M.B. Hart, in 1986 by M.B. Hart, B.A. Tocher and C.M. Taplin, and in 1988 by M.B. Hart and the author. W.K. Christensen provided a sample from the site of the sewerage works excavation in 1975.

All the information collected has been amalgamated and summarised in Figures 1.9-11 and Table 1.1.

The generally poor state of outcrop, particularly the Greensands has resulted in incomplete coverage of the succession. The lower part of the Arnager Greensand Formation is well covered, but there are large gaps in the middle and upper parts of this formation, which are very poorly exposed in the area south and east of Arnager on the coast. The Arnager Limestone Formation is generally well covered with only one minor gap in the succession. Of the 180m of the Bavnodde Greensand Formation only c.70m (?) are covered, again due to extremely poor exposure.

Samples were collected and stored in plastic bags, with approximately 1kg of sediment being collected per sample.

Chapter Two

Previous micropalaeontological work

2.1 Foraminifera

Since Ravn (1918) there has been a smattering of published papers which contain details of the foraminiferal fauna from the Albian to Santonian succession. All previous published papers are reviewed below, in chronological order.

Ravn (1916, 1918, 1921, 1925) was the first worker to describe foraminifera from the Bornholm succession. Ravn (1916) described the macrofauna of the Arnager Greensand Formation, but not the foraminifera. The first description comes in Ravn (1918) which describes the microfauna and macrofauna of the "Turonian" Arnager Limestone Formation. In the study, two species of foraminifera were recorded, *Flabellina elliptica* Nilss, 1872 and *Cristellaria rotulata* Lamarck, 1804. A total of five specimens of *Flabellina elliptica* were recorded from Arnager and Horsemyre odde. Three specimens of *Cristellaria rotulata* were recorded from Arnager. Ravn (1921) described the micro and macrofauna of the "Senonian" Bavnodde Greensand Formation. *Cristellaria rotulata* is recorded, comprising a total of four specimens from Horsemyre odde and Forchammers klint. Ravn (1925) dealt with the fauna of the "basalkonglomerat" (i.e. the phosphatised conglomerate at the base of the Arnager Greensand Formation), but makes no reference to a foraminiferal fauna.

There can be little doubt that Ravn made no serious attempt to describe the foraminiferal fauna, as his main concern was clearly the macrofauna. Specimens of *Lenticulina* (= *Cristellaria*) and *Frondicularia* (= *Flabellina*) are generally large and well preserved; it is probable that Ravn came across these whilst examining macrofossils.

Stenestad (1968) studied the genus *Heterohelix* Ehrenberg, 1843 from the Senonian of Denmark. Included in this work are species of *Heterohelix* from the "lower Santonian" Bavnodde Greensand Formation of Bornholm. *Heterohelix striata* (Ehrenberg, 1840) and *Heterohelix pulchra* (Brotzen, 1936) were recorded from the Bavnodde Greensand Formation. One hundred and thirty one specimens of *Heterohelix striata* were recorded from the formation and included

within a statistical analysis of relative youngest chamber breadth from the Santonian to Maastrichtian of the Danish Upper Cretaceous.

Douglas and Rankin (1969) was the first major published study on the foraminiferal fauna. Nine samples were collected, three from each formation. A total of fifteen species of planktonic foraminifera were described from the succession. Critique of specific taxonomic details of this work can be found within the taxonomy chapter of this thesis. Two species of planktonic foraminifera were recorded from the Arnager Greensand Formation, *Hedbergella portsdownensis* Williams-Mitchell (1948) and *Hedbergella planispira* Tappan (1961). The authors also noted the occurrence of ".....an abundant and diverse benthonic microfauna (more than 25 species)." The Arnager Greensand Formation was interpreted as being deposited in a shallow neritic environment, influenced by deltaic conditions. The planktonic foraminiferal assemblage was considered to be environmentally restricted as it lacked forms such as *Rotalipora*, *Schackoina*, *Globigerinelloides*, *Heterohelix* and *Hedbergella*, which were considered characteristic of more open marine conditions. This conclusion was later to be quashed by Hart (1979).

Ten species of planktonic foraminifera were noted from the Arnager Limestone Formation and benthonic species were recorded as sparse. The formation was determined as Upper Turonian to Coniacian, with the suggestion that a Late Turonian age given by molluscs, may be accounted for by reworking. The Coniacian age was given by the occurrence of *Globotruncana cretacea* (d'Orbigny, 1840) for at least the upper part of the Formation.

Thirteen species of planktonic foraminifera were described from the Bavnodde Greensand Formation and in certain features this formation was taken to resemble the Arnager Greensand Formation ".....such as its lithology and numerous ostracods and other benthonic species..." Planktonic foraminiferal age correlations for the Bavnodde and Arnager Greensand Formations were considered to be in close agreement with molluscan faunas.

The Arnager Limestone Formation and Bavnodde Greensand Formation were seen as denoting a major change in depositional environment, to more pelagic environments, despite the accompanying change from calcareous to clastic facies.

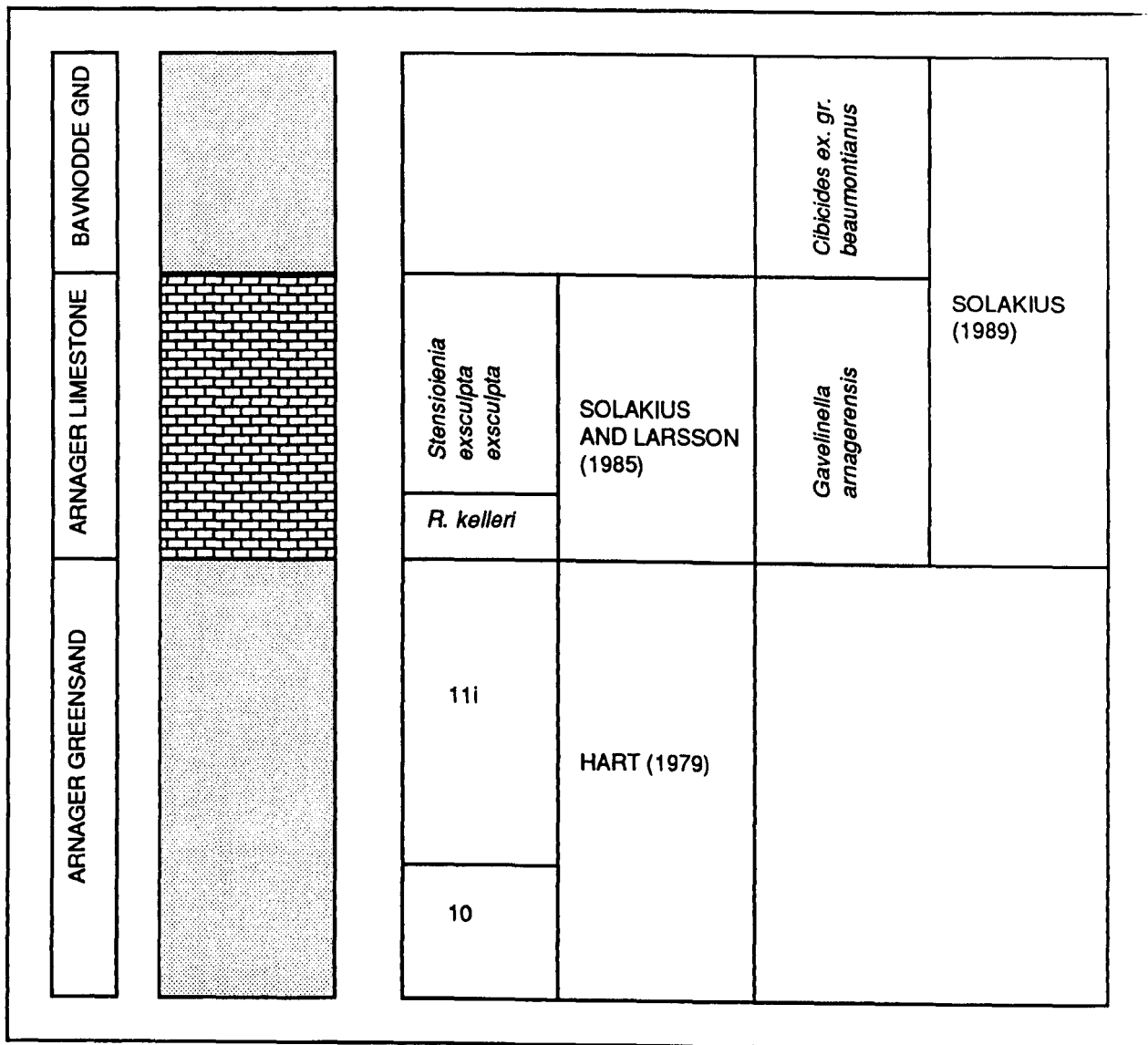


Figure 2.1 Previous micropalaeontological zonation schemes proposed for the Arnager Greensand (Hart, 1979) Arnager Limestone, and Bavnodde Greensand (Solakius and Larsson, 1985; Solakius, 1989).

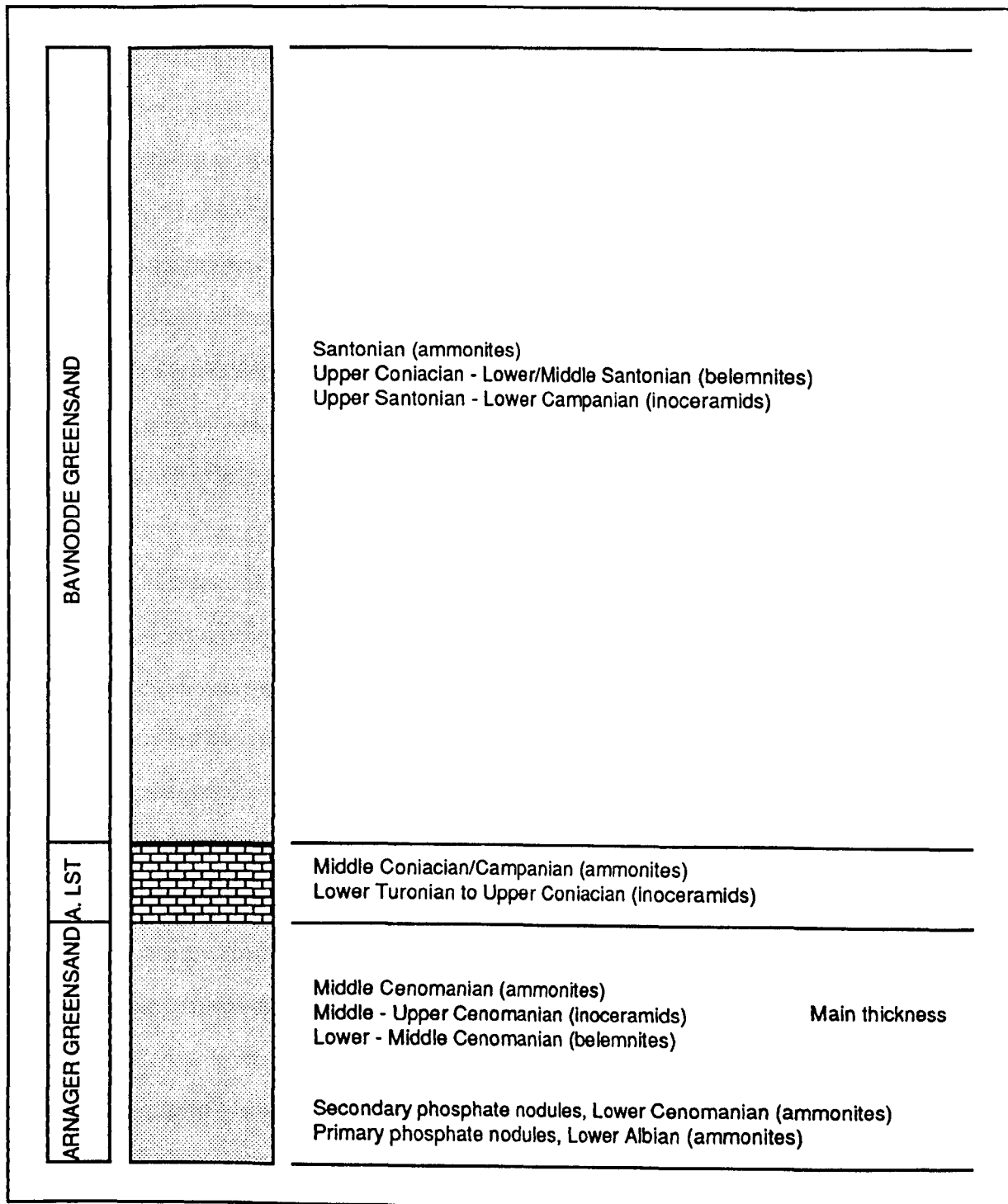


Figure 2.2 Macrofaunal evidence for the age of the Arnager Greensand, Arnager Limestone and Bavnodde Greensand, Bornholm, Denmark. Primary source Christensen (1984)

The authors drew attention to six major characteristics of the assemblages from the Arnager Limestone Formation and Bavnodde Greensand Formation. These they thought to be examples of Lower Senonian Boreal planktonic communities. The six major characteristics are:

1. Compared with coeval Tethyan faunas, the boreal faunas were less diverse.
2. Boreal faunas are dominated by globigerine shaped taxa or they occur in roughly equal numbers. Shifts in population towards a greater proportion of *Hedbergella* were brought about by reduced communication with seaways.
3. *Globotruncana* assemblages were seen as falling into two morphological groups, a double keeled type and a single keeled type. The latter group being rare or absent.
4. The *Globotruncana* species form a recurrent association which was considered to form a distinct pelagic association ".....adapted to marginal pelagic habitats which excluded the majority of planktonic foraminifera"
5. Boreal stocks were immigrants from Tethys, endemic species being rare.
6. Evolution in boreal types proceeded along pathways which modified existing phenotypes.

Although this paper was the first major study of the foraminiferal faunas of the succession, it is limited in its scope. Most importantly the study lacks a range of samples to reflect the succession, with samples concentrated within the middle of each of the three major formations (Samples in fact came from points most accessible on the beach). This restricts its stratigraphic value since major stratigraphic events may have occurred at the base or tops of any of the formations. Recovery methods must also be questioned in the light of later work, for example the restricted planktonic assemblage theory for the Arnager Greensand Formation was shown to be erroneous (Hart, 1979). The limited study on the benthic species is understandable in the context of a project which was part of a wider study of the paleozoogeography of Cretaceous planktonic foraminifera. However, subsequent studies have shown the potential of using benthic species in biostratigraphy (Hart, 1979; Solakius and Larsson, 1985).

Stenestad (1972) outlined the stratigraphic and palaeogeographic distribution of *Gavelinella cenomanica* (Brotzen, 1942) within the Danish subbasin, including Bornholm. He also mentions the Arnager Limestone Formation, which is assigned to the Upper Coniacian on the basis of the foraminiferal fauna, the details of which are not given.

Hart (1979) examined the microfauna of the Arnager Greensand Formation using twelve samples ranging from the base of the formation from its contact with the Jydegaard Formation to its upper contact with the overlying Arnager Limestone Formation. Included in this study was a sample collected by W.K.Christensen from the site of sewerage works excavations, and as Hart(1979) stated ".....this latter material is vitally important as it comes from levels in the succession that have hitherto been inaccessible." Work on this sample showed the presence of *Rotalipora reicheli* Mornod, 1950, indicating a early Middle Cenomanian age for this part of the formation. *Rotalipora reicheli* was recorded in the uppermost levels of the Arnager Greensand and immediately below the major hiatus with the Arnager Limestone. It was shown that surface water movements and depth were probable controlling factors for the distribution of *Rotalipora reicheli*.

The planktonic component of the greensand was shown to be considerably more diverse than had been suggested by Douglas and Rankin (1969). Planktonic forms described were *Hedbergella delrioensis* (Carsey, 1926), *Hedbergella brittonensis* Loeblich and Tappan, 1961; *Heterohelix moremani* (Cushman, 1938), *Guembelitria harrisi* Tappan, 1940; *Globigerinelloides bentonensis* (Morrow, 1934) and *Praeglobotruncana delrioensis* (Plummer, 1931). The occurrence of these forms demonstrate that Douglas and Rankins' (1969) idea of an environmentally restricted fauna was inappropriate.

This paper was also the first to attempt to describe benthic foraminifera in any detail from the succession. By comparison with the UK succession the author was able to show that the overlapping ranges of *Plectina cenomana* Carter and Hart, 1977 and *Lingulogavelinella jarzevae* (Vasilenko, 1961) indicated proximity to the Early/Middle Cenomanian boundary. The lowest 5m were considered to be Early Cenomanian age based on the occurrence of *Lingulogavelinella jarzevae*. It was also shown that the benthic foraminifera showed distinctive affinities with previously described eastern European forms such as *Gavelinella belorussica* (Akimez, 1961), *Cibicides gorbenkoi* (Akimez, 1961) and *Lingulogavelinella ornatissima* (Lipnik, 1961). A total of

thirteen benthic species are named. The principal value of Harts' study lies in the recognition and definition of the hiatus between the top of the Arnager Greensand Formation and the base of the Arnager Limestone Formation.

Bailey and Hart (1979) mentioned the Cretaceous succession of Bornholm, in a paper which established a Lower Senonian biozonation and attempted correlation within northwest Europe, including Bornholm. The authors recognised ten species of foraminifera from the Arnager Limestone and Bavnodde Greensand Formations, suggesting that the Arnager Limestone Formation was Coniacian in age, whilst the Bavnodde Greensand Formation was Late Coniacian-Santonian in age. It was pointed out that many of the benthics might be facies controlled and that the *Stensioeina* fauna which had been successfully used for zonation by authors such as Koch (1977) was very poor. The presence of a distinctive boreal planktonic fauna was noted with the suggestion that temperature was the primary control on distribution.

Solakius and Larsson (1985) studied the Arnager Limestone ".....in an attempt to distinguish the extent of the Turonian sedimentary beds in southwest Skåne and on Bornholm, and to establish a zonation on the basis of foraminifera." This is the most detailed paper published on the Arnager Limestone Formation to date. It contains descriptions of the most biostratigraphically important species defined by the authors. Nineteen samples were collected from the top of the Arnager Greensand Formation through the Arnager Limestone Formation to the base of the Bavnodde Greensand Formation.

Only *Gavelinella cenomanica* is recorded from the top of the Arnager Greensand Formation, with samples at the level of the phosphatised hardground (base Arnager Limestone Formation) being apparently barren. Both planktonic and benthic species were recorded, with two benthic biozones being defined for the formation; the *Reussella kelleri* Vasilenko, 1961 Biozone and the *Stensioeina exsculpta exsculpta* (Reuss, 1860) Biozone. The authors rightly suggest that the presence of *Gavelinella thalmanni* (Brotzen, 1936), *Gavelinella pertusa* (Marsson, 1878) and *Gaudryina rugosa* d'Orbigny at the base of the formation indicates that deposition of the limestone had at least begun in the later part of the early Coniacian. The *Reussella kelleri* Biozone,

established by Amedro *et al.*, (1981) is defined from the first appearance of *Reussella kelleri* to the first appearance of *Osangularia cordieriana* (d'Orbigny, 1840), and represents the lowermost Coniacian. This biozone is not properly defined by Solakius and Larsson (1985) with the top of the biozone being defined by the first occurrence of *Stensioeina exsculpta exsculpta*. The authors also fail to make clear how the top of the *Stensioeina exsculpta exsculpta* Biozone is defined in their work. The authors contend that limestone deposition did not continue into the Santonian with significant Lower Santonian marker species being found in the basal Bavnodde Greensand Formation. They also propose a hiatus at this level with the occurrence of *Loxostomum eleyi* (Cushman, 1927) and *Cibicides ribbingi* (Brotzen, 1936) in the bed overlying the limestone.

The value of this paper lies in its descriptions of many species which had not previously been recognised in the Arnager Limestone Formation. The benthic biozonations and ages may be improved upon.

Solakius (1988) describes the occurrence of *Gavelinella arnagerensis* (Solakius, 1988) from the Arnager Limestone Formation and basal Bavnodde Greensand Formation.
(=*Lingulogavelinella cf. vombensis sensu* Bailey *et al.*, 1983)

Solakius (1989) studied the Arnager Limestone Formation - Bavnodde Greensand Formation boundary, comparing faunas recovered, with the assemblage zones of Bailey *et al.*, (1983). Solakius (1989) assigned the upper part of the Arnager Limestone Formation to a *Gavelinella arnagerensis* Biozone (= *Lingulogavelinella cf. vombensis* Biozone of Bailey *et al.*, (1983). The basal part of the Bavnodde Greensand Formation was assigned to the *Cibicides ex gr. beaumontianus* Biozone of Bailey *et al.*, (1983). The *Loxostomum eleyi* Biozone of Bailey *et al.*, (1983) was found to be missing indicating a hiatus from the Late Coniacian to Early Santonian.

Packer *et al.* (1989) presented a summary of foraminiferal data within a review of the microbiostratigraphy of the whole Bornholm Cretaceous succession. Both planktonic and benthic species were reviewed, covering the papers mentioned above. (Hart, 1979; Bailey and Hart, 1979 and Solakius and Larsson, 1985). Their paper was the first to define changes in palaeo-water

depth using planktonic foraminifera according to the Hart and Bailey (1979) model. Packer *et al.*, (1989) suggested that a decline in water depth through the Arnager Limestone Formation into the Bavnodde Greensand Formation together with a gradual decline in the proportion of keeled taxa is indicative of a reduction in water depth (possibly brought about by sedimentation).

2.2 Ostracoda

There are no known published works on the Ostracoda of the succession. Hart (1979) mentioned that P.P.E. Weaver (IOS) has suggested that the upper part of the Arnager Greensand is Middle Cenomanian in age based on the unpublished ostracod data.

2.3. Palynology

A reconnaissance of the dinoflagellates has been carried out by Dr.B.A. Tocher, with results being published in Packer *et al.*, (1989). Dinoflagellate cysts indicate that the Arnager Greensand Formation is no younger than Middle Cenomanian in age . Samples from the top of the Arnager Greensand Formation and its contact with the overlying Arnager Limestone Formation yielded a complicated assemblage suggesting a ?Late Cenomanian- Late Coniacian age.

Paul Schiøler (Geological Survey of Denmark) has studied the palynology of the Arnager Limestone Formation and given an Early Coniacian age for the formation. (Results were presented in the conference "25 years of Palynology in the North Sea", Nottingham, England, 1989).

2.4 Nannofossils

Forcheimer (1970) examined an unstated number of samples from the Arnager Greensand Formation, sample levels were not indicated. Four species of coccolith were recognised *Coccolithus bornholmensis* Forcheimer, 1970; *Coccolithus cf. barnesae* (Black, 1959), *Discolithina theta* (Black, 1959) and *Deflandrius cantabrigensis* Black, 1967. Coccoliths

were not used for biostratigraphic subdivision, all are referred to as being in "Middle Cenomanian" sediments, on the basis of the macrofauna (Ravn 1916, 1930, and Stolley, 1930).

2.5 Study methods

2.5.1 Sample preparation

1975 samples were prepared by MBH, 1986 samples by the author. In both cases similar techniques were employed. Most of the samples from the Arnager Greensand and Bavnodde Greensand Formations simply required sieving (using a 63 micrometre sieve) with warm water to remove the clays, as most were fairly unconsolidated. Samples of greensand which did not breakdown using this method were boiled with Sodium hexametaphosphate to deflocculate the clays.

Samples of the Arnager Limestone Formation required gentle crushing under water to break down the sediment. White spirit was then added to the dried residue and left to soak, for 24 hours. The white spirit was then decanted and boiling water added to disaggregate the sediment. Samples were then wet sieved using a 63 micrometre sieve. Samples were then oven dried and picked.

Where possible more than 300 individuals per sample were picked, though this was not possible with some samples, particularly those from the Stampen Å river section which were decalcified. In all cases the >63 micrometre, >125 micrometre and >1 millimetre residues were picked.

2.5.2

Scanning electron microscopy

Specimens were examined using a Jeol T-20 SEM, in the E.M. Unit at Polytechnic South West. Selected specimens being mounted on aluminium stubs, coated with gold (c. 14 nanometers), and photographed.

Chapter three

Systematic descriptions.

3.1 Introduction

One hundred and sixty six species, representing sixty eight genera are described herein. These are described systematically following the classification of Loeblich and Tappan (1988). The latter classification is utilised since it provides the most comprehensive and up to date foraminiferal classification. There has been much criticism of this work however, although it remains the most complete guide to foraminiferal taxonomy.

For each species a synonymy is given. These are not full synonymies, giving only the reference for the original description, followed by major generic changes given by later authors and finally a recent reference which quotes the species. A brief description is then given, followed by maximum recorded dimensions. The stratigraphic distribution of each species is stated according to formation (AG = Arnager Greensand; AL = Arnager Limestone; BG = Bavnodde Greensand) and according to biozone, as defined in chapter four. Detailed data on the distribution of particular species is given in the foraminiferal distribution sheets (Enclosures 3-6, Checklist II format). A stratigraphic range is also quoted, which may be from more than one source. Where possible ranges are confirmed from published literature, however, some species are only recorded in unpublished Ph.D theses, e.g. Hart (1970), Bailey (1978), Swiecicki (1980) and Ball (1985), which are therefore utilised.

Geographical data is generally very limited. The majority of smaller benthic foraminifera are described from northwest Europe, with little information available from Tethyan carbonate environments or deep water Alpine successions. Hence correlation is very difficult. The planktonic foraminiferal fauna is distinctly boreal in character and this is discussed fully in chapter five.

3.2 Taxonomy

Order : *Foraminiferida* Eichwald, 1830

Suborder : *Textulariina* Delage and Herouard, 1896

Superfamily : *Lituolacea* de Blainville, 1825

Family : *Haplophragmoididae* Maync, 1952

Genus : *Haplophragmoides* Cushman, 1910

Type species : *Nonionina canariensis* d'Orbigny, 1839

Haplophragmoides sp. A

(Plate 1, Figure 1)

Description : Test free, agglutinated, planispiral, involute and slightly compressed. Consists of 5 to 7 slightly inflated chambers. Periphery broadly rounded. Aperture an equatorial interiomarginal arch.

Size : Maximum diameter 900 microns, maximum height, 600 microns.

Occurrence : AG (Biozone 1)

Remarks: The lack of common well preserved material prevents further attribution of this species.

The inflation of the test is reminiscent of *Recurvoides* Earland, 1934; this is unclear however given the preservation and lack of common material.

Family : *Placopsilinidae* Rhumbler, 1913

Subfamily : *Placopsilininae* Rhumbler, 1913

Genus : *Placopsilina* d'Orbigny, 1850

Type species : *Placopsilina cenomana* Cushman, 1920

Placopsilina sp. A

(Plate 1, Figure 2)

Description : Test attached, finely agglutinated, planispirally coiled. Initial whorl followed by a whorl of five chambers gradually increasing in size as added. Sutures depressed, curved. Keel developed at the margins. Aperture terminal rounded.

Size : Diameter 400 microns, maximum height 80-100 microns.

Occurrence : AG (Biozones 1, 2).

Remarks : The regular coiling of this species distinguishes it from *Placopsilina cenomana* (d'Orbigny, 1850).

Superfamily : *Verneuilinacea* Cushman, 1911

Family : *Prolixoplectidae* Loeblich and Tappan, 1985

Genus : *Plectina* Marsson, 1878

Type species : *Gaudryina ruthenica* Reuss, 1851

Plectina cenomana Carter and Hart, 1977

(Plate 1, Figure 3)

1977 *Plectina cenomana* Carter and Hart, pp.12-13, pl.2, fig.9.

1981 *Plectina cenomana* Carter and Hart; Hart *et al.*, p.176, pl.7.2, fig.10.

1989 *Plectina cenomana* Carter and Hart; Hart *et al.*, p.318, pl.7.2, fig.10.

Description : Test free, trochospiral, agglutinated, consists of 2-3 whorls of 5 chambers per whorl. Triserial in appearance, chambers gently inflated, sutures depressed. Aperture rounded to oval in a slight depression on final chamber.

Size : Maximum height 870 microns, maximum width 400 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Middle to Late Cenomanian (Hart *et al.*, 1981, and Hart *et al.*, 1989). This species occurs throughout the Arnager Greensand.

Plectina mariae (Franke, 1928)

(Plate 1, Figure 4)

1928 *Gaudryina ruthenica* Reuss var. *mariae* Franke, p.146, pl.13, fig.15a,b.

1937 *Plectina ruthenica* (Reuss) var. *mariae* (Franke); Cushman, p.106, pl.11, fig.15.

1972 *Plectina ruthenica mariae* (Franke); Gawor-Biedowa, p.34, pl.3, fig.3a,b.

1977 *Plectina mariae* (Franke); Carter and Hart, p.13, pl.2, fig.8.

Description : Test free, trochospiral, agglutinated. Initially appearing triserial, becoming distinctly biserial. Sutures depressed. Test tapers towards base. Aperture oval in slight depression in face of final chamber.

Size : Height 650 microns, width 300 microns

Occurrence : AG (Biozones 1, 3)

Stratigraphic range : Cenomanian to Early Turonian (Carter and Hart, 1977)

Family : *Verneuilinidae* Cushman, 1911

Subfamily : *Verneuilinoidinae* Suleymanov, 1973

Genus : *Eggerellina* Marie, 1941

Type species : *Bulimina brevis* d'Orbigny, 1840

Eggerellina mariae ten Dam, 1948

(Plate 1, Figure 5)

1948 *Eggerellina mariae* ten Dam, pp.15-16,pl.1,fig.17.

1985 *Eggerellina mariae* ten Dam; Ball, pp.97-98,pl.3,fig.3.

1989 *Eggerellina mariae* ten Dam, Hart *et al.*, p.318, pl.7.2, figs. 1,2.

Description : Test free, finely agglutinated, varying in form from short pyramidal to conical.

Chambers distinct, globulose, inflated, in three to four whorls. Sutures distinct, depressed, slightly curved. Aperture a narrow, elongated interiomarginal slit extending up the apertural face of the final chamber from its base. Test surface generally smooth.

Size : Maximum height 600 microns, maximum width 400 microns.

Occurrence : AG, AL, BG (Biozones 1, 4, 5).

Stratigraphic range : Late Albian to Turonian (Hart *et al.*, 1989)

Subfamily : *Spiroplectinatinae* Cushman, 1928

Genus : *Spiroplectinata* Cushman, 1927

Type species : *Textularia annectens* Parker and Jones, 1863

Spiroplectinata annectens (Parker and Jones, 1863)

(Plate 1, Figure 6)

1863 *Textularia annectens* Parker and Jones, p.92,fig.1.

1937 *Spiroplectinata annectens* (Parker and Jones); Cushman, p.104,pl.14,figs 10-12.]

1972 *Spiroplectinata annectens* (Parker and Jones); Gawor-Biedowa, pp.23-
24,pl.1,fig.8.

1975 *Spiroplectinata annectens* (Parker and Jones); Magniez-Jannin, p.69,pl.5,figs 23-
24.

Description : Test free, elongate, finely agglutinated, compressed. Initial portion triserial, becoming rapidly biserial and finally uniserial. Triserial stage is sometimes difficult to see. Sutures slightly depressed initially, becoming distinctly more depressed in later portion. Test subrectangular in cross section.

Size : Maximum length 1.4mm, maximum width 400 microns.

Occurrence : AG (Biozones, 1, 2).

Stratigraphic range : Aptian to Turonian (Gawor-Biedowa,1972)

Subfamily : *Verneuilinae* Cushman, 1911

Genus : *Gaudryina* d'Orbigny, 1840

Type species : *Gaudryina rugosa* d'Orbigny, 1840

Gaudryina carinata Franke, 1914

(Plate 1, Figure 9)

1914 *Gaudryina carinata* Franke, p.431,pl.27,figs.4-6.

1970 *Gaudryina carinata* Franke; Hanzlikova, p.51,pl.11,fig.4.

Description : Test free, finely agglutinated, gradually tapering towards base. Becomes almost parallel sided. Appears quadriserial with concave sides. Sutures depressed, limbate. Last chamber distinctly globular and larger than previous ones. Aperture slit like at base of final chamber.

Size : Height 700 microns, width 210 microns.

Occurrence : BG (Biozone 5).

Stratigraphic range : Described by Franke (1914) from the Coniacian to Santonian of Germany.

Recorded from the Campanian (Hanzlikova, 1970).

Comments: *Gaudryina carinata* Franke 1914, is similar to *Gaudryina jonesiana* Wright, 1886 and may therefore be a junior synonym. Examination of type material is needed before a final decision is taken.

Gaudryina rugosa d'Orbigny, 1840

(Plate 1 Figure 8)

1840 *Gaudryina rugosa* d'Orbigny, p.44,pl.4,figs 20,21.

1985 *Gaudryina rugosa* d'Orbigny; Solakius and Larsson, pp.24-25.

Description : Test free, large, elongate. Initial triserial part is followed by biserial chambers which increase rapidly in size as added, giving a roughly triangular outline. Sides flat. Sutures distinct, depressed. Test coarsely agglutinated. Aperture crescentic.

Size : Maximum length 900 microns, maximum width 600 microns.

Occurrence : Recorded from the Arnager Limestone and basal Bavnodde Greensand (Solakius and Larsson, 1985). AL, BG (Biozones 4-6).

Stratigraphic range : Coniacian to Early Maastrichtian (Solakius and Larsson, 1985).

Genus : *Verneuilina* d'Orbigny in de la Sagra, 1839

Type species : *Verneuilina tricarinata* d'Orbigny, 1840.

Verneuilina muensteri Reuss, 1854

(Plate 1, Figure 7)

1845 *Verneuilina muensteri* Reuss, p.71,pl.26,fig.5.

1985 *Verneuilina muensteri* Reuss; Solakius and Larsson, pp.23-24,pl.2,fig.24.

1989 *Verneuilina muensteri* Reuss; Hart *et al.*, p.320,pl.7.3,figs.7,8.

Description : Test free, elongate, triangular in section. Sides flat to concave. Chambers distinct, increasing in size as added. Sutures flush to slightly raised, curved. Wall finely agglutinated, smooth. Aperture loop shaped at inner margin of final chamber.

Size : Height 800 microns, maximum width 400 microns.

Occurrence : recorded from the Arnager Limestone to basal Bavnodde Greensand by Solakius and Larsson (1985). AL, BG (Biozones 4-6).

Stratigraphic range : Recorded from the Coniacian (Reuss, 1854) and from the Coniacian to Early Maastrichtian (Hart *et al.*, 1989).

Family : *Tritaxiidae* Plotnikova, 1979

Genus : *Tritaxia* Reuss, 1860

Type species : *Textularia tricarinata* Reuss, 1844

Tritaxia pyramidata Reuss, 1862

(Plate 1, Figure 10)

1862 *Tritaxia pyramidata* Reuss, p.32,pl.88,fig.9a-c.

1981 *Tritaxia pyramidata* Reuss: Hart *et al.*, p.178,pl.7.3,figs 2,3.

Description : Test free, elongate, triserial, triangular in cross section. Sides concave, consisting of up to 9 triserial chambers which overlap. Sutures depressed. Aperture terminal, circular.

Size : Maximum length 700 microns, maximum width 320 microns.

Occurrence : AL (Biozone 3).

Stratigraphic range : Hauterivian to Cenomanian (Hart *et al.*, 1981). Early part of range may be misleading since it can be confused with *Tritaxia singularis* Magniez-Jannin 1975. *Tritaxia singularis* differs in having less cement, more concave sides and in not having a terminal aperture. In carbonate environments which are undersaturated with respect to calcium carbonate in the Lower Cretaceous, the two forms may be confused.

Superfamily : *Ataxophragmiacea* Schwager, 1877

Family : *Ataxophragmiidae* Schwager, 1877

Subfamily : *Ataxophragmiidae* Schwager, 1877

Genus : *Arenobulimina* Cushman, 1927

Notes on the generic subdivision of *Arenobulimina* Cushman, 1927

Barnard and Banner (1980) and subsequently Freig and Price (1982), differentiated subgenera of *Arenobulimina* on the basis of the internal partitioning. *Arenobulimina* (*Arenobulimina*) species were considered to have a simple internal structure, whilst *Arenobulimina* (*Voloshinoides*) species were considered to have complex internal partitioning. This approach has not been adopted in this thesis because of the difficulties in differentiating internal partitions,

and it would appear that the degree of partitioning is highly variable, though this may be a function of preservation or ecophenotypic processes. It is also important to note that the samples used for the Barnard and Banner (1980) study were taken from different localities where the position of the sample in the succession was measured from the base of the chalk. The base of the chalk is diachronous (Carter and Hart, 1977), which may therefore limit the level of confidence of samples supposedly taken in stratigraphic succession.

Type species : *Bulimina presli* Reuss, 1846

Arenobulimina advena (Cushman, 1936)

(Plate 1, Figure 11)

1936 *Hagenowella advena* Cushman, p.43,pl.6,fig.21 a,b.

1969 *Arenobulimina advena* (Cushman); Gawor-Biedowa, pp.86-90,pl.8,figs.1-4,text figs 7,8.

1977 *Arenobulimina advena* (Cushman); Carter and Hart, p.14,pl.2,fig.4.

1981 *Arenobulimina (Voloshinoides) advena* (Cushman); Barnard and Banner, pp.405-406,pl.4,figs 6-8,pl.7,figs.10-12.

1989 *Arenobulimina advena* (Cushman); Hart *et al.*, p.316,pl.7.1.,fig.5.

Description : Test free, trochospiral, agglutinated. Last three chambers occupying over half of test. Chambers slightly inflated. Sutures distinct, depressed. Interior of test divided by complex partitions which may appear as light and dark bands on the surface of the test. Aperture an interiomarginal loop, set in hollow face of last chamber.

Size : Maximum height 600 microns, maximum width 400 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Latest Albian to Late Cenomanian (Hart *et al.*, 1989)

Arenobulimina anglica Cushman, 1936

(Plate 1, Figure 12)

1936 *Arenobulimina anglica* Cushman, p.27,pl.4,figs 8a,b.

1977 *Arenobulimina anglica* Cushman; Carter and Hart, p.27,pl.2,fig.3.

1980 *Arenobulimina (Voloshinoides) anglica* Cushman; Barnard and Banner, pp.407-408,pl.6,figs 12,13.

1989 *Arenobulimina anglica* Cushman; Hart *et al.*, pl.7.7,fig.6.

Description : Test free, finely to medium agglutinated giving a sugary appearance, trochospiral. Last whorl occupies over half of the test, chambers rounded to slightly inflated, last chamber almost rounded. Sutures depressed. Aperture an interiomarginal loop, set in hollow face of last chamber.

Size : Maximum height 1mm, maximum width 600 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Early to Middle Cenomanian (Hart *et al.*, 1989); Early Cenomanian (Carter and Hart, 1977).

Arenobulimina bulletta (Barnard and Banner, 1981)

(Plate 2, Figures 1,2)

1981 *Arenobulimina (Voloshinoides) bulletta* Barnard and Banner, pp.408-410,pl.3,figs.1-6,pl.6,figs 14-20.

1987 *Arenobulimina bulletta* Barnard and Banner; Leary, p.63,pl.6,figs 1-4.

Description : Test free, agglutinated, distinctly rifle bullet shaped. Test quadriserial, very high trochospiral, chambers uninflated, forming obliquely to the coiling axis, 3-4 chambers per whorl.

Circular in cross section, tapering, becoming nearly parallel sided. Sutures depressed. Apertural face flattened, aperture narrow.

Size : Height 2.1mm, maximum width 1mm

Occurrence : AG (Biozones 1, 3).

Stratigraphic range : Cenomanian (Barnard and Banner, 1981)

Comments: *Arenobulimina bulletta* differs from *Arenobulimina truncata* (Reuss, 1846) in having a circular final whorl, which is not truncated. The final whorl of *Arenobulimina truncata* is truncated at a high angle.

Arenobulimina courta (Marie, 1941)

(Plate 2, Figure 3)

1851 ?*Bulimina obesa* Reuss, p.40,pl.4,fig.12.

1941 *Hagenowella courta* Marie, p.43,pl.7,figs 68a,b.

1953 *Hagenowella courta* Marie; Barnard and Banner, p.202,text fig.6,j-o.

1978 *Arenobulimina courta* (Marie); Bailey, pp.73-74,pl.1,fig.13.

1982 *Arenobulimina (Hagenowella) courta* (Marie); Freig and Price, p.55, pl.2.1,k.

Description : Test free, finely agglutinated, globular, gently conical. Initial chambers form angle at base of trochospire, often very indistinct. Final whorl distinctive comprising 3 or 4 slightly inflated chambers which make up over two thirds of the test. Sutures distinct, set in depressions.

Aperture ovate formed at the angle of the chambers of the final whorl.

Size : Diameter 300 microns, maximum height 200 microns.

Occurrence : AG, AL (Biozones 1, 3, 4).

Stratigraphic range : Cenomanian to Maastrichtian (Freig and Price, 1982).

Arenobulimina obliqua (d'Orbigny, 1840)

(Plate 2, Figure 4)

1840 *Bulimina obliqua* d'Orbigny, p.40,pl.4,figs 7,8.

1934 *Arenobulimina obliqua* (d'Orbigny); Cushman and Parker, p.28,pl.5,figs 5,6.

1978 *Arenobulimina obliqua* (d'Orbigny); Bailey, pp.76-77,pl.1,fig.15.

Description : Test free, trochospiral, finely agglutinated, cone shaped. Greatest width across final chamber. Test tapering towards base. Chambers arranged obliquely, large, slightly inflated. Final chamber lobate, strongly overlapping previous whorl. Sutures depressed. Aperture interiomarginal arch formed at the base of the last chamber.

Size : Maximum height 700 microns, maximum width 400 microns.

Occurrence : AG, AL (Biozones 1, 3).

Stratigraphic range : Coniacian to Maastrichtian (Hart and Swiecicki, 1987); Late Albian to Late Cenomanian (Freig and Price, 1982); Campanian (d'Orbigny, 1840).

Arenobulimina truncata (Reuss, 1846)

(Plate 2, Figure 5)

1846 *Bulimina truncata* Reuss, p.37,pl.8,fig.73.

1937 *Arenobulimina truncata* (Reuss); Cushman, p.40,pl.4,figs 15,16.

1982 *Arenobulimina (Pasternakia) truncata* (Reuss); Freig and Price, p.63,pl.2.3,b,c.

Description : Test free, finely agglutinated, trochospiral, elongate, wedge shaped. Consists of up to four whorls, with three chambers per whorl initially, later four. Chambers uninflated, as high as wide, sutures depressed. Apertural face slightly concave truncated at approximately 45 degrees. Aperture with an apparent tooth. Wall smooth.

Size : Maximum height 500 microns, maximum width 200 microns.

Occurrence : AG, AL (Biozones 1, 3).

Stratigraphic range : ?Late Albian to Turonian (Freig and Price, 1982). Turonian (Reuss, 1846).

Comments: The truncated apertural face is characteristic of this species. Differences to *Arenobulimina bulletta* are given under that species.

Arenobulimina sp.A

(Plate 2, Figure 6)

Description : Test free, ?trochospiral, agglutinated, oval. No apparent chamber arrangement.

Aperture indistinct, set in slight hollow on top of chamber.

Size : Diameter 300 microns, maximum height 200 microns.

Occurrence : AG (Biozone 1).

Remarks : Probably the same form is mentioned by Carter and Hart (1977) page 17, who suggested that these individuals might be immature megalospheric representatives of other *Arenobulimina* species, and are present throughout the Albian and Cenomanian.

Arenobulimina sp. B

(Plate 2, Figure 7)

Description : Test free, finely agglutinated, trochospiral. Rounded outline. Last whorl occupies over half of the test, consisting of four chambers, each being distinctly wider than high. Final chamber compressed and flattened, overlapping previous chambers of whorl. Initial whorl with 3 uninflated chambers. Aperture loop shaped formed at inner margin of final chamber. Sutures depressed.

Size : Maximum height 900 microns, maximum width 700 microns.

Occurrence : AG (Biozone 1).

Remarks: This species is reminiscent of *Arenobulimina advena*, in having a last whorl which occupies over half of the test, it differs in having chambers which are distinctly wider than high.

Genus : *Ataxophragmium* Reuss, 1860

Type species : *Bulimina variabilis* d'Orbigny, 1840

Ataxophragmium variabile (d'Orbigny, 1840)

(Plate 2, Figures 10,11)

1840 *Bulimina variabile* d'Orbigny, p.40,pl.4,figs 9-11.

1937 *Ataxophragmium variabile* (d'Orbigny); Cushman, p.175,pl.21,figs 10-15.

1978 *Ataxophragmium variabile* (d'Orbigny); Bailey, pp.83-84,pl.2,figs 6,7.

Description : Test free, finely agglutinated, trochospiral. Consists of 2-3 loosely coiled whorls, initial whorl totally enclosed. Chambers increase rapidly in size as added, reniform, interiors simple, without partitions. Sutures depressed. Wall smooth, apertural face flat. Aperture simple semi-circular hole formed on inner margin of final chamber.

Size : Diameter 400 microns, height 300 microns.

Occurrence : AG, AL, BG (Biozone 1-6).

Stratigraphic range : Cenomanian to Maastrichtian (Hart and Swiecicki, 1987)

Ataxophragmium variabile (d'Orbigny, 1840) var. A

(Plate 2, Figure 12)

Description : Test free, coarsely agglutinated, trochospiral. Consists of 2-3 loosely coiled whorls. Initial whorl totally enclosed. Chambers increase rapidly in size as added, reniform, interiors simple,

without partitions. Sutures depressed. Aperture simple semi-circular hole formed on inner margin of final chamber.

Size : Diameter 1mm, maximum height 900 microns.

Occurrence : AG (Biozones 1, 3).

Remarks : As for *A. variabile*, but is distinguished by being more coarsely agglutinated, and in the last chamber which forms at a distinct angle to the previous chamber of the whorl.

Distinction as a separate species would seem dubious as this form is not consistently encountered and is morphologically very close to *A. variabile*.

Ataxophragmium depressum (Perner, 1892)

(Plate 2, Figures 8,9)

1892 *Bulimina depressa* Perner, p.55,pl.3,fig.3.

1970 *Ataxophragmium depressum* (Perner); Hanzlikova, p.61,pl.13,fig.13.

1980 *Ataxophragmium depressum* (Perner); Gawor-Biedowa, p.20-21,pl.2,figs. 14,15.

Description : Test free, finely agglutinated, trochospiral. Consisting of 2-3 whorls, initial whorl enclosed. Chambers increase rapidly in size as added. Interiors simple, without partitions. Sutures depressed. Wall generally smooth. Apertural face distinctly depressed. Aperture semi-circular hole.

Size : 420 microns, in diameter, 300 microns in height.

Occurrence : AG, AL, BG (Biozones 1, 3, 5).

Stratigraphic range : Cenomanian to Santonian (Gawor-Biedowa, 1980)

Remarks : Similar to *A. variabile*, differs only in having distinctly depressed apertural face.

Family : *Textulariellidae* Gronhagen and Luterbacher, 1966

Genus : *Pseudotextulariella* Barnard in Barnard and Banner, 1953.

Type species : *Textulariella cretosa* Cushman, 1932

Pseudotextulariella cretosa (Cushman, 1932)

(Plate 2, Figure 13)

1932 *Textulariella cretosa* Cushman, p.97,pl.11,figs 17-19.

1953 *Pseudotextulariella cretosa* (Cushman); Barnard, in Barnard and Banner, p.198,text
figs 66-i.

1977 *Pseudotextulariella cretosa* (Cushman); Carter and Hart, p.23,pl.2,fig.12.

1989 *Pseudotextulariella cretosa* (Cushman); Hart *et al.*, p.318,pl.7.2,figs. 11,12.

Description : Test free, very large, finely agglutinated, subconical. Early stage triserial but rarely seen, followed by biserial part. Chambers internally complex with horizontal and vertical partitions.

Aperture interior marginal.

Size : Height 1.2 mm, diameter 900 microns.

Occurrence : Uppermost AG (Biozone 3).

Stratigraphic range : Early to Middle Cenomanian. Rare occurrences in the Late Albian Red Chalk, of Yorkshire and Humberside (Hart *et al.*, 1989).

Superfamily : *Textulariaceae* Ehrenberg, 1838

Family : *Eggerellidae* Cushman, 1937

Subfamily : *Dorothiinae* Balakhamatova, 1972

Genus : *Marssonella* Cushman, 1933

Type species : *Gaudryina oxycona* Reuss, 1860

Marssonella trochus (d'Orbigny, 1840)

(Plate 2, Figure 14)

1840 *Textularia trochus* d'Orbigny, p.45,pl.4,figs 25,26.

1840 *Textularia turris* d'Orbigny, p.46,pl.4,figs 27,28.

1860 *Gaudryina oxycona* Reuss, p.229,pl.12, fig.3.

1985 *Marssonella trochus* (d'Orbigny); Ball, pp.89-92,pl.2,fig.7a,b.

Description : Test free, finely agglutinated, broadly conical with circular to oval cross section.

Trochospiral with four to five chambers per whorl, but decreasing rapidly and becoming biserial.

Chambers distinct in later parts of test, uniflated, broader than high, the last two being flattened.

Sutures flush to slightly depressed in distal portion. Aperture, interiomarginal slit in re-entrant of final chamber.

Size : Maximum height 800 microns, maximum 500 microns.

Occurrence : AG, AL, BG (Biozones 1-6).

Stratigraphic range : Cenomanian to Campanian, various authors, see below.

Remarks : *Marssonella trochus* (d'Orbigny, 1840); *Marssonella turris* (d'Orbigny, 1840) and *Marssonella oxycona* (Reuss, 1860) are considered synonymous, early authors separating the various forms by the degree of flaring of the test. For full discussion and synonymies see Owen (1970), Hart (1970), Swiecicki (1980), Ball (1985) and Leary (1987).

Recent work by Leary and Hart (pers. comm.) have shown that changes in apical angle may be a function of oxygen content of the sediment, following analysis of specimens across the Cenomanian - Turonian anoxic event.

Family : *Textulariidae* Ehrenberg, 1838

Subfamily : *Textulariinae* Ehrenberg, 1838

Genus : *Textularia* De France in de Blainville, 1824

Type species : *Textularia sagittula* De France in de Blainville, 1824.

Textularia chapmani Lalicker, 1935

(Plate 2, Figure 15)

1935 *Textularia chapmani* Lalicker, p.13,pl.2,figs.8a-c,9.

1975 *Textularia chapmani* Lalicker; Magniez-Jannin, p.54,pl.3,figs 1-9.

1981 *Textularia chapmani* Lalicker; Hart *et al.*, p.178,pl.7.3,fig.1.

Description : Test free, finely agglutinated, small, biserial. Consists of 8-10 uninflated chambers. Test widens rapidly giving a broad distal portion. Sutures slightly depressed. Aperture a low arch at base of final chamber.

Size : Maximum height 500 microns, maximum width 375 microns.

Occurrence : AG (Biozone 3).

Stratigraphic range : Late Albian to Late Cenomanian (Hart *et al.*, 1981).

Suborder : *Spirillinina* Hohenegger and Piller, 1975

Family : *Patellinidae* Rhumbler, 1906

Subfamily : *Patellininae* Rhumbler, 1906

Genus : *Patellina* Williamson, 1858

Type species : *Patellina corrugata* Williamson, 1858

Patellina subcretacea Cushman and Alexander, 1930

(Plate 3, Figure 1)

1930 *Patellina subcretacea* Cushman and Alexander, p.10,pl.3,figs 1a,b.

1949 *Patellina subcretacea* Cushman and Alexander: Loeblich and Tappan,
p.264,pl.51,fig.3.

1970 *Patellina subcretacea* Cushman and Alexander: Hanzlikova, p.89,pl.22,fig.3.

Description : Test free, conical. Ventral side concave, dorsal side very convex. Test consists of an elongate spiral undivided tubular chamber of several coils. Later chambers narrow and elongate. Sutures flush to slightly raised. Wall calcareous, thin, translucent, perforate. Aperture at base of ventral side, low arch.

Size : Maximum diameter 700 microns, maximum height 400 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Albian to Campanian (Hanzlikova, 1970)

Suborder : *Miliolina* Delage and Herouard, 1896

Superfamily : *Miliolacea* Ehrenberg, 1839

Family : *Hanerinidae* Schwager, 1876

Subfamily : *Hauerininae* Schwager, 1876

Genus : *Quinqueloculina* d'Orbigny, 1826

Type species : *Serpula seminulum* Linné, 1758.

Quinqueloculina antiqua (Franke, 1928)

(Plate 3, Figures 2,3)

1891 *Miliolina venusta* Karrer: Chapman, p.9,pl.9,figs 5,6.

1928 *Miliolina (Quinqueloculina) antiqua* Franke, p.126,pl.11,fig.26.

1950 *Quinqueloculina antiqua* (Franke): ten Dam, p.17,pl.1,fig.18.

1972 *Quinqueloculina antiqua* (Franke): Gawor-Biedowa, pp.35-36,pl.3,fig.6a-c.

1977 *Quinqueloculina antiqua* (Franke): Carter and Hart, p.25,pl.1,figs 7,8.

Description : Test free, quinqueloculine, oval to slightly elongate in outline. Transverse section, irregularly triangular, corners rounded. Last chamber distinctly longer than previous and reaching back over lower part of test. Four chambers visible on convex side, three on flattened side.

Aperture terminal, semilunar, with small rectangular tooth formed on inner wall of neck.

Size : Maximum height 320 microns, maximum width 200 microns.

Occurrence : AG (Biozones 1-2).

Stratigraphic range : Late Albian to Turonian (Gawor-Biedowa, 1972); Albian to Cenomanian (Carter and Hart, 1977)

Quinqueloculina moremani Cushman, 1937

(Plate 3, Figure 4)

1937 *Quinqueloculina moremani* Cushman, p.100,pl.15,fig.1.

1970 *Quinqueloculina moremani* Cushman: Eicher and Worstell, p.283,pl.2,fig.7.

Description : Test free, quinqueloculine, rounded, elongate outline. Transverse section irregular, with chambers distinctly angular. Last chamber distinctly larger reaching back under base of test, with very angular margin. Aperture terminal, produced on short neck, no obvious tooth.

Size : Maximum height 420 microns, maximum width 190 microns.

Occurrence : AL, BG (Biozones 4-6).

Stratigraphic range : Cenomanian to Turonian (Eicher and Worstell, 1970)

Remarks : Tooth structures have been recorded in this species. None were noted in this study.

Suborder : *Lagenina* Delage and Herouard, 1896

Superfamily : *Nodosariacea* Ehrenberg, 1838

Family : *Nodosariidae* Ehrenberg, 1838

Subfamily : *Nodosariinae* Ehrenberg, 1838

Genus : *Dentalina* Risso, 1826

Type species : *Nodosaria (Dentalina) cuvieri* d'Orbigny, 1826

Dentalina catenula Reuss, 1860

(Plate 3, Figure 5)

1860 *Dentalina catenula* Reuss, p.185,pl.3,fig.6.

1946 *Dentalina catenula* Reuss: Cushman, pp.67-68,pl.23,figs 27-32.

1970 *Dentalina catenula* Reuss: Hart, p.130,pl.8,fig.11.

Description : Test free, elongate, tapering towards base. Proloculus may have small spine.

Chambers globular increasing gradually in size as added. Sutures distinct, strongly depressed.

Wall smooth, aperture terminal radiate.

Size : Height up to 2.1mm,width up to 500 microns.

Occurrence : AG, AL, BG (Biozones 3, 4, 6).

Stratigraphic range : Middle Albian to Early Cenomanian (Hart, 1970).

Dentalina debilis (Berthelin, 1880)

(Plate 3, Figure 6)

1880 *Marginulina debilis* Berthelin, p.35, pl.3, fig.28.

1940 *Vaginulina debilis* (Berthelin): Tappan, pp.108-109, pl.16, figs 2a,b.

1965 *Dentalina debilis* (Berthelin): Neagu, p.21, pl.5, fig.19.

1982 *Dentalina debilis* (Berthelin): Haig, p.7, pl.2, figs 12-14.

Description : Test free, elongate, arcuate, tapering. Subtriangular in cross section. Chambers inflated, increasing in size as added. Ventral margin indented. Sutures distinct, depressed, at an angle to the axis of the test. Wall smooth. Aperture radiate, produced at dorsal angle.

Size : Maximum length 1.5 mm, maximum width 100 microns.

Occurrence : AG (Biozones 1, 3).

Stratigraphic range : Albian to Cenomanian (Haig, 1982)

Dentalina intermedia Reuss, 1860

(Plate 3, Figure 7)

1860 *Dentalina intermedia* Reuss, p.186, pl.2, fig.8.

1967 *Dentalina intermedia* Reuss: Fuchs, p.287, pl.7, fig.3.

Description : Test free, elongate, arcuate. Consists of up to 8 chambers, which gradually increase in size as added. Ventral margin only slightly indented. Base may be apiculate. Chambers higher than broad. Sutures distinct, depressed, curved. Aperture radiate, produced at dorsal angle.

Size : Maximum length 1.6 mm, maximum width 120 microns.

Occurrence : AG, AL, BG (Biozones 1, 4, 6).

Stratigraphic range : Albian (Price, 1975; Fuchs, 1967). It would appear that this form ranges well into the Santonian, as it is recorded from the Arnager Limestone and Bavnodde Greensand.

Dentalina megapolitana Reuss, 1855

(Plate 3, Figure 8)

1855 *Dentalina megapolitana* Reuss, p.267,pl.8,fig.10.

1978 *Dentalina megapolitana* Reuss: Bailey, pp.94-95,pl.3,fig.3

Description : Test free, large, tapering at both ends. Test ovate to elliptical in cross section, consisting of up to 9 uninflated, barrel shaped chambers. Sutures usually horizontal, flush to depressed. Wall calcareous, smooth, thick. Aperture, terminal, radiate, produced.

Size : Length 2.2 mm, maximum width 400 microns.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Turonian (Reuss, 1855), Coniacian-Santonian (Bailey, 1978)

Dentalina sp. A

(Plate 3, Figure 9)

Description : Test free, consisting of 3-4 chambers, gradually increasing in size, last chamber may be considerably larger than previous and distinctly globular. Base apiculate. Sutures distinct,

depressed, oblique to axis of test. Aperture radiate produced on neck which is oblique to axis of test.

Size : Maximum height 300 microns, maximum width 110 microns

Occurrence : BG (Biozone 5).

Remarks: The large globular last chamber is very distinctive.

Genus : *Nodosaria* Lamarck, 1812.

Type species : *Nautilus radicola* Linne, 1758

Nodosaria aspera Reuss, 1845

(Plate 3, Figure 10)

1846 *Nodosaria (Nodosaria) aspera* Reuss, p.26,pl.13,figs 14,15.

1928 *Nodosaria aspera* Reuss: Franke, p.50,pl.4,fig.14.

1978 *Nodosaria aspera* Reuss: Bailey, p,86,pl.2,fig.8.

Description : Test free, uniserial, consisting of 3 to 5 subglobular chambers, which increase gradually in size as added, circular in cross section. Sutures depressed, straight. Chambers distinctly spinose. Aperture terminal, produced on slender neck.

Size : Height 600 microns, width 370 microns.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Turonian (Reuss, 1846), Santonian (Bailey, 1978)

Nodosaria obscura Reuss, 1845

(Plate 3, Figure 11)

1845 *Nodosaria obscura* Reuss, p.26,pl.13,figs 7-9.

1967 *Nodosaria obscura* Reuss: Fuchs, p.280,pl.6,fig.2.

1975 *Nodosaria obscura* Reuss: Magniez-Jannin, pp.192-194,pl.12,figs 22-34,text
fig.105.

Description : Test free, rectilinear, consisting of up to 5 globular chambers which increase in size to the centre of the test when they gradually reduce in size. Sutures straight, depressed, perpendicular to axis of test. Surface ornamented by 6 raised, thin costae which run the length of the test and are not interrupted at the sutures.

Size : Maximum length 600 microns, maximum width 180 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Albian (Magniez-Jannin, 1975, Fuchs, 1967,). Cenomanian (Magniez-Jannin, 1975), Turonian (Reuss, 1845).

Nodosaria orthopleura Reuss, 1863

(Plate 3, Figure 13)

1863 *Nodosaria orthopleura* Reuss, p.89,pl.12,fig.5.

1893 *Nodosaria orthopleura* Reuss: Chapman, p.595,pl.9,figs 22, 23.

1982 *Nodosaria orthopleura* Reuss: Haig, p.14,pl.2,figs 33-35.

Description : Test free, long and slender, gradually tapering towards base. Initial part pointed or apiculate. Chambers slightly inflated, twice as long as broad, sutures depressed, straight. Surface ornamented by 4 to 6 ribs, which are straight, running the length of the test and are slightly constricted at the sutures. Aperture terminal, radiate, produced at end of short neck.

Size : Maximum length upto 2.5 mm, maximum width 400 microns.

Occurrence : AG, AL, BG (Biozones 1, 3, 5, 6).

Stratigraphic range : Albian (Reuss, 1863). Albian to Early Cenomanian (Haig, 1982); Middle Albian to Late Cenomanian (Hart, 1970). Records in the Bavnodde Greensand suggest that this species ranges into the Santonian.

Nodosaria paupercula Reuss, 1845

(Plate 3, Figure 12)

1845 *Nodosaria (Nodosaria) paupercula* Reuss, p.26,pl.12,fig.12.

1925 *Nodosaria paupercula* Reuss: Franke, p.42,pl.3,fig.38.

1967 *Nodosaria paupercula* Reuss: Fuchs, p.281,pl.6,fig.1.

Description : Test free, rectilinear, consisting of 6-7 chambers gradually increasing in size as added, giving a distinctive tapered appearance to the test. Sutures distinct, depressed, perpendicular to the axis of the test. Surface ornamented by up to 10 distinct ribs which run the length of the test, these are uninterrupted at the sutures. Aperture, terminal, radiate.

Size : Height 540 microns, width 120 microns.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Previously recorded from the Albian (Fuchs, 1967). Turonian (Reuss, 1846). The presence of this form in the Bavnodde Greensand, indicates that it probably ranges into the Santonian.

Nodosaria sceptrum Reuss, 1863

(Plate 4, Figure 1)

1863 *Nodosaria (Nodosaria) sceptrum* Reuss, p.37,pl.2,figs 3a,b.

1893 *Nodosaria sceptrum* Reuss: Chapman, p.592,pl.9,fig.9.

1970 *Nodosaria sceptrum* Reuss: Hart, pp.125-126,pl.7,fig.15.

1975 *Nodosaria sceptrum* Reuss: Magniez-Jannin, p.197,pl.12,figs 43a,b.

1982 *Nodosaria sceptrum* Reuss: Haig,pp.14-15,pl.2,figs 29-32.

Description : Test free, narrow, elongate, flaring upwards from an apiculate base. Chambers higher than broad increasing gradually in size as added. Last chamber is distinctly larger than previous chambers. Sutures depressed to flush. Surface ornamented by thin costae, which run the length of the test and are interrupted at the sutures. Aperture terminal, radiate, at end of long neck.

Size : Maximum length 600 microns, maximum width 180 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Albian (Reuss, 1863). Middle Albian to Early Turonian (Hart, 1970)

Nodosaria sp. A

(Plate 4, Figure 2)

Description : Test free, small, consisting of two globular chambers. Suture distinct, depressed, straight. Aperture, terminal, radiate, produced on short neck.

Size : Maximum length 350 microns, maximum width 150 microns.

Occurrence : AG, BG (Biozones 1, 6).

Remarks: The small, two chambered test is distinctive.

Nodosaria sp. B

(Plate 4, Figure 3)

Description : Test free, elongate, consisting of two chambers. Proloculus is slightly elongate, with apiculate base, being slightly higher than broad. Final chamber is more globular. Aperture is terminal, radiate, formed on short neck. Sutures depressed.

Size : Maximum height 600 microns, maximum width 200 microns.

Occurrence : AG (Biozones 1, 3).

Nodosaria(?) sp. C

(Plate 4, Figure 4)

Description : Test free, initially slender, becoming more globose. Proloculus and initial chambers are difficult to see, appearing to gradually increase in size slightly as added. Final chamber is distinctly larger and globose. Sutures appear horizontal and depressed. Thin striations run from the base of the test to the base of the final chamber, obscuring early chambers. Aperture, terminal, radiate.

Size : Maximum height 700 microns, maximum width 300 microns.

Occurrence : AL (Biozone 4).

Remarks: The aperture usually appears centrally on the last chamber, though in some specimens it appears to be more produced at an angle. If so it might be better placed in *Marginulina*.

Nodosaria sp. D

(Plate 4, Figure 5)

Description : Test free, bullet shaped. Chamber number impossible to determine. Surface covered by approximately eighteen raised costae, which do not always run the full length of the test, some bifurcate and die out. Aperture terminal, radiate, produced on convex end of test.

Base of test is slightly flattened.

Size : Maximum height 700 microns, maximum width 210 microns

Occurrence : AL (Biozone 4).

Remarks: The specimens recovered may represent single chambers of a larger individual. The thin dense, bifurcating costae are very distinctive.

Nodosaria (?)sp. E

(Plate 4, Figure 6)

Description : Test free, large, only broken individuals recovered. Chambers squared, broad as high. Sutures depressed straight, perpendicular to axis of test. Surface ornamented by many straight thin costae. Aperture not seen.

Size : Chamber width 400 microns.

Occurrence : AG, AL, BG (Biozones 3, 5, 6).

Remarks : This form is tentatively placed in *Nodosaria*, though since the aperture is not seen this cannot be verified.

Genus : *Pseudonodosaria* Boomgaard, 1949

Type species : *Glandulina discreta* Reuss, 1850.

Pseudonodosaria sp. A

(Plate 4, Figure 7)

Description : Test free, uniserial, elongate. Base slightly apiculate, followed by very elongate second chamber, which is slightly inflated. Final chamber distinct, as broad as high. Suture distinct, depressed, horizontal, straight. Aperture radiate, formed on end of cone extending from final chamber.

Size : Maximum height 650 microns, maximum width 180 microns.

Occurrence : AG (Biozone 1).

Subfamily : *Lingulininae* Loeblich and Tappan, 1961

Genus : *Lingulina* d'Orbigny, 1826.

Type species : *Lingulina carinata* d'Orbigny, 1826

Lingulina furcillata Berthelin, 1880

(Plate 4, Figure 8)

1880 *Lingulina furcillata* Berthelin, p.65,pl.4(27),figs 6a-c.

1940 *Lingulina furcillata* Berthelin: Tappan, p.106,pl.16,figs 18a-c.

Description : Test free, elongate to squat, uniserial, compressed. Chambers arched centrally, gently inflated. Sides nearly parallel. Sutures distinct, depressed, arched. Wall calcareous, smooth. Aperture an elongate slit at top of final chamber.

Size : Maximum length 300 microns, maximum width 150 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Late Albian (Tappan, 1940). Records from the Amager Greensand indicate that this species clearly ranges into the Cenomanian.

Lingulina (?)sp. A

(Plate 4, Figure 9)

Description : Test free, highly compressed. Broken specimen only, consists of broad, flat chambers with slightly raised sutures arched towards centre of test. Aperture not seen.

Size : Maximum width 300 microns, estimated length 1.5mm

Occurrence : AL (Biozone 4).

Remarks : the compressed nature of the test suggests that this form is a *Lingulina*. Though since the aperture was not observed this is equivocal.

Subfamily : *Froniculariinae* Reuss, 1860

Genus : *Fronicularia* De France in d'Orbigny, 1826.

Type species : *Renulina complanata* De France, 1826

Fronicularia archiaciana d'Orbigny, 1840.

(Plate 4, Figure 10)

1840 *Fronicularia archiaciana* d'Orbigny, p.20, pl.1, figs 34-36.

1946 *Fronicularia archiaciana* d'Orbigny: Cushman, p.91, pl.37, figs 8-20.

Description : Test free, elongate, compressed, gently tapering. Sides flattened, periphery truncate. Chambers uninflated, very gradually increasing in size as added. Sutures distinct, raised, limbate. Wall smooth. Proloculus often has 3-4 raised ribs on its surface. Aperture terminal, radiate.

Size : Maximum height 620 microns, maximum width 220 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Campanian (d'Orbigny, 1840), Late Cretaceous (Cushman, 1946)

Fronicularia cf. striatula Reuss, 1845

(Plate 4, Figure 11)

1844 *Fronicularia striatula* Reuss, p.212.

1946 *Frondicularia striatula* Reuss: Cushman, p.90,pl.37,figs 3,4.

1970 *Frondicularia striatula* Reuss: Hanzlikova, p.66,pl.15,fig.8.

Description : Test free, elongate, compressed, consisting of up to 5 uninflated chambers, which increase gradually in size as added. Greatest width is made by the last formed chamber. Sutures distinct, thickened and limbate. Base may be apiculate. Wall ornamented by a few thickened vertical ribs which are not continuous over test.

Size : Height 1.2 mm, width 220 microns maximum.

Occurrence : BG (Biozone 6).

Stratigraphic range : Recorded from the Turonian to Campanian (Cushman, 1946; Hanzlikova, 1970)

Remarks : Specimens recovered differ slightly from the forms illustrated by Cushman (1946) and Hanzlikova (1970) in that they lack ribs on all chambers.

Frondicularia watersi Cushman, 1936

(Plate 4, Figure 12)

1936 *Frondicularia watersi* Cushman, p.14,pl.3,figs 14,15.

1946 *Frondicularia watersi* Cushman: Cushman,p.91,pl.37,figs 6,7.

Description : Test free, lanceolate, compressed, flattened. Base of test curved with basal spine. Chambers narrow, elongate, increasing regularly in size as added. Sutures slightly raised. Wall smooth, aperture radiate, at end of short neck.

Size : Maximum height 920 microns, maximum width 300 microns.

Occurrence : AG (Biozone 3).

Stratigraphic range : Late Cretaceous (Cushman, 1946)

Fronicularia sp. A

(Plate 5, Figure 1)

Description : Test free, lanceolate, sides flattened. Chambers increase gradually in size as added.

Sutures distinct, raised, arched towards the centre of the test. Chambers ornamented by thin ribs over each individual chamber, parallel to axis of test. Aperture terminal, central, radiate.

Size : Maximum length 3 mm, maximum width 1 mm.

Occurrence : AG, AL (Biozones 2-4).

Fronicularia sp. B

(Plate 5, Figure 2)

Description : Test free, diamond shaped. Consists of globular proloculus, followed by two chevron shaped chambers. Sides flattened. Proloculus is ornamented by two distinct vertical ribs.

Sutures raised. Aperture terminal, radiate, on short neck.

Size : Maximum height 620 microns, maximum width 300 microns.

Occurrence : AG, AL, BG (Biozones 1-6).

Fronicularia sp. C

(Plate 5, Figure 3)

Description : Test free, palmate, flattened, chambers low and broad, last chamber reaching back to level of proloculus. Test is probably arrow shaped, but poor preservation prevents confirmation of this. Proloculus is striate and globular. Sutures raised slightly and thickened.

Size : Height estimated at 2 mm, maximum width 1.5 mm

Occurrence : BG (Biozone 5).

Genus : *Tristix* Macfadyen 1941

Type species : *Rhabdogonium liasinum* Berthelin, 1879

Tristix insigne (Reuss, 1862)

(Plate 5, Figure 4)

1862 *Rhabdogonium insigne* Reuss, p.56,pl.5,fig.2a,b.

1970 *Tristix insigne* (Reuss): Hart, p.168,pl.14,fig.13.

Description : Test free, uniserial, triangular in section. Base slightly pointed and gradually flaring as later chambers are added. Sutures distinct, depressed. Chambers gently inflated. Surface smooth. Aperture terminal, rounded, slightly produced.

Size : Maximum height 310 microns, maximum width 200 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Middle Albian to Late Cenomanian (Hart, 1970)

Tristix sp. A

(Plate 5, Figure 5)

Description : Test free, uniserial, triangular in cross section. Triangular in outline, with distinctly rounded margins. Sutures thickened and raised. Chambers broad and uninflated. Base rounded with test flaring rapidly. Aperture terminal, rounded.

Size : Maximum height 400 microns, maximum width 400 microns.

Occurrence : AG (Biozones 1, 2).

Family : *Vaginulinidae* Reuss, 1860

Subfamily : *Lenticulininae* Chapman, Parr and Collins, 1934

Genus : *Lenticulina* Lamarck, 1804

Type species : *Lenticulites rotulata* Lamarck, 1804

Lenticulina gaultina (Berthelin, 1880)

(Plate 5, Figure 6)

1880 *Cristellaria gaultina* Berthelin, p.49,pl.3,figs 15-19.

1940 *Lenticulina gaultina* (Berthelin): Tappan, p.101,pl.15,figs 11a,b.

1967 *Lenticulina (Lenticulina) gaultina* (Berthelin): Fuchs, pp.293-294,pl.11,figs 4a,b.

1970 *Lenticulina gaultina* form *gaultina* (Berthelin): Hart, pp.138-139,pl.10,figs. 1-2.

Description : Test free, lenticular, involute, thinly keeled, biumbonate. Peripheral outline evenly rounded. 10 to 13 chambers in final whorl, uninflated. Sutures flush, straight to slightly oblique.

Aperture radiate at peripheral angle.

Size : Maximum diameter 800 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Middle and Late Albian (Hart, 1970). Records from the Arnager Greensand indicate that this species ranges into the Cenomanian

Lenticulina lepida (Reuss, 1846)

(Plate 5, Figure 7)

1846 *Robulus lepida* Reuss, p.109,pl.24,fig.46.

1970 *Lenticulina lepida* (Reuss): Hart, p.140,pl.10,fig.7.

Description : Test free, lenticular, biumbonate. Ventral margin rounded, dorsal margin distinctly straight. Up to ?14 chambers in the final whorl, gradually increasing in size as added. Sutures flush, initially, becoming slightly depressed. Aperture radiate at peripheral angle.

Size : Maximum diameter 700 microns.

Occurrence : AG (Biozone 3).

Stratigraphic range : Middle Albian to Early Cenomanian (Hart, 1970). Turonian (Reuss, 1846).

Lenticulina rotulata (Lamarck, 1804)

(Plate 5, Figure 8)

1804 *Lenticulites rotulata* Lamarck, p.185.

1941 *Lenticulina rotulata* (Lamarck): Marie, pp.104-105,pl.10,figs 111-112.

1970 *Lenticulina gaultina* form *rotulata* (Berthelin): Hart, pp.139-140,pl.10,fig.4.

Description : Test free, lenticular, involute, biumbonate. Peripheral outline rounded. Up to 12 chambers in final whorl, uninflated, gradually increasing in size as added. Sutures flush initially, later becoming raised. Aperture radiate at peripheral angle.

Size : Maximum diameter 1.1 mm

Occurrence : AG, AL, BG (Biozones 1-6).

Stratigraphic range : Early Cenomanian to Early Turonian (Hart, 1970); Coniacian-Santonian, Bailey, (1978).

Lenticulina sp. A

(Plate 5, Figure 9)

Description : Test free, lenticular, biumbonate, very large. Peripheral outline curved. Thinly keeled. Final whorl with up to 18 chambers gradually increasing in size as added and becoming distinctly uncoiled. Sutures flush to slightly raised, curved. Aperture radiate at peripheral angle.

Size : Maximum length 3 mm

Occurrence : AG (Biozones 1, 2).

Remarks: This may well be an uncoiled variant of *Lenticulina rotulata*.

Genus : *Saracenaria* De France in de Blainville, 1824.

Type species : *Saracenaria italica* De France, 1824.

Saracenaria bononiensis (Berthelin, 1880)

(Plate 5, Figure 10)

1880 *Cristellaria bononiensis* Berthelin, p.55,pl.3,figs 23a-c.

1940 *Saracenaria bononiensis* (Berthelin): Tappan, pp.105-106,pl.16,figs 16a,b.

1982 *Saracenaria bononiensis* (Berthelin): Haig, pp.22-23,pl.4,figs 17-20

Description : Test free, initially tightly coiled, becoming rectilinear. Chambers increasing gradually in size as added. Chambers broader than high. Triangular in cross section. Wall smooth, except for carinate rib which runs along the dorsal margin. Aperture terminal, radiate, at peripheral angle.

Size : Maximum height 1 mm, maximum width 300 microns.

Occurrence : AG (Biozone 3).

Stratigraphic range : Late Albian (Haig, 1982). Middle Albian to Late Cenomanian (Hart, 1970).

Saracenaria planiuscula (Reuss, 1863)

(Plate 5, Figure 11)

1863 *Cristellaria* (*Cristellaria*) *planiuscula* Reuss, p.71,pl.7,figs.15a,b.

1951 *Lenticulina* (*Astacouls*) *planiuscula* (Reuss): Noth, p.44,pl.3,fig.6.

1982 *Saracenaria planiuscula* (Reuss): Haig, pp.24-25,pl.4,figs.21-23.

Description : Test free, consists of initial coil of 2-3 chambers, later becoming rectilinear.

Chambers are wider than high, gradually increasing in size as added. Sutures straight, depressed.

Aperture terminal, radiate, at peripheral angle.

Size : Maximum height 800 microns, maximum width 300 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Albian (Reuss, 1863, Haig, 1982).

Saracenaria triangularis (d'Orbigny, 1840)

(Plate 5, Figure 12)

1840 *Cristellaria triangularis* d'Orbigny, p.27,pl.2, figs 21-22.

1946 *Saracenaria triangularis* (d'Orbigny): Cushman, p.58,pl.28,figs 1-3.

1967 *Lenticulina* (*Saracenaria*) *triangularis* (d'Orbigny): Fuchs, p.302,pl.12,fig.3.

1970 *Saracenaria triangularis* (d'Orbigny): Hanzlikova, p.72,pl.16,fig.10.

Description : Test free, early portion completely coiled, later chambers uncoiling. Test triangular in section. Face of final chamber directed back towards initial coil. Sutures flush, curved, wall smooth. Dorsal margin keeled. Aperture terminal, radiate at peripheral angle.

Size : Maximum height 400 microns, maximum width 380 microns.

Occurrence : AG, AL, BG (Biozones 1-6).

Stratigraphic range : Albian (Fuchs, 1967). Turonian to Campanian (Hanzlikova, 1970)

Subfamily : *Palmulinae* Saidara, 1981

Genus : *Neoflabellina* Bartenstein, 1948

Type species : *Flabellina rugosa* d'Orbigny, 1840.

Neoflabellina baudouiniana (d'Orbigny, 1840)

(Plate 5, Figure 13)

1840 *Flabellina baudouiniana* d'Orbigny, p.24,pl.2,figs 8-11.

1954 *Neoflabellina baudouiniana* (d'Orbigny): Pozaryska, pp.262-263,text fig. 10.

1985 *Neoflabellina baudouiniana* (d'Orbigny): Ball, pp.115-116,pl.5,fig.1.

Description : Test free, compressed, palmate, initially planispiral, later becoming uncoiled.

Chambers curved initially becoming much broader than high. Sutures raised and thickened.

Aperture terminal, produced at end of short neck.

Size : Height 500 microns, maximum width 400 microns.

Occurrence : BG (Biozone 6).

Stratigraphic range : Recorded from the Turonian (Owen, 1970), Early Santonian (Bailey, 1978;

Ball 1985) and Campanian (d'Orbigny, 1840; Ball, 1985).

Neoflabellina deltoidea (Wedekind, 1940)

(Plate 5, Figure 14)

1940 *Flabellina deltoidea* Wedekind, pp.186,190,194,figs 3,4,6.

1956 *Neoflabellina deltoidea* (Wedekind): Hiltermann and Koch, p.37, fig.4,nos.1-6,pl1,2,fig.2.

1985 *Neoflabellina deltoidea* (Wedekind): Ball, pp.117-118,pl.5,fig.2.

Description : Test free, palmate, compressed, rhomboid in outline, sides flat and parallel. Consists of weak planispiral coil which is completely enclosed by later chambers. Chambers subtriangular, becoming broader in later part. Sutures distinct, raised into ridges. Aperture terminal at end of short neck.

Size : Height 1.1 mm, width 800 microns.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Recorded from the mid-Campanian (Ball, 1985), Santonian (Bailey, 1978).

Comments: *Neoflabellina deltoidea* appears to differ from *Neoflabellina suturalis suturalis* (Cushman, 1935) in being less palmate, though it should be noted that the two species are considered synonymous by Koch (1977).

Neoflabellina praerugosa Hiltermann, 1952

(Plate 5, Figure 15)

1952 *Neoflabellina praerugosa* Hiltermann, p.53,fig.3,nos.12,13.

1985 *Neoflabellina praerugosa* Hiltermann: Ball, pp.118-119,pl.5,fig.3.

Description : Test free, palmate, compressed. Consists of initial weakly developed planispiral coil, later becoming uncoiled. Chambers triangular, becoming broader. Sides flat, parallel. Sutures raised into thickened ridges and separated in the centre by remnant apertural neck. Aperture terminal, radiate.

Size : Height 600 microns, maximum width 400 microns.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Coniacian to Santonian (Bailey, 1978).

Neoflabellina suturalis suturalis (Cushman, 1935)

(Plate 5, Figure 16)

1935 *Flabellina suturalis* Cushman, pp.86-87,pl.13,figs 9-18.

1969 *Neoflabellina suturalis* (Cushman): Ohmert, p.12,pl.17,18,20,figs 22,25,35-37,51,56,57,75,76,80,82,83,90,91,93-95.

1977 *Neoflabellina suturalis suturalis* (Cushman): Koch, p.43,pl.16,fig.9.

Description : Test free, palmate, somewhat rhomboid, compressed. Early coil is followed by uncoiled chevron shaped chambers. Width of chambers gradually increases in size as added. Sutures distinct, high. Wall smooth, polished, aperture radiate, terminal often with slight neck.

Size : Height 1.6 mm, width 1.2 mm.

Occurrence : Recorded from the basal Bavnodde Greensand (Solakius and Larsson, 1985). BG (Biozone 6).

Stratigraphic range : Santonian to Early Campanian (Koch, 1977)

Genus : *Palmula* Lea, 1833.

Type species : *Palmula sagittaria* Lea, 1833

Palmula cordata (Reuss,1844)

(Plate 6, Figure 1)

1844 *Flabellina cordata* Reuss, p.213.

1970 *Palmula cordata* (Reuss): Hart, p.147,pl.11,fig.8.

Description : Test free, large, flattened, palmate. Indistinct early coil, followed by uncoiled and rectilinear portion, which consists of up to 9 broad, arched, equitant chambers. Final chamber reaches back over half length of test. Surface smooth. Aperture terminal, radiate.

Size : Maximum height 3.16 mm, maximum width 2.6 mm

Occurrence : AG,AL,BG (Biozones 1, 2, 3, 6).

Stratigraphic range : Late Albian to Late Cenomanian (Hart, 1970). Records from the Arnager Limestone and Bavnodde Greensand indicate that this species ranges into the Santonian.

Palmula pilulata Cushman, 1938

(Plate 6, Figure2)

1938 *Palmula pilulata* Cushman, p.37,pl.6,fig.2.

1946 *Palmula pilulata* Cushman: Cushman, pp.84-85,pl.32,figs 18-21.

Description : Test free, flattened, palmate. Early portion coiled, increasing gradually in size, later becoming uncoiled and unevenly rectilinear. Final chamber is distinctly longer than previous ones, reaching back towards initial coil. Sutures flush to slightly raised. Wall smooth. Aperture terminal, radiate, slightly produced.

Size : Maximum height 1.1 mm, maximum width 1 mm

Occurrence : AG (Biozone 1).

Stratigraphic range : Late Cretaceous (Cushman, 1946)

Subfamily : *Marginulininae* Wedekind, 1937

Genus : *Marginulina* d'Orbigny, 1826

Type species : *Marginulina raphanus* d'Orbigny, 1826

Marginulina inaequalis Reuss, 1860

(Text Figure 3.1)

1860 *Marginulina inaequalis* Reuss, p.207,pl.7,fig.3.

1982 *Marginulina inaequalis* Reuss, Haig, pp.25-26,pl.5, figs 4-6.

Description : Test free, elongate, early portion slightly enrolled. Consists of up to 8 gently inflated chambers. Dorsal outline lobulate. Sutures straight, oblique, depressed. Wall smooth. Aperture radiate at peripheral angle.

Size : Maximum length 1.2 mm, maximum width 420 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Aptian to Albian (Haig, 1982). The presence of this species in the Arnager Greensand clearly indicate that it ranges into the Cenomanian.

Text Figure 3.1 *Marginulina inaequalis* Reuss, 1860



Marginulina jonesi (Reuss, 1862)

(Plate 6, Figure 3)

1862 *Cristellaria* (*Marginulina*) *jonesi* Reuss, p.61,pl.5,fig.19.

1899 *Marginulina jonesi* (Reuss): Egger, p.100,pl.10,fig.11.

1970 *Marginulina jonesi* (Reuss): Hart, pp.143-144,pl.10,figs 13-14.

1972 *Marginulina jonesi* (Reuss): Gawor-Biedowa, p.39, pl.3, fig.8.

1987 *Marginulinopsis acuticostata* Reuss: Leary, p.83,pl.18,figs 6-8.

Description : Test free, initially partially enrolled, becoming rectilinear. Consists of 5-6 gently inflated chambers which are broader than high. Sutures distinct, straight and depressed. Test ornamented by up to 10 distinct ribs which run the length of the test and are uninterrupted at the sutures.

Size : Maximum length 800 microns, maximum width 300 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Middle Albian to Late Cenomanian (Hart, 1970).

Marginulina sp. A

(Plate 6, Figure 4)

Description : Test free, early portion very slightly enrolled, becoming rectilinear. Consists of up to 5 globular chambers which gradually increase in size as added. Sutures distinct, depressed, slightly oblique. Surface ornamented by 9-10 thick costae which run the length of the test and are uninterrupted at the sutures. Aperture radiate at dorsal angle.

Size : Maximum length 790 microns, maximum width 200 microns.

Occurrence : BG (Biozone 6).

Marginulina sp. B

(Plate 6, Figure 5)

Description : Test free, elongate, slightly arcuate. Globular proloculus only distinct chamber. Second? chamber is elongate. Margins flattened and thickened. Test tapers gently towards aperture. Aperture radiate at dorsal angle.

Size : Maximum length 220 microns, maximum width 100 microns.

Occurrence : AL, BG (Biozones 4-6).

Genus : *Vaginulinopsis* Silvestri, 1904

Type species : *Vaginulina soluta* Silvestri var. *carinata* Silvestri, 1898

Vaginulinopsis scalariformis Porthault, 1970

(Plate 6, Figure 6)

1970 *Vaginulinopsis scalariformis* Porthault in Donze *et al.*, pp.51-52,pl.8,fig1,2,text
fig.3a,b.

1985 *Vaginulinopsis scalariformis* Porthault: Ball, pp.124-125,pl.5,fig.6.

1985 *Vaginulinopsis scalariformis* Porthault: Solakius and Larsson, p.40,pl.3,fig.5.

Description : Test free, large, compressed, ovate to elliptical in cross section. Initial coil is followed by uniserial part. Chambers are distinct, low, of greater width than height. Sutures distinct, subhorizontal. Test surface marked by distinctive thickened transverse septal ridges. Aperture terminal radiate, at peripheral angle of final chamber.

Size : Height 2.1 mm, width 500 microns.

Occurrence : BG (Biozone 5).

Stratigraphic range : Recorded from the Senonian of France (Porthault, 1970; Robaszynski, 1980), SE England (Bailey, 1978; Hart *et al.*, 1989), and from the southern North Sea basin (Ball, 1984; 1985). Recorded from the basal Bavnodde Greensand (Solakius and Larsson, 1985)

Remarks : Two forms are recognisable in the Bavnodde Greensand, *V. scalariformis sensu stricto*, which has diagnostic thickened transverse septal ridges and *V. scalariformis sensu lato*. This form differs in having distinctive thickened transverse septal ridges which are only slightly elevated from the test surface, in contrast to the *sensu stricto* form which has a distinctly indented

profile in lateral view. Only the *sensu lato* form is illustrated as the single specimen referable to *sensu stricto*, was fragmentary. The *sensu stricto* form is well illustrated by Solakius and Larsson (1985).

Subfamily : *Vaginulininae* Reuss, 1860

Genus : *Citharina* d'Orbigny in de la Sagra, 1839

Type species : *Vaginulina (Citharina) strigillata* Reuss, 1846.

Citharina arambourgi Marie, 1938

(Plate 6, Figure 7)

1938 *Citharina arambourgi* Marie, pp.98-99,pl.8,figs 12-13.

1970 *Citharina arambourgi* Marie: Hart, p.127,pl.8,fig.1.

Description : Test free, flattened, subtriangular in outline. Globular proloculus is followed by up to 8 uninflated chambers. Surface is ornamented by numerous costae which run vertically the length of the test. Inner margin indented at base, becoming gently curved. Outer margin straight to slightly convex. Aperture terminal radiate.

Size : Maximum length 2.5 mm, maximum width 600 microns

Occurrence : AG (Biozone 1).

Stratigraphic range : Cenomanian (Hart, 1970)

Citharina sp. A

(Plate 6, Figure 8)

Description : Test free, flattened, subtriangular in outline, consisting of 8-10 chambers, extending nearly to base at inner margin. Wall striate, sutures distinct, depressed, aperture radiate produced at outer margin.

Size : Height 800 microns, width 180 microns.

Occurrence : BG (Biozone 5).

Remarks: The subtriangular test shape separates this form from *C. arambourgi*.

Genus : *Citharinella* Marie, 1938

Type species : *Flabellina karrei* Berthelin, 1880

Citharinella chapmani (Marie, 1938)

(Plate 6, Figure 9)

1894 *Frondicularia strigillata* Chapman (not Reuss), p.157,pl.3,figs 13-14.

1938 *Citharinella chapmani* Marie, p.100,pl.7,figs 5-6.

1965 *Citharinella chapmani* Marie: Neagu, p.25,pl.6,fig.17.

1970 *Citharinella chapmani* Marie: Hart, p.127,pl.8,fig.2.

Description : Test free, large, flattened, lanceolate. Initial uniserial part rapidly passes into low, broad, chevron shaped chambers. Sutures thickened and raised, distinct. Surface ornamented by numerous short vertical ribs. Test broad, arrowhead shaped. Aperture terminal radiate, produced on short neck.

Size : Maximum length 2.2 mm, maximum width 1.1 mm.

Occurrence : AG (Biozone 1).

Stratigraphic range : Middle Albian to Early Turonian (Hart, 1970)

Citharinella laffitei Marie, 1938

(Plate 6, Figure 10)

1938 *Citharinella laffitei* Marie, p.101,pl.8,fig.3.

1981 *Citharinella laffitei* Marie: Hart *et al.*, 1981, p.186,pl.7.7,fig.1.

Description : Test free, large, lanceolate. Early uniserial part indistinct, chambers rapidly becoming chevron shaped, and symmetrical. 10-12 chambers, last chamber extends almost half way back down test. Chambers ornamented by numerous short narrow ribs, which are interrupted at sutures. Aperture terminal, radiate.

Size : Maximum length 2.1 mm, maximum width 850 microns.

Occurrence : AG (Biozones 2, 3).

Stratigraphic : Late Albian (Hart *et al.*, 1981). The record of this species in the Arnager Greensand indicates that it ranges into the Cenomanian.

Genus : *Planularia* De France *in* De Blainville, 1826

Type species : *Peneroplis auris* De France *in* De Blainville, 1826.

Planularia cenomana (Schacko, 1897)

(Plate 6, Figure 11)

1897 *Cristellaria cenomana* Schacko, p.162.

1928 *Planularia cenomana* (Schacko): Franke, p.105,pl.18,figs 14a,b,15a,b.

1972 *Planularia cenomana* (Schacko): Gawor-Biedowa, p.41,pl.4,fig.1.

Description : Test free, elongate, arcuate, compressed. Initial part tightly coiled and possessing a small boss. Later chambers broad, elongate, gradually increasing in size as added. Sutures flush to slightly raised. Aperture terminal, radiate at dorsal angle.

Size : Maximum height 610 microns, maximum width 400 microns.

Occurrence : AG (Biozones 1, 2).

Stratigraphic range : Albian to Early Turonian (Gawor-Biedowa, 1972)

Planularia liebusi Brotzen, 1936.

(Plate 6, Figure 12)

1936 *Planularia liebusi* Brotzen, pp.60-61,pl.4,figs 5a,b,6a,b,text fig. 18.

1970 *Planularia liebusi* Brotzen: Hanzlikova, p.71,pl.16,figs 8,9.

1978 *Planularia liebusi* Brotzen: Bailey, pp.117-118,pl.5,fig.1.

Description : Test free, compressed, margins truncated. Chambers flat, compressed oblique, limbate, later becoming arc like. Wall smooth. No obvious ornament. Sutures raised. Aperture terminal radiate.

Size : Maximum height 300 microns, maximum width 180 microns.

Occurrence : AG, AL, BG (Biozones 2, 3, 5).

Stratigraphic range : Recorded from the Cenomanian to Santonian of Poland (Hanzlikova, 1970), from the Coniacian-Santonian of southern England (Bailey, 1978).

Genus : *Vaginulina* d'Orbigny, 1826

Type species : *Nautilus legumen* Linne, 1758.

Vaginulina recta Reuss, 1863

(Plate 7, Figure 1)

1863 *Vaginulina recta* Reuss, p.48,pl.3,figs 14-15.

1972 *Vaginulina recta* Reuss, Gawor-Biedowa, pp.49-50,pl.4,fig.11.

Description : Test free, elongate, compressed, sides nearly parallel. Periphery slightly concave. Chambers increase very gradually in size as added. Chambers twice as broad as high. Sutures flush to slightly raised. Test smooth. Aperture, radiate, produced at dorsal angle.

Size : Maximum height 1 mm, maximum width 210 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Valanginian to Cenomanian (Gawor-Biedowa, 1972)

Vaginulina sp. A

(Plate 7, Figure 2)

Description : Test free, small, oval, compressed, consisting of two chambers. Proloculus globular, slightly inflated, second chamber large, slightly arched. Suture flush, indistinct. Periphery distinctly flattened. Aperture terminal, radiate.

Size : Maximum height 400 microns, maximum width 240 microns.

Occurrence : AG (Biozone 2).

Remarks: The oval outline of the test is distinctive.

Family : *Lagenidae* Reuss, 1862

Genus : *Lagena* Walker and Jacob in Kanmacher, 1798.

Type species : *Serpula (Lagena) sulcata* Walker and Jacob, 1798.

Lagena apiculata (Reuss, 1850)

(Plate 7, Figure 3)

1850 *Oolina apiculata* Reuss, p.22,pl.1,fig.1.

1863 *Lagena apiculata* Reuss: pp.318-319,pl.1,figs 4-8,10-11.

1940 *Lagena apiculata* Reuss, Tappan: pp.111-112,pl.17,figs 15a,b.

Description : Test free, small, unilocular, ovate. Distinct apical spine at base. Wall smooth.

Aperture simple, at end of short neck.

Size : 400 microns in height, maximum width 350 microns.

Occurrence : AL, BG (Biozones 3-6).

Stratigraphic range : Cenomanian (Eicher and Worstell, 1970). Turonian (Reuss, 1850). This species appears to range into the Santonian as it occurs in the Bavnodde Greensand.

*Lagena ellipsoidal*s Schwager, 1878

(Plate 7, Figure 4)

1878 *Lagena ellipsoidal*s Schwager, p.512,pl.1,fig.1.

1978 *Lagena ellipsoidal*s Schwager: Bailey, p.104,pl.4,fig.1.

Description : Test free, distinctly ellipsoidal, unilocular. Chamber smooth. Spine may be found at base of chamber, although this appears to be variable. Smooth wall. Aperture simple at end of central apertural tube.

Size : Height 110 microns, width 100 microns.

Occurrence : BG (Biozone 5).

Stratigraphic range : Coniacian-Santonian (Bailey, 1978).

Lagena isabella d'Orbigny, 1840

(Plate 7, Figure 5)

1840 *Lagena isabella* d'Orbigny, p.20,pl.5,fig.28.

1978 *Lagena isabella* d'Orbigny: Bailey, p.106,pl.4,fig.3.

Description : Test free, unilocular, globular, wider at base. Spine may be present. Surface of test is ornamented by 10 plus ribs which run from base to aperture. Aperture simple, rounded, produced at end of short neck.

Size : BG (Biozones 5, 6).

Occurrence : Height 160 microns, width 80 microns.

Stratigraphic range : Coniacian-Santonian (Bailey, 1978). Campanian (d'Orbigny, 1840).

Lagena sulcata (Walker and Jacob, 1798)

(Plate 7, Figure 6)

1798 *Serpula (Lagena) sulcata* Walker and Jacob, p.634,pl.14,fig.5.

1943 *Lagena sulcata* (Walker and Jacob): Tappan, p.504,pl.80,fig.33-34.

1967 *Lagena cf. sulcata* (Walker and Jacob): Fuchs, p.291,pl.8,fig.6.

Description : Test free, small, unilocular flask shaped chamber. Surface ornamented by 8-12 vertical ribs. Aperture terminal, simple, at end of short neck. Base may be slightly apiculate.

Size : Maximum height 200 microns, maximum width 180 microns.

Occurrence : AG, AL, BG (Biozones 3-6).

Stratigraphic range : Albian (Tappan, 1943; Fuchs, 1967). Common mid-Cretaceous species (Tappan, 1943). The occurrence in the Bavnodde Greensand indicates that this form ranges into the Santonian.

Lagena sp. A

(Plate 7, Figure 7)

1970 *Lagena sulcata* (Walker and Jacob), Eicher and Worstell, p.286,pl.2,figs 8-9.

Description : Test free, unilocular, simple. Widest point at base. Surface ornamented by 6 ribs. Aperture terminal, simple, at end of short neck.

Size : Maximum height 220 microns, maximum width 180 microns.

Occurrence : AG (Biozone 1).

Remarks : Described as *Lagena sulcata* by Eicher and Worstell (1970), this is clearly erroneous since *Lagena sulcata* should possess more than 8 ribs, usually 10. This form only has 6 and is distinctly wider at the base.

Genus : *Oolina* d'Orbigny, 1839

Type species : *Oolina laevigata* Galloway and Wissler, 1927

Oolina sp. A

(Plate 7, Figure 9)

Description : Test free, small, globular. Surface smooth. Base of test slightly apiculate. Aperture simple, low, rounded.

Size : Maximum height 200 microns, maximum width 180 microns.

Occurrence : AG (Biozone 1).

Family : *Polymorphinidae* d'Orbigny, 1839

Subfamily : *Polymorphininae* d'Orbigny, 1839

Genus : *Eoguttulina* Cushman and Ozawa, 1930.

Type species : *Eoguttulina anglica* Cushman and Ozawa, 1930

Eoguttulina sp. A

(Plate 7, Figure 9)

Description : Test free, small. Chambers gently inflated, added in planes at 90 degrees, each further removed from base. Sutures distinct, depressed. Wall smooth. Aperture terminal, radiate.

Size : Maximum length 500 microns, maximum width 300 microns.

Occurrence : AL (Biozone 4).

Remarks: The few specimens recorded were generally poorly preserved, hindering better attribution.

Genus : *Globulina* d'Orbigny, 1839

Type species : *Polymorphina (Globulina) gibba* d'Orbigny, 1826

Globulina lacrima Reuss, 1845

(Plate 7, Figure 10)

1845 *Polymorphina (Globulina) lacrima* Reuss, p.40,pl.2,fig.6,pl.13,fig.83.

1851 *Globulina lacrima* Reuss, p.27,pl.4,fig.9.

1946 *Globulina lacrima* Reuss: Cushman, p.96,pl.40,figs.11-12.

1970 *Globulina lacrima* Reuss: Hart, p.158,pl.13,figs.5,6.

Description : Test free, subglobular. Base broadly rounded, gradually tapering towards aperture.

Sides slightly curved. Chambers few, extending back to base. Sutures flush, wall smooth.

Aperture terminal, radiate, produced on short neck.

Size : Maximum length 400 microns, maximum width 200 microns.

Occurrence : AG, BG (Biozones 1, 3, 5, 6).

Stratigraphic range : Middle Albian to Cenomanian (Hart, 1970). Turonian (Reuss, 1845). This typical inner shelf form occurs in some numbers in the Santonian Bavnodde Greensand, suggesting that it is persistent beyond the Turonian, in shelf sediments.

Genus : *Guttulina* d'Orbigny, 1839

Type species : *Polymorphina (Guttulina) communis* d'Orbigny, 1826.

Guttulina adhaerens (Olszewski, 1875)

(Plate 7, Figure 11)

1875 *Polymorphina adhaerens* Olszewski, p.119,pl.1,fig.11.

1930 *Guttulina adhaerens* (Olszewski): Cushman and Ozawa, p.36,pl.1,figs 9a-c,pl.6,figs 7a,b.

1946 *Guttulina adhaerens* (Olszewski): Cushman, p.96,pl.40,figs 8-10.

1970 *Guttulina adhaerens* (Olszewski): Hart, p.160,pl.13,fig.12.

Description : Test free, ovate. Rounded at base, becoming broader towards centre of test, tapering to an acute apertural end. Chambers clavate, formed in a quinqueloculine series, each successively more removed from the base than earlier chambers. Sutures depressed, wall smooth. Aperture radiate, slightly produced.

Size : Maximum height 1 mm, maximum width 700 microns.

Occurrence : AG, BG (Biozones 1, 5, 6).

Stratigraphic range : Cenomanian (Hart, 1970). An inner shelf morphotype which clearly ranges into the Santonian.

Guttulina trigonula (Reuss, 1845)

(Plate 7, Figure 12)

1845 *Polymorphina trigonula* Reuss, p.40,pl.13,fig.84.

1930 *Guttulina trigonula* (Reuss): Cushman and Ozawa, p.28,pl.4,figs 2a-c.

1978 *Guttulina trigonula* (Reuss): Bailey, p.123,pl.5,fig.7.

Description : Test free, globular to ovate. Base rounded, gradually tapering towards aperture. Chambers rounded, slightly inflated, strongly overlapping. Sutures depressed, wall smooth. Aperture terminal, radiate, produced.

Size : Maximum height 600 microns, maximum width 500 microns.

Occurrence : AG, AL, BG (Biozones 1-6).

Stratigraphic range : Common Late Cretaceous form (Cushman, 1946).

Genus : *Spirofrondicularia* Schubert, 1902.

Type species : *Polymorphina frondicularoides* Chapman, 1894.

Spirofrondicularia sp. A

(Plate 7, Figure 13)

Description : Test free, large, early chambers inflated, tetraloculine, added in planes 90 degrees apart. Sutures depressed. Aperture terminal, radiate.

Size : Maximum height 2mm, maximum width 1 mm

Occurrence : AG (Biozone 1).

Subfamily : *Ramulininae* Brady, 1884

Genus : *Ramulina* Jones in Wright, 1875.

Type species : *Ramulina laevis* Jones, 1875.

Ramulina aculeata Wright, 1886.

(Plate 7, Figures 15, 16)

1886 *Ramulina aculeata* Wright: p.331,pl.27,fig.11.

1943 *Ramulina aculeata* Wright: Tappan, p.506,pl.81,figs 6-7.

1970 *Ramulina aculeata* Wright: Hart, pp.164-165,pl.14,fig.3.

Description : Test free, consists of globular chambers and branching stoloniferous tubes, chambers increasing in size as added. Inflated chambers, sutures distinct, constricted. Wall calcareous, surface ornamented with spines of varying sizes. Aperture a rounded opening at end of chamber.

Size : Diameter of stoloniferous tubes approximately 200 microns. Chambers up to 450 microns in diameter.

Occurrence : AG, AL, BG (Biozones 3-6).

Stratigraphic range : Middle Albian to Early Turonian (Hart, 1970). Coniacian to Santonian Bailey (1978). Campanian to Maastrichtian (Wright, 1886).

Superfamily : *Conorboidacea* Thalmann, 1952

Family : *Conorboididae* Thalmann, 1952.

Genus : *Conorboides* Hofker, 1952

Type species : *Conorbis mitra* Hofker, 1951

Conorboides minutissima (Tappan, 1943)

(Plate 8, Figure 1)

1943 *Discorbis minutissima* Tappan, p.5111,pl.82,figs 5,6.

1970 *Conorboides minutissima* (Tappan): Eicher and Worstell, p.295,
pl.6,figs.9,11a,b,pl.7,fig1.

1982 *Conorboides minutissima* (Tappan): Haig, p.43,pl.9,figs 6-9.

Description : Test free, small, trochospiral. Spiral side flattened to slightly convex, chambers increasing rapidly in size as added. Sutures oblique, depressed, curved. Umbilical side gently concave, sutures straight and depressed. Aperture a low arch , at base of final chamber on umbilical side.

Size : Maximum diameter 500 microns.

Occurrence : BG (Biozone 5).

Stratigraphic range : Albian to Turonian (Haig, 1982; Eicher and Worstell, 1970). Presence in the Bavnodde Greensand suggests that this species may range into the Santonian.

Comments: It has been suggested by Bailey (pers comm.) that this form is synonymous with *Discorbis scanicus* Brotzen, 1942. This may explain confusion over range data.

Conorboides sp. A

(Plate 8, Figure 2)

Description : Test free, small, trochospiral. Spiral side convex consisting of three whorls with 3-4 chambers per whorl. Sutures raised, curved. Periphery rounded, slightly lobulate. Umbilical side concave, sutures flush, radial. Aperture at base of last chamber.

Size : Maximum diameter 320 microns.

Occurrence : AG, AL (Biozones 1, 2, 4).

Suborder : *Globigerinina* Delage and Herouard, 1896

Superfamily : *Heterohelicacea* Cushman, 1927

Family : *Guembelitriidae* Montanaro-Gallitelli, 1957

Genus : *Guembelitria* Cushman, 1933.

Type species : *Guembelitria cretacea* Cushman, 1933.

Guembelitria cenomana (Keller, 1935)

(Plate 8, Figure 3)

1935 *Guembelitria cenomana* Keller, pp.547-548,pl.2,figs 13-14.

1939 *Guembelitria cenomana* (Keller): Maslakova, p.118,pl.15,fig.6.

1977 *Guembelitria harrisi* Tappan: Carter and Hart, p.26,pl.2,fig.11.

1981 *Guembelitra cenomana* (Keller): Hart *et al.*, p.202,pl.7.15,fig.6.

1989 *Guembelitra cenomana* (Keller): Hart *et al.*, p.345,pl.7.15,fig.6.

Description : Test free, small, triserial throughout. Chambers globular and inflated, sutures distinct, depressed. Aperture a low interiomarginal arch at base of last chamber.

Size : Maximum height 120 microns, maximum width 40 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Middle Albian to earliest Turonian (Hart *et al.*, 1981)

Remarks: See Hart *et al.*, (1989) for discussion of taxonomic problems associated with this species.

Family : *Heterohelicidae* Cushman, 1927

Subfamily : *Heterohelicinae* Cushman, 1927

Genus : *Heterohelix* Ehrenberg, 1843.

Type species : *Spiroplecta americana* Ehrenberg, 1844.

Heterohelix globulosa (Ehrenberg, 1840)

(Plate 8, Figure 4)

1840 *Textularia globulosa* Ehrenberg, p.135,pl.4,figs 2,4,5,7,8.

1957 *Heterohelix globulosa* (Ehrenberg): Montanaro-Gallitelli, p.137,pl.31,figs 12-15.

1978 *Heterohelix globulosa* (Ehrenberg): Bailey, pp.144-146,pl.6,figs 12,13.

Description : Test free, small, biserial. Chambers globular, increasing rapidly in size as added, test tapering towards base. Sutures distinct, depressed. Wall smooth to finely striate. Aperture low arch on the inner margin of the final chamber.

Size : Maximum length 340 microns, width 200 microns.

Occurrence : AL, BG (Biozones 3-6).

Stratigraphic range : Coniacian to Santonian, (Bailey, 1978).

Heterohelix moremani (Cushman, 1938)

(Plate 8, Figure 5)

1938 *Guembelitra moremani* Cushman, p.10,pl.2,figs.1-3.

1967 *Heterohelix moremani* (Cushman): Pessagno, pp.260-261,pl.48,figs 10-11,pl.89,figs 1,2.

1985 *Heterohelix moremani* (Cushman): Caron, p.60,pl.24,figs 6,7.

1989 *Heterohelix moremani* (Cushman): Hart *et al.*, p.346,pl.7.16,fig.9.

Description : Test free, small, slender, consisting of 6-9 pairs of chambers, which are uninflated and very gradually increasing in size. Test biserial and gently tapering. Aperture a low interiomarginal arch formed at base of last chamber, bordered by a narrow imperforate lip.

Size : Maximum length 120 microns, maximum width 50 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Middle Albian to Late Cenomanian (Hart *et al.*, 1989)

Heterohelix pulchra (Brotzen, 1936)

(Plate 8, Figure 6)

1936 *Guembelina pulchra* Brotzen, p.121,pl.9,figs.3a,b,not figs 2a,b.

1962 *Heterohelix pulchra* (Brotzen): Pessagno, p.358,pl.1,fig.3.

1977 *Heterohelix pulchra* (Brotzen): Masters, p.349,pl.2,fig.2.

Description : Test free, biserial, gradually increasing in size as added. Last few chambers are distinctly broadened. Sutures distinct, depressed, arcuate. Aperture interiomarginal, symmetrical.

Size : Maximum length of test 120 microns.

Occurrence : Recorded from the Bavnodde Greensand (Douglas and Rankin, 1969), AL, BG (Biozones 4-6).

Stratigraphic range : Campanian to Maastrichtian (Pessagno, 1962), Turonian to Maastrichtian (Eicher and Worstell, 1970), Turonian to Campanian (Masters, 1977).

Heterohelix reussi (Cushman, 1938)

(Plate 8, Figure 7)

1938 *Guembelina reussi* Cushman, p.11,pl.2,figs 6a,b.

1967 *Heterohelix reussi* (Cushman): Pessagno, p.263,pl.85,figs.1-9,pl.86,figs 1,2.

1978 *Heterohelix reussi* (Cushman): Bailey, p.147,pl.6,figs 14,15.

1985 *Heterohelix reussi* (Cushman): Caron, p.60,pl.24,figs 10-11.

Description : Test free, small, biserial, tapering. Chambers globular, rapidly increasing in size, sutures strongly depressed, giving subtriangular depressions around central sutures. Wall slightly striate. Aperture an interiomarginal arch at base of last chamber.

Size : Maximum length 260 microns, maximum width 160 microns.

Occurrence : AG, AL, BG (Biozones 3-6).

Stratigraphic range : Turonian to Santonian (Caron, 1985). Coniacian to Santonian, (Bailey, 1978).

Remarks : Distinguished from *Heterohelix globulosa* by the presence of distinct triangular depressions between the chambers and by being more compressed.

Superfamily : *Planomalinea* Bolli, Loeblich and Tappan, 1957.

Family : *Globigerinelloididae* Longoria, 1974.

Subfamily : *Globigerinelloidinae* Longoria, 1974

Genus : *Globigerinelloides* Cushman and ten Dam, 1948.

Type species : *Globigerinelloides algeriana* Cushman and ten Dam, 1948

Globigerinelloides asperus (Ehrenberg, 1854)

(Plate 8, Figure 8)

1854 *Phanerostomum asperum* Ehrenberg, p.23,pl.30,fig.26a,b.

1964 *Globigerinelloides aspera* (Ehrenberg): Barr and Cordey, p.309.

1967 *Globigerinelloides asperus* (Ehrenberg): Pessagno, pp.274-275,pl.60,figs 4,5.

1978 *Globigerinelloides asperus* (Ehrenberg): Bailey, pp.148-149,pl.7,fig.1.

Description : Test free, small, planispiral, partially evolute, biumbilicate. Consists of 2-3 whorls.

Only final whorl visible which consists of 5-6 slightly inflated globular chambers. Sutures depressed, radial straight. Wall perforate, calcareous, hispid. Aperture a low interiomarginal arch.

Size : Diameter 120 microns, width 40 microns.

Occurrence : AL, BG (Biozones 4-6).

Stratigraphic range : Coniacian-Santonian (Bailey, 1978)

Globigerinelloides bentonensis (Morrow, 1934)

(Plate 8, Figure 9)

1934 *Anomalina bentonensis* Morrow, p.201,pl.30,fig.4a,b.

1961 *Globigerinelloides bentonensis* (Morrow): Loeblich and Tappan, p.267,pl.2,figs 8-10.

1977 *Globigerinelloides bentonensis* (Morrow): Carter and Hart, pp.27-28,pl.1,fig.11,pl.2,figs.19,20.

1985 *Globigerinelloides bentonensis* (Morrow): Caron, p.47,pl.29,figs 8,9.

1989 *Globigerinelloides bentonensis* (Morrow): Hart *et al.*, p.340,pl.7.13,figs.7-9.

Description : Test free, planispiral, involute, biumbilicate. Consists of 2 whorls, with 6-9 chambers in final whorl, which gradually increases in size. Sutures depressed, radial, straight, showing a slight curvature towards the umbilicus. Aperture a low interiomarginal arch, with lip. Relict apertural lips are visible around the umbilicus on both sides of test. Wall perforate.

Size : Diameter 110 microns, width 30-40 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Latest Albian to Cenomanian (Hart *et al.*, 1981)

Remarks: Carter and Hart (1977) and Hart *et al.*, (1989) contain discussions of the taxonomic history of this species.

Globigerinelloides rowei (Barr, 1962)

(Plate 8, Figure 10)

1962 *Planomalina rowei* Barr, p.564,pl.69,i,f,g.2a,b.

1978 *Globigerinelloides rowei* (Barr): Bailey, p.150,pl.7,fig.3.

Description : Test free, small, planispiral, partially evolute, biumbilicate. Consists of 2 whorls, final whorl with 4-5 globular chambers, with the final chamber becoming elongate. Outline appears quadrilateral. Sutures radial, straight, depressed. Wall hispid. Aperture an interiomarginal, equatorial arch.

Size : Diameter 140 microns, width 40 microns.

Occurrence : AL, BG (Biozones 4-6).

Stratigraphic range : Coniacian to Santonian (Bailey, 1978).

Superfamily : *Rotaliporacea* Sigal, 1958

Family : *Hedbergellidae* Loeblich and Tappan, 1961

Subfamily : *Hedbergellinae* Loeblich and Tappan, 1961

Genus : *Hedbergella* Bronniman and Brown, 1958.

Type species : *Anomalina lorneiiana* d'Orbigny var. *trochoidea* Gandolfi, 1942.

Comment: The separation of *Whiteinella* and *Hedbergella* in this thesis follows Robaszynski and Caron (1979), the principal difference being the location of the aperture, which in *Hedbergella* is more extended towards the periphery. The position of the aperture is affected by the position of the last chamber, which is added at a late stage in the life cycle. If it assumes an overhanging position, it makes the aperture look umbilical. Some species, for example *Whiteinella brittonensis* fulfill criteria for *Hedbergella* in the Cenomanian and *Whiteinella* in the Turonian, hence the questionable validity of using either generic name.

Hedbergella delrioensis (Carsey, 1926)

(Plate 8, Figures 11-13)

1926 *Globigerina cretacea* d'Orbigny var. *delrioensis* Carsey, p.43.

1961 *Hedbergella delrioensis* (Carsey): Loeblich and Tappan, p.275,pl2,figs 11-13.

1967 *Hedbergella delrioensis* (Carsey): Pessagno, pp.282-283,pl.48,figs 1-5.

1979 *Hedbergella delrioensis* (Carsey): Robaszynski and Caron, pp.123-

128,pl.22,figs 1a-c,2a-c,pl.23,figs 1a-c,2a-c,3a-c.

Description : Test free, trochospiral, biconvex. Equatorial periphery lobulate. Spiral side with 4-6 chambers in final whorl, gradually increasing in size as added, circular. Sutures radial and depressed, sometimes slightly curved. Umbilical side has 4-6 globular chambers. Chamber surfaces spinose and papillate, except for the last chamber, which may be smooth. Sutures radial and depressed. Aperture an extraumbilical-umbilical arch extending to peripheral margin, with spatulate lip. Umbilicus narrow 1/6 to 1/5 of maximum diameter of the test.

Size : Maximum diameter up to 450 microns, maximum height 200 microns.

Occurrence : AG, AL, BG (Biozones 1-6).

Stratigraphic range : Middle Aptian to Early Santonian (Caron, 1985)

Hedbergella flandrini Porthault, 1970

(Plate 9, Figure 1)

1970 *Hedbergella flandrini* Porthault, pp.64-65,pl.10,figs 1-3.

1979 *Hedbergella flandrini* Pothault: Robaszynski and Caron, pp.129-134,pl.24,figs 1,2,pl.25,figs 1-3.

Description : Test free, low trochospiral, compressed. Equatorial periphery lobulate. Sutures radial, depressed on spiral side. Chambers spatulate in shape increasing rapidly in size as added. Primary aperture extraumbilical-umbilical. Sutures on umbilical side radial and depressed, umbilicus 1/5 of maximum diameter of test.

Size : Maximum diameter 120 microns.

Occurrence : AG (Biozone 3).

Stratigraphic range : Late Turonian to Santonian (Robaszynski and Caron, 1979). Specimens in the Arnager Greensand are recorded in Biozone Three suggesting that they have been emplaced into the top of the formation and are derived from the Arnager Limestone.

Hedbergella planispira (Tappan, 1940)

(Plate 9, Figures 2-4)

1940 *Globigerina planispira* Tappan, p.122,pl.19,fig.12.

1961 *Hedbergella planispira* (Tappan): Loeblich and Tappan, pp.276-277,pl.5,figs 4-11.

1977 *Hedbergella planispira* (Tappan): Carter and Hart, pp.36-37,pl.4,figs 4-6.

1979 *Hedbergella planispira* (Tappan): Robaszynski and Caron, pp.139-144,pl.27,figs
1a-c,2a-c,3a-c,pl.28,figs 1a-c,2a-c,3a-c,4a-c.

Description : Test free, very low trochospiral, appears asymmetrical, with a flat spiral side.

Equatorial periphery lobulate with 6-8 chambers in final whorl, which gradually increase in size as added. Sutures radial and depressed, chambers globular with smooth surface. Umbilical side with 6-8 globular chambers with a smooth surface. Sutures radial and depressed. Umbilicus 1/3 diameter of test. Primary aperture extraumbilical-umbilical, extending to periphery, bordered by narrow lip.

Size : Maximum diameter 210 microns, maximum height 80 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Albian to Turonian (Robaszynski and Caron, 1979)

Genus : *Whiteinella* Pessagno, 1967.

Type species : *Whiteinella archaeocretacea* Pessagno, 1969.

Whiteinella archaeocretacea Pessagno, 1967

(Plate 9, Figures 5-7)

1967 *Whiteinella archaeocretacea* Pessagno, pp.298-299,pl.51,figs 2-4.

1979 *Whiteinella archaeocretacea* Pessagno: Robaszynski and Caron, pp.161-168,pl.33,figs 1-3,pl.34,figs 1,2.

Description : Test free, low trochospiral, chambers oval. Spiral side, equatorial periphery lobulate, sutures depressed, radial and curving forwards in the direction of coiling between chambers. Chambers increase rapidly in size as added and become elongate in the direction of coiling. Umbilical side, 4-5 chambers, sutures radial, depressed, straight, later curving forwards in the direction of coiling. Umbilicus shallow and wide 1/4 to 1/3 of diameter of test. Primary aperture extraumbilical-umbilical. Portici extending to centre of umbilicus. Peripheral border nearly imperforate.

Size : Maximum diameter 400 microns, maximum height 200 microns.

Occurrence : AG/AL boundary. (Biozone 3).

Stratigraphic range : Latest Cenomanian to Early Coniacian (Robaszynski and Caron, 1979)

Whiteinella aprica (Loeblich and Tappan, 1961)

(Plate 9, Figures 8-10)

1961 *Ticinella aprica* Loeblich and Tappan, p.292,pl.4,figs.14-16.

1979 *Whiteinella aprica* (Loeblich and Tappan); Robaszynski and Caron, pp.157-160,pl.32,figs 1a-c,2a-c.

1985 *Whiteinella aprica* (Loeblich and Tappan): Ball, pp.189-190,pl.10,fig.4a-c.

Description : Test free, low trochospiral consisting of two or two and a half whorls. Equatorial periphery lobulate. Spiral side 5-7 globulose chambers with pustulose surface, increasing slowly in size as added, sutures radial and depressed. Umbilical side, 5-7 globulose, pustulose chambers. Sutures radial and depressed, umbilicus shallow and wide upto a 1/4 of the diameter of

the test. Aperture extraumbilical-umbilical extending towards the periphery, bordered by a porticus.

Size : Maximum diameter 500 microns, height 200 microns.

Occurrence : AL (Biozone 4).

Stratigraphic range: Latest Cenomanian to Late Turonian (Robaszynski and Caron, 1979)

Remarks : Distinguished from *Whiteinella brittonensis* (Loeblich and Tappan, 1961) by its lower trochospire and flaps in the umbilicus.

Whiteinella baltica Douglas and Rankin, 1969

(Plate 9, Figures 11-13)

1969 *Whiteinella baltica* Douglas and Rankin, p.197,fig.9a-1.

1979 *Whiteinella baltica* Douglas and Rankin: Robaszynski and Caron, pp.169-174,pl.35,figs 1a-c,2a-c,3,4a,b,5,pl.36,figs 1a-c,2a-c.

Description : Test free, trochospiral, chambers circular. Equatorial periphery lobulate. Spiral side 4-5 chambers, globulose and rapidly increasing in size as added. Umbilical side, 3 and a half to 5 chambers, globose and spinose. Sutures radial and depressed, umbilicus narrow, less than 1/4 of test diameter. Primary aperture extraumbilical to umbilical bordered by porticus, covering umbilicus.

Size : Maximum diameter upto 450 microns, maximum height 200 microns.

Occurrence : Recorded and first described from the Arnager Limestone and Bavnodde Greensand (Douglas and Rankin, 1969). AG, AL, BG (Biozones 2-6).

Remarks : *Hedbergella bornholmensis* Douglas and Rankin (1969) is synonymous (Bailey, 1978; Robaszynski and Caron, 1979; Ball, 1985) and is probably a juvenile form of *W. baltica*. The last chamber of *W. baltica* makes the aperture appear umbilical and is therefore placed in *Whiteinella*

and as such is a good example of the problems associated with *Hedbergella/Whiteinella* generic taxonomy.

Whiteinella brittonensis (Loeblich and Tappan, 1961)

(Plate 9, Figures 14-16)

1961 *Hedbergella brittonensis* Loeblich and Tappan, pp.274-275,pl.4,figs 1-8.

1979 *Whiteinella brittonensis* (Loeblich and Tappan): Robaszynski and Caron, pp.175-180,pl.37,figs 1a-c,2a-c,pl.38,figs 1a-c,2a-c.

Description : Test free, trochospiral, asymmetrical. Equatorial periphery almost circular. Spiral side 5-7 globular chambers which gradually increase in size as added. Sutures radial and depressed. Umbilical side 5-7 globular, spinose chambers. Sutures radial and depressed. Umbilicus narrow 1/5 to 1/4 of maximum diameter of test. Primary aperture extraumbilical-umbilical, not extending to periphery, bordered by a porticus. Umbilicus filled with previous portici, though rarely seen.

Size : Maximum diameter 400 microns, maximum height 200 microns.

Occurrence : AG, AL, BG (Biozones 2-6).

Stratigraphic range : Late Cenomanian to Santonian (Robaszynski and Caron, 1979). Generic differentiation follows Robaszynski and Caron (1979). See comments under the genus *Hedbergella*.

Subfamily : *Rotundininae* Bellier and Salaj, 1977

Genus : *Praeglobotruncana* Bermudez, 1952

Type species : *Globorotalia delrioensis* Plummer, 1931

Praeglobotruncana delrioensis (Plummer, 1931)

(Plate 10, Figures 1-3)

1931 *Globorotalia delrioensis* Plummer, p.199,pl.13,fig.2a-c.

1952 *Praeglobotruncana delrioensis* (Plummer): Bermudez, p.52,pl.7,fig.1.

1977 *Praeglobotruncana delrioensis* (Plummer): Carter and Hart, pp.38-39,pl.4,figs 22-24.

1979 *Praeglobotruncana delrioensis* (Plummer): Robaszynski and Caron, pp.29-32,pl.43,figs1a-c,2a-c.

Description : Test free, biconvex, low trochospiral, consisting of 2 to 2 and a half whorls. Equatorial periphery lobulate. Spiral side, with final whorl of 5-6 petaloidal chambers, sutures curved, thickened or beaded. Chambers increase very gradually in size as added. Umbilical side has 5-6 triangular chambers, which are gently inflated and papillate. Umbilicus less than 1/5th of maximum diameter of the test. Sutures radial and depressed. Primary aperture extraumbilical-umbilical extending to periphery, bordered by narrow lip. Chamber margins marked by an accumulation of pustules.

Size : Maximum diameter 420 microns, maximum height 170 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Late Albian to Middle Cenomanian (Robaszynski and Caron, 1979)

Family : *Rotaliporidae* Sigal, 1958

Subfamily : *Rotaliporinae* Sigal, 1958

Genus : *Rotalipora* Brotzen, 1942

Type species : *Rotalipora turonica*=*Globorotalia cushmani* Morrow, 1934

Rotalipora reicheli Mornod, 1950

(Plate 10, Figures 4-6)

1950 *Globotruncana (Rotalipora) reicheli* Mornod, p.583,fig.5(4a-c),fig.6(nos.1-6),pl.15,fig.2.

1954 *Rotalipora reicheli* Mornod: Hagn and Zeil, p.25,pl.1,fig.2,pl.4,figs 1-2,pl.7,fig.11.

1979 *Rotalipora reicheli* Mornod: Hart, pp.88-89,text fig.3a,b,c.

1979 *Rotalipora reicheli* Mornod: Robaszynski and Caron, pp.99-106,pl.16,figs 1a-c,pl.17,figs 1a-c,pl.18,figs 1a-c,2a-c.

Description : Test free, planoconvex. low trochospiral coil of 2-3 whorls. Peripheral outline lobate, with distinct keel. Spiral side flat to moderately convex, with distinct raised, curved sutures.

Chambers crescent shaped, 6-7 per whorl. Umbilical side has depressed radial, nearly straight sutures, with umbilicus forming a half to third of area. Umbilical shoulders distinct, thickened, may be nodose. Primary aperture an interiomarginal, extraumbilical/umbilical arch with a distinct imperforate lip. Secondary sutural apertures developed on umbilical side, each with slight lip.

Size : Maximum diameter 570 microns, maximum height 300 microns.

Occurrence : Recorded by Hart (1979) from the the Arnager Greensand, approximately 5m below the boundary with the Arnager Limestone. AG (Biozone 2).

Stratigraphic range : Occurs at, or about the Early-Middle Cenomanian boundary (Robaszynski and Caron, 1979)

Remarks : Similar to *Rotalipora deeckeii* (Franke, 1925), but can be distinguished by its more flattened spiral side and depressed umbilical sutures. Hart (1979) found that specimens from Bornholm generally possessed a higher spire than those from further South.

Superfamily : *Globotruncanacea* Brotzen, 1942

Family : *Globotruncanidae* Brotzen, 1942

Subfamily : *Globotruncaninae* Brotzen, 1942

Genus : *Globotruncana* Cushman, 1926

Type species : *Pulvinulina arca* Cushman, 1926

Globotruncana bulloides Vogler, 1941

(Plate 10, Figures 7-9)

1936 *Globotruncana ventricosa* White: Brotzen, pp.171-177,pl.13,fig.4.

1941 *Globotruncana linnei* (d'Orbigny) *bulloides* Vogler, p.287,pl.23,figs 29-32.

1967 *Globotruncana bulloides* Vogler: Pessagno, p.324-326,pl.64,figs 15-17,p.67,figs
1-3.

1984 *Globotruncana bulloides* Vogler: Robaszynski *et al.*, p.186,pl.6,figs 1-4.

Description : Test free, low trochospiral, biconvex. Outline lobate on spiral side. Equatorial periphery truncated by two keels, equally developed and parallel, separated by an imperforate band. Keel is parallel to the coiling axis, or may be deflected towards umbilicus. Chambers distinct, inflated with 5-7 in final whorl, increasing gradually in size as added. Sutures curved, raised and beaded on spiral side, curved to straight and depressed on umbilical side. Umbilicus 1/3 to 1/2 of the maximum diameter. Tangential or oblique adumbilical ridges may be developed. Aperture umbilical. Evidence of tegilla is rarely seen.

Size : Maximum diameter 350 microns, maximum height 150 microns.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Mid-Santonian to Early Maastrichtian (Robaszynski *et al.*, 1984)

Globotruncana linneiana (d'Orbigny, 1839)

(Plate 10, Figures 10-12)

1839 *Rosalina linneiana* d'Orbigny, p.110,pl.5,figs.10-12.

1956 *Globotruncana linneiana* (d'Orbigny): Bronnimann and Brown, pp.540-542,pl.20,figs 13-17,pl.21,figs 16-18.

1984 *Globotruncana linneiana* (d'Orbigny): Robaszynski *et al.*, pp.200-202,pl.13,figs 1-4,pl.14,figs 1-5.

1985 *Globotruncana linneiana* (d'Orbigny): Ball, pp.215-218,pl.14,fig.1a,b,c.

Description : Test free, low trochospiral, consisting of two and a half to three whorls. Spiral and umbilical surfaces appear almost flat in lateral view. Outline subcircular, weakly lobate. Periphery is truncated by two keels, equally developed and parallel, which are separated by a wide imperforate band. Keels and band are generally parallel to coiling axis. Chambers distinct, petaloid spirally, elongate umbilically, usually 5-7 in number. Sutures curved, depressed on umbilical side; curved to straight, raised or beaded and joining spiral suture nearly at right angles on spiral side. Umbilicus 1/3 to 1/4 of maximum diameter, adumbilical ridges are present. Aperture umbilical, covered by tegilla, which are not always seen.

Size : Maximum diameter upto 400 microns, maximum height upto 200 microns.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Coniacian to mid-Maastrichtian (Robaszynski *et al.*, 1984)

Remarks : This species can be separated from *G. bulloides* by chamber convexity, in that the chambers are always flat to slightly convex and not inflated as in *G. bulloides*. Differs from *Marginotruncana pseudolinneiana* Pessagno in having an umbilical primary aperture and possessing tegilla.

Genus : *Marginotruncana* Hofker, 1956

Type species : *Rosalina marginata* Reuss, 1845

Marginotruncana marginata (Reuss, 1845)

(Plate 11, Figures 1-3)

1845 *Rosalina marginata* Reuss, p.36,pl.8,figs 54a,b,pl.13,figs 68a,b.

1967 *Marginotruncana marginata* (Reuss): Pessagno, pp.307-310,pl.54,figs 7-12,16-18,pl.56,figs 10-12,pl.99,figs 5-7.

1979 *Marginotruncana marginata* (Reuss): Robaszynski and Caron, pp.107-113,pl.63,figs 1a-c,2a-d,pl.64,figs 1a-c,2a-d.

Description : Test free, low trochospiral, with two keels separated by a narrow imperforate peripheral band. Spiral side, outline lobulate, sutures oblique, depressed, chambers petaloid, increasing in size as added. Umbilical side, sutures radial, marked by 'u' shaped rims. Chambers smooth to slightly rugose. Primary aperture extraumbilical-umbilical. Umbilicus 1/4 of total test diameter. Portici present.

Size : Maximum diameter 700 microns.

Occurrence : Upper AG, AL (Biozones 3, 4).

Stratigraphic range : Late Turonian to Santonian (Robaszynski and Caron, 1979)

Marginotruncana coronata (Bolli, 1945)

(Plate 11, Figures 4-6)

1945 *Globotruncana lapparenti* Brotzen subsp. *coronata* Bolli, p.233,text fig. 1,21,22,pl.9,fig.15,not14.

1967 *Marginotruncana coronata* (Bolli): Pessagno, pp.305-306,pl.65,figs 11-13,pl.100,fig.6.

1979 *Marginotruncana coronata* (Bolli): Robaszynski and Caron, pp.103-106,pl.62,figs1,2.

Description : Test free, low trochospiral, appearing almost symmetrical, with two keels separated by narrow imperforate band, outline compressed. Spiral side, lobulate, sutures raised, chambers petaloid and flat, increasing in size as added. Umbilical side, sutures raised, sigmoidal, chambers flat, umbilicus 1/3 diameter of test. Primary aperture extraumbilical to umbilical. Portici present.

Size : 700 microns in diameter (maximum)

Occurrence : Upper AG, AL (Biozones 3, 4).

Stratigraphic range : Mid-Turonian to Santonian (Robaszynski and Caron, 1979)

Marginotruncana pseudolinneiana Pessagno, 1967

(Text figure 3.2)

1967 *Marginotruncana pseudolinneiana* Pessagno, p.310,pl.65,figs 24-27.

1979 *Marginotruncana pseudolinneiana* Pessagno: Robaszynski and Caron, pp.123-128,pl.67,figs 1,2,pl.68,figs 1,2.

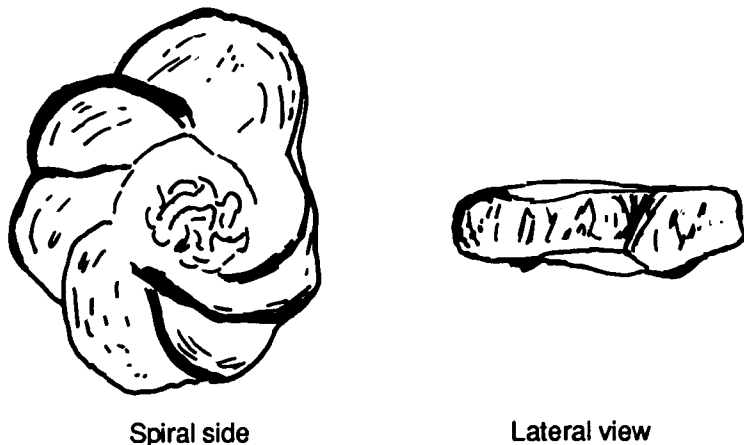
Description : Test free, low trochospiral, outline rectangular. Two keels, separated by a wide imperforate band. Spiral side lobulate, sutures raised, curved, chambers elongate with a flat surface and gradually increasing in size as added. Umbilical side, sutures sigmoidal, raised, umbilicus wide upto 1/3 of test diameter. Primary aperture extraumbilical-umbilical, umbilicus covered by portici.

Size : Maximum diameter 600 microns.

Occurrence : Upper AG, AL (Biozones 3, 4).

Stratigraphic range : Mid-Turonian to mid-Coniacian (Robaszynski and Caron, 1979)

Text figure 3.2 *Marginotruncana pseudolinneiana* Pessagno, 1967



Genus : *Dicarinella* Porthault, 1970

Type species : *Globotruncana indica* Jacob and Sastry, 1950

Dicarinella asymetrica (Sigal, 1952)

(Plate 11, Figures 7-9)

1952 *Globotruncana asymetrica* Sigal, p.35,fig.35.

1979 *Dicarinella asymetrica* (Sigal): Robaszynski and Caron, pp.61-66,pl.51,figs 1,2,pl.52,figs 1,2.

1985 *Dicarinella asymetrica* (Sigal): Caron, p.43,figs 17.3,4.

Description : Test free, low trochospiral. Asymmetrical, planoconvex to concavo-convex in side view. Equatorial periphery lobulate. Two close keels, separated by thin imperforate band. Periumbilical ridge truncates profile, angle between two faces of the last chambers= 70-90 degrees. Sutures radial and depressed on umbilical side, sutures oblique on spiral side meeting inner whorl perpendicularly, slightly thickened to beaded. Chambers petaloid on spiral side, slowly increasing in size as added, early chambers may be globigerine like. 5-6 chambers visible on

umbilical side, rugose, with periumbilical ridges. Umbilicus at least 1/3 of maximum diameter of test. Aperture umbilical. Portici not seen.

Size : Diameter 600 microns, height 230 microns.

Occurrence : Basal BG (Biozone 5).

Stratigraphic range : Mid to Late Santonian (Robaszynski *et al.*, 1984)

Remarks : Weak periumbilical ridges, suggest that these forms from the greensand may be close to *Dicarinella concavata* (Brotzen, 1934)

Dicarinella canaliculata (Reuss, 1854)

(Plate 11, Figures 10-12)

1854 *Rosalina canaliculata* Reuss, p.70,pl.26,figs 4a,b.

1960 *Globotruncana canaliculata* (Reuss): Trujillo, p.341,pl.50,figs 1a-c.

1979 *Dicarinella canaliculata* (Reuss): Robaszynski and Caron, pp.67-70,pl.53,figs 1-3.

Description : Test free, low trochospiral. with sub triangular profile, marked by two widely spaced keels and imperforate peripheral band. Spiral side, periphery lobulate, sutures raised, curved, chambers petaloid, flat. Umbilical side with 5-7 chambers, sutures radial and depressed, primary aperture extraumbilical, bordered by porticus. Umbilicus 1/4 of maximum diameter of test.

Size : Maximum diameter 450 microns.

Occurrence : AL (Biozone 4).

Stratigraphic range : Turonian to Santonian (Robaszynski and Caron, 1979)

Remarks : Differs from *Marginotruncana pseudolinneiana* in having radial umbilical sutures.

Dicarinella concavata (Brotzen, 1934)

(Plate 12, Figures 1,2)

1934 *Rotalia concavata* Brotzen, p.66,pl.3,fig.6.

1979 *Dicarinella concavata* (Brotzen): Robaszynski and Caron, pp.71-78,pl.54,figs
1,2,pl.55,figs 1,2.

1985 *Dicarinella concavata* (Brotzen): Caron, p.45,figs.17.7,8.

Description : Test free, concavo-convex, angle between faces of last chambers 70-90 degrees. Two close keels surrounded by narrow imperforate band. Spiral side, periphery lobulate, sutures oblique, thickened, chambers petaloid, gently concave. Umbilical side, sutures radial and depressed. Chambers pustulate and aligned round umbilicus. Primary aperture extraumbilical-umbilical covered by porticus. Umbilicus 1/3 diameter of test.

Size : Maximum diameter 500 microns.

Occurrence : Topmost AL (Biozone 4).

Stratigraphic range : Middle Coniacian to early Late Santonian (Caron, 1985).

Remarks: This weakly ornamented form is difficult to compare to true coeval Tethyan forms, but it possesses all the important characters. The rare individuals recorded from Bornholm were probably at the limits of their ecological tolerance.

Dicarinella imbricata (Mornod, 1950)

(Plate 12, Figures 3-5)

1950 *Globotruncana (Globotruncana) imbricata* Mornod, pp.589-590,fig.5(3a-d).

1976 *Dicarinella imbricata* (Mornod): Caron, pp.332-333,figs 3a-c.

1979 *Dicarinella imbricata* (Mornod): Robaszynski and Caron, pp.87-92,pl.58,figs
1,2,pl.59,figs 1,2.

Description : Test free, low trochospiral. Spiral side, equatorial periphery lobulate, chambers petaloid, flat to slightly convex, sutures curved, raised. 5-6 chambers in final whorl which gradually increase in size as added. Umbilical side, 5-6 chambers, sutures radial and depressed, chambers globulose and pustulose except for the last one or two. Primary aperture extraumbilical-umbilical, bordered by narrow lip. Umbilicus 1/4 of test diameter. Margins with 2 keels separated by an imperforate band. Keel band appears discontinuous, obliquely diverging from one chamber to the next giving an imbricated sequence.

Size : Maximum diameter 420 microns.

Occurrence : AG/AL boundary. (Biozone 3).

Stratigraphic range : Latest Cenomanian to Early Coniacian (Robaszynski and Caron, 1979)

Family : *Rugoglobigerinidae* Subbotina, 1959

Genus : *Archaeoglobigerina* Pessagno, 1967

Type species : *Archaeoglobigerina blowi* Pessagno, 1967.

Archaeoglobigerina blowi Pessagno, 1967

(Plate 12, Figures 6-8)

1967 *Archaeoglobigerina blowi* Pessagno, p.316, pl.59, figs 5-7.

1979 *Archaeoglobigerina blowi* Pessagno: Robaszynski and Caron, pp.169-172, figs 1,2.

Description : Test free, low trochospiral, chambers rounded with two faint, well spaced keels and imperforate peripheral band. Spiral side, periphery distinctly lobulate, consisting of 4 globular chambers, which increase rapidly in size as added. Umbilical side, consists of 4-5 globular

chambers, with a granular surface, umbilicus deep, 1/4 of the diameter of the test, umbilicus covered by tegilla. Aperture umbilical.

Size : Maximum diameter 450 microns.

Occurrence : AL, BG (Biozones 4-6).

Stratigraphic range : Coniacian to Late Maastrichtian (Robaszynski *et al.*, 1984)

***Archaeoglobigerina bosquensis* Pessagno, 1967**

(Plate 12, Figures 9-11)

1967 *Archaeoglobigerina bosquensis* Pessagno, pp.316-317, pl.60, figs 10-12.

1969 *Archaeoglobigerina bosquensis* Pessagno, pp.199-200, figs. 10, 11.

1985 *Archaeoglobigerina bosquensis* Pessagno: Caron, p.43, figs 16.5-6.

Description : Test free, high trochospiral. Chambers spherical, 6-7 in final whorl, tending to shift towards umbilicus, with coiling. Umbilicus deep, 1/4 of maximum diameter of test. Two keels present with indistinct peripheral band. Sutures radial and depressed, both spirally and umbilically.

Aperture umbilical.

Size : Maximum diameter 400 microns.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Late Coniacian to Santonian (Caron, 1985).

Suborder : *Rotaliina* Delage and Herouard, 1896

Superfamily : *Bolivinacea* Glaessner, 1937

Family : *Bolivinidae* Glaessner, 1937

Genus : *Tappanina* Montanaro-Gallitelli, 1955

Type species : *Bolivinita selmensis* Cushman, 1933

Tappanina eouvigeriniformis (Keller, 1935)

(Plate 13, Figure 1)

1935 *Bolivinita eouvigeriniformis* Keller, pp.548-549,pl.3,figs 20-21.

1965 *Tappanina eouvigeriniformis* (Keller): Beckmann and Koch, pp.53-54,pl.7,figs 1-5.

1972 *Tappanina eouvigeriniformis* (Keller): Gawor-Biedowa, pp.56-57,pl.5,fig.5a,b.

Description : Test free, small, flattened, wedge like, biserial. Rhomboid in outline. Transverse section rectangular. 5 pairs of chambers, with flattened surface. Sutures oblique initially, and having a distinct raised irregular rib like structure. Last chamber convex, smooth. Aperture comma shaped running up from the inner margin of the final chamber.

Size : Maximum height 180 microns, maximum width 100 microns.

Occurrence : AG (Biozones 1-3).

Stratigraphic range : Cenomanian to Coniacian (Gawor-Biedowa, 1972)

Superfamily : *Loxostomatacea* Loeblich and Tappan, 1962

Family : *Loxostomidae* Loeblich and Tappan, 1962

Genus : *Loxostomum* Ehrenberg, 1854

Type species : *Loxostomum subrostratum* Cushman, 1927

Loxostomum eleyi (Cushman, 1927)

(Plate 13, Figure 2)

1859 *Textularia obsoleta* Reuss, Eley, p.202,pl.8,fig.11, p.195,fig.11.

1927 *Bolivinita eleyi* Cushman, p.91,pl.91,fig.11.

1964 *Loxostomum eleyi* (Cushman): Loeblich and Tappan, p.C736,fig.603,figs 2-5.

1978 *Loxostomum eleyi* (Cushman): Bailey, pp.182-184,pl.11,figs 11,12.

1985 *Loxostomum eleyi* (Cushman): Solakius and Larsson, p.40,pl.3,fig.9.

Description : Test free, elongate, compressed, biserial. Margins truncated, subangular. Chambers flat, reniform. Sutures distinct, flush to raised, curved; aperture a terminal ovoid slit, surrounded by slightly raised lip.

Size : 200-500 microns in height.

Occurrence : Found throughout the Bavnodde Greensand, first occurrence being in sample AK18 at the base of the Greensand. Solakius and Larsson (1985) also record a first occurrence at this level. BG (Biozones 5, 6).

Stratigraphic range : Santonian to Middle/Late Campanian, Hart *et al.*, (1981). Bailey (1978) noted a constant first appearance in the UK succession towards the base of Assemblage zone C.

Superfamily : *Eouvigerinacea* Cushman, 1927

Family : *Eouvigerinidae* Cushman, 1927

Genus : *Eouvigerina* Cushman, 1926

Type species : *Eouvigerina americana* Cushman, 1926

Eouvigerina aculeata (Ehrenberg, 1854)

(Plate 13, Figure 3)

1854 *Loxostomum aculeatum* Ehrenberg, p.22,pl.27,figs 21-22.

1970 *Eouvigerina aculeata* (Ehrenberg): Porthault, p.57,pl.8,fig.25.

1978 *Eouvigerina aculeata* (Ehrenberg): Bailey, pp.131-134,pl.6,fig.2,3.

1985 *Eouvigerina aculeata* (Ehrenberg): Solakius and Larsson, pp.22-23,pl.3,fig.13.

Description : Test free, small, biserial. Chambers distinct, elongate, pyriform. Final chamber centrally positioned. Sutures flush to slightly depressed. Chambers flanged. Aperture slit like, with small lip, produced on short apertural neck.

Size : Maximum height 200 microns, maximum width 110 microns.

Occurrence : Recorded from the Arnager Limestone (Solakius and Larsson, 1985), AL, BG (Biozones 4-5).

Stratigraphic range : Coniacian to Early Maastrichtian (Solakius and Larsson, 1985)

Subfamily : *Turrilincea* Cushman, 1927

Family : *Turrilinidae* Cushman, 1927

Genus : *Praebulimina* Hofker, 1953

Type species : *Bulimina ovulum* Reuss, 1844.

Praebulimina sp. A

(Plate 13, Figure 4)

Description : Test free, small, slender, gradually, flaring from base. Triserial throughout. Chamber inflation variable, and compressed or slightly elongate. Sutures distinct, depressed. Aperture subterminal to terminal, loop or arch shaped in face of final chamber.

Size : Maximum length 400 microns, maximum width 280 microns.

Occurrence : AG, AL, BG (Biozones 1-6).

Remarks : *Praebulimina* sp. A includes all elongate, slender forms. The stratigraphic utility of forms such as *Praebulimina carseyae* (Plummer, 1931), *Praebulimina laevis* (Beissel, 1891), *Praebulimina obtusa* (d'Orbigny, 1840) and *Praebulimina parva* (Franke, 1928) is limited because of the obvious difficulty in defining the morphological limits of each. This problem is obvious in the

literature (cf. Bailey, 1978; Swiecicki, 1980 and Ball, 1985). Forms recovered from the studied sections were found to represent a range of the above species, and it is therefore my view that all should be placed within this single morphotype.

Praebulimina sp. B

(Plate 13, Figure 5)

Description : Test free, small, rapidly expanding from base giving a distinct globose shape to the test. Chambers triserial throughout. Sutures distinct, slightly depressed. Aperture usually slit like or slightly arched at base of final chamber.

Size : Maximum length 350 microns, maximum width 270 microns.

Occurrence : BG (Biozones 5, 6).

Remarks : The *Praebulimina* sp. B morphotype is clearly distinguishable from the much more slender A type. It is very similar to *Praebulimina reussi* (Morrow, 1934), but can appear to grade into more globose forms of *Praebulimina obtusa*. Morphotype B is considered to represent the more distinctive globose forms of *Praebulimina*.

Superfamily : *Buliminacea* Jones, 1875

Family : *Reussellidae* Cushman, 1937

Genus : *Reussella* Galloway, 1933

Type species : *Verneuilina spinulosa* Reuss, 1850

Reussella cushmani Brotzen, 1936

(Plate 13, Figure 6)

1936 *Reussella cushmani* Brotzen, pp.135-136, pl.8, figs.7a-c, text fig.47.

1957 *Reussella cushmani* Brotzen: Hofker, p.205-207, text figs.248-250.

1985 *Reussella cushmani* Brotzen: Solakius and Larsson, pp.16-17, pl.1, figs.3,9.

Description : Test free, triangular in outline, triserial. Chambers triangular overlapping, sutures distinct, flush, curved. Test surface smooth. Aperture slit like, perpendicular to inner margin of final chamber, surrounded by variable raised lip.

Size : Height 300 microns, maximum width 190 microns.

Occurrence : AL, BG (Biozones 4-6).

Stratigraphic range : Recorded from the Early Santonian (Brotzen, 1936), Santonian to Early Campanian (Hofker, 1957), Late Coniacian to Early Campanian (Kuntz and Monciardini, 1981). Recorded throughout the Arnager Limestone by Solakius and Larsson (1985) and Stenestad (1972).

Remarks : Can be separated from *Reussella kelleri* Vasilenko, 1961, by its distinctly smooth test.

Reussella kelleri Vasilenko, 1961

(Plate 13, Figure 7)

1935 *Reussella* aff. *spinulosa* Keller, p.550, pl.2, figs 9-11.

1961 *Reussella kelleri* Vasilenko, pp.176-178, pl.38, figs 3-5, 12, 13.

1975 *Reussella kelleri* Vasilenko: Robaszynski, p.19, fig.2.

1977 *Reussella kelleri* Vasilenko: Carter and Hart, fig.3, no.12.

1978 *Reussella kelleri* Vasilenko: Bailey, pp.140-141, pl.6, figs 6-8.

1981 *Reussella kelleri* Vasilenko: Hart *et al.*, p.216, pl.7.22, figs 5,6.

1985 *Reussella kelleri* Vasilenko: Solakius and Larsson, pp.17-18, pl.1, figs 1,2.

Description : Test free, subtriangular in outline, triserial, edges angular. Chambers triangular and overlapping. Sutures distinct, curved, raised, spinose and developing small flanges which project. Aperture slit like, perpendicular to inner margin of final chamber.

Size : Height 300 microns, width 150 microns.

Occurrence : Recorded by Solakius and Larsson (1985) from the Arnager Limestone and basal Bavnodde Greensand. AG, AL, BG (Biozones 3-6).

Stratigraphic range : Recorded from the Turonian-Coniacian boundary (Monciardini, 1978), the Turonian-Coniacian (Amedro *et al.*, 1978), the Turonian-Coniacian boundary (Kuntz and Monciardini, 1981), the latest Turonian-Coniacian (Robaszynski, 1983), the Coniacian-Santonian (Vasilenko, 1961) and Coniacian-Santonian (Bailey, 1978)

Reussella szajnochae praecursor De Klasz and Knipscheer, 1954.

(Plate 13, Figure 8)

1954 *Reussella szajnochae praecursor* De Klasz and Knipscheer, pp.603-604,fig.1a-c.

1978 *Reussella szajnochae* (Grzybowski) *praecursor* De Klasz and Knipscheer: Bailey, pp.141-142,pl.6,fig.9.

1989 *Reussella szajnochae praecursor* De Klasz and Knipscheer: Hart *et al.*,p.358,pl.7.22,fig.7.

Description : Test free, triangular in section, triserial. Test margins serrate, spinose. Chambers distinct, subtriangular, overlapping, sutures raised, limbate. Wall calcareous smooth. Aperture slit like extending up inner margin of final chamber.

Size : Height 180 microns, width 150 microns.

Occurrence : Bavnodde Greensand, between samples BO15 to BO17. (Biozone 5).

Stratigraphic range : Santonian to Middle Campanian, Hart *et al.*, (1989)

Remarks: This species is differentiated from *R. kelleri*, by its smaller size, more spinose, generally non-carinate, test angles and raised limbate sutures. (Hart *et al.*, 1989)

Superfamily : *Fursenkoinacea* Loeblich and Tappan, 1961

Family : *Fursenkoinidae* Loeblich and Tappan, 1961

Genus : *Cassidella* Hofker, 1951

Type species : *Virginulina tegulata* Reuss, 1846.

Cassidella tegulata (Reuss, 1845)

(Plate 13, Figure 9)

1845 *Virginulina tegulata* Reuss, p.40,pl.13.fig.81.

1951 *Cassidella tegulata* (Reuss): Hofker, p.265,fig.175.

1967 *Cassidella tegulata* (Reuss): Kent, pp.1449-1451,pl.184,fig.3.

1980 *Cassidella tegulata* (Reuss): Gawor-Biedowa, pp.39-40,pl.8,figs 1-3.

Description : Test free, narrow, elongate, gently tapering. Early triserial part, rapidly becoming biserial. Chambers slightly inflated, sutures distinct, depressed, curved. Wall smooth, perforate.

Aperture elongate, narrow, extending up face of final chamber.

Size : Maximum length 300 microns, maximum width 100 microns.

Occurrence : AL (Biozone 4).

Stratigraphic range : Cenomanian to Maastrichtian (Gawor-Biedowa, 1980)

Superfamily : *Pleurostomellacea* Reuss, 1860

Family : *Pleurostomellidae* Reuss, 1860

Subfamily : *Pleurostomellinae* Reuss, 1860

Genus : *Pleurostomella* Reuss, 1860

Type species : *Dentalina subnodosa* Reuss, 1851

Pleurostomella reussi Berthelin, 1880

(Plate 13, Figure 10)

1880 *Pleurostomella reussi* Berthelin, p.28,pl.1,figs.10a,b,11,12.

1950 *Pleurostomella reussi* Berthelin: ten Dam, p.44,pl.2,fig.15.

1970 *Pleurostomella reussi* Berthelin: Hart, p.206,pl.21,figs 8,9.

Description : Test free, elongate, cuneate, becoming uniserial. Sutures depressed, oblique.

Chambers increasing rapidly in size as added. Surface smooth, test circular in cross section.

Aperture terminal and crescentic with a projecting drawn out hood. Tooth structures indistinct.

Size : Maximum length 300 microns, maximum width 100 microns.

Occurrence : BG (Biozone 5, 6).

Stratigraphic range : Middle Albian to Early Cenomanian (Hart, 1970)

Remarks : Similar to *Pleurostomella barroisi* Berthelin, 1880. Can be distinguished by hood structure, *P. barroisi* possessing a distinct prominent hook developed over the aperture. Records of this species in the Bavnodde Greensand suggest that it may range into the Santonian.

Pleurostomella subnodosa Reuss, 1860

(Plate 13, figure 11)

1860 *Pleurostomella subnodosa* Reuss, p.60,pl.8,fig.2

1978 *Pleurostomella subnodosa* Reuss: Bailey, pp.179-180,pl.11,figs.6,7.

Description : Test free, elongate, cuneate, becoming uniserial. Chambers slightly inflated, gradually increasing in size as added, becoming elongate. Sutures subhorizontal, depressed.

Wall smooth. Aperture subterminal, crescentic, with hood and bifid tooth.

Size : Maximum length 300 microns, maximum width 90 microns.

Occurrence : AL, BG (Biozones 4,5).

Stratigraphic range : Coniacian to Santonian (Bailey, 1978)

Superfamily : *Discorbacea* Ehrenberg, 1838

Family : *Conorbinidae* Reiss, 1963

Genus : *Conorbina* Brotzen, 1936

Type species : *Conorbina marginata* Brotzen, 1936

Conorbina marginata Brotzen, 1936

(Plate 13, Figure 12)

1936 *Conorbina marginata* Brotzen, pp.141-143,pl.10,fig.5a-e,text. fig. 50.

1973 *Conorbina marginata* Brotzen: Norling *in*. Bergstrom *et al.*,p.108,pl.4,fig.4,figs 1-4.

Description : Test free, planoconvex, low trochospiral. Chambers increasing in breadth as added. Sutures oblique and curved on spiral side, nearly radial on the umbilical side. Approximately five chambers in final whorl. Aperture a low slit at base of final chamber.

Size : Diameter 200 microns, height 120 microns

Occurrence : BG (Biozone 5).

Stratigraphic range : Santonian (Norling, 1973).

Family : *Bagginidae* Cushman , 1927

Subfamily : *Baggininae* Cushman, 1927

Genus : *Valvulineria* Cushman, 1926.

Type species : *Valvulineria californica* Cushman, 1926

Valvulineria lenticula (Reuss, 1845)

(Plate 3, Figures 13,14.)

1845 *Rotalia lenticula* Reuss, p.35,pl.12,fig.17.

1936 *Valvulineria lenticula* (Reuss): Brotzen, pp.151-153,pl.11,fig.5a-c,text figs.54,55.

1957 *Valvulineria lenticula* (Reuss): Harris and McNulty, pp.866-867,pl.97,figs 1-5.

1978 *Valvulineria lenticula* (Reuss): Bailey, pp.142-144,pl.6,figs 10-11.

1981 *Valvulineria lenticula* (Reuss): Hart *et al.*, p.222,pl.7.25,figs 8,9.

Description : Test free, low trochospiral, biconvex, periphery rounded. Chambers indistinct, except in last whorl, sutures only seen in later stages, radial, curved. Spiral side flattened, umbilical side convex. Aperture a narrow slit like opening, along inner margin of final chamber. Umbilicus covered by flap.

Size : Maximum diameter 220 microns.

Occurrence : AL, BG (Biozones 3-6).

Stratigraphic range : Turonian to Early Maastrichtian (Hart *et al.*, 1981)

Family : *Eponidae* Hofker, 1951

Subfamily : *Eponidinae* Hofker, 1951

Genus : *Eponides* De Monfort, 1808

Type species : *Nautilus repandus* Fichtel and Moll, 1798

Eponides concinna Brotzen, 1936

(Plate 13, Figure 15)

1936 *Eponides concinna* Brotzen, p.167,pl.12,fig.4a-c.

1966 *Eponides* cf. *concinna* Brotzen: Barr, p.505,pl.79,fig.2a-c.

1978 *Eponides* cf. *concinna* Brotzen: Bailey, pp.172-173,pl.10,fig.7,8.

1989 *Eponides concinna* Brotzen: Hart *et al.*, p.332,pl. 7.9,figs. 6,7.

Description : Test free, low trochospiral, plano to biconvex, periphery circular becoming more lobate towards end of whorl. 7-10 chambers in final whorl, uninflated. Sutures indistinct on dorsal side, depressed on ventral side. Umbilicus variable, may be filled with a calcite boss. This variability is discussed in Barr (1966) and Bailey (1978) and Brotzen (1936). Aperture a narrow slit along inner margin of final chamber with lip.

Size : Diameter 400 microns, height 230 microns.

Occurrence : BG (Biozone 5).

Stratigraphic range : Santonian to Campanian (Hart *et al.*, 1989)

Superfamily : *Planorbulinacea* Schwager, 1877

Family : *Cibicididae* Cushman, 1927

Subfamily : *Cibicidinae* Cushman, 1927

Genus : *Cibicides* De Montfort, 1808

Type species : *Cibicides refluens* De Montfort, 1808

Cibicides beaumontianus (d'Orbigny, 1840)

(Plate 14, Figures 1,2)

1840 *Truncatulina beaumontiana* d'Orbigny, p.35,pl.3,figs 17-19

1934 *Cibicides beaumontiana* (d'Orbigny): Brotzen, p.61.

1956 *Cibicides beaumontianus* (d'Orbigny): Hofker, p.218,fig.37.

1989 *Cibicides beaumontianus* (d'Orbigny): Hart *et al.*, p.326,pl.7.5,figs.9,10.

Description : Test attached, planoconvex or may be enrolled, outline variable, though more usually margins rounded. Five to six subglobular chambers in final whorl, rapidly increasing in size as added, inflated. Sutures distinct, straight and depressed. Aperture slit like or semi circular at base of final chamber. Wall perforate.

Size : Maximum length up to 650 microns.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Santonian to Maastrichtian (Hart *et al.*, 1989)

Cibicides gorbenkoi Akimez, 1961

(Plate 14, Figures 3,4)

1961 *Cibicides (Cibicoides) gorbenkoi* Akimez p.166,pl.16,figs 6a,b,w,7a,b,w.

1972 *Cibicides gorbenkoi* Akimez: Gawor-Biedowa, p.91,pl.12,figs 5a-c,6a-c,text fig.4.

Description : Test free, trochospiral, planoconvex. Oval outline, possessing a narrow keel. Dorsal side flat, evolute with all whorls visible, with 9-11 chambers in the final whorl. Ventral side conical

with only last whorl visible. Chambers indistinct. Large calcite node makes up the apex of the test, forming the cone. Sutures flush to slightly depressed. Aperture semilunar, with thin lip, extending from periphery to dorsal side.

Size : Diameter 400 microns, maximum height 150 microns.

Occurrence : AG (Biozones 1, 2).

Stratigraphic range : Late Albian to Early Turonian (Gawor-Biedowa, 1972)

Cibicides ribbingi Brotzen, 1936

(Plate 14, Figures 5,6)

1936 *Cibicides ribbingi* Brotzen, pp.186-189,pl.13,figs 5a-c,6a-c,text figs 67,68.

1985 *Cibicides ribbingi* Brotzen: Solakius and Larsson, p.40,pl.3,figs 6,7,10-12.

1989 *Cibicides ribbingi* Brotzen: Hart *et al.*, p.326,pl.7.6,figs.1-3.

Description : Test attached, planoconvex, ventral side slightly inflated, peripheral outline variable, becoming irregular as later chambers are added. Margins acute. Sutures flush on dorsal side, slightly depressed on ventral side, straight, radiate. Wall smooth, perforate. Aperture slitlike on inner margin of final chamber, extending towards umbilicus.

Size : Extremely variable, usual sizes around 250 microns in length, 100-150 microns in height.

Occurrence : BG (Biozones 5, 6).

Stratigraphic range : Santonian to Early Maastrichtian (Hart *et al.*,1989)

Superfamily : *Chilostomellacaea* Brady, 1881

Family : *Quadriforminidae* Saidova, 1981

Genus : *Quadriformina* Finlay, 1939

Type species : *Valvulina allomorphinoides* Reuss, 1860

Quadriformina allomorphinoides (Reuss, 1860)

(Plate 14, Figure 7)

1860 *Valvulina allomorphinoides* Reuss, p.223,pl.11,fig.6a-c.

1939 *Quadriformina allomorphinoides* (Reuss): Finlay, p.325.

1978 *Quadriformina allomorphinoides* (Reuss): Bailey, pp.184-185,pl.11,figs 13-14.

Description : Test free, biconvex, trochospiral. Evolute on spiral side, involute umbilical side.

Chambers inflated and rounded, particularly in final whorl. Sutures flush, straight, radial. Wall smooth. Aperture slit like on umbilical side, following inner margin of the final chamber, covered by flap.

Size : Maximum diameter 300 microns

Occurrence : Recorded from the Amager Limestone and basal Bavnodde Greensand as *Valvulineria allomorphinoides* (Solakius and Larsson, 1985). AL, BG (Biozones 4-6).

Stratigraphic range : Middle Albian to Late Cenomanian (Hart, 1970), Santonian to Palaeocene (King *et al.*, 1989). There appears to be a notable gap in the range of this species in the mid-Cretaceous, from the Turonian to Coniacian.

Quadriformina trochoides (Reuss, 1845)

(Plate 14, Figure 8)

1845 *Globigerina trochoides* Reuss, pp.36-37,pl.12,fig.22a,b.

1925 *Allomorphina cretacea* Reuss: Franke, p.28,pl.2,fig.26.

1978 *Quadriformina trochoides* (Reuss): Bailey, pp.185-186,pl.11,figs 15,16.

Description : Test free, small, trochospiral, margins rounded. Final whorl very inflated, chambers globular to slightly compressed. Final chamber half the diameter of the test. Sutures slightly depressed. Wall smooth. Aperture slit like at inner margin of final chamber.

Size : Maximum diameter 340 microns.

Occurrence : AL, BG (Biozones 4-6).

Stratigraphic range : (Bailey, 1978), Santonian.

Family : *Globorotalitidae* Loeblich and Tappan, 1984

Genus : *Globorotalites* Brotzen, 1942

Type species : *Globorotalia multisepta* Brotzen, 1936

Globorotalites micheliniana (d'Orbigny, 1840)

(Plate 14, Figures 9, 10)

1840 *Rotalina micheliniana* d'Orbigny, pp.31-32,pl.3,figs 1-3.

1958 *Globorotalites micheliniana* (d'Orbigny): Witwicka, p.227,pl.9,fig.37a-d.

1981 *Globorotalites micheliniana* (d'Orbigny): Hart *et al.*, p.200,pl.7.14,figs 1,2.

Description : Test free, trochospiral, planoconvex. Spiral side flat to slightly convex, sutures indistinct. Umbilical side conical, involute, umbilicate. Outline circular with a slight keel, sutures slightly depressed. Aperture narrow elongate interiomarginal slit, which may have lip. Wall smooth, perforate.

Size : Diameter 400 microns, maximum height 220 microns.

Occurrence : Recorded by Solakius and Larsson (1985) from the Arnager Limestone and basal Bavnodde Greensand. AL, BG (Biozones 4-6).

Stratigraphic range : Turonian to Campanian (Hart *et al.*, 1981)

Globorotalites polonica Gawor-Biedowa, 1972

(Plate 14, Figure 11)

1972 *Globorotalites polonica* Gawor-Biedowa, pp.97-98,pl.13,fig.6a-c.

Description : Test free, small, conical. Dorsal side flat to slightly convex, evolute. Two and a half whorls visible, 5-6 chambers in final whorl. Sutures arcuate and thickened connecting with keel. Ventral side involute, conical with only last whorl visible. Chambers high, strongly convex, directed in towards centre of test, triangular in outline. Sutures radial, depressed. Umbilicus deep, narrow. Aperture slit like situated between umbilicus and periphery with narrow lip.

Size : 200 microns in diameter, height 100 microns.

Occurrence : AG (Biozones 1).

Stratigraphic range : Late Albian (Gawor-Biedowa, 1972). This form appears to range into the Cenomanian, as it consistently occurs in the Arnager Greensand.

Globorotalites subconicus (Morrow, 1934)

(Plate 14, Figure 12)

1934 *Globorotalia subconica* Morrow, p.200,figs 11a-c.

1954 *Globorotalites subconicus* (Morrow): Frizzell, p.130,pl.20,fig.32a-c.

1970 *Globorotalites subconicus* (Morrow): Owen, pp.206-207,pl.26,figs 14-16.

Description : Test free, planoconvex, conical. Ventral side subconical, involute and umbilicate, with test sides concave. Periphery has distinct poreless keel. Consists of two to two and a half whorls with 6-8 chambers if final whorl, which gradually increase in size. Sutures flush. Large ventral pseudumbilicus is surrounded by prominent angular shoulders. Dorsal side flat to slightly

convex. Wall smooth. Aperture interiomarginal-extraumbilical, bordered by a thin narrow lip.

Apertural face may be indented.

Size : Diameter 350 microns, maximum 150 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Recorded from the Turonian (Owen, 1970). Recorded from the Arnager Greensand suggesting that it is first recorded in the Cenomanian.

Family : *Osangulariidae* Loeblich and Tappan, 1964

Genus : *Osangularia* Brotzen, 1940

Type species : *Osangularia lens* Brotzen, 1940

Osangularia whitei (Brotzen, 1936)

(Plate 14, Figures 13-15)

1936 *Eponides whitei* Brotzen, pp.167-169,pl.12,figs 6-8.

1981 *Osangularia whitei* (Brotzen): Hart *et al.*, pp.21-213,pl.7.20,figs 9.10.

Description : Test free, biconvex, margins angled, becoming carinate. 7-8 chambers in final whorl, gradually increasing in size as added. Sutures straight to slightly oblique, flush. Aperture slit like on inner margin of final chamber.

Size : AG, AL, BG (Biozones 3-6).

Stratigraphic range : Mid-Coniacian to earliest Campanian (Hart *et al.*, 1981)

Remarks : Very similar to *Osangularia cordieriana* (d'Orbigny, 1840), but is distinguished by having a horizontal periphery, in contrast to *O. cordieriana* which has a sigmoidal periphery (Hart *et al.*, 1981). These species are probably part of the same lineage and are difficult to separate. The sigmoidal periphery may be variable according to ecophenotypic constraints.

Osangularia sp. A

(Plate 15, Figures 1-3)

Description : Test free, trochospiral, biconvex. Spiral side slightly convex, with upto 14 chambers in the final whorl. Ventral side slightly convex, chambers indistinct. Sutures flush. Test rounded, margin acutely angled, horizontal. Aperture slit like lying along base of final chamber and splitting to extend back up apertural face.

Size : Maximum diameter 220 microns.

Occurrence : AG (Biozones 1-3).

Remarks: This form may be similar to *Osangularia* sp.1 *sensu* Burnhill and Ramsay (1981), from the Cenomanian of the Central North Sea. *Osangularia schloenbachi* (Reuss), differs in having raised and thickened sutures.

Family : *Gavelinellidae* Hofker, 1956

Subfamily : *Gyroidinoidinae* Saidova, 1981

Genus : *Gyroidinoides* Brotzen, 1942

Type species : *Rotalina nitida* Reuss, 1844

Gyroidinoides nitidus (Reuss, 1844)

(Plate 15, Figures 4-6)

1844 *Rotalina nitida* Reuss, p.214.

1845 *Rotalina nitida* Reuss: Reuss,p.35,pl.8,fig.52,pl.12,figs 8,20.

1942 *Gyroidinoides nitida* (Reuss): Brotzen, p.19,fig.6.3.

1973 *Gyroidinoides nitidus* (Reuss): Koch, p.21.

1978 *Gyroidinoides nitidus* (Reuss): Bailey, pp.191-193,pl.12,figs 6,7,8.

Description : Test free, trochospiral, planoconvex to biconvex. Spiral side low to flat, umbilical side strongly convex. 7-8 chambers in final whorl, sutures flush to slightly depressed, radial, straight. Periphery broadly rounded. Wall smooth, perforate, calcareous. Aperture elongate, narrow slit along the inner margin of the final whorl. Umbilicus small, open.

Size : Diameter 500 microns, maximum height 400 microns.

Occurrence : Recorded from the Arnager Limestone and basal Bavnodde Greensand (Solakius and Larsson, 1985). AL, BG (Biozones 3-6).

Stratigraphic range : Recorded from the Turonian-Coniacian (Gawor-Biedowa, 1972). Coniacian-Santonian (Bailey, 1978).

Remarks : *G. nitidus* is distinctly more convex on the umbilical side than *Gyroidinoides parva* (Khan, 1950) which is ancestral (Hart, 1970).

Gyroidinoides parva (Khan, 1950)

(Plate 15, Figures 7,8)

1950 *Valvulineria parva* Khan, p.275,pl.2,figs 12-14,19.

1970 *Gyroidinoides parva* (Khan): Hart, pp.208-209,pl.22,figs 5,6,7.

Description : Test free, trochospiral, planoconvex, to biconvex. Spiral side very slightly convex. Umbilical side slightly convex. 6-7 chambers in final whorl. Chambers gradually increasing in size as added. Sutures flush to slightly depressed, radial, straight to gently curved. Periphery broadly rounded. Wall smooth, perforate, calcareous. Aperture elongate, narrow slit along inner margin of final whorl. Umbilicus small, open.

Size : Diameter 410 microns, maximum height 300 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Middle Albian to Early Turonian (Hart, 1970)

Remarks: Further work is required to examine the relationships between Aptian-Albian forms described in Magniez-Jannin (1975).

Genus : *Stensioeina* Brotzen, 1936

Type species : *Rotalia exsculpta* Reuss, 1860

Stensioeina exsculpta exsculpta (Reuss, 1860)

(Plate 15, Figures 9-11)

1860 *Rotalia exsculpta* Reuss, p.78,pl.11,fig.4.

1936 *Stensioeina exsculpta* (Reuss): Brotzen, pp.165-166,pl.11,fig.8.

1968 *Stensioeina exsculpta exsculpta* (Reuss): Trumper, pp.25-26,pl.8,figs 1-4,pl.9,fig.1a-c.

1978 *Stensioeina exsculpta exsculpta* (Reuss); Bailey, pp.206-208,pl.14,figs 4-6.

1985 *Stensioeina exsculpta exsculpta* (Reuss): Ball, pp.281-282,pl.24,fig.2a-c.

1985 *Stensioeina exsculpta exsculpta* (Reuss): Solakius and Larsson, pp.26-27,pl.1,figs 16-18,pl.2,figs 8-10.

Description : Test free, planoconvex to biconvex, margins acute, outline circular. Involute on umbilical side, evolute with two and a half whorls visible on the spiral side (dorsal), chambers distinct, subrectangular, sutures distinct sharply raised forming elevated septal ridges. Sutures on umbilical side flush to slightly depressed. Aperture an elongate slit along the inner margin of the final chamber.

Size : Maximum diameter 400 microns, height 120 microns.

Occurrence : Solakius and Larsson (1985) recorded this species from sample 7 in the Amager Limestone, through to sample Hs-7 at the base of the Bavnodde Greensand. In this study true forms of this species are considered to be present between AK18 to AK32/BO16 within the

Bavnodde Greensand. It should be noted that forms illustrated by Solakius and Larsson (1985) are from the basal Bavnodde Greensand, not the Arnager Limestone. Some forms in the Bavnodde Greensand show a tendency to become higher spired towards *Stensioeina exsculpta gracilis*. (Biozones 4?, 5-6).

Stratigraphic range : Mid-Coniacian to Santonian (Hart *et al.*, 1981)

Stensioeina granulata granulata Witwicka, 1958

(Plate 15, Figures 15-17)

1942 *Rotalia exsculpta granulata* Olbertz, p.132,pl.5,fig.2.

1977 *Stensioeina granulata granulata* (Olbertz): Koch, pp.35-36,pl.9,figs 1-3.

1981 *Stensioeina granulata granulata* (Olbertz): Hart *et al.*, p.220,pl.7.24,figs 4-6.

Description : Test free, low trochospiral, periphery narrow subangular to rounded. Chambers distinct on both sides, nine in final whorl, increasing gradually in size as added. Sutures distinct and slightly raised into septal ridges on the spiral side, flush and radial on the umbilical side. Aperture a narrow interiomarginal slit along the ventral side of the final chamber. Surface perforate on the umbilical side, partially granular on the spiral side.

Size : Diameter 400 microns, height 100 microns.

Occurrence: BG (Biozone 6).

Stratigraphic range : Mid-Coniacian to basal Santonian (Hart *et al.*, 1981)

Remarks : This subspecies is distinguished from *Stensioeina granulata polonica* (Olbertz), in having a well developed granular ornament. Some forms recovered from the Bavnodde Greensand do show a probable tendency in developing towards *Stensioeina granulata polonica*.

Subfamily : *Gavelinellinae* Hofker, 1956

Genus : *Gavelinella* Brotzen, 1942

Type species : *Discorbina pertusa* Marsson, 1878

Gavelinella pertusa (Marsson, 1878)

(Plate 16, Figures 1-3)

1878 *Discorbina pertusa* Marsson, p.166,pl.4,fig.35a-e.

1925 *Anomalina pertusa* (Marsson): Franke, P.86,pl.7,fig.16a,b.

1942 *Gavelinella pertusa* (Marsson): Brotzen, pp.41-43,pl.1,figs 1,2,p.6,text fig.1a-c,pl.18,text fig.6,fig.2,text fig.14.

1978 *Gavelinella pertusa* (Marsson): Bailey, pp.197-199,pl.13,figs 1,2.

1981 *Gavelinella pertusa* (Marsson): Edwards, pp.397-398,pl.56,figs 7-9.

Description : Test free, low trochospiral, broadly rounded. Spiral side slightly convex to flattened, ventral side sharply concave with distinct open, wide umbilicus. 8-9 chambers in final whorl, sutures flush to slightly depressed, radial. Test perforate. Aperture an arcuate slit, following inner margin of final chamber.

Size : Maximum diameter 390 microns, maximum height up to 200 microns

Occurrence : Recorded by Solakius and Larsson (1985) from the Arnager Limestone and basal Bavnodde Greensand. AL, BG (Biozones 4-6).

Stratigraphic range : Recorded from the Coniacian to Maastrichtian (Hart *et al.*, 1981). First appearance is in the mid-Coniacian (Edwards, 1981).

Gavelinella baltica Brotzen, 1942

(Plate 16, Figures 4-6)

1942 *Gavelinella baltica* Brotzen, p.50,pl.1,fig.7.

1962 *Gavelinella baltica* Brotzen: Jefferies,pl.1.78,fig.9a-c.

1977 *Gavelinella baltica* Brotzen: Carter and Hart, pp.46-48,pl.1,figs 36-38.

1981 *Gavelinella baltica* Brotzen: Hart *et al.*, p.192,pl.7.10,figs 3-5.

Description : Test free, low trochospiral, biconvex, periphery rounded. Consists of two to two and a half whorls, with eight to twelve chambers in the final whorl. Chambers gradually increase in size as added, all slightly inflated, until the last three to four chambers which are distinctly inflated. Sutures flush to slightly raised initially, becoming depressed distally. Aperture an interiomarginal slit extending from periphery to umbilicus.

Size : Diameter 250 microns, height 100 microns.

Occurrence : AG (Biozones 1, 2).

Stratigraphic range : Latest Albian to Late Cenomanian (Hart *et al.*, 1981)

Gavelinella cenomanica (Brotzen, 1942)

(Plate 16, figure 7)

1942 *Cibicidoides (Cibicides) cenomanica* Brotzen, p.54,pl.2,fig.2a-c.

1966 *Gavelinopsis cenomanica* (Brotzen): Micheal, p.436,pl.50,figs 16-17.

1972 *Gavelinella (Gavelinella) cenomanica* (Brotzen): Gawor-Biedowa, p.126-128,p.17,fig.4a-c.

1973 *Gavelinella cenomanica* (Brotzen): Hart, p.278, text fig.3.

1981 *Gavelinella cenomanica* (Brotzen): Hart *et al.*, p.192,pl.7.10,figs 10-11.

Description : Test free, biconvex, trochospiral, consisting of two to two and a half whorls, with nine to twelve chambers in final whorl, gradually increasing in size as added, sutures depressed. Oval outline, periphery slightly angled. Umbilicus has a very distinctive calcite rim formed around the central depression. Aperture a low interiomarginal slit.

Size : Diameter 800 microns, maximum height 400 microns.

Occurrence : Recorded from the top of the Arnager Greensand (Solakius and Larsson, 1985), AG (Biozones 1-3).

Stratigraphic range : Latest Albian to Cenomanian (Carter and Hart, 1977)

Gavelinella intermedia (Berthelin, 1880)

(Plate 16, Figures 8-10)

1880 *Anomalina intermedia* Berthelin, p.67,pl.4,fig.14a,b.

1942 *Gavelinella intermedia* (Berthelin): Brotzen, p.52, text fig.18.

1972 *Gavelinella (Berthelina) intermedia* (Berthelin): Gawor-Biedowa, pp.120-122,pl.15,figs 7-9(a-c)

1972 *Gavelinella (Berthelina) belorussica* (Akimez): Gawor-Biedowa, pp.116-118,pl.16,figs 5,6,text fig.10.

1977 *Gavelinella intermedia* var. A (Berthelin): Price, p.516,pl.60,figs 9-11.

1977 *Gavelinella intermedia* (Berthelin): Price, p.516,pl.60,figs 7,8.

1977 *Gavelinella intermedia* (Berthelin): Carter and Hart, p.48,pl.1,figs 33-35.

Description : Test free, low trochospiral, periphery rounded and slightly angled, biconvex.

Consists of one and a half to two whorls, with ten to twelve chambers in the final whorl. Sutures depressed to slightly raised, arcuate. Shallow umbilicus on ventral side. Aperture interiomarginal-equatorial arch, with lip.

Size : Diameter 500 microns, height 280 microns.

Occurrence: AG (Biozones 1-3).

Stratigraphic range : Common Albian to Cenomanian species (Hart *et al.*, 1981; Price, 1977; Gawor-Biedowa, 1972)

Remarks : Forms with a distinctive dorsal boss occur within the Amager Greensand. There has been much taxonomic confusion over these forms (see Price, 1977, p.518). The presence of a dorsal boss is considered to be a variable attribute within the limits of definition of the species. It is therefore prudent to include all biconvex dorsally bossed gavelinellids with characteristics attributable to *intermedia*, within the *intermedia* species. *Gavelinella intermedia* var. A (Berthelin) and *Gavelinella (Berthelina) belorussica* (Akimez) are thus synonymous with *Gavelinella intermedia*. Planoconvex, bossed forms, of Cenomanian to Turonian age are distinctive and are referred to *Gavelinella berthelini* (Keller, 1935), (Price, 1977).

Gavelinella lorneiana (d'Orbigny, 1840)

(Plate 16, Figures 11-13)

1840 *Rosalina lorneiana* d'Orbigny, p.36,pl.3,figs 20-22.

1964 *Gavelinella lorneiana* (d'Orbigny): Loeblich and Tappan, p.C759,fig.621,no.6.

1981 *Gavelinella lorneiana* (d'Orbigny): Edwards, pp.396-397,pl.56,figs 1-5.

1985 *Gavelinella lorneiana* (d'Orbigny): Ball, pp.266-268,pl.21,fig.3a-c.

Description : Test free, low trochospiral, consisting of two and a half to three whorls. Outline circular, becoming lobate in final whorl. Periphery broadly rounded to subacute. Concave and evolute on the spiral side, convex and involute with narrow umbilicus ventrally. Chambers indistinct, 8-10 in final whorl, sutures depressed. Aperture a low interiomarginal slit, bordered by an indistinct lip extending into umbilicus which is covered by umbilical flaps.

Size : Diameter up to 400 microns, maximum height upto 150 microns.

Occurrence : AG, AL, BG (Biozones 3-6).

Stratigraphic range : Turonian to Late Campanian (Edwards, 1981, Hart *et al.*, 1981)

Remarks : *Gavelinella lomeiana* is taken to include forms within *Gavelinella ammonoides* (Reuss, 1844), following examination of various descriptions in several works (Edwards, 1981; Bailey, 1978; Brotzen, 1942 and Hart *et al.*, 1981)

Gavelinella reussi (Khan, 1950)

(Plate 17, Figure 1)

1863 *Rosalina complanata* Reuss var. Reuss, p.86,pl.11,fig.3a-c.

1950 *Anomalina complanata* Reuss var. *reussi* Khan, p.277,pl.2,figs 17-18.

1970 *Gavelinella reussi* (Khan): Hart, pp.213-214,pl.23,figs 7-9.

1987 *Gavelinella reussi* (Khan): Leary, p.114,pl.31,figs 4-5.

Description : Test free, low trochospiral, planoconvex. Dorsal side gently convex, consisting of two and a half to three whorls, chambers low broad, gradually increasing in size as added. Sutures slightly depressed, curved. Low boss present obscuring early whorls. Ventral side flat, involute, with shallow umbilicus. Aperture interiomarginal slit extending from periphery into umbilicus.

Size : Diameter 350 microns, maximum height 70 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Middle Albian to Early Turonian (Hart, 1970); Middle Albian to Early Cenomanian (Hart and Swiecicki, 1987).

Gavelinella schloenbachi (Reuss, 1862)

(Plate 17, Figures 2-4)

1862 *Rotalia schloenbachi* Reuss, p.84,pl.10,fig.5.

1935 *Anomalina schloenbachi* (Reuss): Keller, p.553,pl.3,figs 22-24.

1965 *Planulina schloenbachi* (Reuss): Neagu, p.32,pl.8,fig.3a-c.

1972 *Gavelinella (Gavelinella) schloenbachi* (Reuss): Gawor-Biedowa, p.129,pl.16,
fig.2a-c.

1981 *Gavelinella schloenbachi* (Reuss): Edwards, p.402,pl.56,figs 10-12.

Description : Test free, planoconvex, flat and thin, consisting of two to three whorls. Dorsal side slightly convex and evolute, ventral side concave. Final whorl consists of nine to ten uninflated chambers. Sutures flush to slightly depressed, translucent. Umbilicus narrow, partially covered by triangular flaps. Aperture interiomarginal extending into the umbilicus.

Size : Maximum diameter 400 microns, maximum height 100 microns.

Occurrence : AL, BG (Biozones 3-6).

Stratigraphic range : Recorded from the Albian to Turonian (Gawor-Biedowa, 1972) and the Albian to Campanian (Edwards, 1981)

Remarks: This species is not recognised by Hart and Swiecicki (1987). It is morphologically very different from the Early Cretaceous form *Osangularia schloenbachi* (Reuss), which is biconvex and ribbed.

Gavelinella stelligera (Marie, 1941)

(Plate 17, Figures 5-7)

1941 *Planulina stelligera* Marie, p.245,pl.37,fig.344a-c.

1963 *Anomalina (Pseudovalvulineria) stelligera* (Marie): Kaptarenko-Chernousova *et al.*,
pl.20,fig.5a-c.

1981 *Gavelinella stelligera* (Marie): Edwards, p.404,pl.58,figs 12-14.

1985 *Gavelinella stelligera* (Marie): Solakius and Larsson, p.19,pl.1,figs 6-8.

Description : Test free, planoconvex, strongly compressed, low trochospiral, consisting of two and a half to three whorls. Periphery rounded, outline circular. Twelve to thirteen chambers in the final whorl, increasing very gradually in size as added. Sutures oblique, curved and flush. Aperture a narrow interiomarginal slit, passing into shallow umbilicus. Umbilicus filled by chamber flaps. Wall smooth.

Size : Diameter 300 microns, height 120 microns.

Occurrence : Recorded from the Arnager Limestone and basal Bavnodde Greensand (Solakius and Larsson, 1985). AL, BG (Biozones 4-6).

Stratigraphic range : Recorded from the Late Coniacian to Campanian (Edwards, 1981).

Gavelinella thalmani (Brotzen 1936)

(Plate 17, Figures 8-10)

1936 *Cibicides thalmani* Brotzen, pp.190-191,pl.14,figs 7a-c.

1956 *Anomalina (Gavelinella) sculptilis* Hiltermann and Koch, p.38,pl.3,fig.3.

1977 *Gavelinella thalmani* (Brotzen): Koch, p.41,pl.48,figs 1-3.

1985 *Gavelinella thalmani* (Brotzen): Solakius and Larsson, pp.20-21,pl.1,figs 11-13,pl.2,fig.3.

Description : Test free, very low trochospiral, can appear planispiral. Dorsal side slightly compressed, possessing a distinct umbilicus, ventral side, umbilicate and distinctly flattened. Umbilicus covered by flaps. Chambers indistinct in early whorl increasing gradually in size as added, ten to twelve in final whorl. Sutures flush, straight and radial. Sutures on ventral side are indistinct, may be flush or raised, forming an irregular ornament. Aperture an interiomarginal slit, extending from the periphery into the umbilical area.

Size : Diameter 310 microns, height 100 microns.

Occurrence : Recorded by Solakius and Larsson (1985) from the Arnager Limestone and basal Bavnodde Greensand. AL, BG (Biozones 4-6).

Stratigraphic range : Recorded from the Coniacian to Santonian of Sweden (Norling, 1978; Chatziemmanouil, 1982), and from the mid-Coniacian to mid-Campanian of the UK (Hart and Swiecicki, 1987).

Gavelinella cf. tormarpensis Brotzen, 1942

(Plate 17, Figures 11-13)

1942 *Gavelinella tormarpensis* Brotzen, p.52,pl.1,fig.6.

1977 *Gavelinella tormarpensis* Brotzen: Carter and Hart, p.48,pl.1,figs 31-32.

1986 *Gavelinella tormarpensis* Brotzen: Sandman, pp.40-41, pl.4,figs 3-4.

Description : Test free, small, low trochospiral, periphery rounded. Spiral side slightly convex, umbilical side distinctly concave. Five to six chambers in final whorl, gradually increasing in size as added with final chamber inflated. Sutures depressed on dorsal side, though this may be quite indistinct, depressed and arcuate on umbilical side. Small boss may be present on spiral side.

Aperture interiomarginal slit. Test perforate, smooth.

Size : Diameter 320 microns, maximum height 280 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Albian to Early Cenomanian (Sandman, 1986)

Remarks : The stellate dorsal pattern is not well seen in specimens recovered, hence the use of "cf".

Gavelinella tourainensis (Butt, 1966)

(Plate 18, Figures 1-3)

1966 *Gavelinopsis tourainensis* Butt, p.176,pl.4,figs 1-3.

1977 *Gavelinella cf. tourainensis* (Butt): Carter and Hart, pp.330-331,figs 3,9.

1978 *Gavelinella* sp. B Bailey, p.202,pl.13,figs 10-12.

1985 *Gavelinella cf. tourainensis* (Butt): Ball, pp.274-275,pl.22,fig.4a-c.

Description : Test free, planoconvex. Dorsal side partially evolute, ventral side involute. Dorsal side possesses a distinct large boss. Periphery subacute, with variable development of a slight keel. Ten to eleven chambers visible in final whorl. Sutures curved and depressed on dorsal side, depressed on ventral side. Aperture an interiomarginal slit extending into umbilicus.

Size : Diameter 400 microns, height 300 microns.

Occurrence : Recorded from the Amager Limestone as *Gavelinella cf. tourainensis* by Solakius and Larsson (1985). AG, AL (Biozones 3, 4).

Stratigraphic range : Recorded from the Late Cenomanian to Late Turonian (Robaszynski, 1983), from the Turonian to Coniacian (Hart and Swiecicki, 1987), from the Coniacian (Monciardini, 1981)

Remarks : This morphotype is clearly part of the *Gavelinella reussi* (Khan, 1863) - *Gavelinella berthelini* (Keller, 1935) lineage. (Bailey, 1978; Ball, 1985)

Gavelinella tumida Brotzen, 1942

(Plate 18, Figures 4-6)

1936 *Anomalina lorneiana* (d'Orbigny): Brotzen, p.178,pl.12,figs 1,2.

1942 *Gavelinella tumida* Brotzen: pp.47-48,fig.15.

1973 *Gavelinella tumida* Brotzen: Norling, p.112,pl.8,figs 2,3.

1978 *Gavelinella tumida* Brotzen: Bailey, pp.200-201,pl.13,figs 8,9.

Description : Test free, low trochospiral. Dorsal side flat to slightly convex, ventral side distinctly involute and umbilicate. Chambers distinct, up to eight in final whorl, with the final two or three chambers highly inflated. Sutures radial, straight, constricted where chambers are inflated. Wall smooth, perforate. Aperture slit like, extending from periphery into umbilicus.

Size : Maximum diameter 300 microns, height up to 210 microns.

Occurrence : AL, BG (Biozones 4-6).

Stratigraphic range : Recorded from the Late Turonian to Middle Santonian (Hart and Swiecicki, 1987) and the Turonian to Early Campanian (Norling, 1973).

Gavelinella sp. A

(Plate 15, Figures 12-14)

Description : Test free, low trochospiral, dorsal side flat to slightly concave, ventral side involute. Chambers indistinct, ?probably up to nine in final whorl. Sutures distinct flush, often difficult to see. Wall smooth, margins rounded. Aperture slit like extending from periphery into umbilicus.

Size : Maximum diameter 250 microns.

Occurrence : AL (Biozone 4).

Remarks : An indistinct species of which only two specimens were recovered.

Notes on the evolution of the genus *Gavelinella*.

Hart and Swiecicki (1987) outline two clear evolutionary lineages within the *Gavelinella* group; the *G. barremiana* - *G. intermedia* lineage and the *G. ammonoides* - *G. lorreiana* - *G. clementiana* lineage. Elements of these two distinctive lineages may be recognised within the succession. Edwards (1981) also recognised two lineages in Senonian *Gavelinella*, one derived

from *G. ammonoides* stock in the Turonian and one derived from *G. schloenbachi* stock throughout the Turonian and Senonian.

Gavelinella schloenbachi is not recognised by Hart and Swiecicki (op. cit). This species was recorded by Edwards (op. cit) and has been recognised from the Bornholm succession from the Arnager Limestone. This form is clearly very different from the Albian *Osangularia schloenbachi*.

The Arnager Greensand is characterised by typical Cenomanian *Gavelinella*, principally, *G. cenomanica*, *G. intermedia* and *G. baltica*, these species were probably derived from *G. rudis* in the Late Albian (Hart and Swiecicki, op. cit)

The Arnager Limestone and the Bavnodde Greensand contain a typical Senonian *Gavelinella* fauna. There is a clear morphological similarity between *G. ammonoides* and *G. lorneiana*, and these species were not split in this study, since the two are probably synonymous. It is also possible that the *intermedia* group is ancestral to the *ammonoides/lorneiana* group given their general morphological similarities.

The occurrence of *G. schloenbachi* at the base of the limestone and subsequent appearances of *G. thalmani* and *G. stelligera* suggest that Edwards (op. cit, p.411) model for the evolution of this group is correct. *G. stelligera* clearly appears earlier in the Coniacian, than is suggested by both papers mentioned above.

Gavelinella tumida is difficult to fit into a lineage, and an ancestral form cannot be recognised. *G. pertusa* is clearly part of the *G. schloenbachi* group, separating in the Coniacian. Bailey (pers comm.) has suggested that *Gavelinella tumida* may be related to *Gavelinella pertusa* in being more inflated.

ALBIAN	CENOMANIAN	TURONIAN	CONIACIAN	SANTONIAN
				<i>Gavelinella pertusa</i>
<i>Osangularia schloenbachi</i>				
				<i>Gavelinella thalmanni</i>
<i>Gavelinella reussi</i>		<i>Gavelinella tourainensis</i>		
<i>Gavelinella kelleri</i>				
	<i>Gavelinella baltica</i>			
	<i>Gavelinella intermedia</i>			
	<i>Gavelinella cenomanica</i>			
			<i>Gavelinella ammonoides</i> / <i>Gavelinella lomeiana</i>	

Figure 3.1 Suggested evolutionary interpretation of the genus *Gavelinella* during the Albian - Santonian. Based on Hart and Swiecicki (1988) and Edwards (1981).

Genus : *Lingulogavelinella* Malapris, 1965

Type species : *Lingulogavelinella albiensis* Malapris, 1965

Lingulogavelinella jarzevae (Vasilenko, 1954)

(Plate 18, Figures 7-9)

1954 *Cibicides (Cibicides) jarzevae* Vasilenko, p.121,pl.17,fig.3a-c.

1977 *Lingulogavelinella jarzevae* (Vasilenko): Carter and Hart, p.49,pl.1,figs 29-30.

1981 *Lingulogavelinella jarzevae* (Vasilenko): Hart *et al.*, p.208,pl.7.18,figs 11-13.

Description : Test free, planoconvex, with rounded periphery. Spiral side irregularly convex, consisting of a distinctive final whorl of 5-7 highly inflated chambers. Sutures very depressed, slightly curved. Apertural side flat, with star shaped pattern made up of relict apertural flaps.

Aperture an interiomarginal slit, extending from periphery to umbilicus.

Size : Diameter 410 microns, maximum height 220 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Latest Albian to Early Cenomanian (Hart *et al.*, 1981)

Lingulogavelinella arnagerensis (Solakius, 1988)

(Plate 18, Figures 10-12)

1945 *Pseudovalvulineria vombensis* Brotzen, pp.50-51,pl.1,13a-c,fig.9,1-4.

1981 *Gavelinella vombensis* (Brotzen): Edwards, pp.404-405,pl.56,figs 1-3.

1981 *Lingulogavelinella* sp. cf. *vombensis* (Brotzen): Hart *et al.*, p.210,pl.7.19,figs 1-3.

1988 *Gavelinella arnagerensis* (Solakius); pp.198-201,figs 2E-P,3A-J.

Description: Test free, low trochospiral. Spiral side possesses distinct boss, covering earlier whorls. Periphery rounded. Last whorl with 9-12 chambers which gradually increase in size as added. Sutures curved and slightly depressed on spiral side. Umbilical side involute, with distinct stellate pattern with thread like depressions. Aperture a narrow interiomarginal slit, with apertural flap. Test surface smooth.

Size : Maximum diameter 700 microns.

Occurrence : Recorded by Solakius (1988) from the Arnager Limestone and lower part of the Bavnodde Greensand. AL, BG (Biozones 3-5).

Stratigraphic range : Turonian to Coniacian (Solakius, 1988)

Remarks : The presence of a distinctive stellate pattern on the umbilical side suggests that this species should be placed within *Lingulogavelinella*.

***Lingulogavelinella ciryi inflata* Malapris-Bizouard (1977)**

(Plate 19, Figures 1-3)

1977 *Lingulogavelinella ciryi inflata* Malapris-Bizouard, pp.139-

141,pl.1,fig.20,pl.2,figs 21-22.

Description : Test free, very low trochospiral, consisting of two and a half to three whorls. Outline oval, with distinctive flattened periphery. Dorsal side slightly concave and flattened initially. Chambers indistinct, until last four which are inflated. Sutures flush and indistinct becoming distinct and depressed distally, curved. Ventral side involute, flattened, with shallow umbilicus partially covered by earlier chamber flaps. Test smooth. Aperture interiomarginal slit extending into umbilicus, with lip.

Size : Diameter 200 microns, maximum height 80 microns.

Occurrence: AG (Biozones 1-3).

Stratigraphic range : Cenomanian, King *et al.*, (1989).

Remarks : This species has been previously recorded from France and the central North Sea Basin (King *et al.*, 1989)

Lingulogavelinella ornatissima (Lipnik, 1961)

(Plate 19, Figures 4-6)

1961 *Cibicides (Anomalinoidea) ornatissimus* Lipnik, pp.59-60,pl.6,fig.4a-c.

1972 *Lingulogavelinella ornatissima* (Lipnik): Gawor-Biedowa, pp.110-111,pl.15,fig.6a-c,text fig.8.

Description : Test free, low trochospiral, involute, biconvex, without distinct umbilicus, probably composed of two to two and a half whorls. Only the last whorl is visible on both sides, consisting of nine to ten very gently inflated chambers. Chambers terminate in the centre of the test on both sides in triangular flaps. These may fuse initially on either side of the test. Tubercles may develop in the centre of the test on one side. Aperture interiomarginal, equatorial. Test finely perforate.

Sutures flush to depressed, radial.

Size : Diameter 400 microns, maximum height 150 microns.

Occurrence : AG (Biozone 1).

Stratigraphic range : Cenomanian to Early Turonian (Gawor-Biedowa, 1972).

Chapter Four

Biostratigraphy

4.1 Introduction.

A new micropalaeontological biozonation based on the foraminiferal stratigraphic record is defined.

The approach to the zonation is twofold. Firstly individual species and assemblages are compared to previously published information in order to provide an age for the formations studied.

Secondly a local biozonation is proposed for the succession. This reflects particular events not only within the evolution and extinction of various microfaunal groups, but more importantly events occurring within the basin during deposition which may have a profound influence on the type of microfauna recovered. These basin events comprise facies changes and hiatuses, the causes of which are likely to be basin wide events such as transgression / regression, block faulting or inversion. It is hoped that the zonation produced will therefore be useful for correlation within the basin, should more information ever become available.

It must be pointed out that since this zonation is described from a positive area within the basin it is very likely to be incomplete when compared to thicker, more complete sequences within the graben areas. Biostratigraphic and lithostratigraphic features of the described section should still be correlatable with more complete sequences, however.

There are two main limiting factors which affect the zonation described. Firstly the presence of a major hiatuses within the sequence, and secondly the major facies changes that occur.

The presence of a major hiatus at the Arnager Greensand / Arnager Limestone boundary is in itself a finite problem since the sediments either side of the boundary can be dated, but the actual boundary itself can only be dated by correlation with regional events and some equivocal micropalaeontological data. The lithological characteristics of the boundary limit microfaunal recovery.

The facies changes within the sequence represent differing palaeoenvironmental settings, with differing physico-chemical conditions, e.g. water depth, energy regime,

substrate. This variation in physico-chemical conditions will affect the temporal occurrence of certain morphotypes. As will be seen, assemblages from the "Greensands" are very different in morphogroup composition from those of the limestone facies, this is partly due to preservation, but is more importantly the result of palaeoenvironmental control. One major advantage of this sandwich like alternation of facies is that it provides a unique opportunity to examine morphotypic variation in the same substrate setting, within different temporal regimes. This will be examined more fully in chapter five.

From a biostratigraphic view this change in facies raises the immediate question as to whether the influx of a particular species is an event that is primarily controlled by time or by environmental conditions or by a combination of both.

These limiting factors are of course present within any sequence to a certain degree, but the problem of major facies changes has not for example been encountered by major studies on the chalk (cf. Bailey and Hart, 1979), onshore. Work on the North Sea Basin has however resulted in the presentation of two separate zonations for the shelf and more basinal facies (King *et al.*, 1989). This clearly shows that facies variations may have a profound affect on the microfaunal zonations produced, since most benthic foraminifera are facies dependant. ("Facies variations" here is taken to include differences in water depth etc., that limit the fauna present in a particular section.)

The zonation presented for the Bornholm succession, must therefore be regarded as an "event" zonation. The highest occurrence of a particular taxon may be the result of a process other than its evolutionary demise.

4.2 Description of Biozones.

The biozonal scheme is presented in Figure 4.1 and described below. The description includes the definition of each biozone, its microfaunal content, its extent within the sequence, and its geological age by comparison of the faunal content to previously published work.

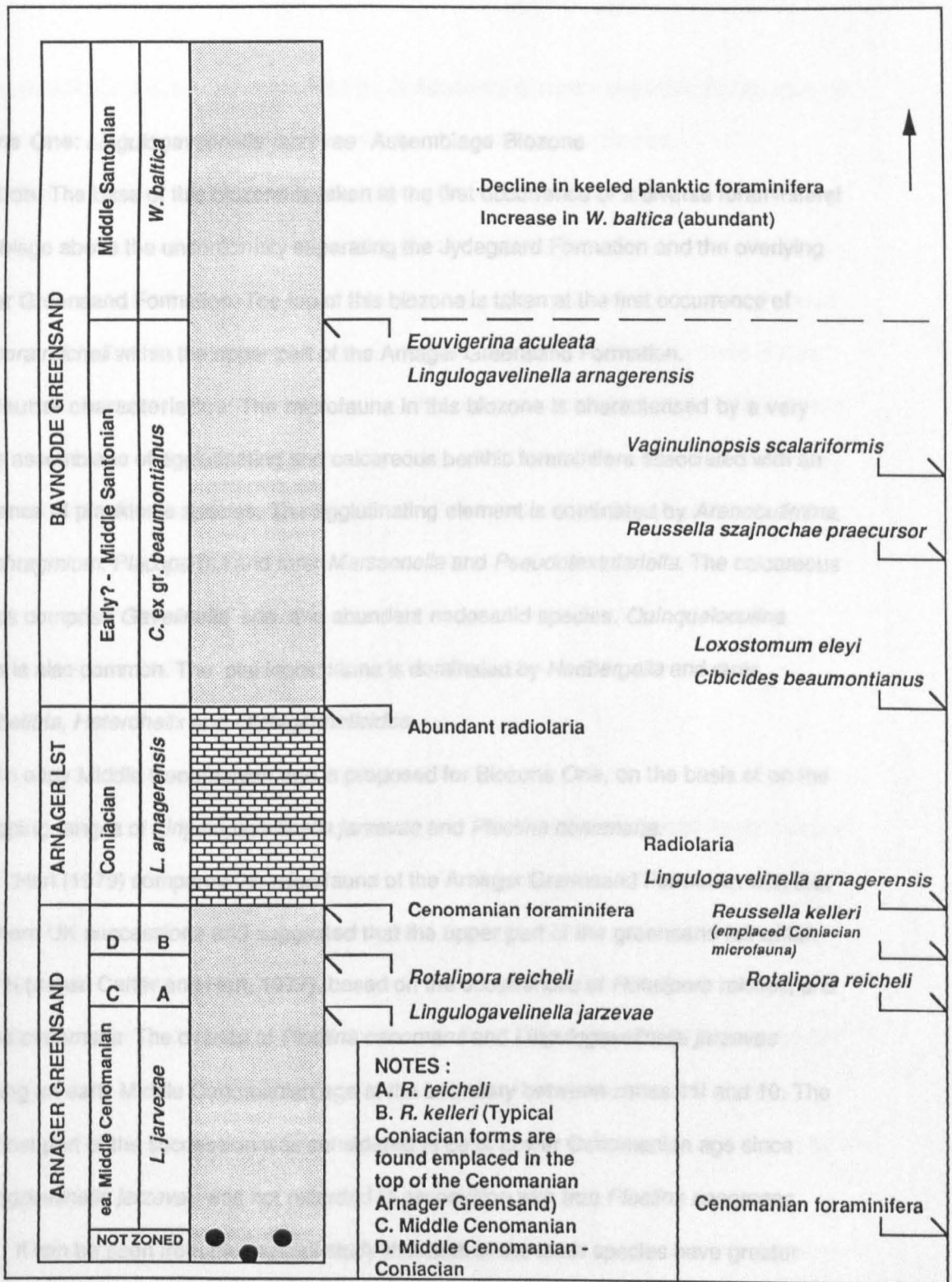


Figure 4.1 Micropalaeontological zonal scheme for the Albian-Santonian of Bornholm. (Not to scale)

Biozone One: *Lingulogavelinella jarzevae* Assemblage Biozone

Definition: The base of this biozone is taken at the first occurrence of a diverse foraminiferal assemblage above the unconformity separating the Jydegaard Formation and the overlying Arnager Greensand Formation. The top of this biozone is taken at the first occurrence of *Rotalipora reicheli* within the upper part of the Arnager Greensand Formation.

Microfaunal characteristics: The microfauna in this biozone is characterised by a very diverse assemblage of agglutinating and calcareous benthic foraminifera associated with an abundance of planktonic species. The agglutinating element is dominated by *Arenobulimina*, *Ataxophragmium*, *Placopsilina* and rarer *Marssonella* and *Pseudotextulariella*. The calcareous benthics comprise *Gavelinella* spp. and abundant nodosariid species. *Quinqueloculina antiqua* is also common. The planktonic fauna is dominated by *Hedbergella* and rarer *Guembelitra*, *Heterohelix* and *Globigerinelloides*.

Age: An early Middle Cenomanian age is proposed for Biozone One, on the basis of on the overlapping ranges of *Lingulogavelinella jarzevae* and *Plectina cenomana*.

Hart (1979) compared the microfauna of the Arnager Greensand Formation with that of onshore UK successions and suggested that the upper part of the greensand fell within zone 11i (*sensu* Carter and Hart, 1977), based on the occurrences of *Rotalipora reicheli*, and *Plectina cenomana*. The overlap of *Plectina cenomana* and *Lingulogavelinella jarzevae* indicating an early Middle Cenomanian age at the boundary between zones 11i and 10. The lowermost part of the succession was considered to be of Lower Cenomanian age since *Lingulogavelinella jarzevae* was not recorded in association with true *Plectina cenomana*.

It can be seen from the present study that both of the latter species have greater ranges within the greensand than previously indicated by Hart (1979), based on more complete sampling of the succession. *Lingulogavelinella jarzevae* occurs in samples above the level indicated by Hart (*op. cit.*), and specimens of *Plectina cenomana* are present from the base of the Arnager Greensand. These forms are slightly shorter than true *P. cenomana*, but are considered here to be within the morphological limits of this species. Consequently this interpretation means that the whole of Biozone One is considered to be early Middle

Cenomanian in age (i.e. no older than the 11i / 10 boundary of Carter and Hart, 1977), apart of course from the basal conglomerate which clearly contains older ammonites.

This conclusion fits with ammonite data suggesting that the greater part of the Arnager Greensand Formation is of early Middle Cenomanian age.

The presence of Albian ammonites within primary phosphate nodules (at the base of the Arnager Greensand) indicates that deposition occurred during the Albian. There is little foraminiferal evidence for this, which is not surprising, given that the Albian ammonites occur within nodules that are Cenomanian in age (Kennedy *et al.*, 1981). Many of the taxa recorded within the Arnager Greensand are typically Albian - Cenomanian, but distinctive Albian elements cannot be recognised. *Gavelinella tormarpensis* is recognised as being restricted to the Albian (Hart and Swiecicki, 1987; Hart, 1970), though it has been recorded from the Lower Cenomanian (Sandman, 1986).

Biozone Two: *Rotalipora reicheli* Assemblage Biozone

Definition: The base of this biozone is taken at the first occurrence of *Rotalipora reicheli* and associated acme of *Plectina cenomana*. The top of the zone is taken at the first occurrence of *Reussella kelleri* and associated Coniacian fauna at the base of Biozone Three.

Microfaunal characteristics : *Rotalipora reicheli* was recorded from a single sample recovered from a temporary exposure (in 1975), (see Hart, 1979). The interval just above this level, approximately 4m below the level of the phosphatised conglomerate was augered by the author and MBH in 1988. It was found to contain a highly decalcified fauna dominated by *Plectina cenomana*.

The sample with *Rotalipora reicheli* present was found to contain abundant *Plectina cenomana*, and a diverse agglutinating and calcareous fauna, including abundant planktics. *Rotalipora reicheli* is known to occur within a thin interval in the UK onshore succession (Carter and Hart, 1977) and it would seem that the same is true for the Bornholm succession. The impoverished *Plectina* fauna above the level of *Rotalipora reicheli* probably reflects the influence of local groundwater conditions, as samples of the Arnager Greensand above beach level do contain a more abundant calcareous fauna, than those recovered by augering.

Age: Middle Cenomanian, indicated by *Rotalipora reicheli* (cf. Hart *et al.*, 1989)

Biozone Three: *Reussella kelleri* Assemblage Biozone.

Definition: The base of this zone is defined on the first occurrence of *Reussella kelleri* and an associated influx of a Coniacian foraminiferal fauna. The top of the zone is taken at the highest occurrence of the Cenomanian foraminiferal fauna

Microfaunal characteristics: This biozone comprises the highly bioturbated interval just below the phosphatised conglomerate at the base of the Arnager Limestone Formation. The Coniacian fauna encountered within typical Cenomanian assemblages is clearly derived from the lower part of the Arnager Limestone, and has probably been emplaced in the very top of the Arnager Greensand by the action of burrowing organisms. The typical Middle Cenomanian fauna is found to top within sample AK4, just below the level of the phosphatised conglomerate.

Age: There is then evidence of a major hiatus from the Middle Cenomanian to Coniacian. However the presence of rare forms of *Whiteinella aprica* within this biozone may suggest that deposition occurred during the Late Cenomanian to Late Turonian. This line of evidence has to be regarded as equivocal however, because the few specimens recovered were poorly preserved, and at least some might be confused with the *Archaeoglobigerina* group, which are more typical of the Coniacian. The suggestion that deposition may have continued at a reduced rate through the Late Cenomanian / Turonian is supported by evidence from dinoflagellate cyst assemblages at this level. Packer *et al.*, (1989) show that mixed dinocyst assemblages at the junction between the Arnager Greensand and Arnager Limestone indicate a ?Late Cenomanian to Late Coniacian age.

Whilst it is accepted that the above evidence for continued deposition through the Late Cenomanian to Turonian is by no means conclusive, it would conversely be an oversimplification to state that there is a single hiatus from the Middle Cenomanian to Coniacian at this level.

The presence of this disconformity and associated turnover in microfauna clearly indicates an event from the Middle Cenomanian onwards, the causes of which will be discussed in later chapters.

From the above, it is concluded that Biozone Three represents an interval from the Middle Cenomanian to Coniacian.

Biozone Four *Lingulogavelinella arnagerensis* Assemblage Biozone.

Definition: The base of this zone is taken at the highest occurrence of Middle Cenomanian taxa, at the level of the phosphatised conglomerate at the base of the Arnager Limestone Formation. The top of the zone is taken at the first appearance of *Loxostomum eleyi* and *Cibicides beaumontianus* just above the top of the Arnager Limestone, at the base of Biozone Five. Biozone Four comprises the whole of the Arnager Limestone.

Microfaunal characteristics: The foraminiferal fauna is characterised by abundant calcareous benthic species, dominated by *Gavelinella*, *Osangularia*, *Valvulineria*, *Reussella*, *Praebulimina*, *Globorotalites* and abundant nodosariids. The agglutinating benthic fauna is comprised mainly of three genera, *Gaudryina*, *Arenobulimina* and *Ataxophragmium*.

The planktonic fauna is characterised by abundant *Dicarinella*, *Marginotruncana*, *Whiteinella*, *Globigerinelloides* and rarer *Heterohelix*. The keeled taxa show a gradual decline through the Arnager Limestone Formation, whilst the non keeled planktics show a slight increase. Radiolaria are common to abundant throughout the limestone.

Age: The presence of *Gavelinella thalmani* and *Gavelinella pertusa* at the base of the Arnager Limestone Formation suggest that deposition of the limestone began in the mid-Coniacian. *Gavelinella thalmani* is reported to have its first occurrence in the mid-Coniacian (Hart and Swiecicki, 1987), and *Gavelinella pertusa* is also reported to have its first occurrence in the mid-Coniacian, Edwards (1981).

Solakius and Larsson (1985) suggested that deposition of the Arnager Limestone Formation began at least in the latest early Coniacian, on the basis of the occurrences of *Gavelinella thalmani*, *Gavelinella pertusa* and *Gaudryina rugosa*, near the base of the limestone.

The above evidence suggests that there is a hiatus at this level with part of the Coniacian missing or condensed as part of the conglomerate complex represented in Biozone Three.

There is no microfaunal evidence for the Arnager Limestone Formation being any younger than Coniacian. The first occurrence of *Lingulogavelinella arnagerensis* (*Lingulogavelinella* sp. cf. *L. vombensis* of Bailey *et al.*, 1983) towards the base of the limestone suggests a stratigraphic level equivalent to the base of the *L. sp. cf. L. vombensis* assemblage zone defined by Bailey *et al.*, (1983) from southern England, which falls within the upper part of the *M. cortestudinarium* Zone. The absence of *Loxostomum eleyi* until the basal part of the overlying Bavnodde Greensand Formation could suggest that deposition of the Arnager Limestone is restricted to an interval within the Coniacian equivalent to and just below the *L. sp. cf. L. vombensis* zone of Bailey *et al.*, (op. cit). This conclusion was also reached by Solakius (1989).

Solakius and Larsson (1985) proposed two biozones for the Arnager Limestone Formation, a *Reussella kelleri* Biozone and *Stensioeina exsculpta exsculpta* Biozone. The *Reussella kelleri* Biozone is not properly defined as *Stensioeina exsculpta exsculpta* is used to define the top of the zone, as opposed to *Osangularia cordieriana* which strictly defines the top of the zone according to Amedro *et al.*, (1978). This biozone is not therefore considered valid in its present usage as defined by Solakius and Larsson (1985). It is also clear that *Reussella kelleri* occurs well below the level indicated by the authors. Solakius (1989) does appear however to revise this by stating that the limestone falls within the *Lingulogavelinella* sp. cf. *L. vombensis* Zone of Bailey *et al.*, (1983.)

Stensioeina exsculpta exsculpta has not been recovered in the present study from the levels in the Arnager Limestone Formation indicated by Solakius and Larsson (1985). This species clearly occurs within the overlying Bavnodde Greensand Formation and is well preserved. The presence of *Stensioeina exsculpta exsculpta* within the limestone as indicated by the latter authors would be consistent with its first occurrence within the *L. sp. cf. L. vombensis* zone as defined by Bailey *et al.*, (1983). It should be noted however that

Stensioeina granulata granulata has not been recorded from the limestone which would be expected through this interval.

The planktonic foraminifera recorded from the Arnager Limestone Formation are consistent with a Coniacian age. The highest occurrence of *Marginotruncana pseudolinneiana* in sample AK16 at the top of the Arnager Limestone may be important. According to Robaszynski and Caron (1979) this species ranges no higher than the Middle Coniacian. *Dicarinella concavata* occurs near the top of the limestone, this species ranges from the mid-Coniacian - early-Late Sartonian (Caron, 1975).

From the above it is concluded that the Arnager Limestone, encompassed within Biozone 4 is of Mid-Coniacian age or possibly younger within the Coniacian.

Biozone Five: *Cibicides ex. gr.beaumontianus* Assemblage Biozone.

Definition: The base of this biozone is taken at the first occurrence of *Loxostomum eleyi* and *Cibicides ex. gr.beaumontianus* at the base of the Bavnodde Greensand. The top of this biozone is taken at the highest occurrence of *Eouvigerina aculeata* and *Lingulogavelinella amagerensis*. This level is coincident with an increase of *Whiteinella baltica* at the base of Biozone Six. This biozone comprises the lower part of the Bavnodde Greensand Formation.

Microfaunal characteristics: The foraminiferal fauna through this biozone shows a marked change from Biozone 4 below. Just above the boundary between the Arnager Limestone and Bavnodde Greensand many new taxa occur for the first time, including *Cibicides ribbingi*, *Cibicides ex. gr.beaumontianus*, *Loxostomum eleyi*, *Neoflabellina* spp. and *Globotruncana* spp. Calcareous benthic taxa are common, while agglutinating benthic taxa are less so, the most important genera being *Arenobulimina* and *Ataxophragmium*. Keeled planktonic genera are common, consisting mainly of *Globotruncana linneiana* and *Globotruncana bulloides*. Non-keeled taxa are also abundant, dominated by *Whiteinella* spp. Radiolaria also occur sporadically through this biozone.

Age: The presence of *Cibicides ex. gr.beaumontianus* and *Loxostomum eleyi* at the base of this biozone in association with *Lingulogavelinella amagerensis* suggests a level equivalent to

the *Cibicides ex. gr. beaumontianus* assemblage Zone of Bailey *et al.*, (1983), within the Santonian near the top of the *M. coranguinum* Zone.

The occurrence of *Vaginulinopsis scalariformis* within this biozone suggests an earliest Santonian age. Hart *et al.*, (1989), indicate that *V. scalariformis* may be an important zonal species for the earliest Santonian.

Stensioeina exsculpta exsculpta occurs through this interval and includes forms which are trending towards *Stensioeina exsculpta gracilis*. *Stensioeina granulata granulata* is also recorded near the top of this biozone. The lack of *Stensioeina granulata polonica* cannot be explained, if it is assumed that this zone may be equivalent to the *C. ex. gr. beaumontianus* Zone cited earlier. It is possible that the *Stensioeina* group is showing a facies preference, with the absence of *Stensioeina granulata polonica* related to the development of a greensand facies. Conversely the trend towards *Stensioeina exsculpta gracilis*, and the absence of *Stensioeina granulata polonica* may indicate levels within the later Middle Santonian.

Globotruncana bulloides occurs from the base of the Bavnodde Greensand Formation, and has its first stratigraphic occurrence in the Middle Santonian (Robaszynski *et al.*, 1984). (It should be noted that the separation of *Marginotruncana pseudolinneiana* and *Globotruncana linneiana* at this time is considered to be difficult taxonomically.) *Dicarinella asymetrica* also occurs within this interval and again this species first occurs in the Middle Santonian (Robaszynski *et al.*, 1984).

On balance then it would seem that a Middle Santonian age is most appropriate for this biozone, however the occurrence of *Vaginulinopsis scalariformis* would indicate an Early Santonian age. It is therefore concluded that this biozone is ?Early- Middle Santonian age.

Recent macrofossil evidence, Christensen (1984) and Christensen (pers. comm.) suggests that lower parts of the Bavnodde Greensand Formation are Late Coniacian in age. Foraminiferal evidence for this is lacking, though this question might be resolved by further sampling and detailed work on the *Stensioeina* lineage.

Biozone Six: *Whiteinella baltica* Assemblage Biozone.

Definition: The base of this biozone is defined on the highest occurrences of *Lingulogavelinella arnagerensis*, *Eouvigerina aculeata* and the associated acme of *Whiteinella baltica* above this level. The top of this biozone is constrained by the top of the Bavnodde Greensand exposure.

Microfaunal characteristics: The foraminiferal assemblages through this interval comprise a diverse suite of calcareous benthics which are generally dominated by nodosariid species. Other benthics are represented by *Gavelinella*, *Loxostomum*, *Praebulimina*, *Gyroidinoides* and *Globorotalites*. Planktonic foraminifera are dominated by *Whiteinella* spp., mainly *Whiteinella baltica*, which becomes very abundant through this interval.

Archaeoglobigerina is also common to abundant, whilst the keeled *Globotruncana* spp. show a marked decline in abundance up section.

Age: The highest occurrence of *Gavelinella tumida* within this biozone suggests that it is no younger than Middle Santonian. Hart and Swiecicki (1987) suggest that *Gavelinella tumida* ranges from the Late Turonian to Middle Santonian. It should be noted however that Norling and Bergstrom (1984) have recorded this species from the Campanian.

By comparison with Bailey *et al.*, (1983) it would seem improbable that the Bavnodde Greensand is any younger than *Cibicides* ex. gr. *beaumontianus* Zone in age, since marker species more typical of levels higher than this including *Gavelinella cristata*, *Stensioeina granulata perfecta* and *Bolivinooides strigillatus* were not recorded. It should be borne in mind however that comparisons made here are between local benthic assemblage zones where facies differences may affect stratigraphical distributions.

4.3 Comparison of ages with macrofaunal data.

4.3.1. The age of the Arnager Greensand.

Ammonite evidence (Kennedy *et al.*, 1984) clearly shows that Albian faunas are present within the primary nodules at the base of the greensand. Secondary nodules were found to contain Early Cenomanian faunas. There is no micropalaeontological evidence to support this dating (nodules were sectioned, but these yielded no foraminiferal data), but this

is not unexpected since intense phosphatisation and diagenetic processes would have destroyed any foraminiferal fauna.

The main part of the greensand was dated as early-Middle Cenomanian on ammonites by Kennedy *et al.*, (op. cit) and the microfaunal evidence clearly supports this dating, (Biozones One and Two)

4.3.2 The age of the contact between the Arnager Greensand and the Arnager Limestone.

There appears to be very little information on this boundary, though Christensen (1984) reports the occurrence of *Echinocorys ex gr. gravesi* Desor, which has been recovered from the phosphatised conglomerate bed at the base of the Arnager Limestone. This species ranges from the Turonian to Early Coniacian.

On the basis of previously described foraminiferal and palynological data (see description of Biozone Three), and the above evidence, it is proposed that the phosphatised conglomerate and the mixed zone below the Arnager Limestone (zone 3), spans an interval from the Middle Cenomanian to Coniacian.

4.3.3 The age of the Arnager Limestone Formation.

As stated by Christensen (1984) the age of this formation is enigmatic. On the basis of foraminifera described herein (Biozone Four), and previous work (see chapter two), the Arnager Limestone Formation is considered to be of Middle Coniacian age or possibly younger within the Coniacian. This is supported by palynological evidence. (Schoiler, unpublished, see chapter two).

4.3.4 The age of the Bavnodde Greensand.

Results of recent macrofossil work (Christensen, 1984) suggests that "the greensand probably embraces the Upper Coniacian - Lower/Middle Santonian".

Foraminiferal evidence suggests that lower parts of the greensand may fall within an interval assigned to the Lower? - Middle Santonian (Biozone Five) and Middle Santonian or younger (Biozone Six). As has been noted this evidence is open to interpretation, though is

reasonably consistent with macrofossil evidence outlined by Christensen (1984). The problem of the formation being Late Coniacian in age would however appear to be at variance with data presented here.

4.4 Limitations of the micropalaeontological zonal scheme.

The zonal scheme presented is only intended for local usage, within the basins around the Bornholm area, and the following limitations should be borne in mind when applying the scheme.

(a) The location of the sequence studied on a structural high within the Fennoscandian Border zone has resulted in the presence of hiatuses through the Phanerozoic succession of the island. Three levels of reduced sedimentation and or non deposition are clearly evident within the Albian to Santonian interval: at the base of the Arnager Greensand, at the base of the Arnager Limestone/top of the Arnager Greensand and at the Arnager Limestone / Bavnodde Greensand boundary. It is likely that these intervals may be expanded within the local graben areas.

(b) The greensand facies developed may represent more marginal basin facies when compared to the surrounding graben areas. Consequently the microfaunas may show significant compositional variability, related to facies characteristics.

(c) Microfaunas from the Arnager Limestone are poorly preserved and may become broken during extraction, reducing the true character of the fauna through the loss of more delicate species.

(d) Better age definition may be achieved by further sampling and analysis of certain foraminiferal lineages, plus further integration with other disciplines.

Chapter Five

Palaeoecology and palaeogeography

5.1 Introduction.

Microfaunal samples from the studied sections have been systematically logged to provide detailed information on the distribution and relative abundance of foraminiferal groups. Foraminiferal assemblages have been recognised as valuable indicators of environment, both in the Phanerozoic and Recent, where studies of modern populations have greatly enhanced palaeoenvironmental interpretations, eg. the work of Phleger (1960); Murray (1973); Boltovskoy and Wright (1976); papers in Schafer and Pelletier (1976); Brazier (1980) and Koutsoukos and Hart (1990).

Great attention has been paid to the distribution and palaeoecology of Cretaceous planktonic foraminifera. There has also been a plethora of work on recent planktonic foraminiferal distribution patterns, e.g. Bandy (1967), Rottman (1978), Bé and Hutson, (1977), Berger (1970a; 1970b; 1971), Lipps (1979), Anderson *et al.*, (1979), Bé (1977), Bé *et al.*, (1981), Bé (1982), Caron *et al.*, (1982), Thunell *et al.*, (1983), Hemleben and Spindler, (1983), Hemleben *et al.*, (1985) and Brummer *et al.*, (1986). The interplay of factors affecting the distribution patterns of Cretaceous planktonics has been examined in various works: e.g. Douglas and Rankin (1969), Sliter (1972), Bailey and Hart (1979), Hart (1980a; 1980b), Wonders (1980), Caron (1983), Caron and Homewood (1983), Butt (1982), Douglas (1972) and Leckie (1987). Cretaceous benthic foraminifera have clearly not received the same attention, with palaeoecological synthesis being minimal in the majority of foraminiferal papers with the exception of works such as Sliter and Baker (1972), Chatziemmanouil (1982), Leary (1987), Koutsoukos and Hart (1990) and Sikora and Olsson (in press).

5.2 Methods of analysis.

Samples from the Bornholm Cretaceous succession have been systematically statistically analysed to provide a basis for palaeoecological synthesis. For each sample the percentage of planktonic foraminifera has been recorded, the relative abundance of foraminiferal groups, i.e. calcareous benthic, porcelaneous benthic, agglutinating and

planktonic. The planktonic foraminifera have been broken down by morphology (see below). Diversity has also been measured in terms of number of species.

5.2.1 General limitations.

Standard techniques have been applied to the preparation and picking of samples, see 2.5., though clearly an inevitable bias will occur as preparation and picking has been undertaken by three different individuals. Preservational factors will limit the comparative value of conclusions. For example extraction of "clean" foraminifera from the hard Arnager Limestone was more difficult than from the more unconsolidated greensands. This factor affects the number of specimens recovered and their identification. For example planktonics are difficult to identify at certain levels within the Arnager Limestone and Bavnodde Greensand because of their poor preservation.

5.2.2 The planktonic / benthic ratio.

The P/B ratio has been used by many workers for an index of relative water depth for the Cretaceous, e.g. Carter and Hart (1975), Chatziemmanouil (1982), Leckie (1987). The various possible limiting factors of the P/B ratio have long been recognised e.g. preservational limitations, transport, dissolution. These are summarised in Chatziemmanouil (1982) and Leckie (1987).

5.2.3 Relative abundance of foraminiferal groups.

The relative abundance of planktonic foraminifera, calcareous benthic foraminifera, porcelaneous benthic foraminifera and agglutinated foraminifera has been calculated for each sample. This method allows the vertical analysis of foraminiferal assemblages, pointing to parts of the succession where major ecological changes may be taking place.

5.2.4 Relative abundance of planktonic foraminifera.

Planktonic foraminifera have been divided into five morphological groups for statistical analysis. They are "keeled", which includes those forms with a distinct keel, e.g. *Dicarinella*,

Marginotruncana, *Globotruncana*, *Rotalipora*. "Pustulate" includes forms such as *Archaeoglobigerina* and *Praeglobotruncana*. "Globigerine" is primarily species of *Hedbergella* and *Whiteinella*, whilst "Heterohelicidae" contains forms such as *Heterohelix*, *Globigerinelloides* and *Guembelitra*. "Undifferentiated" are forms generally from levels within the Arnager Limestone and Bavnodde Greensand which cannot be differentiated due to poor preservation.

These planktic groups have been plotted to provide indications of relative depths through the succession, following the Hart and Bailey (1979) model and Leckie (1987).

5.3 Discussion of changes in foraminiferal composition through the succession.

The general characteristics of each formation and their associated contacts are given below. Planktonic depth zones used are numbered 1-4 and follow Hart and Bailey (1979), these are relative depths, 1 being the shallowest and 4 being the deepest, no actual depth is implied. For benthic species, the bathymetric classification of Sliter and Baker (1972) has been used. All foraminiferal counts are based on the >63 micrometre fractions.

5.3.1 The Arnager Greensand.

Planktonic foraminifera: Values for the greater part of the exposed Arnager Greensand succession, that is , below the level of the influx of *Rotalipora reicheli* for the P/B ratio generally lie between 5-25% planktics. The planktonic population is dominated by *Hedbergella* species with fewer *Globigerinelloides*, *Guembelitra* and *Heterohelix* species, and rare *Praeglobotruncana* species. This indicates a generally shallow planktonic fauna, depth zones 1-2, though dominantly of zone 1. The percentage of planktonics is low when compared to the rest of the succession where values are generally greater than 25%. This again suggests relatively shallow water.

At the level of the inception of *Rotalipora reicheli* P/B ratio values begin to climb, with the percentage of planktonics reaching a maximum of 70% in sample AK2. The increase in the P/B ratio and inception of *Rotalipora reicheli*, which indicates depth zone 3, clearly suggests gradually increasing water depths. This level is however complicated, as samples

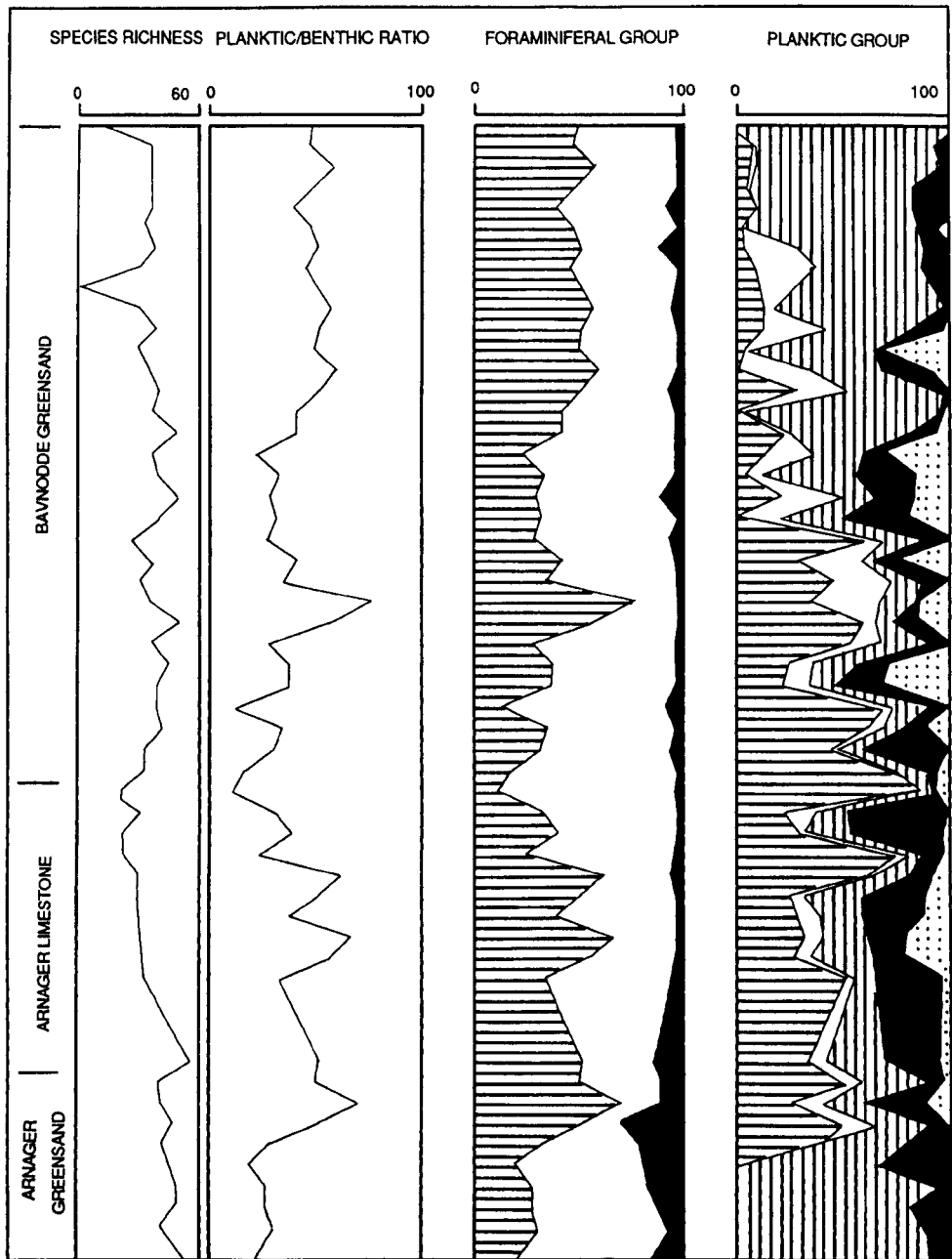


Figure 5.1 Distribution of foraminiferal groups, richness and planktic / benthic ratio for the Arnager Greensand, Arnager Limestone and Bavnodde Greensand, from coastal exposures.

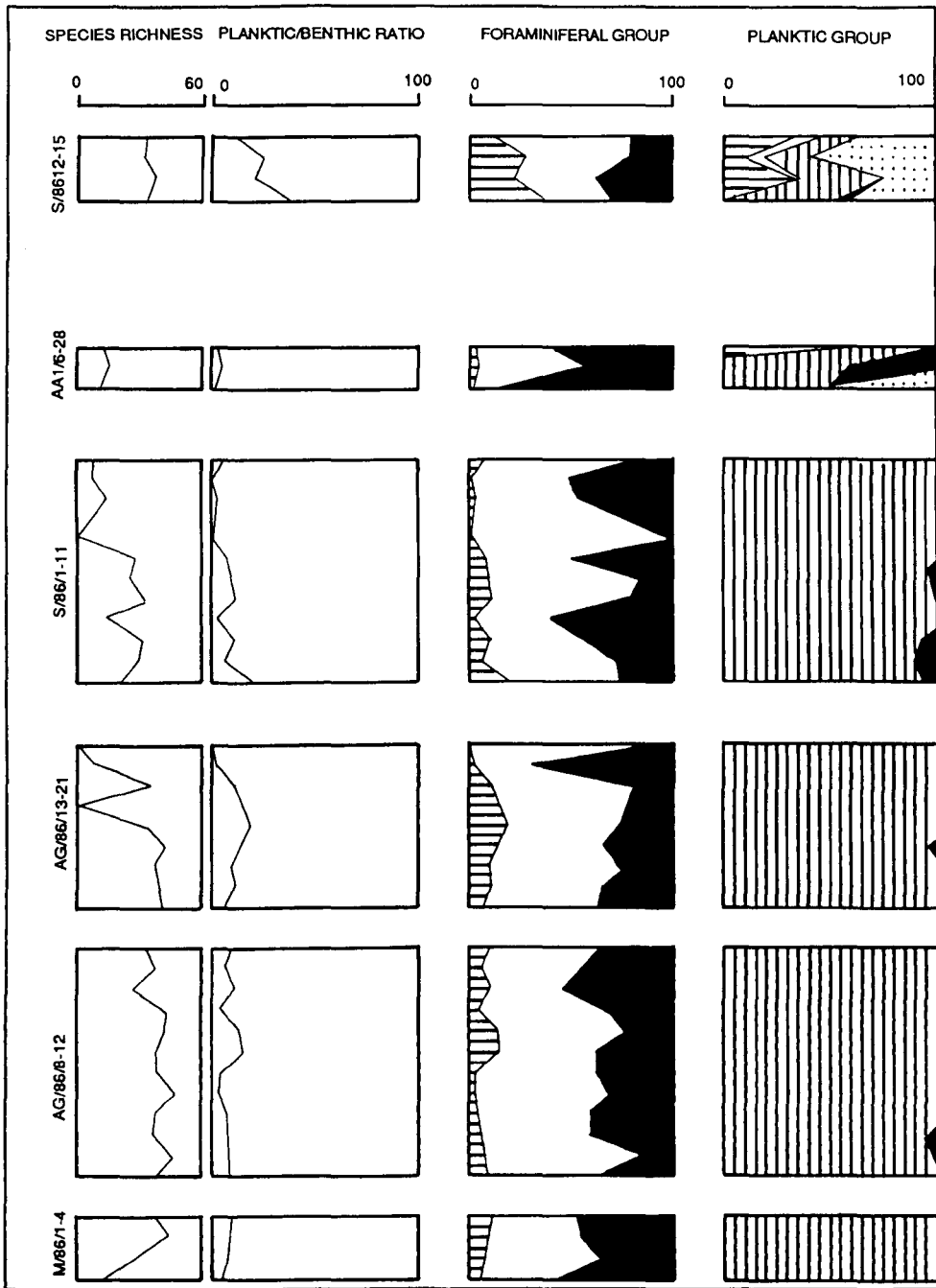
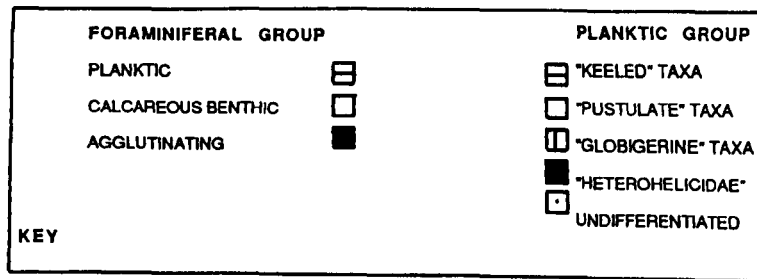


Figure 5.2 Distribution of foraminiferal groups, richness and planktic / benthic ratio for the Amager Greensand, and Amager Limestone, from the Stampe A river area.



KEY TO FIGURES 5.1 AND 5.2

above WKC are undoubtedly influenced by contamination through bioturbation from the overlying Arnager Limestone.

Benthic foraminifera: The composition of the benthic foraminiferal assemblages clearly changes at the *Rotalipora reicheli* inception level. Below this level the agglutinating fauna makes up as much as 70% of samples, though is generally around 30-40%. This figure begins to decline after sample AK1 above the *Rotalipora* level. Up to this level the benthic microfauna is generally more characteristic of an "Inner shelf" fauna, with *Quinqueloculina* sp., *Placopsilina* sp., *Guttulina* sp., *Globulina* sp. and abundant nodosariids. *Gavelinella* spp., do suggest a slightly deeper outer shelf fauna, though the abundance of other genera listed above favours a more "Inner shelf" fauna.

The abundance of agglutinating species suggests shallower waters, which fits with the planktonic foraminiferal data. A relative increase in water depth appears to take place above sample WKC with the change in planktonic fauna and associated decline in agglutinating benthic species. The calcareous benthic fauna also takes on a more "outer shelf" aspect above this level with increases in nodosariids, *Gavelinella* spp., and a decline in miliolids and *Placopsilina* spp.

Palaeobathymetry: "Inner" shelf to *Rotalipora* level (sample WKC). "Inner-outer" shelf above this level.

Palaeosalinity/Oxygenation: The microfauna recorded is typical of normal marine, well oxygenated conditions.

5.3.2 The Arnager Greensand-Arnager Limestone boundary.

As has been stated above, samples from the top of the Arnager Greensand clearly have to be treated with some caution, as they have been affected by bioturbation from the Arnager Limestone. The distinct trend shown from analysis of samples just in and below the phosphatised conglomerate level is towards increasing water depth, shown by the abundance of planktic foraminifera, and associated decrease in benthic species. Planktonic assemblages are also dominated by keeled forms, suggesting greater water depth at the boundary between the two formations.

5.3.3 The Arnager Limestone Formation.

Planktonic foraminifera: P/B values through the Arnager Limestone are variable ranging from 23% to 66% planktonics. This is probably due in part to the poor recovery achieved from some of the limestone samples. It would seem however that true levels probably range from between 40-60% planktonics. The planktonic fauna contains abundant keeled taxa which may form up to 70% of the total fauna, particularly in the upper part of the limestone.

"Globigerine" type planktonics form a significantly lower proportion of the populations, whilst "pustulate" taxa retain a steady level of around 10% of the total planktonic fauna through the limestone. "Heterohelicidae" planktonics show a general decline in the upper part of the limestone, though this is variable. For the greater part of the limestone planktonic depth zones 1-3 are recognised and in the uppermost limestone and basal Bavnodde Greensand, depth zone 4 is recognised, with the occurrence of rare *Dicarinella concavata* forms, though it should be noted that these are extremely rare.

Benthic foraminifera: The benthic foraminiferid population differs considerably from the underlying Arnager Greensand. The agglutinating fauna shows a steady decline from the base of the Arnager Limestone, where levels start at around 15% and through the rest of the limestone, maintains consistent levels of around 5%. Agglutinating foraminiferid diversity is low, and the fauna is dominated by *Gaudryina* and *Ataxophragmium*, with rare *Arenobulimina* and *Verneuilina*. The calcareous benthic foraminifera maintain levels between 40-60%, and are dominated by *Gavelinella*, *Osangularia*, *Eouvigerina*, *Gavelinopsis*, *Reussella*, *Gyroidinoides* and nodosariids. This fauna is placed within the "outer shelf" group of Sliter and Baker (1972), though it does show affinities with the latter authors "upper slope" fauna, but lacks distinctive genera such as *Bathysiphon*, though this may be due in part to the difficulty of extracting these forms from this lithology.

Palaeobathymetry: Microfaunal evidence suggests "outer shelf - upper slope" depths of deposition for the Arnager Limestone. This would appear to be consistent with the palaeoenvironmental interpretation for the Arnager Limestone presented by Nøe-Nygaard and Surlyk (1985). A shallowing trend towards the top of the limestone is indicated by

increasing clastic content, (see Christensen, 1984). However the presence of deeper water planktonics through this interval is somewhat at variance with this.

Palaeosalinity/Oxygenation: Normal marine salinities, well oxygenated.

5.3.4 The Arnager Limestone - Bavnodde Greensand boundary.

The sedimentological evidence suggests declining water depth through the Arnager Limestone, though the presence of deeper water planktonic foraminifera may suggest an increase in effective water depth. The overlying Bavnodde Greensand is clearly deposited in shallower conditions.

5.3.5 The Bavnodde Greensand.

Planktonic foraminifera: P/B ratios show great variability through the lower part of the Bavnodde Greensand, up to sample AK32, with values ranging between 12-75% planktonic foraminifera, with an average around 30%. Through this interval "keeled" taxa remain at moderately high levels, generally between 20-70%. Above sample AK32 a notable change takes place with an increase in the P/B ratio to a fairly persistent level around 50% planktonics. The composition of the planktonics clearly changes with a strong decline in the "keeled" and "pustulate" forms and an increase in the "Globigerine" and "heterohelicidae" groups. The "Globigerine" taxa are dominated by abundant *Whiteinella baltica*. This trend suggests a reduction in water depth.

Benthic foraminifera: Calcareous benthic foraminifera, comprise between 40-50% of the total fauna and suggest a return to more "inner shelf" assemblages, including probable encrusting *Cibicides ribbingi*, abundant nodosariids, occasional miliolids, *Neoflabellina*, *Gavelinella* and *Loxostomum*. Agglutinating foraminifera show a slight pick up in abundance, with levels between 3-10% of the total fauna.

Palaeobathymetry: An "inner shelf" regime would be consistent with shelf greensand facies, with coarser levels in the greensand probably representing storm events. Further sedimentological work may resolve the genetic processes of these units.

Palaeosalinity/Oxygenation: Normal marine salinity, well oxygenated.

5.4 Palaeogeographic setting.

During the Late Cretaceous the Bornholm / southern Sweden area lay within a major "seaway" extending roughly west-east, bordered to the north by the Fennoscandian Shield and to the south by the central European "islands", or Bohemian massif. Inundation and sedimentation around the margins of this "seaway" would have been related to tectonic and eustatic events. This is seen for example on the southern margins of the Fennoscandian Shield where variable carbonate - clastic sequences and associated breaks in sedimentation are found through the Upper Cretaceous successions, including Bornholm, southern Sweden and the Russian platform and further south into the Polish end of the Polish-Danish trough: cf. Christensen (1984), Marcinowski (1974), Chatziemmanouil (1982), Alexandrowicz (1966), Pozaryska (1962; 1967), Naidin *et al.*, (1980) and Walaszczyk (1987).

Estimates for palaeolatitudes for the Vomb trough place this area at approximately 47 degrees plus or minus 5 degrees North (Chatziemmanouil, 1982), hence Bornholm probably lay c.2-3 degrees South of this area, around 45 degrees North. (cf. Hart, 1979).

Palaeocurrent patterns for the Late Cretaceous are examined in Bailey and Hart (1979), following palaeogeographic reconstructions of Hancock (1975) and oceanic circulation patterns following Luyendyk *et al.*, (1972). The Bornholm / southern Scandinavian area would have been influenced by northerly offshoots of a major east-west Tethyan flow, with palaeocurrent directions passing Northwesterly through Southern Europe into Northern Europe, though these will have been influenced more locally by the Alpine mobile belt and the massifs of central Southern Europe.

Work on palaeotemperatures for the Cretaceous of Northwest Europe ; Lowenstam and Epstein (1954) and Bowen (1961), suggests maximum seawater temperatures of 22.5 degrees centigrade for the Coniacian and 21.5 degrees for the Santonian, whilst a temperature of 15.4 degrees was recorded for a belemnite from the Arnager Greensand, Lowenstam and Epstein (1954).

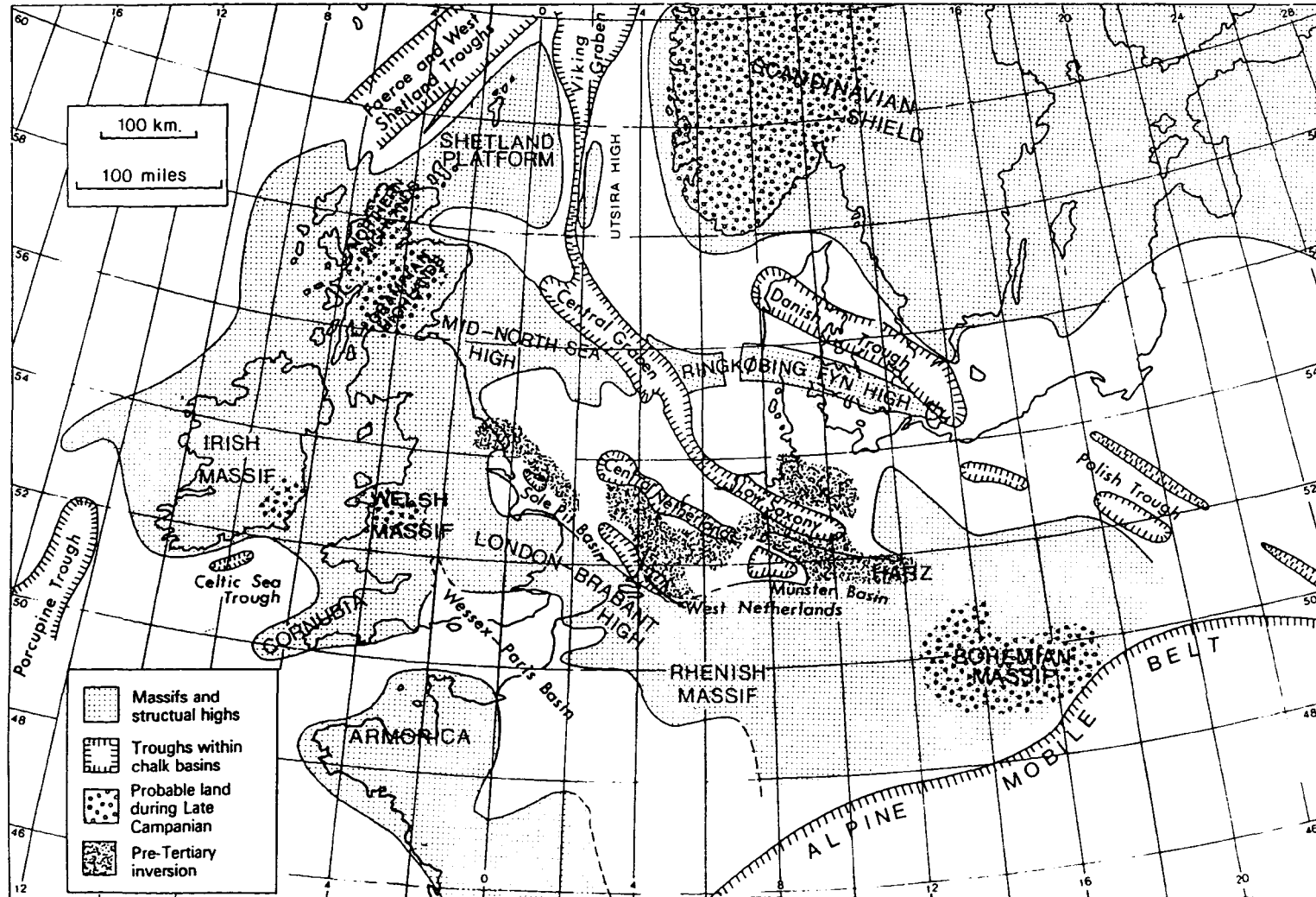


Figure 5.3 Geological setting of the Upper Cretaceous in north-west Europe (Reproduced from Hancock, 1984).

5.5 Provincial aspects of planktonic foraminifera.

Provincialism of Cretaceous planktonics has been examined by Douglas and Rankin (1969), Douglas (1972), Schreibnerova (1971), Sliter (1972), Bailey (1978) and Bailey and Hart (1979). Schreibnerova (1971) recognised a three fold subdivision of Mesozoic biogeoprovinces:

1. Tethyan/Tropical/Equatorial province, palaeolatitudes 0-30 degrees North and South.
2. Transitional province, palaeolatitudes 30-50 degrees North and South.
3. Boreal province, palaeolatitudes 50-90 degrees North and South.

Bailey and Hart (1979) and Edwards (1979) have discussed the provincial aspects of Senonian planktonic foraminifera. Bailey and Hart (*op. cit*) concluded that a distinct early Senonian "Boreal" planktonic microfauna was present in Bornholm, Northern Germany, and Norfolk, England, and in lower numbers in the Anglo-Paris basin. "Tethyan" planktonic species were found to occur in the Anglo-Paris Basin reaching as far north as the London-Brabant Massif, but were not carried further than this due to the barrier effect of the Massif on warm water currents.

Edwards (1979), by contrast found that the planktonic foraminiferal faunas recorded from the Anglo-Paris basin were typical of assemblages characteristic of Northern latitudes. Faunas were found to have a predominantly northern aspect, resembling the boreal faunas described from Bornholm (Douglas and Rankin, 1969).

There is little doubt that the Bornholm planktonic fauna shows a boreal aspect, assemblages comprise abundant *Whiteinella* spp., *Archaeoglobigerina* spp., *Marginotruncana pseudolinneiana*, *Marginotruncana marginata*, and *Globotruncana bulloides*, in the Coniacian and Santonian. The rare occurrences of *Dicarinella concavata* suggest a more transitional influence however. The occurrence of this species this far north and its lack in Holland and Germany may suggest that currents carried these species over central Europe and through into the Polish-Danish trough. The paucity of these specimens suggests that the species was generally unable to survive in any significant numbers, probably as a result of lower temperatures and possibly shallower water depths.

The Cenomanian planktonic foraminifera comprise assemblages dominated by *Hedbergella* spp., *Praeglobotruncana delrioensis*, *Globigerinelloides* spp., *Heterohelix* spp., *Guembelitra cenomana* and *Rotalipora reicheli*. The dominance of *Hedbergella* species is typical of a boreal province aspect. Hart (1979) examined the distribution of *Rotalipora reicheli*, suggesting that this species was nearing the limit of its ecological tolerance this far North, evidenced by the general small size and lack of juveniles within the population examined. Figures 5.5 and 5.6 show the distribution of *Rotalipora reicheli* and *Rotalipora cushmani*. *Rotalipora cushmani* has been recorded from the Vomb Trough (Chatziemmanouil, 1982) and both species are recorded from the North Sea (King *et al.*, 1989). The consistent records of these species at this palaeolatitude may suggest that they were in fact well within their ecological tolerance limits.

5.6 Provincial aspects of benthic foraminifera.

Edwards (1979) recognised that Senonian microfaunas of the Anglo-Paris Basin showed distinct similarities to those further east, i.e the USSR. This was thought to be due to a combination of factors including the evolution of identical forms from a common ancestor in isolated areas, and by transport from the Anglo-Belgian area into the Anglo-Paris basin. The benthic Coniacian / Santonian faunas from Bornholm are generally similar to those recorded in the Anglo-Paris basin, including the genera *Gavelinella*, *Stensioeina*, *Praebulimina*, *Loxostomum*, *Cibicides*, *Arenobulimina*, *Verneuilina* and *Eouvigerina*. There are few notable differences, it would appear that a general uniformity in benthic assemblages had been achieved over Northwest Europe by the Coniacian / Santonian. For example the distribution maps show that *Gavelinella thalmanni*, *Gavelinella stelligera* and *Gavelinella schloenbachi* were well distributed through Europe during the Late Cretaceous.

Interestingly, however the Cenomanian faunas show a more distinctly East European aspect than faunas from the Anglo-Paris Basin. *Cibicides gorbenkoi* and *Lingulogavelinella ornatissima* have only been recorded from Eastern European locations. *Lingulogavelinella ciryi inflata* shows a similar distribution, although it has been recorded from France and the North Sea, (King *et al.*, 1989). This partial isolation may suggest that the east-west seaways

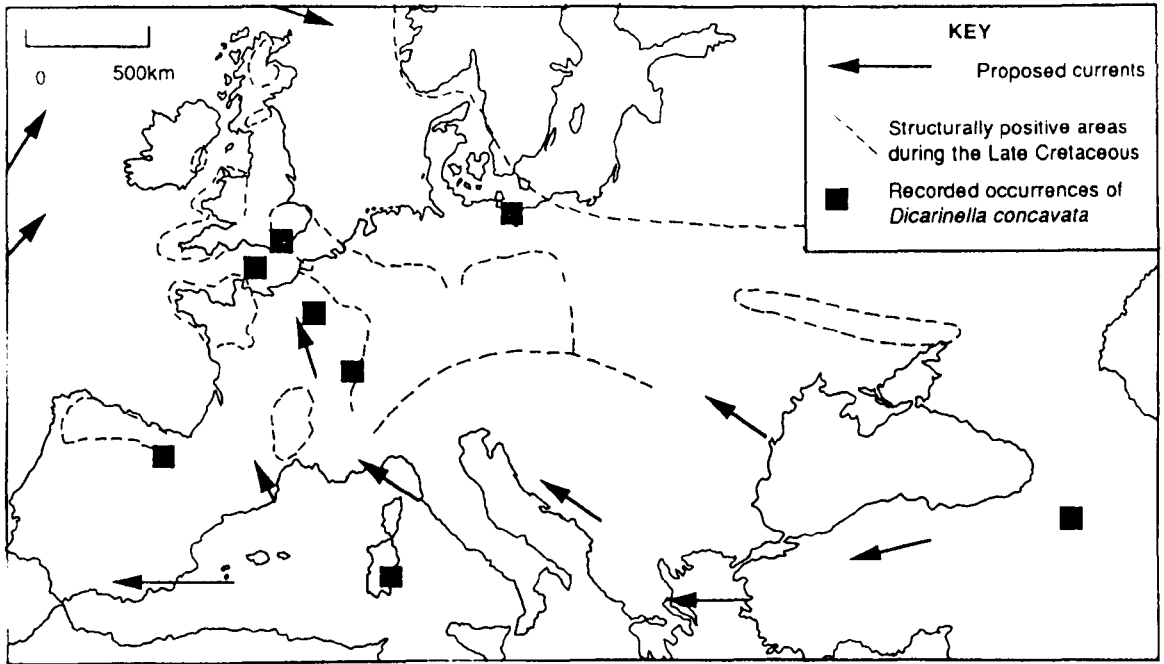


Figure 5.4. The European distribution of *Dicarinella concavata*. (Base map and current patterns based on Bailey and Hart 1979.)

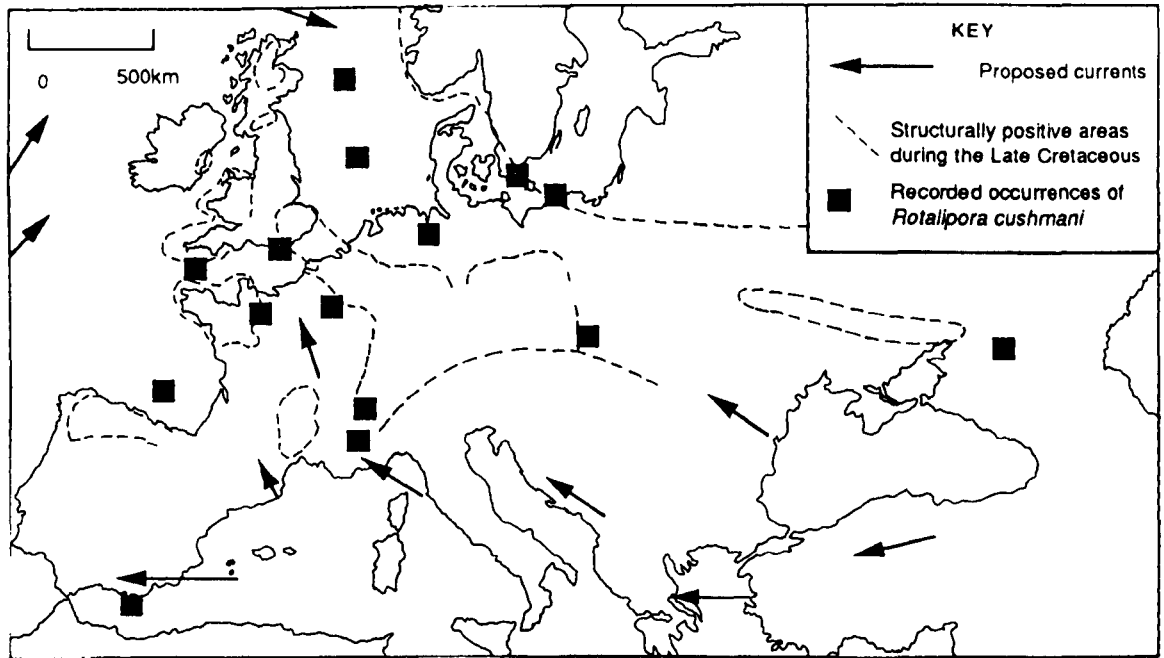


Figure 5.5. The European distribution of *Rotalpora cushmani*. (Base map and current patterns based on Bailey and Hart 1979.)

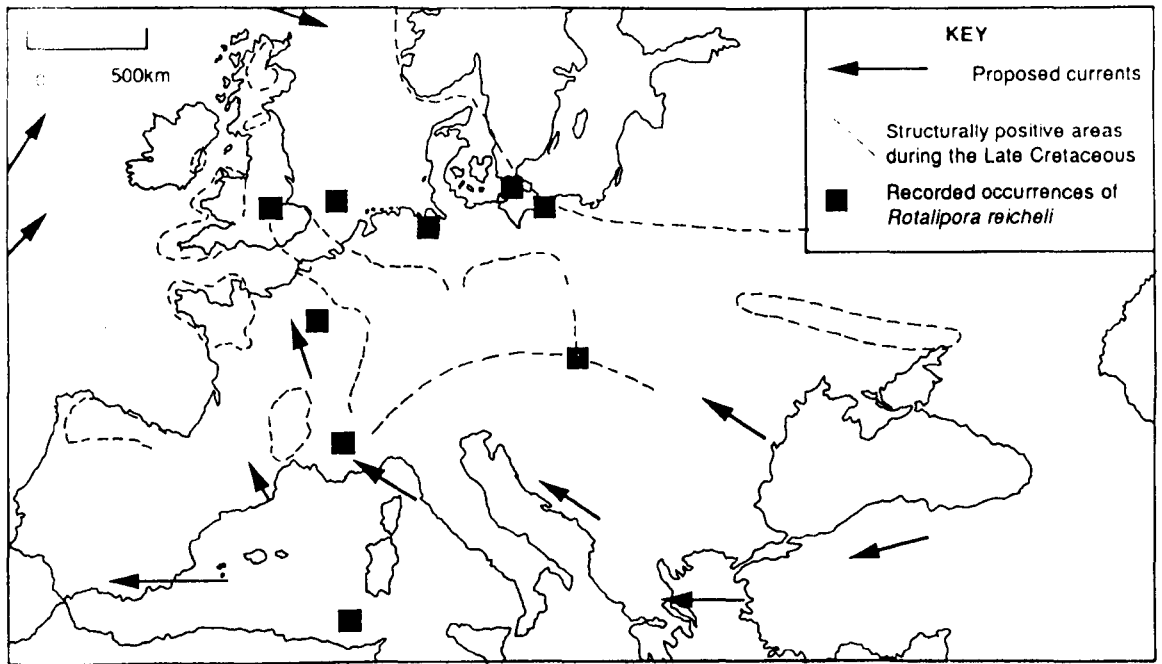


Figure 5.6. The European distribution of *Rotalipora reicheli*. (Base map and current patterns based on Bailey and Hart 1979.)

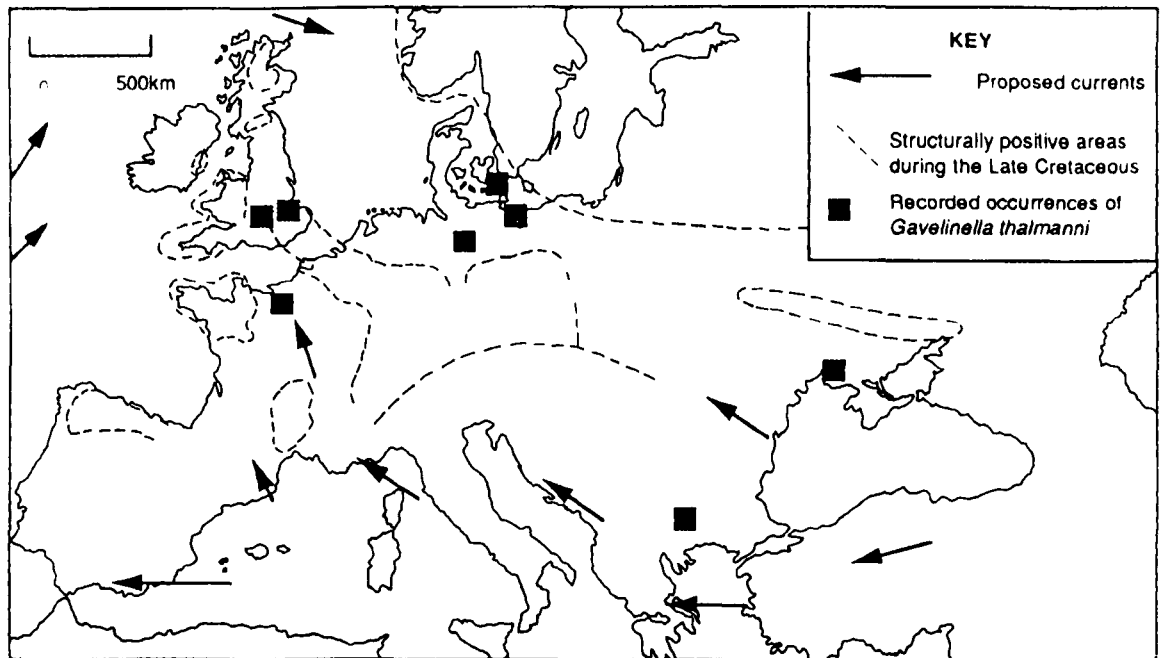


Figure 5.7. The European distribution of *Gavelinella thalmani*. (Base map and current patterns based on Bailey and Hart 1979.) Main source of distribution data, Edwards (1979)

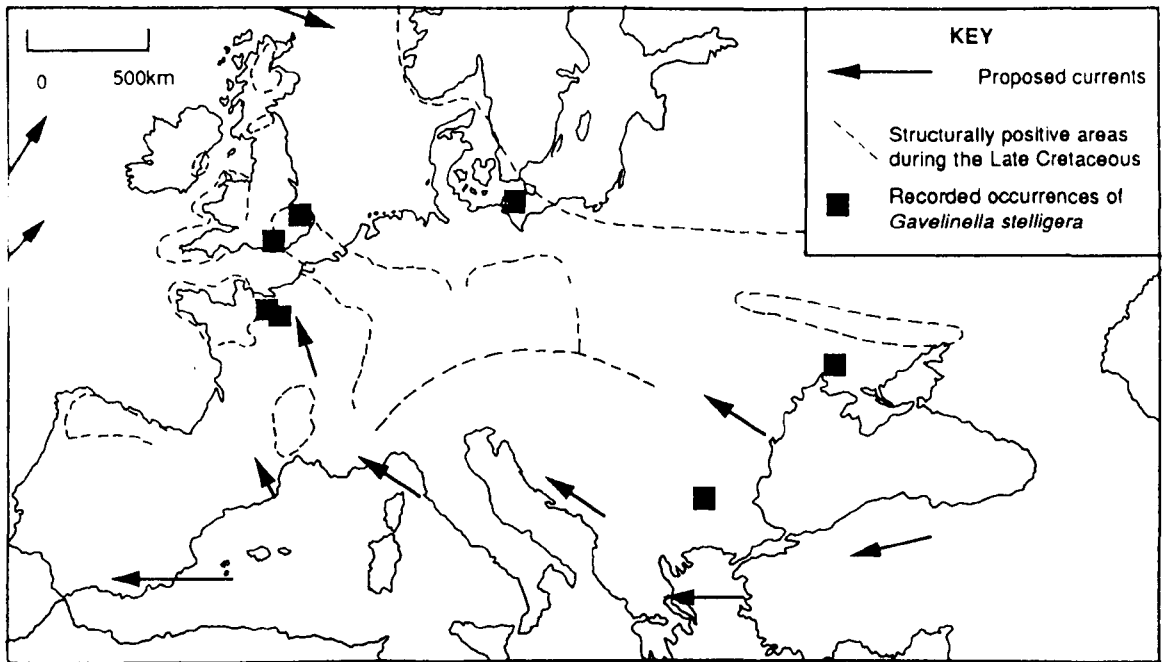


Figure 5.8. The European distribution of *Gavelinella stelligera*. (Base map and current patterns based on Bailey and Hart 1979.) Main source of distribution data Edwards (1979)

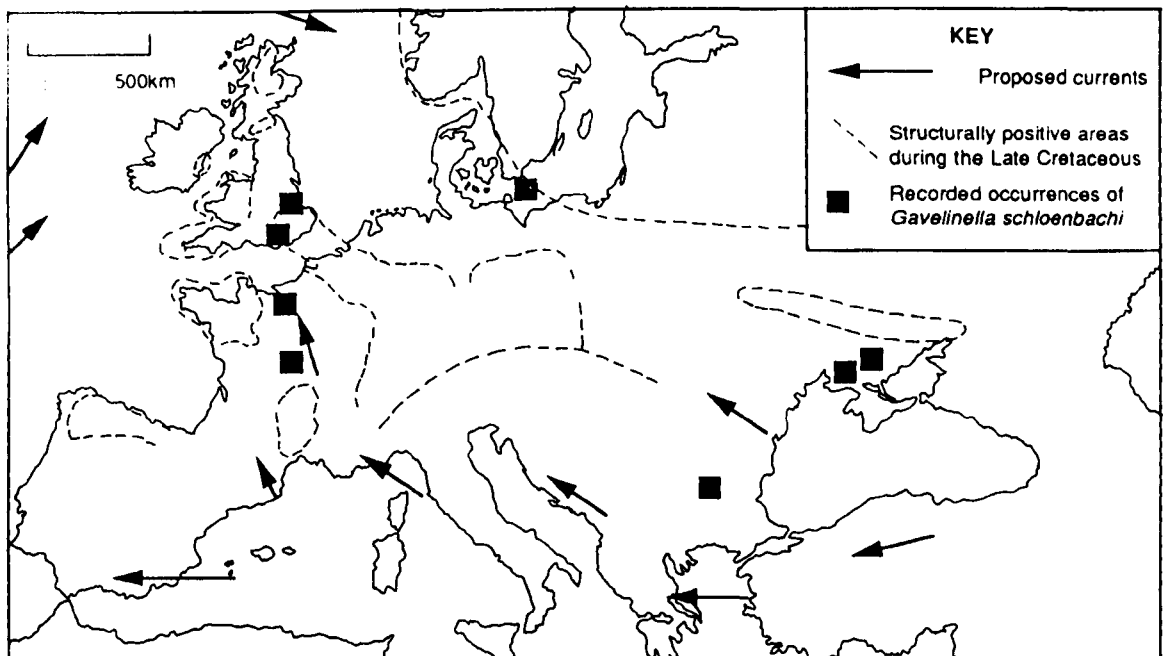


Figure 5.9. The European distribution of *Gavelinella schloenbachi*. (Base map and current patterns based on Bailey and Hart 1979.) Main source of distribution data, Edwards (1979)

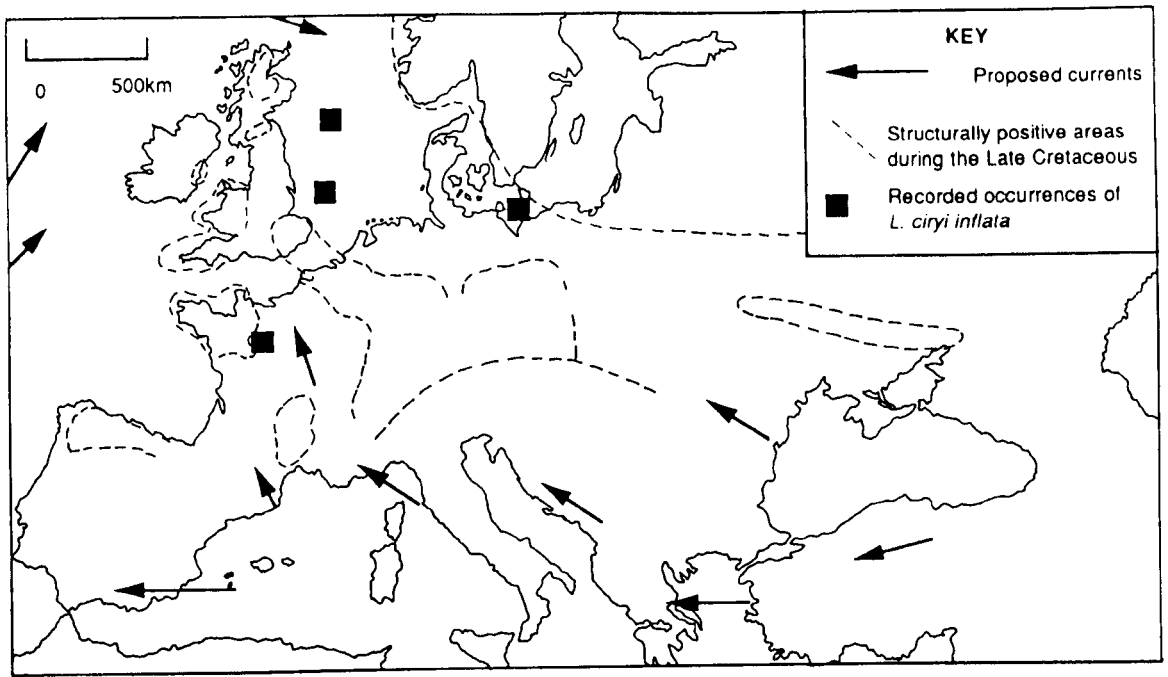


Figure 5.10. The European distribution of *Lingulogavelinella ciryi inflata*. (Base map and current patterns based on Bailey and Hart 1979.) Main sources of distribution data King *et al.*, (1989) and Malapris-Bizouard (1969)

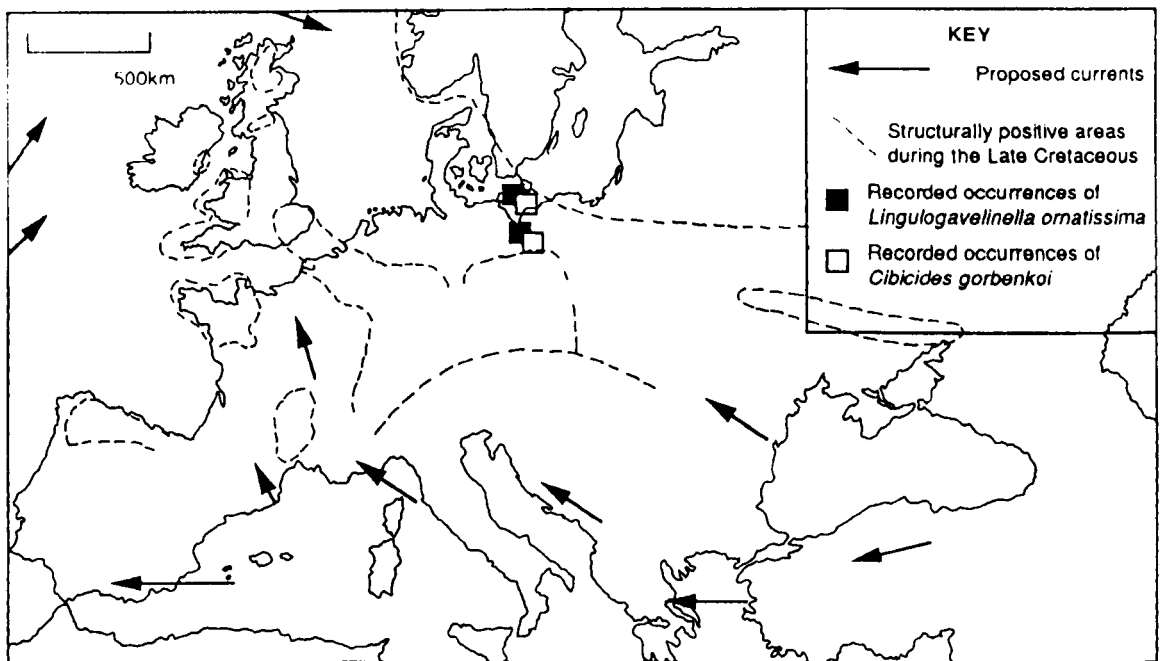


Figure 5.11. The European distribution of *Lingulogavelinella ornatissima* and *Cibicides gorbenkoi*. (Base map and current patterns based on Bailey and Hart 1979.)

were not fully developed until the later Cenomanian. Similar morphological forms are recorded in the Anglo-Paris basin, for example the *Gavelinella reussi* group is similar to *Cibicides gorbenkoi* in gross morphology, while *Lingulogavelinella globosa* is similar in general morphology to *Lingulogavelinella ornatissima*. It is possible that niche separation and evolution related to geographic isolation was taking place at this time, before the establishment of uniform assemblages with the effects of increased sea levels through the Late Cretaceous.

Chapter Six

Sea level changes

6.1 Previous work.

Kennedy *et al.*, (1981), discussed sea level changes during the Albian to Santonian on Bornholm, and recognised transgressive pulses in the Lower Albian, Lower Cenomanian, Middle Cenomanian and Coniacian.

Christensen (1984) developed these ideas as part of a review of the Albian to Maastrichtian stratigraphy of southern Sweden and Bornholm. Work on the Kristianstad Basin by Christensen (1975), Norling and Skoglund (1977) and Norling (1981), had suggested that transgressive events in the basin could be recognised in the Barremian, pre-Cenomanian, Cenomanian, Lower Santonian, mid-Campanian and basal Maastrichtian.

Chatziemmanouil's (1982) work in the Vomb Trough had shown that greatest water depths were recorded during the Coniacian, with decreasing water depths in the Santonian. Outcrop work (Christensen, 1984) suggested that transgressions took place in the Lower Santonian and uppermost Lower Campanian.

Christensen (1984) summarised the gross sea level changes that took place in southern Sweden and Bornholm (Fig.6.1). The following sequence was recognised: large scale transgression in the Albian - Cenomanian, followed by transgression in the Coniacian - Lower Santonian, and further transgressions in the mid-Campanian and basal Maastrichtian. The intervening periods were thought to be regressive. Christensen (*op. cit*) also suggested that because of the synchronicity of the transgressive pulses north of, and within, the border zone, sea level changes were the result of eustatic (global) events rather than being related to local tectonic influences.

This interpretation has been challenged by Packer *et al.*, (1989). Most views of Cretaceous sea level suggest major transgression during the Late Cenomanian to Early Turonian, Hancock (1976), Hancock and Kauffman (1979), Hart and Bailey, (1979), Hart (1980) Haq *et al.*, (1987). Packer *et al.*, (1989) suggested that a marked increase in water depth from Middle Cenomanian times onward isolated the Bornholm horst from sediment

supply and produced the phosphatised conglomerate at the base of the Arnager Limestone Formation.

6.2 Tectonic influence upon sea level change.

The Mesozoic tectonic regime of the Bornholm - Southern Sweden area comprises major periods of basin extension, with associated sedimentation and subsequent compression related to the Alpine deformation front. The tectonic evolution of the area has been summarised by Vejbaek (1985) and Norling and Bergstrom (1987).

The tectonic evolution is discussed in chapter one and is summarised as follows. The initiation of a horst and graben regime was caused by regional crustal extension that led to the subsidence of the Polish-Danish trough and Danish-Norwegian Basin in the Late Carboniferous to Early Permian. It is into these basins that Mesozoic sediments were deposited, with depocentres shifting at various periods.

Sedimentation was probably accompanied by synsedimentary faulting resulting in the erosion of structural highs (*cf.* Gravesen *et al.*, 1982), reflected by abundant hiatuses in the Mesozoic onshore succession.

There is little evidence for major tectonic events on Bornholm during the Albian to Coniacian interval, other than minor local faulting (Vejbaek, 1985). The possibility of inversion and uplift from the Santonian onwards occurring within the Polish-Danish trough seems certain. (*cf.* Gravesen, 1981; Ziegler, 1981, 1982 and Norling and Bergstrom, 1987).

From the above it can be concluded that tectonic influence was minimal during the Albian to Coniacian, but that inversion from the Santonian onwards will have given rise to uplift of the basin and had a subsequent effect upon sedimentation and relative water depth.

6.3 Evidence of sea level change in the Cretaceous (Global).

The plethora of recent work on Cretaceous global sea level change during the Cretaceous has delineated major cycles of global and regional events, with minor variations and discrepancies; eg. Hancock (1976), Cooper (1977), Vail *et al.*, (1977), Jeletzky (1978), Hancock and Kauffman (1979), Hart and Bailey (1979), Hart (1980), Naidin *et al.*, (1980),

Matsumoto (1980), Naidin (1983), Haq *et al.*, (1987), Wilgus *et al.*, (1988) and Hancock (1989) The Haq *et al.*, (1987) model is generally accepted and used by many workers. However, whilst the Haq *et al.* (1987) model provides a global overview of sea level change, local influences (notably tectonism) upon regressive and transgressive cycles need to be assessed. The sequence stratigraphic approach has not, it should be pointed out, been universally accepted, see Hancock, (1989) for discussion. It would seem that Hancock's (1989) scheme is more applicable at the local level in the European area. Subsequent work will undoubtedly challenge and improve upon this model, e.g. Hancock (1989).

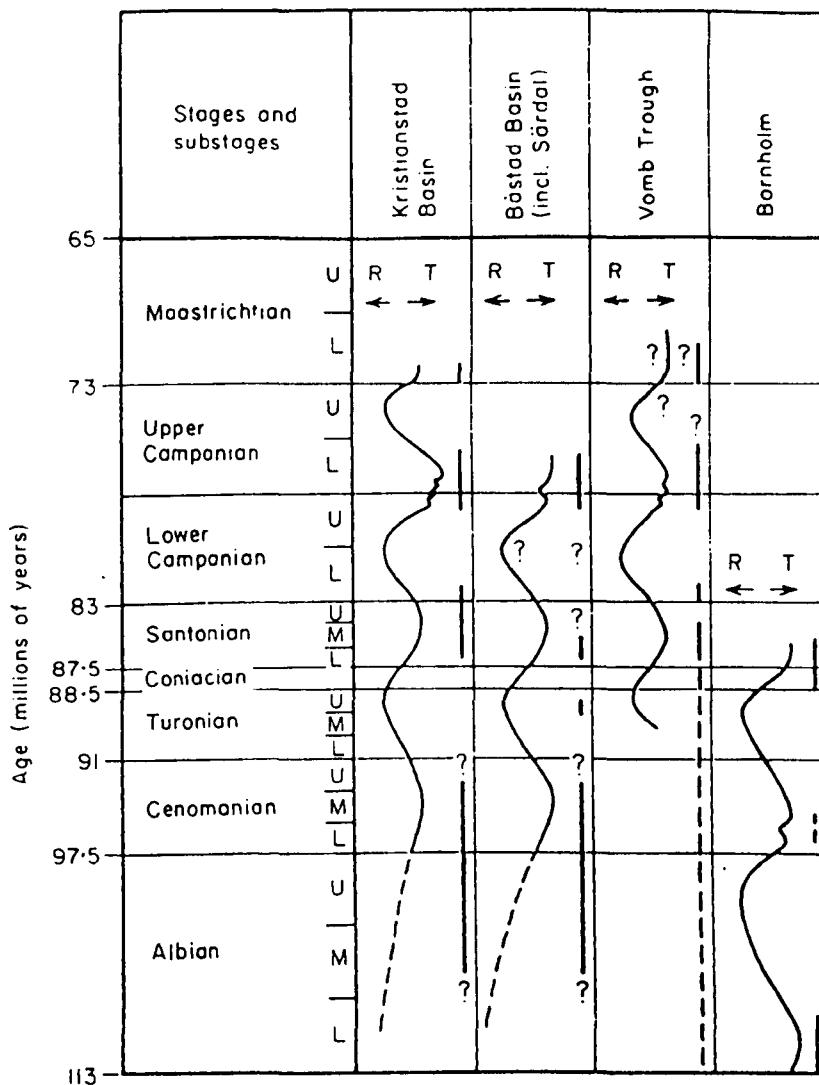
Broadly speaking major transgressive events can be recognised in the early Late Albian, earliest Turonian, Coniacian, Middle Santonian, and Late Campanian-Early Maastrichtian (Hancock and Kauffman, 1979).

The paucity of good macrofossil data from the succession causes problems when attempting to produce very accurate calibrations with published sea level models. Haq *et al.*, (1987), Hart (1980), Christensen (1984) and Hancock (1989) are used herein, though correlations with events described in these schemes can it should be emphasised only be in part estimations. The scheme presented below for the Bornholm succession is only a local scheme, based on the available biostratigraphic and sedimentological evidence.

6.4 Evidence for sea level change for the Albian to Santonian of Bornholm.

Kennedy *et al.*, (1981) proposed that transgressive pulses took place during the Early Albian and Early Cenomanian, following the recovery of Lower Albian ammonite faunas in the primary nodules of the phosphatised conglomerate at the base of the Arnager Greensand (*Leymeriella tardefurcata* and *Douvilleiceras mammilatum* Zones), and Lower Cenomanian faunas from the secondary nodules (*Mantelliceras saxbii* and *Mantelliceras dixonii* Zones).

Deposition rates were clearly low during the Albian and Early Cenomanian, with the whole interval represented by the primary and secondary nodule phases. The lack of a Middle and Upper Albian ammonite faunas suggests regression during this period. Sea level curves for this period (Haq *et al.*, 1987; Hart, 1980) show a tendency for gradually increasing water



Sea-level changes, probably of eustatic origin, in various areas in southern Sweden and Bornholm. T = transgression; R = regression. The vertical bars on the right side of each column show the stratigraphic age of the sediments for the corresponding area. Absolute ages are from Harland *et al.* (1982).

Figure 6.1 Sea level changes in southern Sweden and Bornholm, for the Albian to Maastrichtian, from Christensen (1984).

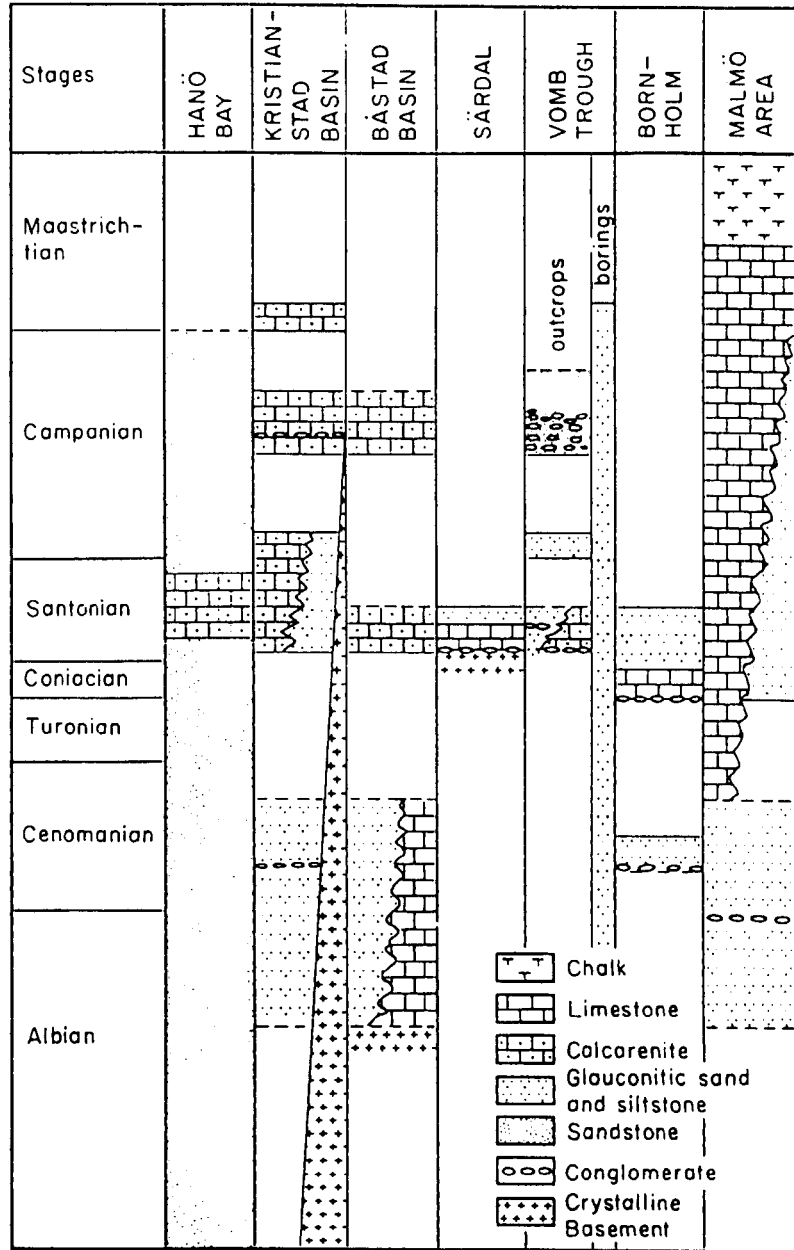


Figure 6.2 Generalised scheme showing Albian to Maastrichtian stratigraphy of southern Sweden and Bornholm. Christensen (1984)

depths, though Haq *et al.*, (1987) show on their short term curve that regressions did occur during this interval, as do Hancock and Kauffman, (1979), and Hancock, (1989).

The present lack of other macrofossil or microfossil evidence for a Middle and Late Albian fauna would tend to support the view of Kennedy *et al.*, (1981) that this period was regressive.

High rates of deposition in the lower Middle and Middle Cenomanian is apparent from fossil evidence. Sea level curves show gradually increasing water depth during the Middle Cenomanian, which is also reflected in the foraminiferal fauna, as outlined below.

Planktonic foraminifera are useful indicators of relative water depth. Hart and Bailey (1979) produced a four fold division of planktonics in the water column for the mid-Cretaceous, from the deepest Zone 4 to the shallowest Zone 1. The Arnager Greensand for the most part is characterised by shallow water planktonics (Zones 1-2), including *Heterohelix*, *Hedbergella*, *Globigerinelloides* and *Praeglobotruncana*. A major water depth increase is then indicated with the influx of *Rotalipora* near the top of the Arnager Greensand (Zone 3).

The benthic fauna of the Arnager Greensand Formation shows a typical inner shelf assemblage (Classification following Sliter and Baker, 1972), consisting of miliolids, polymorphinids, nodosariids and encrusting forms. The fauna shows a progressive increasing water depth, with a gradual decline in polymorphinids, the disappearance of encrusting forms, and associated marked increase in the planktonic component. This is consistent with increasing water depths. The trend then through the Middle Cenomanian Arnager Greensand Formation is towards increasing water depth. This is consistent with global models. Haq *et al.*, (1987) predict a transgressive and a highstand system tract for the *Rhotomagense* Zone. It should be noted though that Hancock (1989) suggests that the *Rhotomagense* Zone represents a low sea level period.

Global models show that a major transgression took place in the Late Cenomanian?-Early Turonian. Previous work (Christensen, 1984) for the Bornholm area has suggested that non-deposition and regression took place during this interval, resulting in the formation of the phosphatised conglomerate seen at the base of the Arnager Limestone Formation. Christensen (1984) correlated this event through southern Sweden using the gap in

sedimentation at the Middle/Late Cenomanian boundary seen on Bornholm, the Kristianstad Basin, the Bastad basin and in the Malmo area. The crucial assumption of this model is that non-deposition is taken to indicate regression. Work by Hart (1980) has shown that a major non-sequence is formed at the Middle/Late Cenomanian boundary associated with a major increase in water depth (Fig.6.3).

The fact that thick sedimentary sequences are not necessarily formed as a result of transgression has been alluded to by Hart (1980). Haq *et al.*, (1987) outlined the types of boundary formed by a transgressive event. Their so called "downlap surface" seen from seismic data, is the surface that "is associated with the condensed section that occurs within the transgressive and highstand system tracts. It depicts an interval of depositional starvation when the rapidly rising sea level moves the sediment depocentres landward. Because of the lack of terrigenous input, the condensed section may be expressed as a zone of high pelagic fossil concentration, or as hardground caused by lithification". Similar condensed sequences to that seen on Bornholm can be recognised at this stratigraphic level in the Polish-Danish trough (Walaszczyk, 1987). The possibility that the conglomerate seen at the base of the Arnager Limestone is of a similar origin is examined below.

Biostratigraphic evidence, both macrofaunal and microfaunal suggests the possibility of at least some deposition within the ?Late Cenomanian to the Coniacian interval. As was pointed out earlier this evidence is not unequivocal, yet it would seem to be an oversimplification to state that there is a single hiatus between the Middle Cenomanian and Coniacian.

It is now proposed that the alternative following scenario could account for the Upper Cretaceous sedimentary succession on Bornholm. Shallow shelf glauconitic sands were developed during the Middle Cenomanian. Increasing water depth eventually removed the clastic depocentre to a more proximal position, probably northeastwards or northerly onto the shield area. Deposition during the Late Cenomanian, Early and Middle Turonian probably consisted of a low pelagic input which was subsequently removed or reworked soon after deposition. The subsequent regression which may then have taken place during the Late Turonian resulted in the reworking of the top of the earlier shelf sands (Arnager Greensand

Formation) and led to the formation of the phosphatised conglomerate, now seen at the base of the Arnager Limestone Formation.

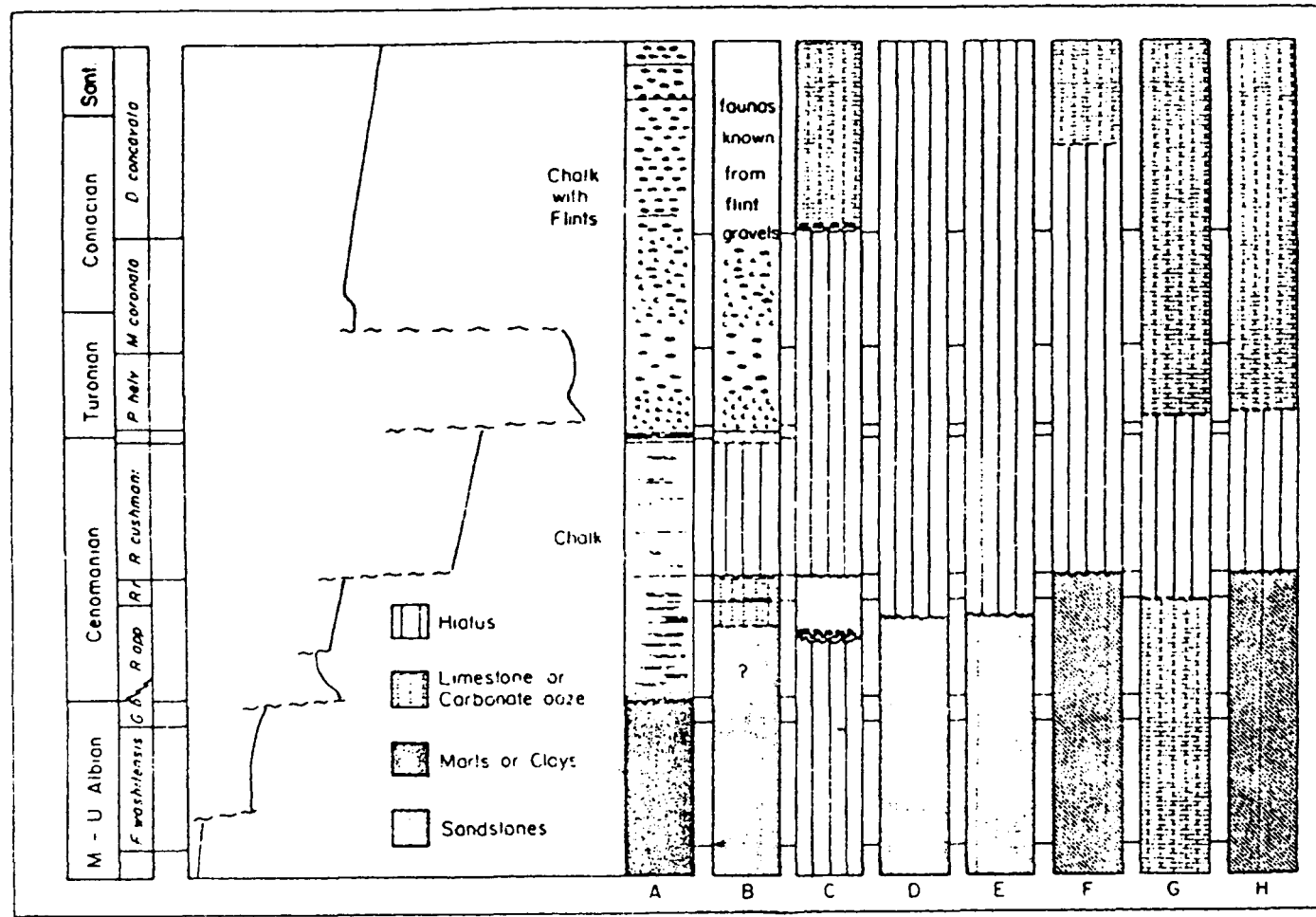
Water depths began to increase again in the Coniacian, with deposition of a pelagic limestone (Arnager Limestone Formation). Outer shelf depths are indicated by the benthic foraminifera and occurrence of abundant radiolaria. Associated planktonic assemblages contain a high proportion of keeled forms, typical of depth zones 3-4. Within the planktonic fauna there is a distinct change in the proportion of keeled to non keeled taxa when passing from the Arnager Limestone into the Bavnodde Greensand. Keeled taxa predominate in the limestone and at the boundary between the two formations, whilst keeled taxa are present in lower numbers in the lower part of the Bavnodde Greensand. Higher in the Bavnodde Greensand the acme of *Whiteinella baltica* and demise of keeled forms clearly indicates a reduction in effective water depth.

Benthic foraminiferal assemblages in the Arnager Limestone suggest outer shelf depths, whilst those from the Bavnodde Greensand clearly indicate inner shelf depths.

An overall shallowing trend is indicated by the change from carbonate (chalk) to clastic deposition from the Arnager Limestone to Bavnodde Greensand. Christensen (1984) suggests that the increasing clastic content of the Arnager Limestone (up succession) may indicate shallowing. This is at variance with the occurrence of deeper water planktonics at the boundary between the two formations.

By comparison with Hancock (1989), the Late Coniacian transgressive phase and following Early Santonian stillstand phase may equate to the upper part of the Arnager Limestone and its boundary with the Bavnodde Greensand. The hiatus at this level, indicated by the foraminiferal data, the evident reworking of the limestone and the appearance of deeper water planktonics at the boundary might indicate increased water depths equivalent to the Late Coniacian peak indicated by Hancock (1989) for the U.K. succession. This scenario is, however, complicated by the increasing clastic content of the limestone, which would tend to suggest shallowing. This problem may only be solved by careful analysis of sedimentological data from the Arnager Limestone-Bavnodde Greensand boundary, in particular the relationship between clastic and carbonate rates of production.

Figure 6.3 Correlation of mid-Cretaceous successions from Hart (1980)



Correlation of various mid-Cretaceous successions using planktonic Foraminifera, showing relationship to the proposed sea level changes. A. S. E. England; B. S. W. England; C. Bornholm; D. Site 398 North Atlantic; E. Site 111 North Atlantic; F. Site 327A South Atlantic; G. Site 310A North West Pacific; H. Site 258 Eastern Indian Ocean.

SYSTEM	SERIES	Proposed equivalent macrofossil biochronozone	Biozonation	Formation	Lithology	Stage	Breaks in deposition	Tectonic events	Proposed basin events	Water depth
CRETACEOUS	UPPER	Uintacrinus socialis or younger	<i>Whiteinella baltica</i> acme	Bavnodde Greensand		Santonian		Uplift and inversion in the Polish Danish trough	GRADUALLY DECLINING WATER DEPTHS THROUGH INCREASING CLASTIC DEPOSITION	
		Uintacrinus socialis	<i>C. ex. gr. beaumontianus</i>							
		V. involutus? - M. cortestudinarium	<i>L. amagerensis</i>	Amager Lst		Coniacian		Quiescent	OUTER SHELF CARBONATE DEPOSITION.	
		Indeterminate	<i>R. kelleri</i>	Amager Greensand		Lower? Coniacian - Middle Cenomanian				
		Turrilites costatus	<i>R. reicheli</i>			Amager Greensand		Middle Cenomanian		
	M. saxbii - M. dixonii	Not zoned	Amager Greensand		Lower Cenomanian				EARLY CENOMANIAN TRANSGRESSION	
	tardefurcata - mammilatum				Lower Albian		Austrian? tectonics	EARLY ALBIAN TRANSGRESSION		

Figure 6.4 Proposed event synthesis for the Bornholm marine Cretaceous succession.

The possibility of uplift of the basin during the Santonian might account for the effective decrease in water depth seen in the higher levels of the Bavnodde Greensand with sedimentary infilling being greater than the gradual rise in sea level through the Santonian.

6.5 Regional evidence for sea level change.

Enclosure 2 summarises well and outcrop data from southern Sweden and Bornholm. This data has been collected from three main sources, Bergstrom *et al.*, (1973), Chatziemmanouil (1982) and Christensen (1984). It is important to note that this information is of variable quality, and that some of the ages proposed are open to reinterpretation. For example Chatziemmanouil (1982) defines the Turonian on at least three different planktonics *Praeglobotruncana delrioensis*, *Rotalipora turonica* and *Rotalipora cushmani*. *P. delrioensis* is typically Cenomanian in age, whilst *R. cushmani* is typically Late Cenomanian and *R. turonica* is synonymous with *R. cushmani*. Because of these inconsistencies and the variability of fossil groups used for age definition, ages on this diagram are tenuous.

Sedimentological detail also varies from highly detailed in Chatziemmanouil (1982), to gross simplifications for large areas in Christensen (1984).

An attempt is made here to examine the sequences from southern Sweden related to possible sea level changes, in the light of Christensen (1984) and other models.

Albian to Cenomanian glauconitic sands are known from Bornholm, Hano Bay, the Malmo area, Kristianstad basin, Kullemlolla-1, Bastad and Sardal. In most instances marine faunas have been recorded from these areas, suggesting similar depositional environments to those found on Bornholm during the Cenomanian.

Evidence for a transgressive event in the Late Cenomanian to Turonian comes from four sources:

1. The occurrence of a Cenomanian non-sequence, seen across the area. In the Bastad Basin, Cenomanian sands are overlain by Santonian? sediments. In the Kristianstad basin Cenomanian sands are overlain by Santonian sands and limestones. Similar non-sequences have been recorded by Hart (1980a,b) and are typically related to the mid-Cenomanian non-sequence, associated with a major eustatic rise in the Late Cenomanian.

2. Late Cenomanian - Turonian sediments are recorded in the Malmo area as limestones and in the Vomb trough as a variable sequence of limestones, claystones, marls and sandstones. Turonian sediments are also recorded from Hano Bay, and Turonian elements are recorded at Sardal. There does therefore seem to have been some marine sedimentation in this interval, though further north on the shield area, which would be consistent with a transgressive event moving clastic depocentres to a more proximal situation in relation to the shield area.

3. There is also evidence that at least some of the above sediments contain faunas diagnostic of relatively deep water, for example *Rotalipora cushmani* which occurs in the Late Cenomanian is recorded from the Vomb trough. This species is typical of Zone 3 of Hart and Bailey (1979).

Coniacian/Santonian sediments are well developed throughout the area, comprising sands, clays and limestones. These thick sequences were probably developed in response to changing water depth conditions similar to the relationships seen on Bornholm. On positive areas it would appear that clastic deposition generally occurs earlier. For example on Bornholm the change from carbonate to clastic deposition takes place in the Middle Santonian after the hiatus which is probably of Middle/Late Coniacian age, whilst in Hano Bay carbonate deposition is more prevalent into the Santonian, suggesting that Bornholm lay closer to a clastic source. Shoreline progradation therefore occurred earlier on Bornholm than in the trough areas such as Hano Bay and the Vomb trough.

6.6. Summary.

The scenario presented above for the Bornholm succession presents an alternative to the Christensen (1984) model and will hopefully promote future work to test the validity of both models. The nature of the succession including major breaks in sedimentation, gaps in the exposed sections, and variable dating result in conclusions that will remain contentious for some time. Future work on the sedimentary facies, particularly of the Arnager Greensand and improved stratigraphic data from palynology may help to improve our understanding of this succession and its relationship to sequences from elsewhere.

Chapter Seven

Summary.

7.1 Micropalaeontology.

Micropalaeontological studies have been carried out on samples taken at roughly one metre intervals through the Upper Cretaceous succession of Bornholm, Denmark. The three formations studied (Arnager Greensand, Arnager Limestone and Bavnodde Greensand) all yielded rich assemblages of foraminifera. Taxonomic studies indicate that the foraminiferal assemblages described can be shown to be typical of well developed Late Cretaceous marine faunas.

The foraminiferal distribution data presented has been synthesised to form a new biozonation scheme for the succession. Six local assemblage biozones are proposed:

Biozone Six: *Whiteinella baltica* Assemblage Biozone
(Age: Middle Santonian)

Biozone Five: *Cibicides beaumontianus* Assemblage Biozone
(Age: Early?-Middle Santonian)

Biozone Four: *Lingulogavelinella arnagerensis* Assemblage Biozone
(Age: Middle? Coniacian)

Biozone Three: *Reussella kelleri* Assemblage Biozone
(Age: Middle Cenomanian-Coniacian)

Biozone Two: *Rotalipora reicheli* Assemblage Biozone
(Age: Middle Cenomanian)

Biozone One: *Lingulogavelinella jarzevae* Assemblage Biozone
(Age: Early Middle Cenomanian)

The foraminiferal zonation scheme compares favourably with previously published macrofossil data and provides a measure of clarification where the macrofossil data has been equivocal.

Relative abundance and foraminiferal group composition have been analysed for the succession. The implications of changes in relative water depth are reflected in foraminiferal group composition. Of particular note is the gradual deepening trend recognised through the Arnager Greensand Formation and the shallowing trend indicated through the Bavnodde

Greensand Formation. Palaeogeographic work suggests that distinctive "East European" elements can be recognised in the microfauna.

7.2. Sea level changes.

A model for relative sea level change is presented for the succession, combining palaeontological, lithological and regional geological data. Transgressive phases are recognised in the Early Albian, Early Cenomanian, Late Cenomanian-Early Turonian. The Coniacian interval overall shows stable outer shelf water depths, whilst the Late Coniacian-Santonian is characterised by an initial phase of increasing water depth followed by a probable tectonically influenced water depth reduction.

7.3. Future Work.

Future biostratigraphic work should see the usage of nannofossils and palynology to increase the degree of biostratigraphic calibration. This would also help to clarify the influence of facies control upon the foraminiferal fauna. Analysis of the radiolarian fauna is underway by the author and M.B.Hart, though it is unlikely that, given the infancy of radiolarian work, a high degree of biostratigraphic resolution can be achieved in the near future.

A full understanding of sea level changes may be improved by a basin wide study combining palaeontological, lithological and seismic data. A reinterpretation of the Scania area and correlation through to Northern Germany and Poland would undoubtedly be of value.

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PLATE ONE

1. <i>Haplophragmoides</i> sp.A	AG/86/2	x100
2. <i>Placopsilina</i> sp. A	AK26	x150
3. <i>Plectina cenomana</i> Carter and Hart, 1977	AK28	x100
4. <i>Plectina mariae</i> (Franke, 1928)	WKC	x150
5. <i>Eggerellina mariae</i> ten Dam, 1950	AK27	x150
6. <i>Spiroplectinata annectens</i> (Parker and Jones, 1863) (Broken specimen).	WKC	x75
7. <i>Verneuilina muensteri</i> Reuss, 1854	BO27	x150
8. <i>Gaudryina rugosa</i> d'Orbigny, 1840	AK8	x100
9. <i>Gaudryina carinata</i> Franke, 1914	BO23	x150
10. <i>Tritaxia pyramidata</i> Reuss, 1862	AK4	x150
11. <i>Arenobulimina advena</i> Cushman ,1936	AK27	x150
12. <i>Arenobulimina anglica</i> Cushman, 1936	AG/86/2	x100

PLATE 1

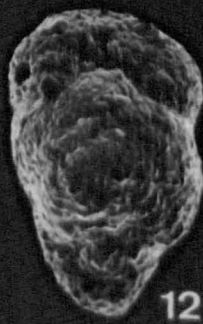
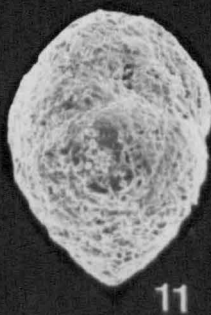
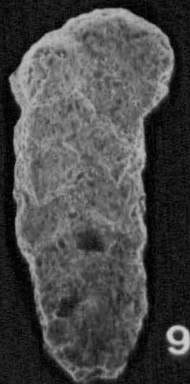
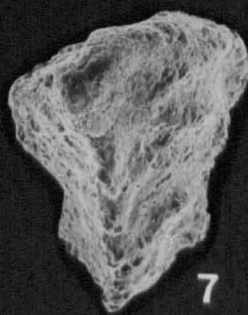
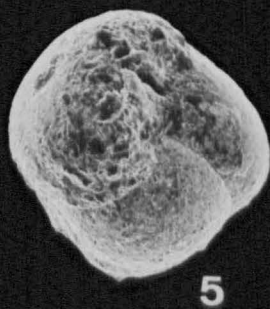
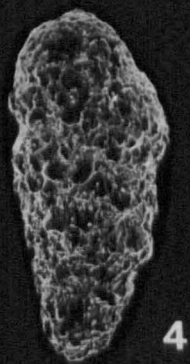
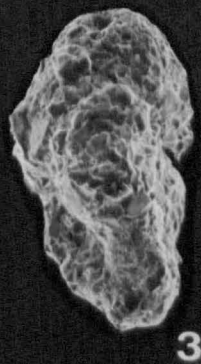
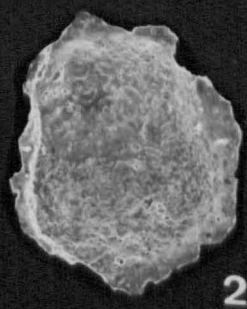


PLATE TWO

1. <i>Arenobulimina bulletta</i> (Barnard and Banner, 1981)	M/86/3	x50
2. <i>Arenobulimina bulletta</i> (Barnard and Banner, 1981) (Apertural view).	M/86/3	x50
3. <i>Arenobulimina courta</i> (Marie, 1941)	AK24	x200
4. <i>Arenobulimina obliqua</i> (d'Orbigny, 1840)	AK27	x150
5. <i>Arenobulimina truncata</i> (Reuss, 1846)	S/86/3	x200
6. <i>Arenobulimina</i> sp. A	AK27	x200
7. <i>Arenobulimina</i> sp. B	AG/86/2	x100
8. <i>Ataxophragmium depressum</i> (Perner, 1892)	AG/86/2	x75
9. <i>Ataxophragmium depressum</i> (Perner, 1892)	AG/86/2	x75
10. <i>Ataxophragmium variabile</i> (d'Orbigny, 1840)	S/86/2	x200
11. <i>Ataxophragmium variabile</i> (d'Orbigny, 1840)	S/86/2	x150
12. <i>Ataxophragmium variabile</i> (d'Orbigny, 1840) var. A	M/86/1	x75
13. <i>Psuedotextulariella cretosa</i> (Cushman, 1932)	M/86/3	x75
14. <i>Marssonella trochus</i> (d'Orbigny, 1840)	AG/86/11	x200
15. <i>Textularia chapmani</i> Lalicker, 1935	AG/86/6	x150

PLATE 2

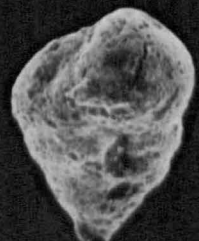
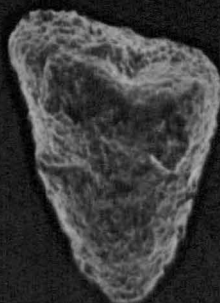
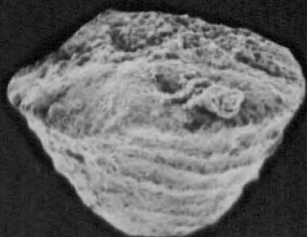
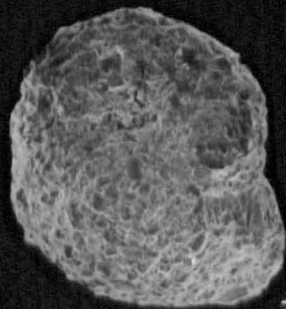
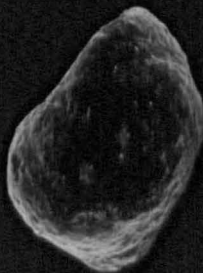
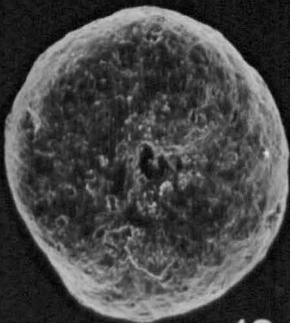
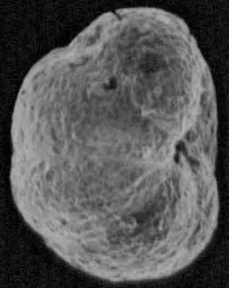
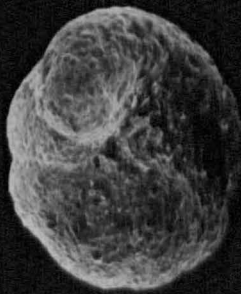
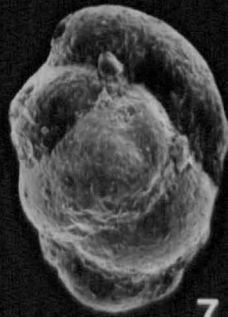
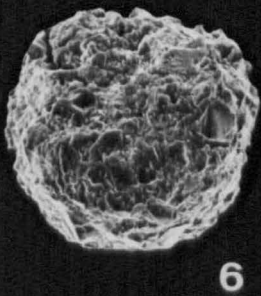
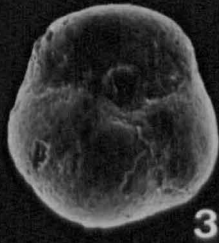
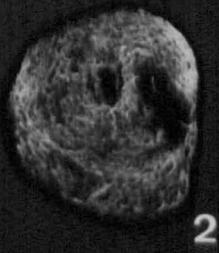
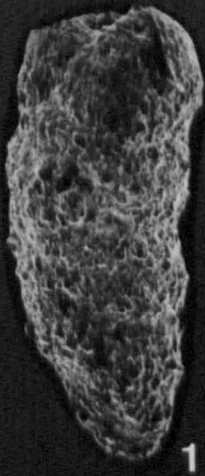
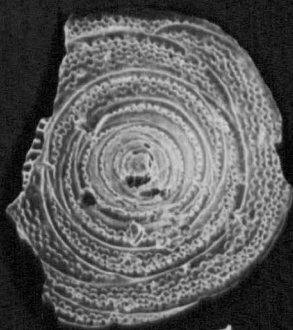


PLATE THREE

1. <i>Patellina subcretacea</i> (Cushman and Alexander, 1930)	AG/86/1	x200
2. <i>Quinqueloculina antiqua</i> Franke, 1928	AK29	x350
3. <i>Quinqueloculina antiqua</i> Franke, 1928 (Apertural view).	AK29	x1500
4. <i>Quinqueloculina moremani</i> Cushman, 1937	AK17	x200
5. <i>Dentalina catenula</i> Reuss, 1860	AG/86/2	x50
6. <i>Dentalina debilis</i> (Berthelin, 1880)	AK24	x200
7. <i>Dentalina intermedia</i> Reuss, 1860	WKC	x100
8. <i>Dentalina megapolitana</i> Reuss, 1855	BO15	x50
9. <i>Dentalina</i> sp. A	BO27	x200
10. <i>Nodosaria aspera</i> Reuss, 1845	BO29	x150
11. <i>Nodosaria obscura</i> Reuss, 1845	AK28	x200
12. <i>Nodosaria paupercula</i> Reuss, 1846	BO26	x200
13. <i>Nodosaria orthopleura</i> Reuss, 1863	AK24	x75

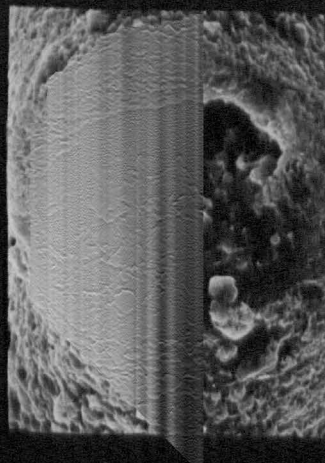
PLATE 3



1



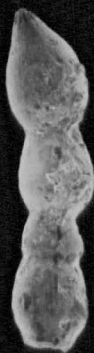
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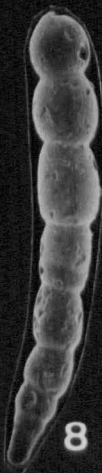
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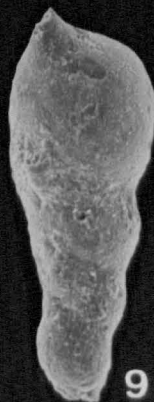
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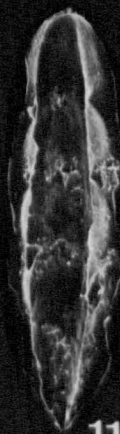
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PLATE FOUR

1. <i>Nodosaria sceptrum</i> Reuss, 1863	AK26	x350
2. <i>Nodosaria</i> sp. A	AK24	x200
3. <i>Nodosaria</i> sp. B	AK4	x350
4. <i>Nodosaria</i> (?) sp. C	AK12	x150
5. <i>Nodosaria</i> sp. D	AK8	x150
6. <i>Nodosaria</i> sp. E	AK2	x100
7. <i>Pseudonodosaria</i> sp. A	AK24	x150
8. <i>Lingulina furcillata</i> Berthelin, 1880	AK24	x300
9. ? <i>Lingulina</i> sp. A	AK14	x150
10. <i>Frondicularia archiaciana</i> d'Orbigny, 1840	M/86/4	x150
11. <i>Frondicularia</i> cf. <i>striatula</i> Reuss, 1845	BO27	x100
12. <i>Frondicularia watersi</i> Cushman, 1936	WKC	x100

PLATE 4

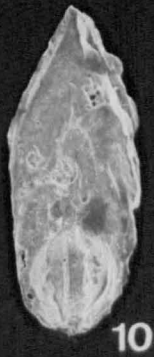


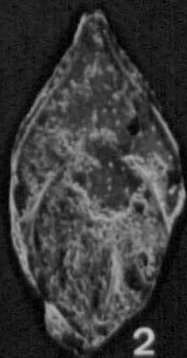
PLATE FIVE

1. <i>Frondicularia</i> sp. A	AK8	x50
2. <i>Frondicularia</i> sp. B	AK4	x350
3. <i>Frondicularia</i> sp. C	BO23	x50
4. <i>Tristix insigne</i> (Reuss, 1862)	WKC	x200
5. <i>Tristix</i> sp. A	AK24	x200
6. <i>Lenticulina gaultina</i> (Berthelin, 1880)	AK27	x100
7. <i>Lenticulina lepida</i> (Reuss, 1846)	AK27	x100
8. <i>Lenticulina rotulata</i> (Lamarck, 1804)	AK24	x150
9. <i>Lenticulina</i> sp. A	AG/86/2	x35
10. <i>Saracenaria bononiensis</i> (Berthelin, 1880)	AK29	x100
11. <i>Saracenaria planiscula</i> (Reuss, 1863)	AK24	x200
12. <i>Saracenaria triangularis</i> (d'Orbigny, 1840)	WKC	x150
13. <i>Neoflabellina baudouiniana</i> (d'Orbigny, 1840)	AK31	x200
14. <i>Neoflabellina deltoidea</i> (Wedekind, 1940)	AK31	x100
15. <i>Neoflabellina praerugosa</i> Hiltermann, 1952	BO19	x200
16. <i>Neoflabellina suturalis suturalis</i> (Cushman, 1935)	BO15	x75

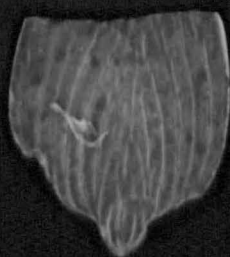
PLATE 5



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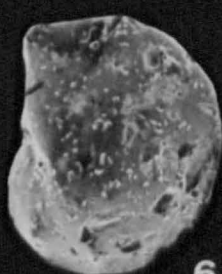
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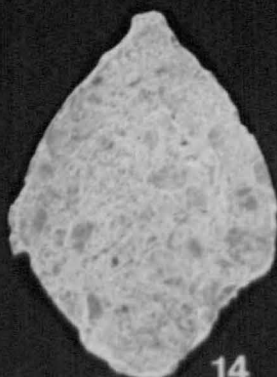
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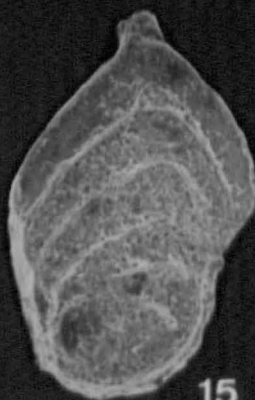
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PLATE SIX

1. <i>Palmula cordata</i> (Reuss, 1844)	AG/86/1	x35
2. <i>Palmula pilulata</i> Cushman, 1938	AG/86/2	x75
3. <i>Marginulina jonesi</i> (Reuss, 1862)	AK28	x150
4. <i>Marginulina</i> sp. A	AK1	x200
5. <i>Marginulina</i> sp. B	BO27	x200
6. <i>Vaginulinopsis scalariformis</i> Porthault, 1970 (<i>s.l.</i>)	BO13	x75
7. <i>Citharina arambourgi</i> Marie, 1938	AK24	x150
8. <i>Citharina</i> sp. A	BO16	x150
9. <i>Citharinella chapmani</i> (Marie, 1938)	AG/86/2	x50
10. <i>Citharinella laffitei</i> Marie, 1938	WKC	x50
11. <i>Planularia cenomana</i> (Schacko, 1897)	AK24	x150
12. <i>Planularia liebusi</i> Brotzen, 1936	AK30	x200

PLATE 6

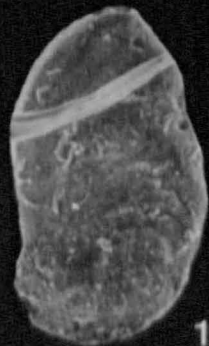
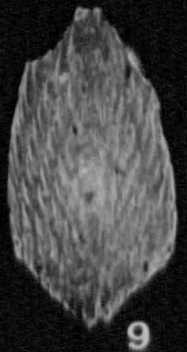
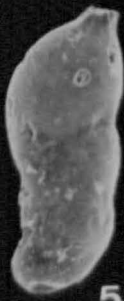
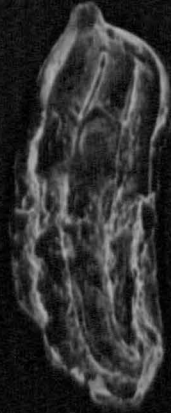
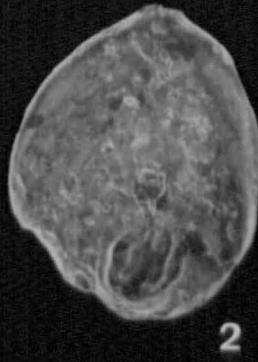
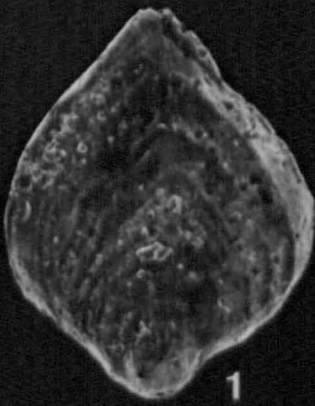
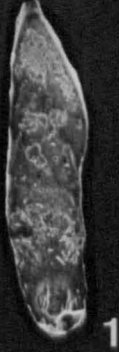


PLATE SEVEN

1. <i>Vaginulina recta</i> Reuss, 1863	WKC	x100
2. <i>Vaginulina</i> sp. A	M/86/1	x200
3. <i>Lagena apiculata</i> (Reuss, 1850)	AK2	x150
4. <i>Lagena ellipsoidalis</i> Schwager, 1878	BO16	x350
5. <i>Lagena isabella</i> d'Orbigny, 1840	BO22	x350
6. <i>Lagena sulcata</i> (Walker and Jacob, 1798)	S/86/2	x350
7. <i>Lagena</i> sp. A	AK24	x350
8. <i>Oolina</i> sp. A	AK24	x350
9. <i>Eoguttulina</i> sp. A	AK8	x200
10. <i>Globulina lacrima</i> Reuss, 1845	AK24	x200
11. <i>Guttulina adhaerens</i> (Olszewski, 1875)	AG/86/15	x100
12. <i>Guttulina trigonula</i> (Reuss, 1845)	AK27	x100
13. <i>Spirofrondicularia</i> sp. A	AG/86/2	x50
14. <i>Ramulina aculeata</i> Wright, 1886	WKC	x75
15. <i>Ramulina aculeata</i> Wright, 1886	WKC	x75

PLATE 7



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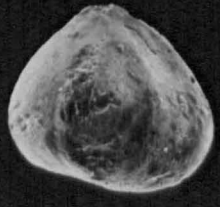
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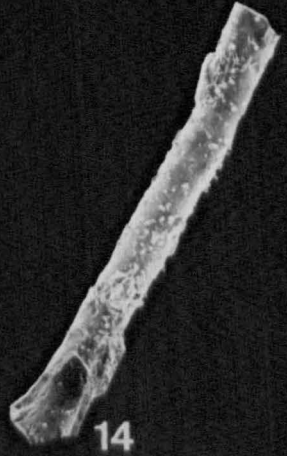
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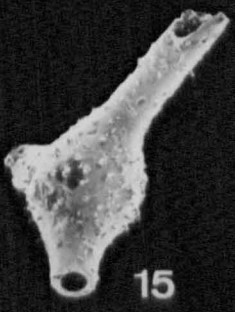
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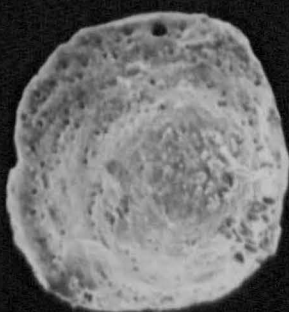
PLATE EIGHT

1. <i>Conorboides minutissima</i> (Tappan, 1943)	AK17	x350
2. <i>Conorboides</i> sp. A	WKC	x350
3. <i>Guembelitria cenomana</i> (Keller, 1935)	AK27	x500
4. <i>Heterohelix globulosa</i> (Ehrenberg, 1840)	AK17	x350
5. <i>Heterohelix moremani</i> (Cushman, 1938)	AK24	x500
6. <i>Heterohelix pulchra</i> (Brotzen, 1936)	AK1	x750
7. <i>Heterohelix reussi</i> (Cushman, 1938)	AK17	x200
8. <i>Globigerinelloides asperus</i> (Ehrenberg, 1854)	AK10	x500
9. <i>Globigerinelloides bentonensis</i> (Morrow, 1934)	AK27	x500
10. <i>Globigerinelloides rowei</i> (Barr, 1962)	AK17	x500
11. <i>Hedbergella delrioensis</i> (Carsey, 1926) (umbilical view).	M/86/3	x350
12. <i>Hedbergella delrioensis</i> (Carsey, 1926) (lateral view).	M/86/3	x350
13. <i>Hedbergella delrioensis</i> (Carsey, 1926) (spiral view).	M/86/3	x350

PLATE 8



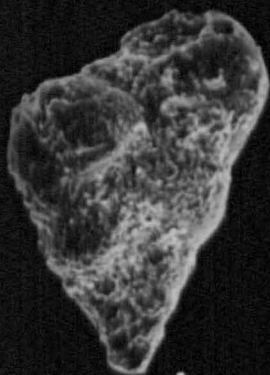
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2



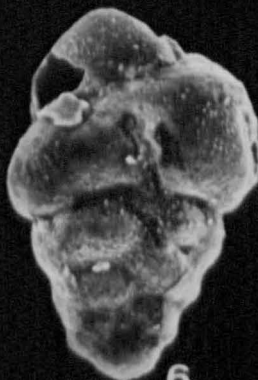
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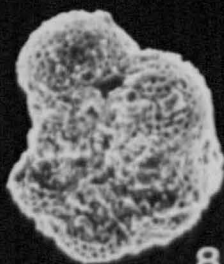
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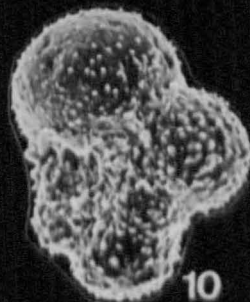
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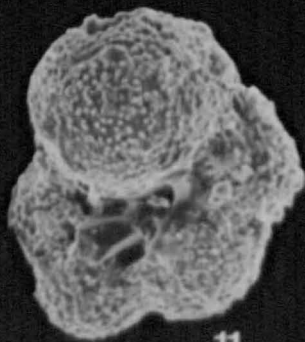
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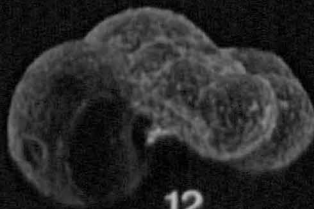
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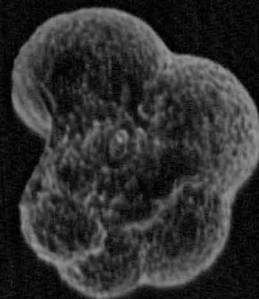
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PLATE NINE

1. <i>Hedbergella flandrini</i> Porthault, 1970	AK2	x500
2. <i>Hedbergella planispira</i> (Tappan, 1940) (umbilical view).	M/86/3	x350
3. <i>Hedbergella planispira</i> (Tappan, 1940) (lateral view).	M/86/3	x350
4. <i>Hedbergella planispira</i> (Tappan, 1940) (spiral view).	M/86/3	x350
5. <i>Whiteinella archaeocretacea</i> Pessagno, 1967 (umbilical view).	AK2	x200
6. <i>Whiteinella archaeocretacea</i> Pessagno, 1967 (lateral view).	AK2	x200
7. <i>Whiteinella archaeocretacea</i> Pessagno, 1967 (spiral view).	AK2	x200
8. <i>Whiteinella aprica</i> (Loeblich and Tappan, 1961) (umbilical view).	AK1	x200
9. <i>Whiteinella aprica</i> (Loeblich and Tappan, 1961) (lateral view).	AK1	x200
10. <i>Whiteinella aprica</i> (Loeblich and Tappan, 1961) (spiral view).	AK1	x200
11. <i>Whiteinella baltica</i> Douglas and Rankin, 1969 (umbilical view).	AK12	x200
12. <i>Whiteinella baltica</i> Douglas and Rankin, 1969 (lateral view).	AK12	x200
13. <i>Whiteinella baltica</i> Douglas and Rankin, 1969 (spiral view).	AK12	x200
14. <i>Whiteinella brittonensis</i> (Loeblich and Tappan, 1961) (umbilical view).	AK12	x200
15. <i>Whiteinella brittonensis</i> (Loeblich and Tappan, 1961) (lateral view).	AK12	x200
16. <i>Whiteinella brittonensis</i> (Loeblich and Tappan, 1961) (spiral view).	AK12	x200

PLATE 9

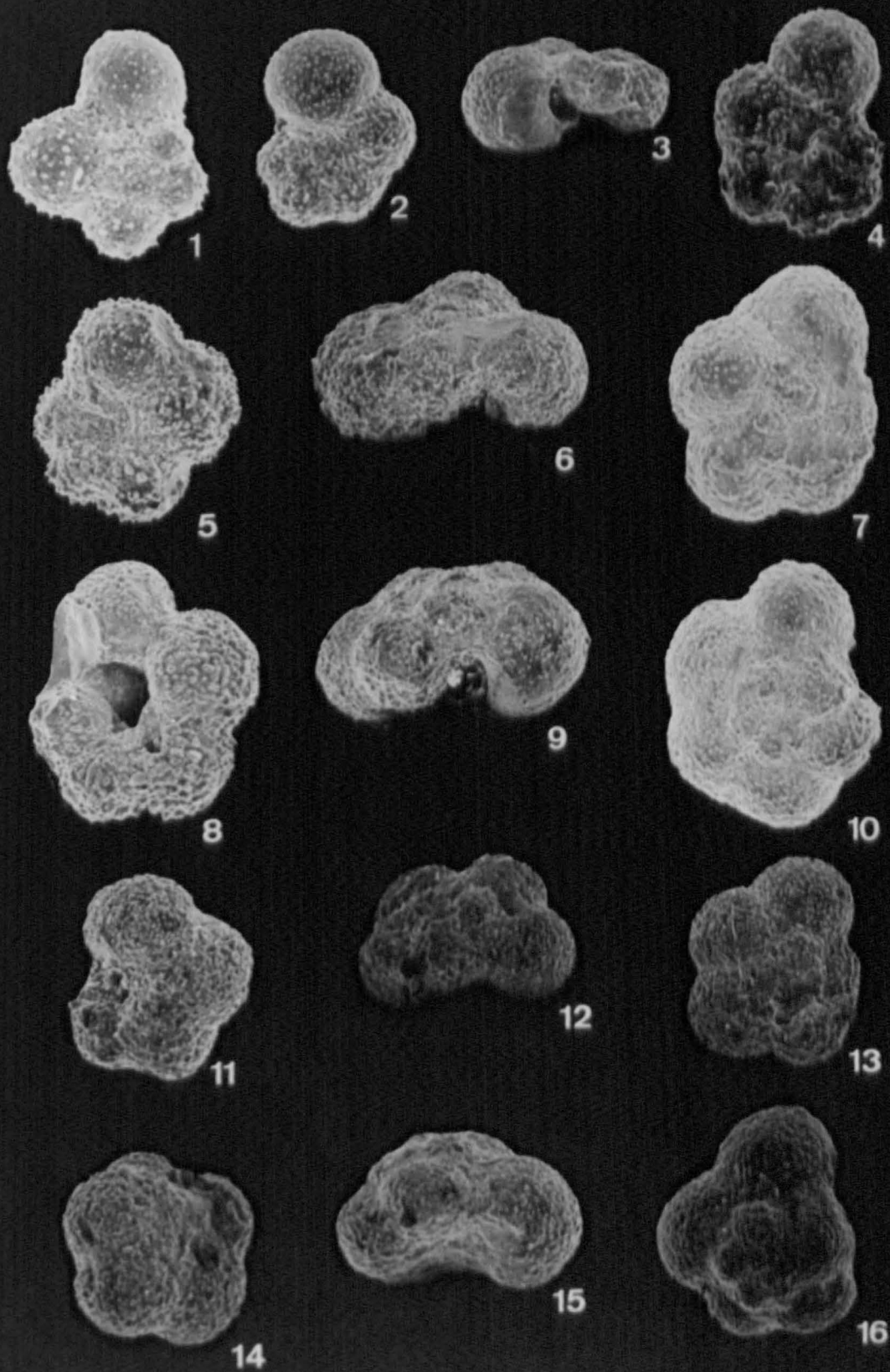
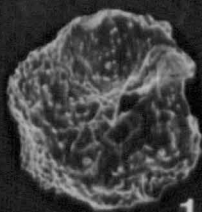


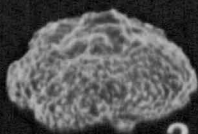
PLATE TEN

1. <i>Praeglobotruncana delrioensis</i> (Plummer, 1931) (umbilical view).	AK24	x200
2. <i>Praeglobotruncana delrioensis</i> (Plummer, 1931) (lateral view).	AK24	x200
3. <i>Praeglobotruncana delrioensis</i> (Plummer, 1931) (spiral view).	AK24	x200
4. <i>Rotalipora reicheli</i> (Mornod, 1950) (umbilical view).	WKC	x150
5. <i>Rotalipora reicheli</i> (Mornod, 1950) (lateral view).	WKC	x150
6. <i>Rotalipora reicheli</i> (Mornod, 1950) (spiral view).	WKC	x150
7. <i>Globotruncana bulloides</i> Vogler, 1941 (umbilical view).	BO15	x200
8. <i>Globotruncana bulloides</i> Vogler, 1941 (lateral view).	BO15	x200
9. <i>Globotruncana bulloides</i> Vogler, 1941 (spiral view).	BO15	x200
10. <i>Globotruncana linneiana</i> (d'Orbigny, 1839) (umbilical view).	BO15	x200
11. <i>Globotruncana linneiana</i> (d'Orbigny, 1839) (lateral view).	BO15	x200
12. <i>Globotruncana linneiana</i> (d'Orbigny, 1839) (spiral view).	BO15	x200

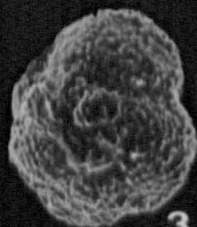
PLATE 10



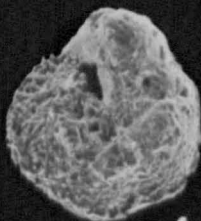
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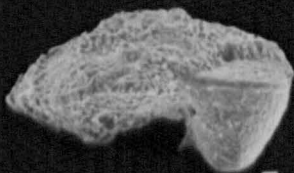
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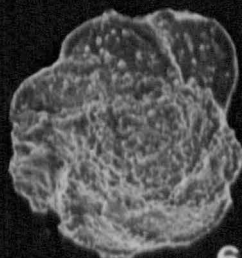
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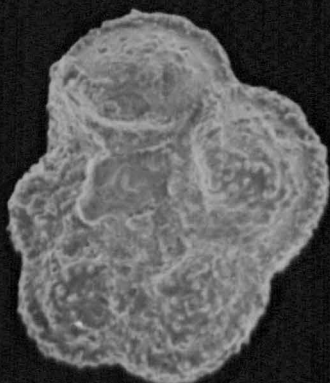
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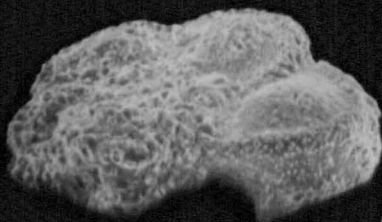
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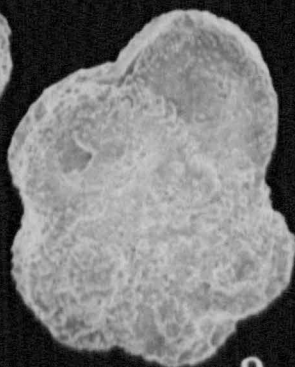
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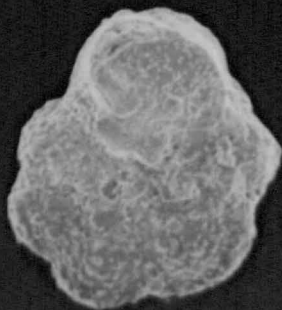
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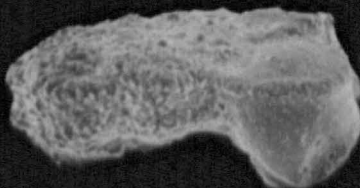
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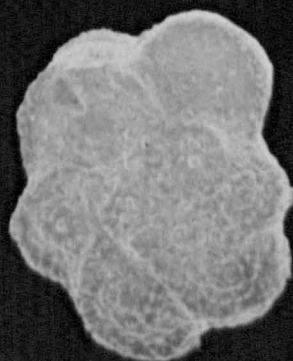
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10



11

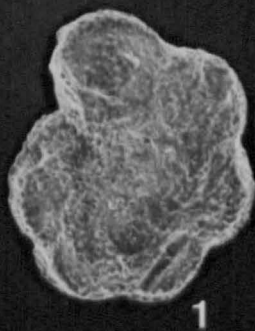


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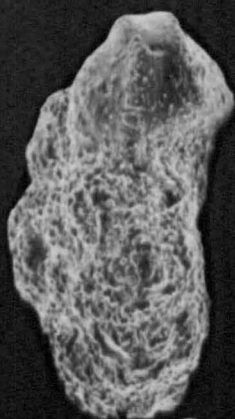
PLATE ELEVEN

1. <i>Marginotruncana marginata</i> (Reuss, 1845) (umbilical view).	AK2	x150
2. <i>Marginotruncana marginata</i> (Reuss, 1845) (lateral view).	AK2	x200
3. <i>Marginotruncana marginata</i> (Reuss, 1845) (spiral view).	AK2	x150
4. <i>Marginotruncana coronata</i> (Bolli, 1945) (umbilical view).	AK13	x150
5. <i>Marginotruncana coronata</i> (Bolli, 1945) (lateral view).	AK13	x150
6. <i>Marginotruncana marginata</i> (Reuss, 1845) (spiral view).	AK13	x150
7. <i>Dicarinella asymetrica</i> (Sigal, 1952) (umbilical view).	BO23	x150
8. <i>Dicarinella asymetrica</i> (Sigal, 1952) (lateral view).	BO23	x150
9. <i>Dicarinella asymetrica</i> (Sigal, 1952) (spiral view).	BO23	x150
10. <i>Dicarinella canaliculata</i> (Reuss, 1854) (umbilical view).	AK12	x200
11. <i>Dicarinella canaliculata</i> (Reuss, 1854) (lateral view).	AK12	x200
12. <i>Dicarinella canaliculata</i> (Reuss, 1854) (spiral view).	AK12	x200

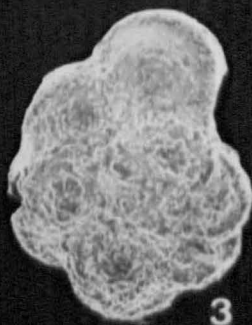
PLATE 11



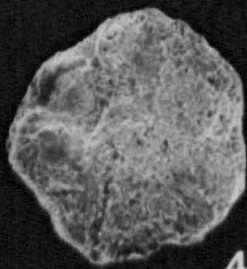
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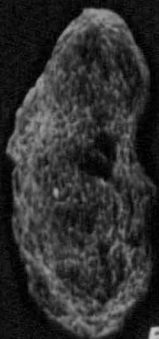
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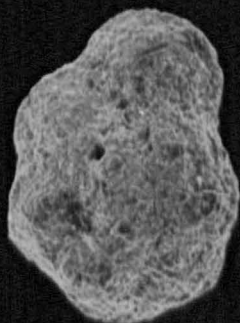
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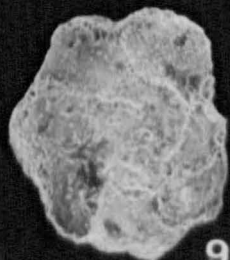
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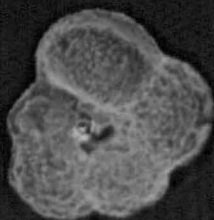
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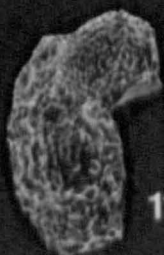
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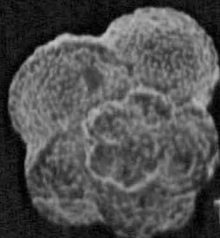
9



10



11



12

PLATE TWELVE

1. <i>Dicarinella concavata</i> (Brotzen, 1934) (lateral view).	AK17	x200
2. <i>Dicarinella concavata</i> (Brotzen, 1934) (spiral view).	AK17	x200
3. <i>Dicarinella imbricata</i> (Mornod, 1950) (umbilical view).	AK1	x150
4. <i>Dicarinella imbricata</i> (Mornod, 1950) (lateral view).	AK1	x150
5. <i>Dicarinella imbricata</i> (Mornod, 1950) (spiral view).	AK1	x150
6. <i>Archaeoglobigerina blowi</i> Pessagno, 1967 (umbilical view).	BO17	x200
7. <i>Archaeoglobigerina blowi</i> Pessagno, 1967 (lateral view).	BO17	x200
8. <i>Archaeoglobigerina blowi</i> Pessagno, 1967 (spiral view).	BO17	x200
9. <i>Archaeoglobigerina bosquensis</i> Pessagno, 1967 (umbilical view).	BO15	x200
10. <i>Archaeoglobigerina bosquensis</i> Pessagno, 1967 (lateral view).	BO15	x200
11. <i>Archaeoglobigerina bosquensis</i> Pessagno, 1967 (spiral view).	BO15	x200

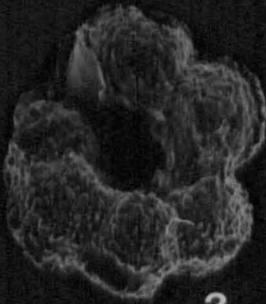
PLATE 12



1



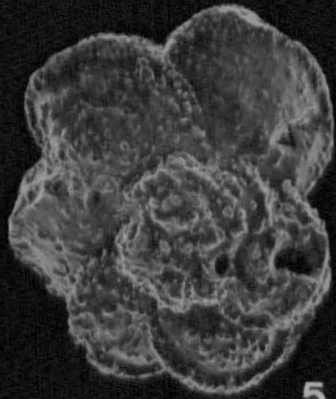
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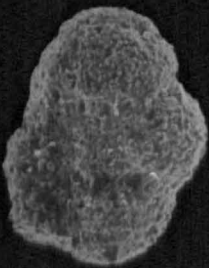
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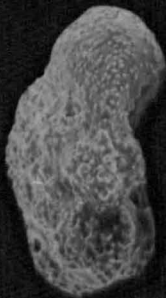
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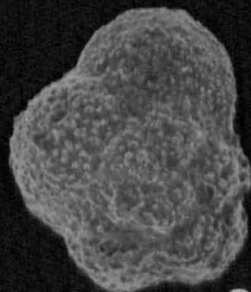
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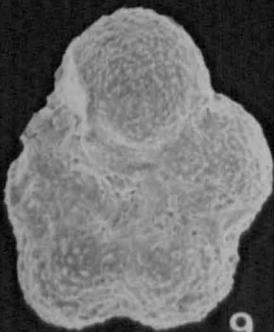
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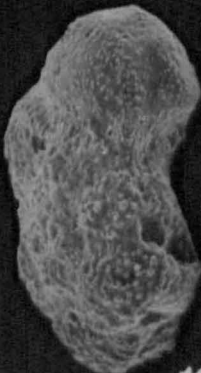
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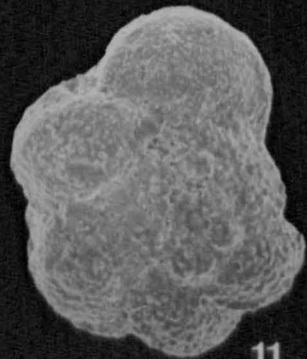
8



9



10



11

PLATE THIRTEEN

1. <i>Tappanina eouvigeriniformis</i> (Keller, 1935)	AK24	x500
2. <i>Loxostomum eleyi</i> (Cushman, 1927)	BO23	x200
3. <i>Eouvigerina aculeata</i> (Ehrenberg, 1854)	AK9	x350
4. <i>Praebulimina</i> sp. A	AK4	x200
5. <i>Praebulimina</i> sp. B	AK9	x200
6. <i>Reussella cushmani</i> (Brotzen, 1936)	AK31	x350
7. <i>Reussella kelleri</i> Vasilenko, 1961	AK31	x350
8. <i>Reussella szajnochae praecursor</i> De Klasz and Knipscheer, 1954	BO22	x350
9. <i>Cassidella tegulata</i> (Reuss, 1854)	AK17	x350
10. <i>Pleurostomella reussi</i> Berthelin, 1880	S/86/5	x350
11. <i>Pleurostomella subnodosa</i> Reuss, 1860	AK10	x350
12. <i>Conorbina marginata</i> Brotzen, 1936	AK30	x350
13. <i>Valvulineria lenticula</i> (Reuss, 1845)	AK10	x350
14. <i>Valvulineria lenticula</i> (Reuss, 1845)	AK10	x350
15. <i>Eponides concinna</i> Brotzen, 1936	AK18	x200

PLATE 13

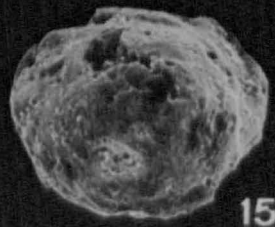
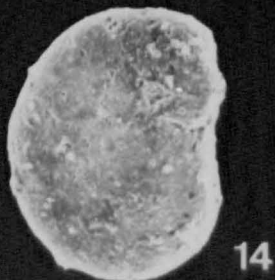
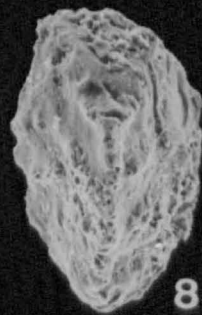
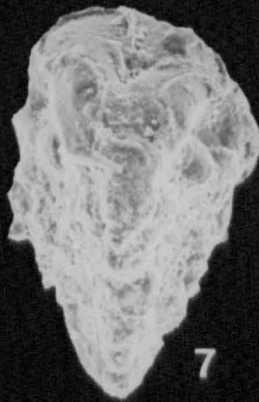
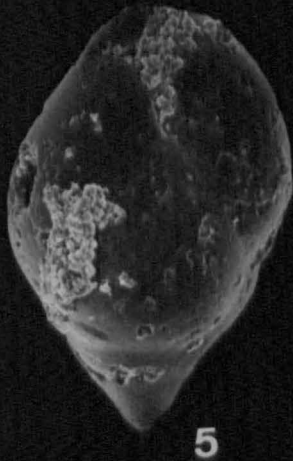
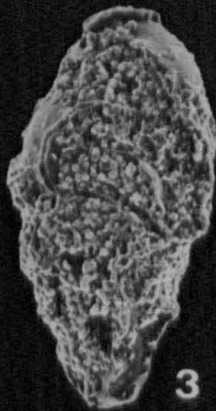


PLATE FOURTEEN

1. <i>Cibicides beaumontianus</i> (d'Orbigny, 1840) (Spiral side, phytal form)	BO23	x200
2. <i>Cibicides beaumontianus</i> (d'Orbigny, 1840) (Umbilical side, phytal form)	BO23	x200
3. <i>Cibicides gorbenkoi</i> Akimez, 1961 (Apertural view)	AK27	x150
4. <i>Cibicides gorbenkoi</i> Akimez, 1961 (Spiral side)	AK27	x150
5. <i>Cibicides ribbingi</i> Brotzen, 1936 (Spiral side)	BO23	x200
6. <i>Cibicides ribbingi</i> Brotzen, 1936 (Lateral view)	BO23	x200
7. <i>Quadrिमorphina allomorphinoides</i> (Reuss, 1860)	AK14	x200
8. <i>Quadrिमorphina trochoides</i> (Reuss, 1845)	AK14	x200
9. <i>Globorotalites micheliniana</i> (d'Orbigny, 1840) (Lateral view)	AK1	x200
10. <i>Globorotalites micheliniana</i> (d'Orbigny, 1840) (Spiral side)	AK1	x200
11. <i>Globorotalites polonica</i> Gawor-Biedowa, 1972 (Spiral side)	AK24	x350
12. <i>Globorotalites subconicus</i> (Morrow, 1934) (Spiral side)	AK24	x200
13. <i>Osangularia whitei</i> (Brotzen, 1936) (Umbilical side))	AK17	x200
14. <i>Osangularia whitei</i> (Brotzen, 1936) (Side view)	AK17	x200
15. <i>Osangularia whitei</i> (Brotzen, 1936) (Spiral side)	AK17	x200

PLATE 14

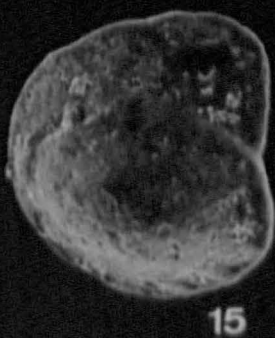
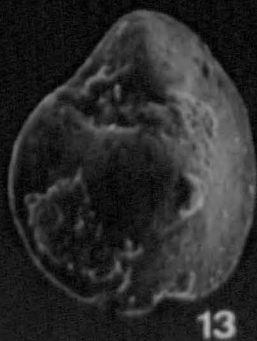
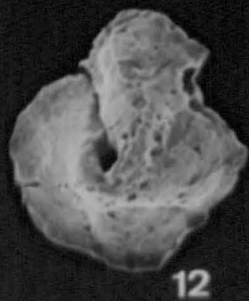
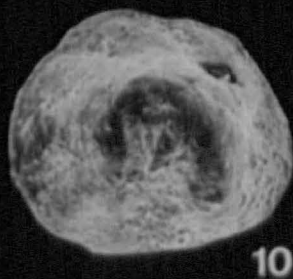
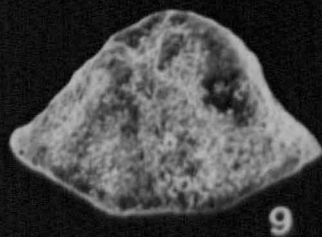
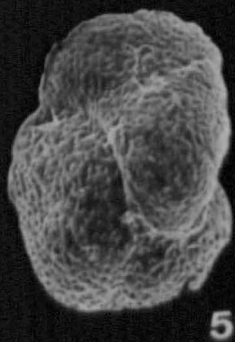
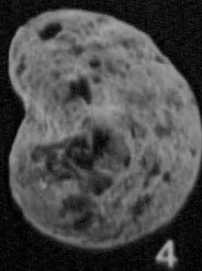
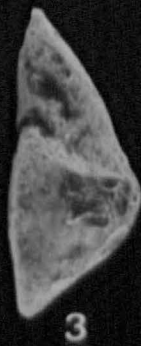
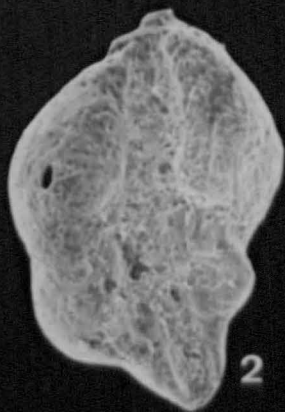
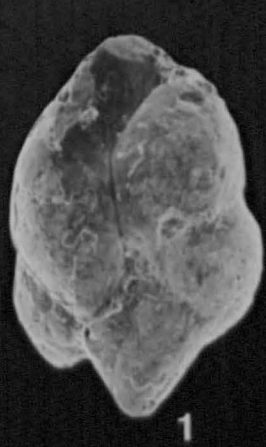


PLATE FIFTEEN

1. <i>Osangularia</i> sp. A (Umbilical side)	AG/86/19	x350
2. <i>Osangularia</i> sp. A (Side view)	AG/86/19	x350
3. <i>Osangularia</i> sp. A (Spiral side)	AG/86/19	x350
4. <i>Gyroidinoides nitidus</i> (Reuss, 1844) (Umbilical side)	AK4	x150
5. <i>Gyroidinoides nitidus</i> (Reuss, 1844) (Side view)	AK4	x150
6. <i>Gyroidinoides nitidus</i> (Reuss, 1844) (Spiral side)	AK4	x150
7. <i>Gyroidinoides parva</i> (Khan, 1950) (Umbilical side)	AK24	x350
8. <i>Gyroidinoides parva</i> (Khan, 1950) (Spiral side)	AK24	x350
9. <i>Stensioeina exsculpta exsculpta</i> (Reuss, 1860) (Umbilical side)	AK31	x200
10. <i>Stensioeina exsculpta exsculpta</i> (Reuss, 1860) (Lateral view)	AK31	x200
11. <i>Stensioeina exsculpta exsculpta</i> (Reuss, 1860) (Spiral side)	AK31	x200
12. <i>Gavelinella</i> sp. A (Umbilical side)	AK10	x350
13. <i>Gavelinella</i> sp. A (Side view)	AK10	x350
14. <i>Gavelinella</i> sp. A (Spiral side)	AK10	x200
15. <i>Stensioeina granulata granulata</i> Witwicka, 1958 (Umbilical side)	BO15	x200
16. <i>Stensioeina granulata granulata</i> Witwicka, 1958 (Side view)	BO15	x200
17. <i>Stensioeina granulata granulata</i> Witwicka, 1958 (Spiral side)	BO15	x200

PLATE 15

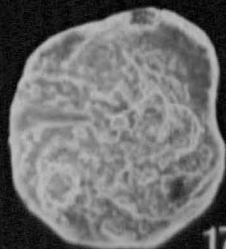
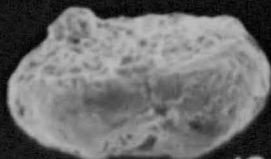
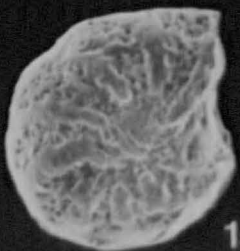
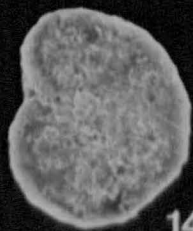
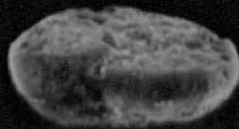
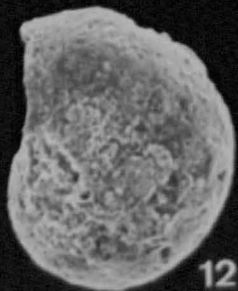
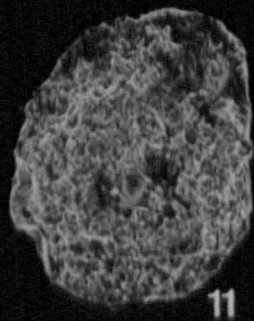
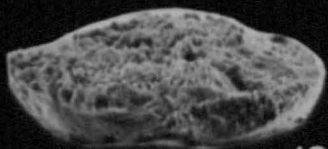
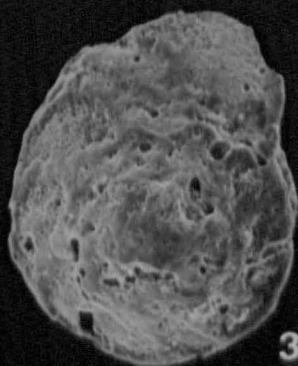
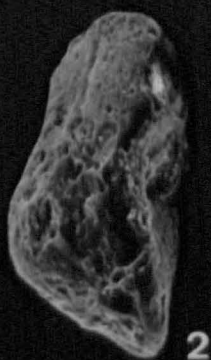
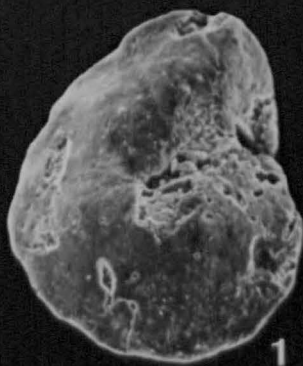


PLATE SIXTEEN

1. <i>Gavelinella pertusa</i> (Marsson, 1878) (Umbilical side)	AK31	x200
2. <i>Gavelinella pertusa</i> (Marsson, 1878) (Lateral view)	AK31	x200
3. <i>Gavelinella pertusa</i> (Marsson, 1878) (Spiral side)	AK31	x200
4. <i>Gavelinella baltica</i> Brotzen, 1942 (Umbilical side)	AG/86/2	x200
5. <i>Gavelinella baltica</i> Brotzen, 1942 (Lateral view)	AG/86/2	x200
6. <i>Gavelinella baltica</i> Brotzen, 1942 (Spiral side)	AG/86/2	x200
7. <i>Gavelinella cenomanica</i> (Brotzen, 1942) (Umbilical side)	S/86/7	x200
8. <i>Gavelinella intermedia</i> (Berthelin, 1880) (Spiral side)	M/86/3	x200
9. <i>Gavelinella intermedia</i> (Berthelin, 1880) (Lateral view)	M/86/3	x200
10. <i>Gavelinella intermedia</i> (Berthelin, 1880) (Spiral side)	M/86/3	x200
11. <i>Gavelinella lorneiana</i> (d'Orbigny, 1840) (Umbilical side)	AK31	x200
12. <i>Gavelinella lorneiana</i> (d'Orbigny, 1840) (Side view)	AK31	x200
13. <i>Gavelinella lorneiana</i> (d'Orbigny, 1840) (Spiral side)	AK31	x200

PLATE 16

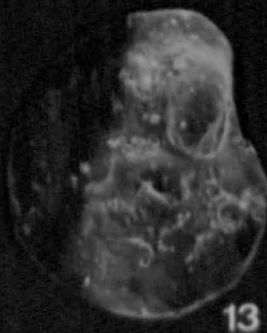
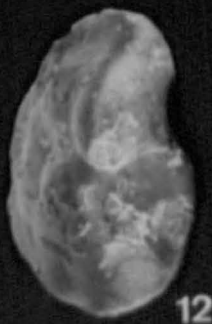
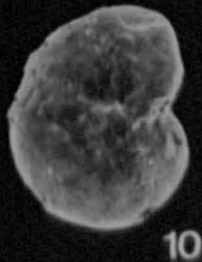
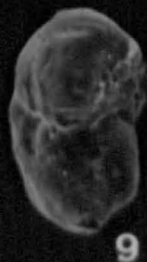
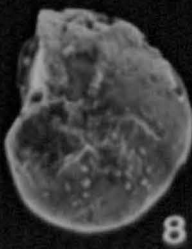
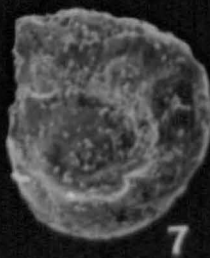
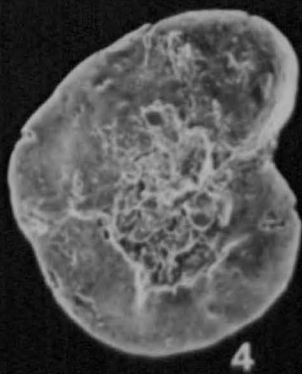
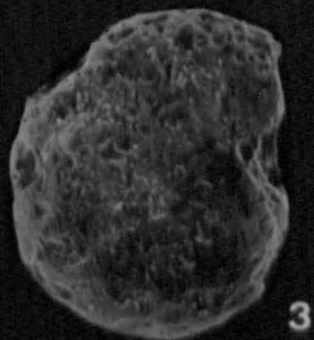
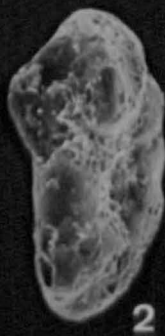
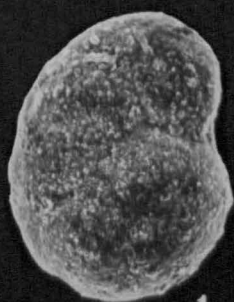


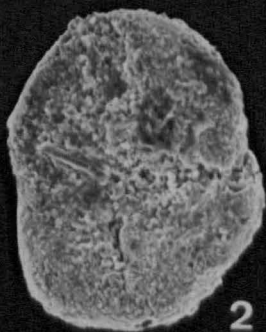
PLATE SEVENTEEN

1. <i>Gavelinella reussi</i> (Khan, 1950) (Spiral side)	S/86/2	x200
2. <i>Gavelinella schloenbachi</i> (Reuss, 1862) (Umbilical side)	BO28	x200
3. <i>Gavelinella schloenbachi</i> (Reuss, 1862) (Lateral view)	BO28	x200
4. <i>Gavelinella schloenbachi</i> (Reuss, 1862) (Spiral side)	BO28	x200
5. <i>Gavelinella stelligera</i> (Marie, 1941) (Umbilical side)	AK30	x350
6. <i>Gavelinella stelligera</i> (Marie, 1941) (Lateral view)	AK30	x350
7. <i>Gavelinella stelligera</i> (Marie, 1941) (Spiral side)	AK30	x350
8. <i>Gavelinella thalmani</i> (Brotzen, 1936) (Umbilical side)	AK31	x350
9. <i>Gavelinella thalmani</i> (Brotzen, 1936) (Lateral view)	AK31	x350
10. <i>Gavelinella thalmani</i> (Brotzen, 1936) (Spiral side)	AK31	x350
11. <i>Gavelinella cf. tormarpensis</i> Brotzen, 1942 (Umbilical side)	AG/86/14	x200
12. <i>Gavelinella cf. tormarpensis</i> Brotzen, 1942 (Lateral view)	AG/86/14	x200
13. <i>Gavelinella cf. tormarpensis</i> Brotzen, 1942 (Spiral side)	AG/86/14	x200

PLATE 17



1



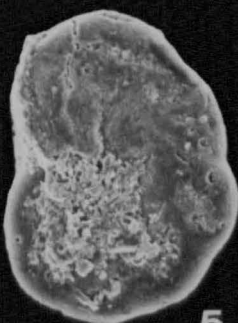
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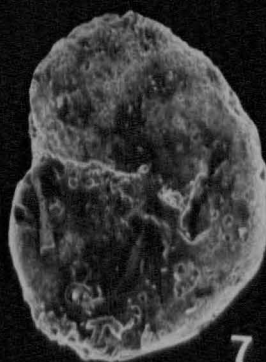
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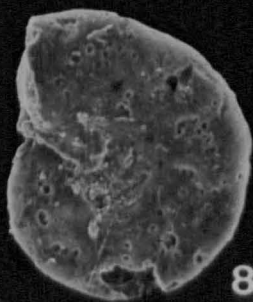
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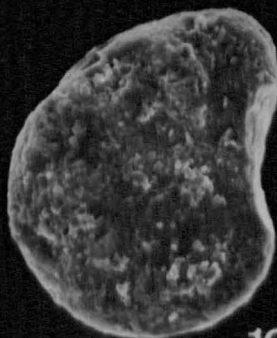
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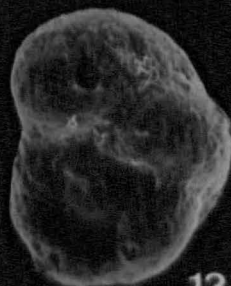
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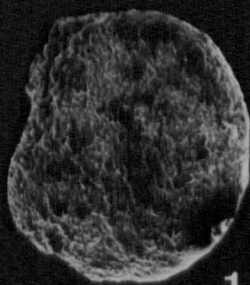


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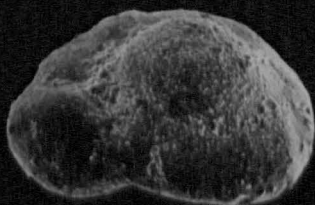
PLATE EIGHTEEN

1. <i>Gavelinopsis tourainensis</i> (Butt, 1966) (Umbilical side)	AK2	x200
2. <i>Gavelinopsis tourainensis</i> (Butt, 1966) (Lateral view)	AK2	x200
3. <i>Gavelinopsis tourainensis</i> (Butt, 1966) (Spiral side)	AK2	x200
4. <i>Gavelinella tumida</i> Brotzen, 1942 (Umbilical side)	AK2	x350
5. <i>Gavelinella tumida</i> Brotzen, 1942 (Lateral view)	AK2	x350
6. <i>Gavelinella tumida</i> Brotzen, 1942 (Spiral side)	AK2	x350
7. <i>Lingulogavelinella jarzevae</i> (Vasilenko, 1954) (Umbilical view)	M/86/3	x350
8. <i>Lingulogavelinella jarzevae</i> (Vasilenko, 1954) (Lateral view)	M/86/3	x350
9. <i>Lingulogavelinella jarzevae</i> (Vasilenko, 1954) (Spiral side)	M/86/3	x350
10. <i>Lingulogavelinella arnagerensis</i> (Solakius, 1988) (Umbilical side)	AK31	x200
11. <i>Lingulogavelinella arnagerensis</i> (Solakius, 1988) (Lateral view)	AK31	x200
12. <i>Lingulogavelinella arnagerensis</i> (Solakius, 1988) (Spiral side)	AK31	x200

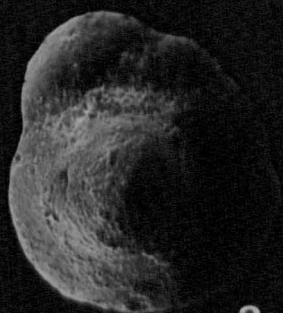
PLATE 18



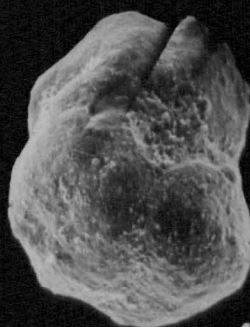
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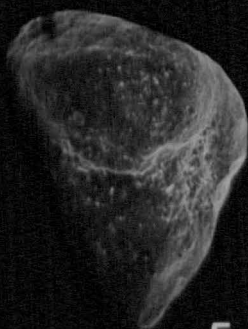
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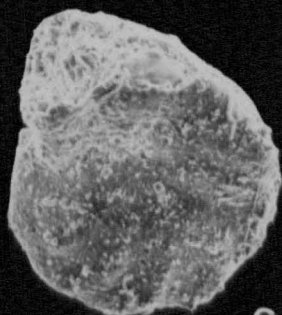
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4



5



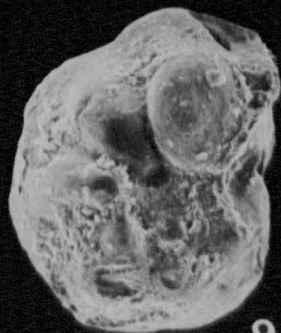
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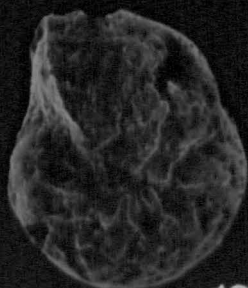
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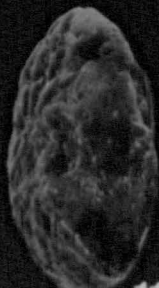
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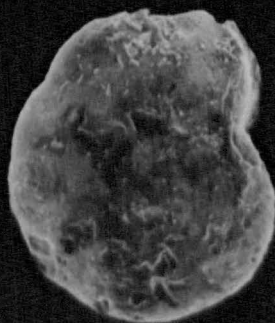
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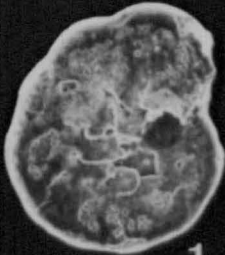


12

PLATE NINETEEN

- | | | |
|--|---------|------|
| 1. <i>Lingulogavelinella ciryi inflata</i> Malapris-Bizouard, 1977
(Umbilical side) | AK27 | x350 |
| 2. <i>Lingulogavelinella ciryi inflata</i> Malapris-Bizouard, 1977
(Lateral view) | AK27 | x350 |
| 3. <i>Lingulogavelinella ciryi inflata</i> Malapris-Bizouard, 1977
(Spiral side) | AK27 | x350 |
| 4. <i>Lingulogavelinella ornatissima</i> (Lipnik, 1961)
(Umbilical side) | AG/86/5 | x200 |
| 5. <i>Lingulogavelinella ornatissima</i> (Lipnik, 1961)
(Lateral view) | AG/86/5 | x200 |
| 6. <i>Lingulogavelinella ornatissima</i> (Lipnik, 1961)
(Spiral side) | AG/86/5 | x200 |

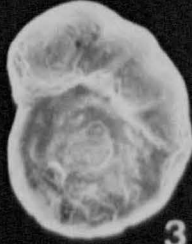
PLATE 19



1



2



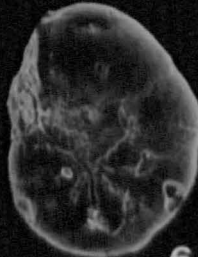
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4



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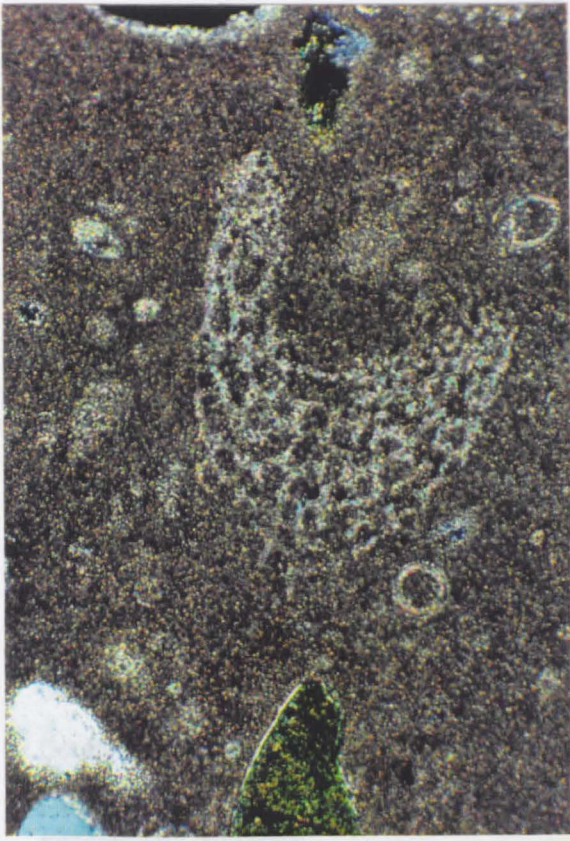


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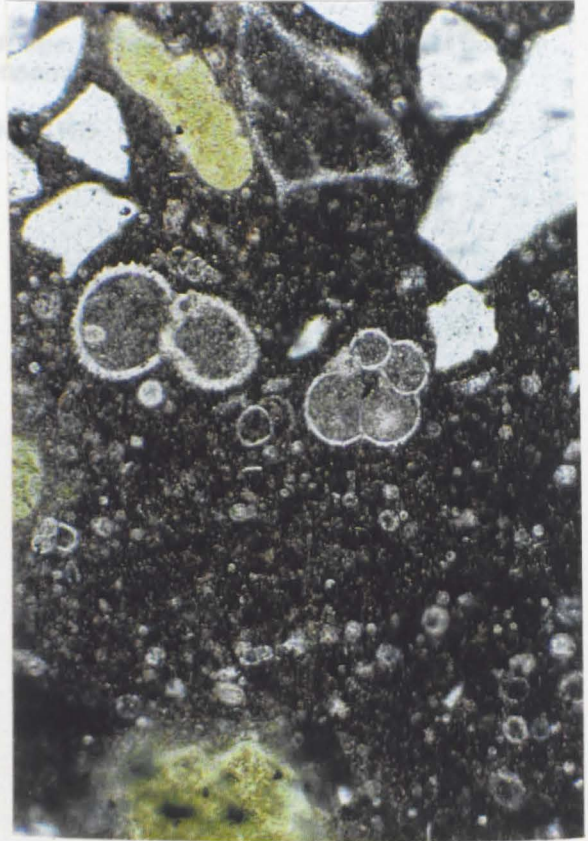
PLATE TWENTY

Thin section photographs of the Arnager Limestone.

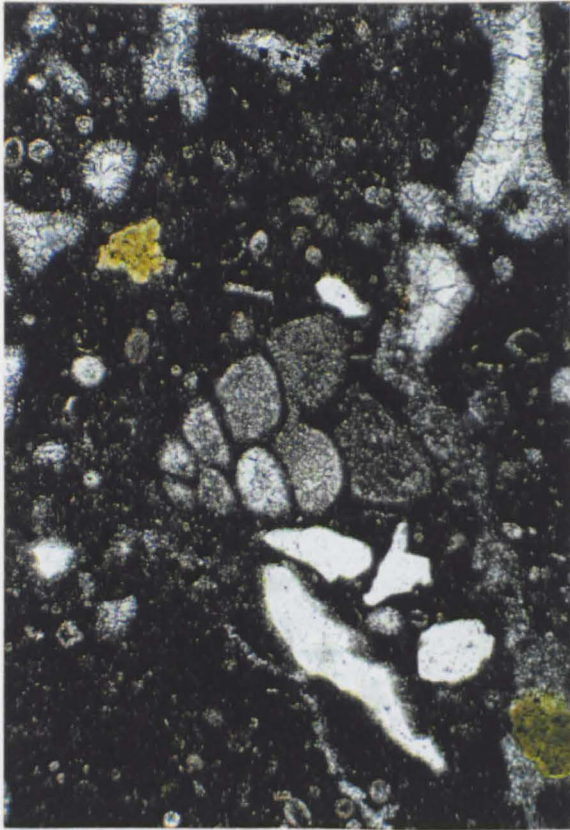
1. Sample AK5 Mag. x20 (eyepiece 2.5x) CPL. FOV 0.645mm
Probable sponge or radiolarian, note detrital quartz and glauconite
2. Sample AK7 Mag. x10 (eyepiece 2.5x) PPL. FOV. 1.29mm
Shot showing common planktics including *Whiteinella* and *Heterohelix* species, and a possible rotaliid.
3. Sample AK7 Mag. x20 (eyepiece 2.5x) PPL. FOV. 0.645mm
Example of well preserved foraminifera in the the Arnager Limestone. Specimen of *Marssonella trochus*.
4. Sample AK7 Mag. x10 (eyepiece 2.5x) PPL. FOV. 1.29mm
Probable specimen of *Archaeoglobigerina*, or *Dicarinella* from the Limestone. The flattened outer margin of the chamber suggests *Archaeoglobigerina*, though these may be true keels.



1



2



3



4

Appendix

Lists of Foraminifera previously recorded from the Arnager Greensand, Arnager Limestone and Bavnodde Greensand.

ARNAGER GREENSAND

Hart (1979)

Rotalipora reicheli
Praeglobotruncana delrioensis
Hedbergella delrioensis
Hedbergella brittonensis
Hedbergella planispira
Globigerinelloides bentonensis
Heterohelix moremani
Guembelitria harrisi
Gavelinella cenomanica
Lingulogavelinella jarzevae
Arenobulimina advena
Psuedotextulariella cretosa

Solakius and Larsson (1985)

Gavelinella cenomanica

Douglas and Rankin (1969)

Hedbergella portsdownensis
Hedbergella planispira

ARNAGER LIMESTONE

Douglas and Rankin (1969)

Hedbergella planispira
Whiteinella baltica
Hedbergella bornholmensis
Hedbergella sp.
Globotruncana coronata
Globotruncana cretacea
Globotruncana marginata
Globotruncana pseudolinneiana
Globigerinelloides ehrenbergi
Heterohelix reussi

Solakius and Larsson (1985)

Reussella kelleri
Reussella cushmani
Stensioeina exsculpta exsculpta
Gavelinella thalmanii
Osangularia whitei
Vernuilina muensteri
Gaudryina rugosa
Eouvigerina aculeata
Gavelinella pertusa
Gavelinopsis cf. tourainensis
Globorotalites micheliniana
Dorothia oxycona
Gyroidinoides nitidus

Valvulineria allomorphinoides
Marginotruncana linneiana - *pseudolinneiana* group
Marginotruncana renzi
Whiteinella baltica
Marginotruncana marginata
Marginotruncana coronata
Gavelinella stelligera
Marginotruncana cf. *angusticarinata*
Cibicides excavata
Vaginulinopsis scalariformis
Archaeoglobigerina bosquensis

Bailey and Hart (1979)

Gavelinella pertusa
Globorotalites cushmani
Osangularia whitei var. *whitei*
Reussella kelleri
Stensioeina spp.

Solakius (1988)

Gavelinella arnagerensis

BAVNODDE GREENSAND

Douglas and Rankin (1969)

Hedbergella planispira
Whiteinella baltica
Hedbergella bornholmensis
Globotruncana coronata
Globotruncana cretacea
Globotruncana marginata
Globotruncana pseudolinneiana
Globotruncana cf. *renzi*
Globotruncana cf. *inomata*
Archaeoglobigerina bosquensis
Globigerinelloides ehrenbergi
Heterohelix reussi
Heterohelix pulchra

Solakius and Larsson (1985)

Reussella kelleri
Stensioeina exsculpta exsculpta
Gavelinella thalmani
Osangularia whitei
Vermeulina muensteri
Gaudryina rugosa
Gavelinella pertusa
Globorotalites micheliniana
Dorothia oxycona
Gyroidina nitida
Valvulineria allomorphinoides
Marginotruncana linneiana - *pseudolinneiana*
Whiteinella baltica
Marginotruncana marginata
Marginotruncana coronata
Gavelinella stelligera
Cibicides excavata
Neoflabellina suturalis

Globotruncana lapparenti
Vaginulinopsis scalariformis
Loxostomum eleyi
Cibicides ribbingi
Archaeoglobigerina bosquensis

Bailey and Hart (1979)

Gavelinella pertusa
Globorotalites cushmani
Osangularia white var whitei
Reussella kelleri
Stensioeina spp.
Loxostomum eleyi
Neoflabellina praerugosa
Praebulimina reussi
Cibicides beaumontianus
Cibicides ribbingi

Solakius (1989)

Loxostomum eleyi
Cibicides ribbingi
Gavelinella amagerensis.

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10

Upper Cretaceous
microbiostratigraphy of
Bornholm, Denmark

S. Packer, M. B. Hart, B. A. Tocher and S. Braley

ABSTRACT

The Upper Cretaceous succession of the Island of Bornholm (Denmark) has been investigated as part of a larger study of northwest European Cretaceous microbiostratigraphy. The strata have been logged in detail and micropalaeontological samples collected at approximately 1 m intervals. The Upper Cretaceous succession (Arnager Greensand, Arnager Limestone and Bavnodde Greensand) is all of marine origin and contains rich assemblages of dinoflagellate cysts, benthonic and planktonic foraminifera. The foraminifera can be used for both international and inter-regional correlation and indicate a mid-Cenomanian to ?late Turonian-early Coniacian hiatus in the succession.

INTRODUCTION

The Danish island of Bornholm lies in the central southern Baltic (55°N, 15°E) 65 km southeast of Ystad, on the Swedish coast (Fig. 1). The greater part of the island is formed of Precambrian gneiss, migmatite and granite with sediments of Mesozoic age exposed only in the southwest corner, in the area immediately north and east of

Rønne. Running northwest-southeast through the island are a series of major faults which are associated with the Fennoscandian Border Zone (Christensen 1984).

Between Rønne and Hasle, on the west coast of the island, is the very edge of a north-south trending graben. The intersection of the two trends (northwest-southeast and north-south) provides the main geological structure, as well as the overall shape of the island. During the Mesozoic the Fennoscandian Border Zone acted as a boundary between the stable Fennoscandian Shield to the north and east and the subsiding Danish sub-basin to the south and west.

The present investigation is part of a larger integrated study involving the biostratigraphy of the major macrofaunal groups (ammonites, belemnites, inoceramids, etc.) that have been recorded from this succession (Christensen 1984, Kennedy *et al.* 1981). Work on the foraminifera, dinoflagellate cysts, ostracods and calcareous nannofossils is still in progress.

THE CRETACEOUS SUCCESSION

The Mesozoic sedimentary succession of Bornholm (Surlyk 1980) consists of only intermittent

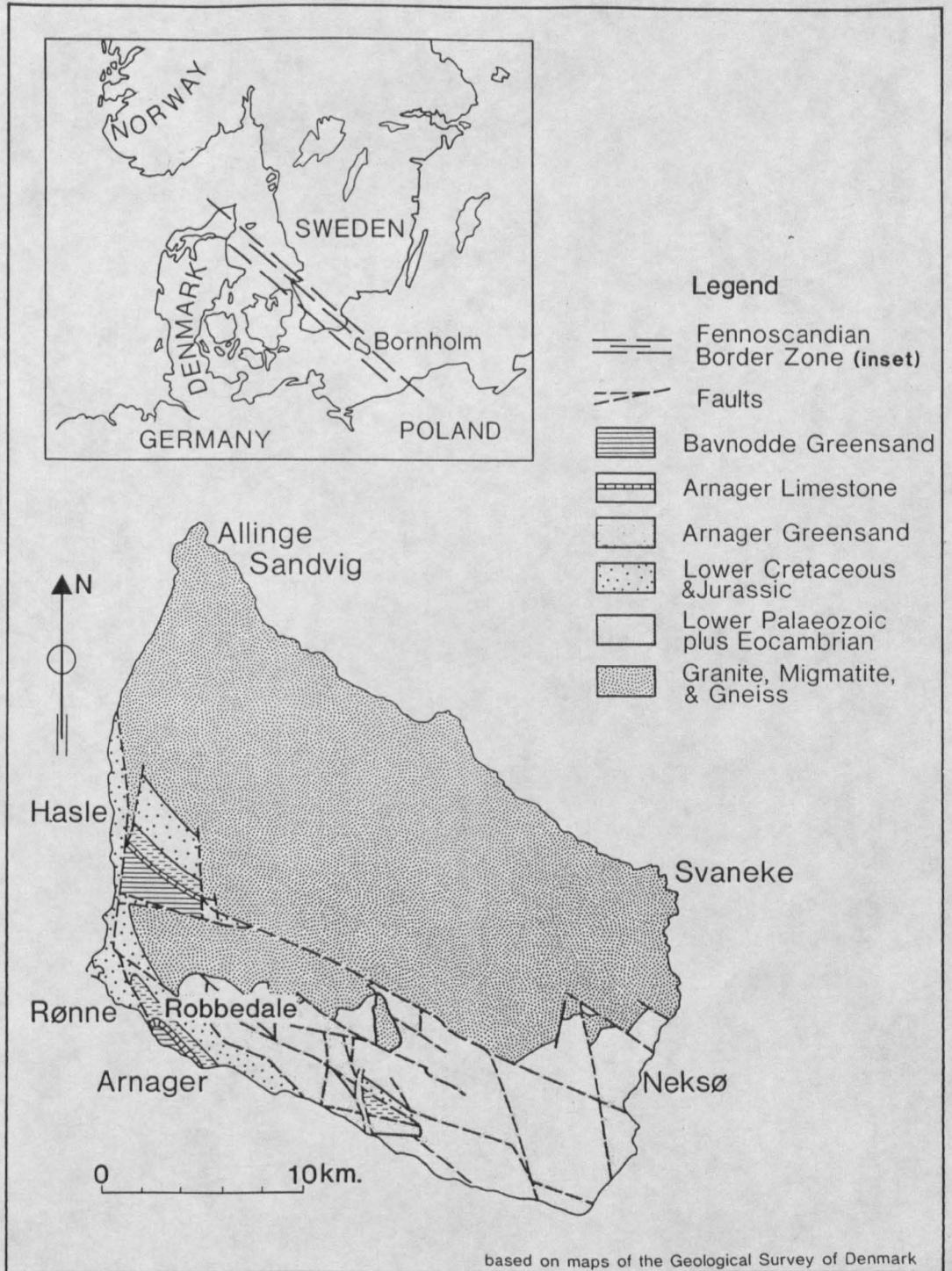


Fig. 1 — Outline geological map of the Island of Bornholm.

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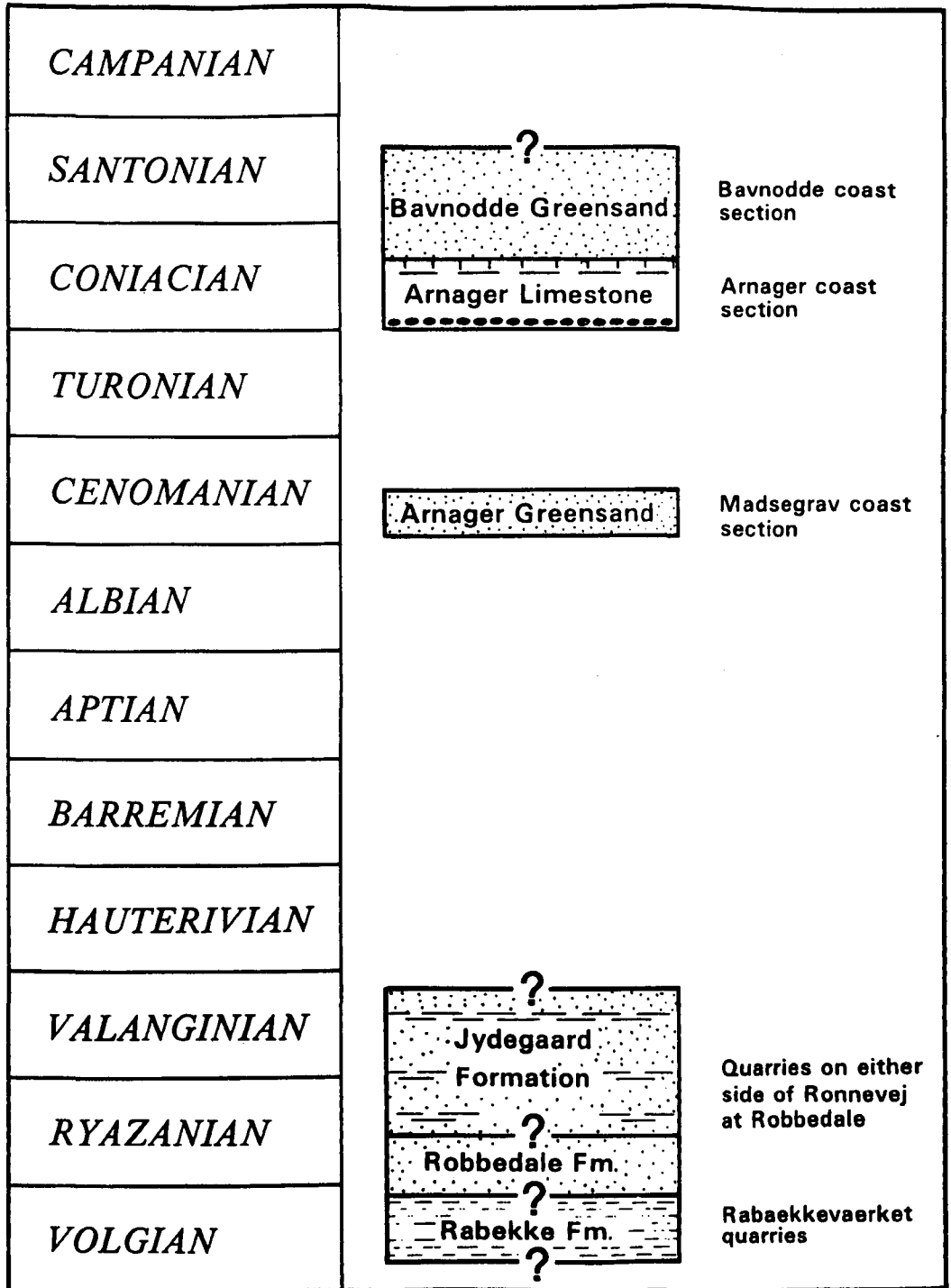


Fig. 2 — The latest Jurassic and Cretaceous succession of Bornholm. The principal localities for each of the intervals investigated are indicated in the right-hand column.

packages of sediment between which there are major intervals of non-deposition and/or erosion. Following deposition of the early Jurassic Sose Beds, Rønne Beds, Hasle Beds and Baga Beds, there is a major hiatus through to the latest Jurassic. Following Cimmerian movements on the Fennoscandian Border Zone, deposition began in the late Volgian. These sediments, which constitute the Rabekke Formation (Fig. 2), rest unconformably on the Jurassic sediments of the Robbedale-Sose Block and also overlap onto the Palaeozoic strata and the Pre-Cambrian basement. The Robbedale Formation of ? latest Volgian-Ryazanian age overlies the Rabekke Formation.

On the south coast at Madsegrav (east of Arnager) the Ryazanian-Valanginian Jydegaard Formation is overlain by glauconitic sandstones of Cenomanian age, thus indicating a major hiatus. The marine sediments of Late Cretaceous age include, from bottom to top (Fig. 2), the Arnager Greensand, Arnager Limestone and Bavnodde Greensand. This succession is exposed on the south coast of the island between Bavnodde (2 km west of Arnager Point) and Madsegrav (1 km east of Arnager Point).

The lower part of the Arnager Greensand at Madsegrav is marked by a distinct conglomerate (Fig. 3) with phosphatic pebbles and boulders of glauconitic sandstone. There is evidence of an early Albian ammonite fauna (Kennedy *et al.* 1981, Christensen 1984) in pebbles which are enclosed in nodules that yield a late Albian to early Cenomanian fauna. The Arnager Greensand itself yields a distinctive early-middle Cenomanian macrofauna and microfauna (Hart 1979). The soft, generally uncemented quartz-glauconitic sands are heavily bioturbated and contain intermittent pebble beds. One major erosion surface has been identified and there may well be other structures present. This was impossible to determine, however, because of the poorly exposed nature of the succession.

The top of the Arnager Greensand and its contact with the Arnager Limestone is exposed at Arnager. The intensely bioturbated horizon (Fig. 4) is overlain by the basal bed (20–25 cm) of the

limestone and contains several generations of phosphatized and glauconitized pebbles (Fig. 5). The Arnager Limestone is approximately 15–20 m thick and is a white to grey splintery brittle calcilutite or calcisiltite. Noe-Nygaard & Surlyk (1985) have described mound bedding within these limestones. Above this the limestone becomes blue-grey and contains a greater proportion of clay, fine sand and silica (Christensen 1984). The contact with the overlying Bavnodde Greensand was seen by one of us (M.B.H.) in 1975 and has recently been excavated by Solakius (1986 pers. comm.).

The Bavnodde Greensand is a thick succession of soft glauconitic sandstone; coarse levels within it may well represent storm sands (Fig. 6).

MICROPALAEONTOLOGICAL ANALYSIS

Samples for micropalaeontological analysis have been collected at approximately 1 m intervals throughout the Arnager Greensand, Arnager Limestone and Bavnodde Greensand, although more detailed sampling was carried out at the complex horizon shown in Figs. 4 and 5. All samples were broken into subsets for foraminiferal, palynological and nannofossil investigation.

The foraminiferal fauna is abundant throughout the marine succession and, apart from in the Arnager Limestone, is well preserved. Planktonic foraminifera are relatively abundant and, surprisingly for such a high palaeolatitude, include many keeled taxa. The lower part of the Arnager Greensand (at Madsegrav) yields *Praeglobotruncana delrioensis* (Plummer), *Hedbergella delrioensis* (Carsey), *H. brittonensis* (Loeblich & Tappan), *H. planispira* (Tappan), *Heterohelix moremani* (Cushman) and *Gumbelitra harrisi* (Tappan). In the Arnager Greensand immediately below the contact with the Arnager Limestone this assemblage is joined by large numbers of *Rotalipora reicheli* Mornod (Hart 1979). The geographical distribution of this taxon (Hart 1979, Fig. 3) is clearly controlled

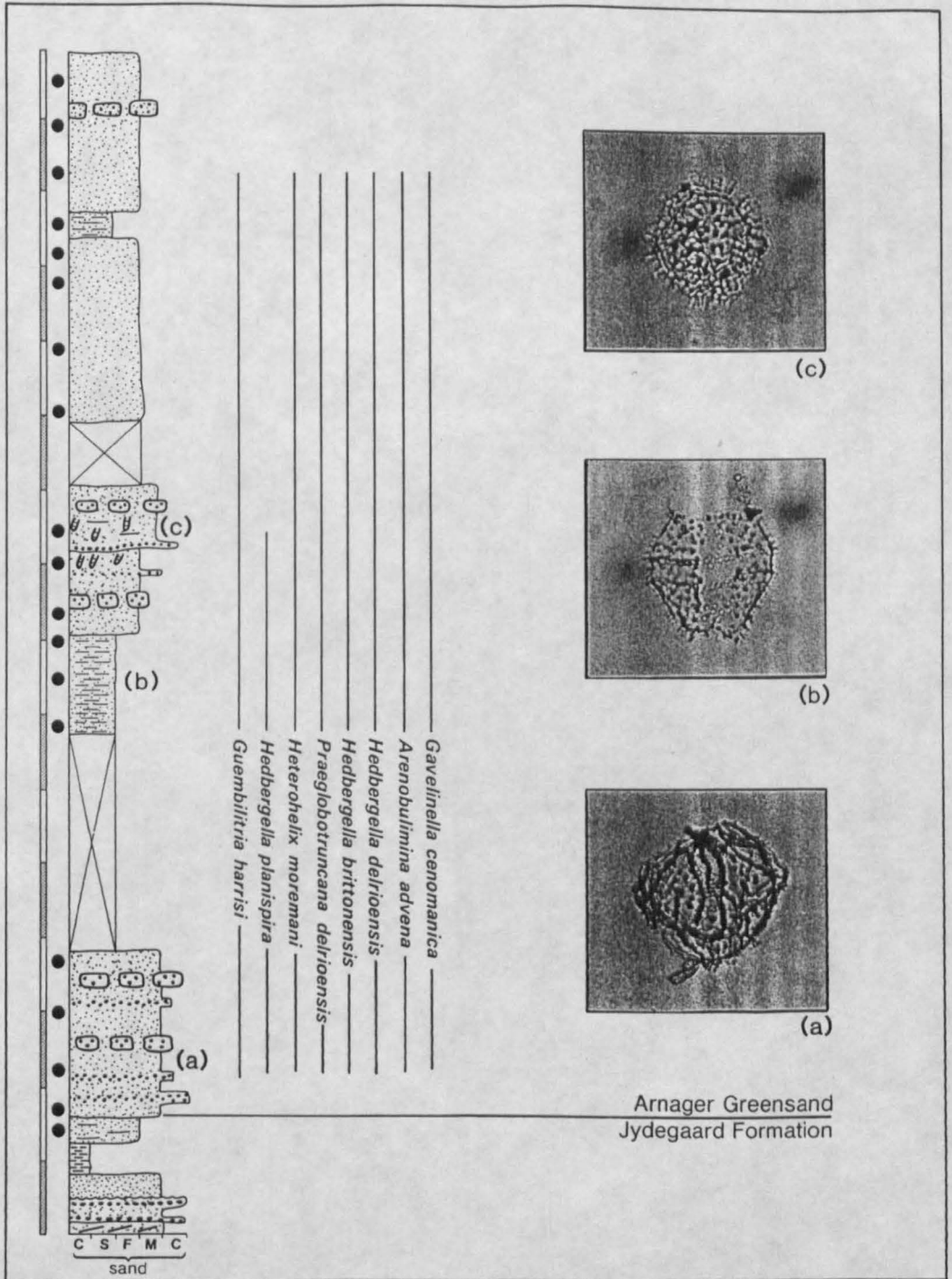


Fig. 3 — Composite sedimentological log of the lower part of the Arnager Greensand exposed at, and just west of, Madsegrav. This log was assembled from six very limited exposures and as such, must be treated with caution. The remainder of the Arnager Greensand succession (some 70 m) is overgrown and covered with sand dunes. Representative dinoflagellate cysts: (a) *Cribroperidinium edwardsii*; (b) *Epelidosphaeridium spinosa*; (c) *Cleistophaeridium? huguiontii*.

ROYAL CANADIAN MOUNTED SERVICE
GEOLOGICAL SURVEY OF CANADA

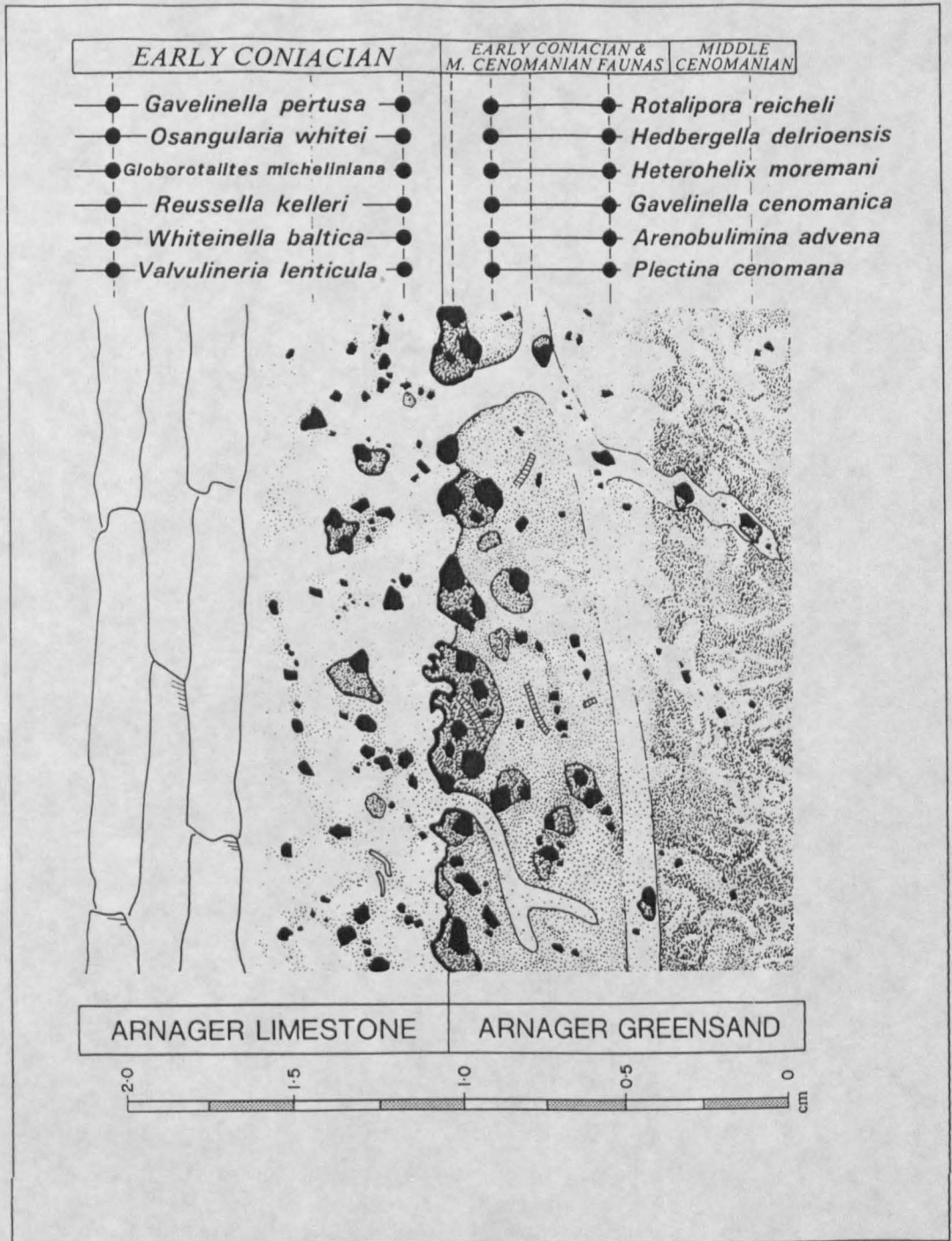


Fig. 4—The Arnager Greensand–Arnager Limestone boundary as it is exposed in the low sea cliff immediately west of the sea front car park at Arnager. The sketch is based on field work by the present authors and that of Bromley (1979). Immediately overlying the Arnager Greensand is a buff-coloured, faintly glauconitic sandstone that contains a mixed Cenomanian–Coniacian fauna and flora.

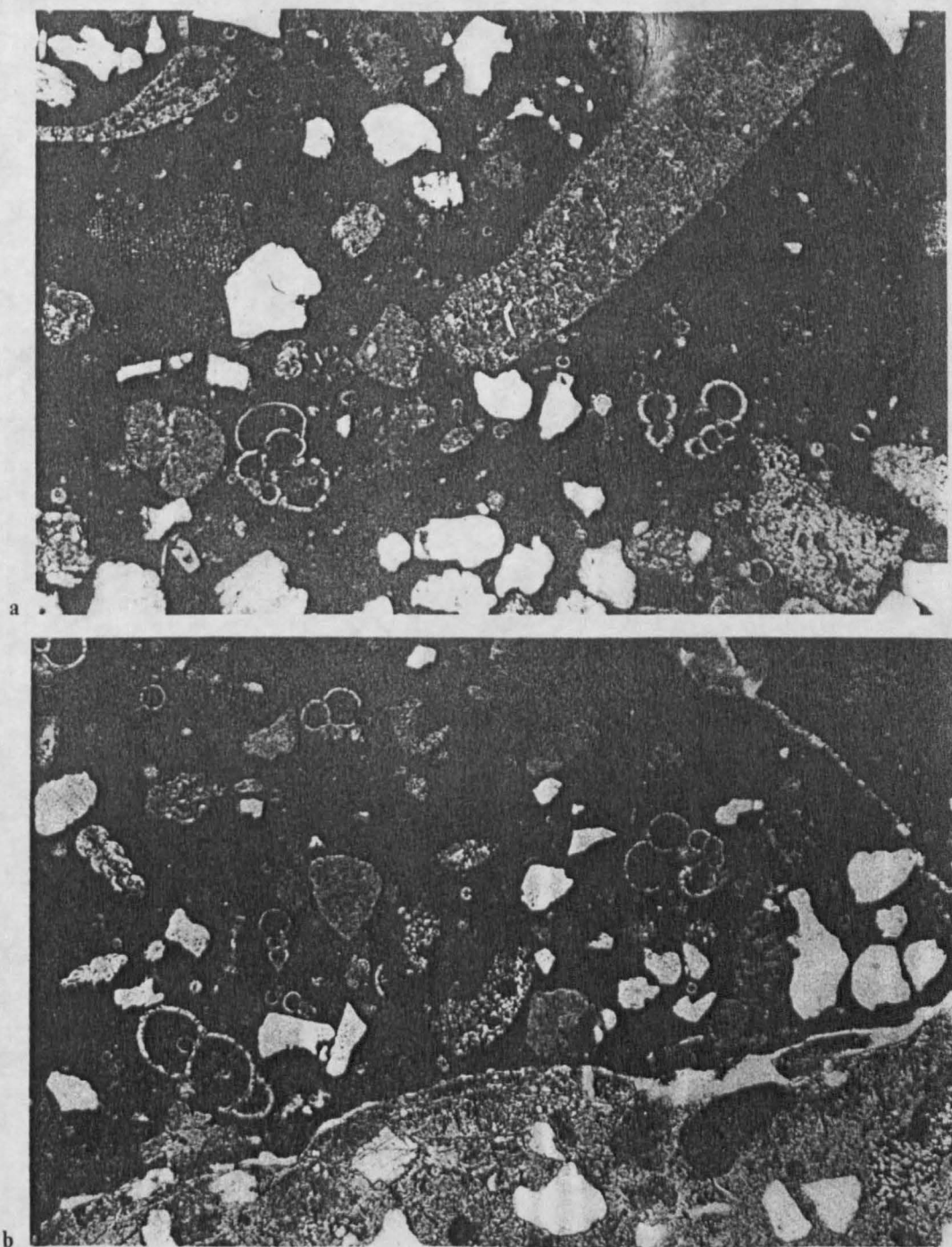


Fig. 5—(a) Thin section of the contact between the phosphatized pebbles shown in Fig. 6 and the overlying limestone. The specimen in the lower left-hand corner is *Whiteinella baltica* Douglas & Rankin. (b) Thin section of the edge of a phosphatized pebble and the adjacent Arnager Limestone. Assemblage dominated by *Whiteinella* spp., *Hedbergella* sp. and *Archaeoglobigerina* sp.

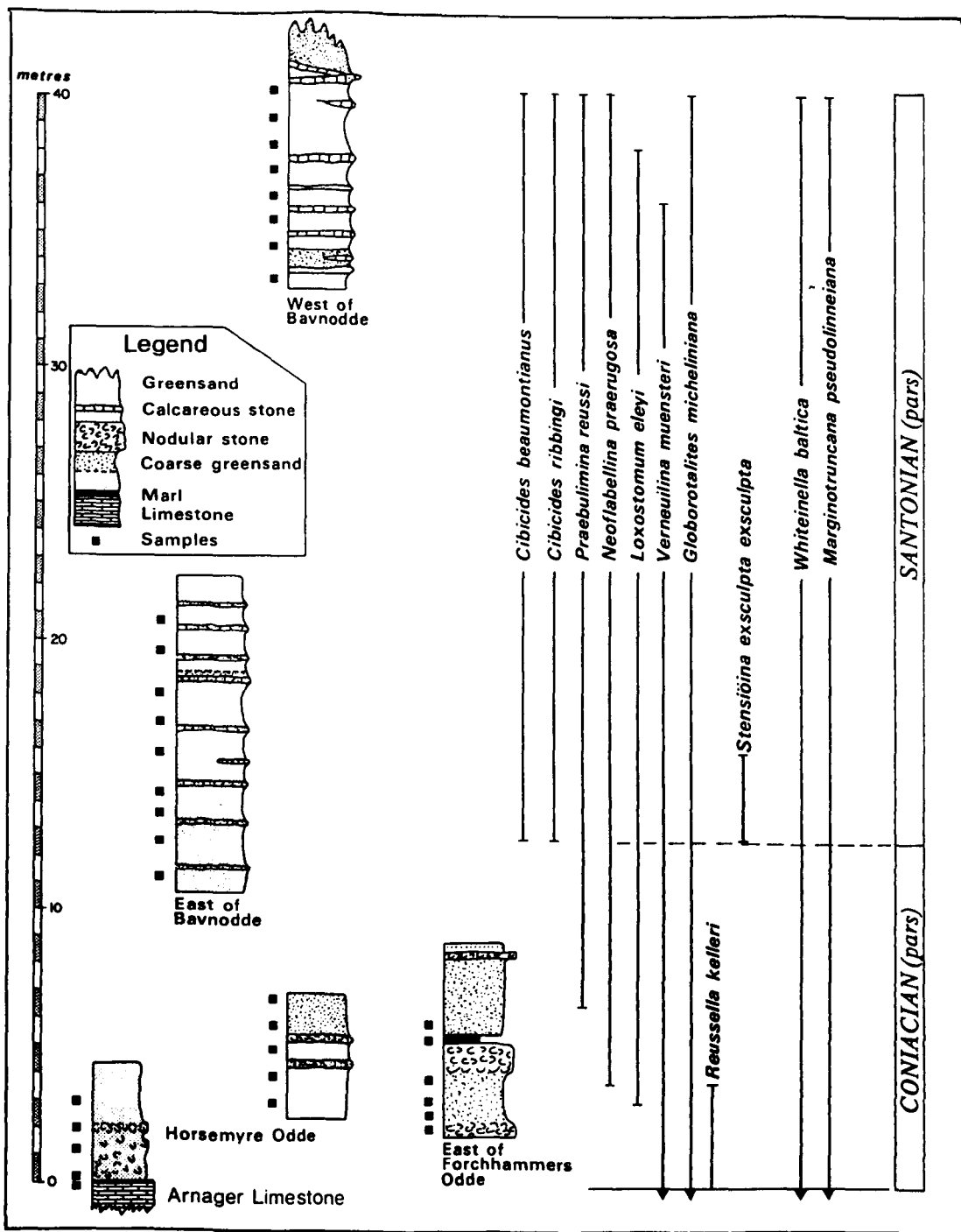


Fig. 6 — Sedimentological logs of the Bavnodde Greensand which is exposed on the south coast between Horsemyre Odde and West Bavnodde (immediately adjacent to the airport perimeter fence), and ranges of some stratigraphically diagnostic Foraminifera (the contact with the Arnager Limestone is no longer exposed). The tentative placing of the Coniacian-Santonian boundary based on the Foraminifera agrees well with the known distribution of belemnites (W. K. Christensen, pers. comm.).

by the increased water depths available in the Danish Sub-basin (Danish Polish Furrow of Hart (1979)). This species probably indicates that the uppermost Arnager Greensand is of earliest middle Cenomanian age.

The Arnager Limestone yields an abundant planktonic fauna although the diversity is low. *Marginotruncana pseudolinneiana* (Pessagno) and *Whiteinella baltica* Douglas & Rankin dominate the fauna while *M. marginata* (Reuss) and *M. coronata* (Bolli) are also recorded. We have not found (as yet) specimens referable to the *Dicarinella primitava/concavata* groups as recorded by Solakius & Larsson (1986). In the Bavnodde Greensand, *Globotruncana bulloides* Vogler appears, together with *Archaeoglobigerina bosquensis* Pessagno and *Heterohelix* spp. Within the planktonic fauna there is a distinct change in the proportion of keeled to non-keeled species in the transition from the Arnager Limestone to the Bavnodde Greensand. Within the limestone, keeled taxa predominate and this is also true within the lowest level of the Bavnodde Greensand. Higher in the Greensand, the proportion of keeled taxa reduces markedly and the fauna gradually becomes dominated by *Whiteinella* and *Archaeoglobigerina*. If Hart & Bailey (1979) are correct, this would imply a gradual reduction of effective water depth during this interval; this was probably caused by sedimentation, there being no sharp dramatic change.

Investigation of the benthonic foraminifera (Hart 1979, Bailey & Hart 1979, Solakius & Larsson 1986) indicate that, throughout the succession, stratigraphically important taxa are present. In the Arnager Greensand the majority of the benthonic taxa—*Arenobulimina advena* (Cushman), *A. depressa* (Perner), *Marssonella trochus* (d'Orbigny), *Plectina mariae* (Franke), *Quinqueloculina antiqua* (Franke), *Gavelinella cenomanica* (Brotzen) and *G. intermedia* (Berthelin)—are well-known long-ranging species characteristic of the Cenomanian; *Gavelinella belorussica* (Akimez), *Cibicides gorbenkoi* Akimez and *Lingulogavelinella* sp. cf. *L. ornatissima* are little-known eastern European species (Gawor-Biedowa 1972), with general Cenomanian ranges. The overlapping ranges of *Plectina cenomana*

(Carter & Hart) and *Lingulogavelinella jarzevae* (Vasilenko) within the Arnager Greensand succession indicate a proximity to the early-middle Cenomanian boundary, which agrees with the occurrence of the *R. reicheli* fauna already reported.

The fauna of the Arnager Limestone has been described by Bailey & Hart (1979) and in more detail by Solakius & Larsson (1986). It is dominated by *Reussella kelleri* Vasilenko, *Verneuilina muensteri* Reuss, *Gavelinella pertusa* Marsson, *G. thalmanni* (Brotzen), *Osangularia whitei* (Brotzen) and *Stensiöeina* sp. The latter are important (Bailey et al. 1983, Hart et al. 1981, Koch 1977) for stratigraphic work but our present material is not well enough preserved to identify the subspecies used in the various zonal schemes for this interval.

The overlying Bavnodde Greensand fauna shows that many of the above taxa continue (except *R. kelleri*) and are joined by *Gavelinella stelligera* (Marie), *Cibicides ribbingi* Brotzen, *C. beaumontianus* d'Orbigny, *Loxostomum eleyi* (Cushman), *Neoflabellina praerugosa* Hiltermann and *Praebulimina reussi* (Morrow). Bailey & Hart (1979) tentatively placed the Arnager Limestone within the Coniacian, there being no evidence of any Turonian indicators. The placing of the Coniacian-Santonian boundary at that time was most difficult and we would now locate this at a level within the lower part of the Bavnodde Greensand. There may be a hiatus at the Arnager Limestone-Bavnodde Greensand boundary as suggested by Solakius & Larsson (1986) although at the present time we have no indication of its relative importance or magnitude.

Samples processed for palynomorphs from the base of this formation yield *Cribroperidium exilicristatum* (Davey) Stover & Evitt, *Cyclonephelium hughesii* Clarke & Verdier, *Exochosphaeridium bifidum* (Clarke & Verdier) Clarke et al., *Florentinia deanei* (Davey & Williams) Davey & Verdier, *Odontochitina costata* Alberti and *Palaeohystrichophora infusorioides* Deflandre, which have previously been recorded (Davey & Verdier 1973) as first appearing in the late Albian in northwest Europe. Furthermore, the presence

of *C. exilicristatum* and *Epelidosphaeridia spinosa* (Cookson & Hughes) Davey is thought to indicate that the succession is no younger than middle Cenomanian (Davey 1969, Tocher 1984). These two forms in association with *Litosphaeridium siphoniphorum glabrum* Lucas-Clark, which has not been recorded in sediments younger than later Cenomanian (Lucas-Clark 1984), are also found in the middle part of the Arnager Greensand succession.

Samples from the top of the Arnager Greensand and its contact with the overlying Arnager Limestone yield a complicated assemblage. Previously useful forms such as *C. exilicristatum*, *E. spinosa* and *L. siphoniphorum glabrum* are absent, although the presence of *Litosphaeridium siphoniphorum siphoniphorum* (Cookson & Eisenack) Davey & Williams, *Florentinia mantellii* (Davey & Williams) Davey & Verdier, *Microdinium ornatum* Cookson & Eisenack and *Stephodinium coronatum* Deflandre suggest an age no younger than late Turonian (Foucher 1979, 1981, Lucas-Clark 1984). However, these species are here found to occur in association with specimens of *Chatangiella tripartita* (Cookson & Eisenack) Lentin & Williams, *Dinogymnium microgranulosum* Clarke & Verdier, *Florentinia deanei*, *Senoniasphaera rotundata* Clarke & Verdier and *Spiniferites? velatus* (Clarke & Verdier) Stover & Evitt. The presence of *F. deanei* indicates an age no younger than late Coniacian, while *D. microgranulosum* and *S.? velatus* have previously been recorded from the Anglo-Paris Basin (Clarke & Verdier 1967, Foucher 1979) as first appearing in the Coniacian and early Santonian, respectively. On the basis of the foraminiferal analysis, however, it is thought the former age is more likely. Thus, at the junction between the Arnager Greensand and the Arnager Limestone there appears to be a mixed assemblage of ?late Cenomanian–late Coniacian forms.

REGIONAL IMPLICATIONS

The Robbedale and Jydegaard Formations represent depositional environments close to a shoreline that appears to be trending WNW–

ESE across the island. This shoreline was probably fault induced by the late Cimmerian movements that affected the Border Zone. Palaeocurrent trends produced by one of us (S.B.) indicate a net transport direction off the Pre-Cambrian basement towards the south, with subordinate trends towards the southeast and southwest. Offshore these sands may thicken to the south and provide some reservoir potential. To the west of Bornholm, in the Rønne Graben, sands of Early Cretaceous age are probably present, although only sediments of Jurassic age are exposed onshore between Rønne and Hasle. To the north, in Hano Bay (Christensen 1984, Norling 1981) sands of mid-Cretaceous age are extensively recorded, including the glauconitic sandstones and siltstones recorded in the Åhus borehole (Christensen 1975). In the central part of Hano Bay, the Barremian–Aptian is reportedly 50–100 m thick with the Albian–Cenomanian attaining a thickness of 75 m. Clearly these sediment thicknesses may be greater in the downfaulted centre of the graben, now well known in the area around Bornholm, and as such could provide suitable reservoir sandstones. Knowledge of their stratigraphy is therefore of paramount importance when considering further offshore exploration.

Recently, Christensen (1984) has provided an interpretation of the sea-level changes represented in the Bornholm succession. He records a maximum level in the middle Cenomanian followed by a gradual regressive phase throughout the Turonian. This minimum in the middle–late Turonian is followed by a transgressive phase (and renewed sedimentation) in the Coniacian to Santonian.

This interpretation appears to be at variance with most views of Cretaceous sea levels (Hancock 1976, Hancock & Kauffman 1979, Hart & Bailey 1979, Hart 1980). Our present data suggest that the hiatus in the middle Cenomanian was produced by a marked increase in water depth (Carter & Hart 1977), thereby isolating the horst (later to become Bornholm) from sediment input. The sea-level high, existing through the late Cenomanian and early–middle Turonian, left Bornholm isolated, receiving little sediment and

creating a phosphate conglomerate (Figs. 4 and 5). Lowering of worldwide sea levels in the late Turonian brought Bornholm back into a depositional domain and sedimentation began in the late Turonian–Coniacian and Santonian. This scenario would agree well with the foraminiferal and palynological data presented here and very nearly comply with the predictions for areas such as south England where the succession is relatively complete (Hart & Bailey 1979, Hart 1980). This interpretation is at some variance with that suggested by Christensen (1984, Fig. 6) and our future research must be directed towards a solution of this problem.

ACKNOWLEDGEMENTS

The authors acknowledge the assistance given by our Scandinavian colleagues: Dr W. K. Christensen, Professor H. J. Hansen, Professor F. Surlyk, Dr R. Bromley, Dr E. Norling, Dr E. Stenestad, J. Gabrielsen and N. Solakius. Professor V. Poulsen is thanked for allowing us to use the University of Copenhagen Field Centre on Bornholm. Our research in southern Scandinavia is funded by the Research Initiative of the National Advisory Body for Public Sector Higher Education.

This paper is dedicated to the memory of Professor Tove Birkelund (University of Copenhagen), who died in the summer of 1986, and who until shortly before that time had been Chairman of the International Subcommittee on Cretaceous Stratigraphy. Her advice and encouragement in the earlier stages of our work were much appreciated.

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Enclosure Eight

Note on the paper by Kennedy and Christensen (1991).

Since the binding of this thesis, the author has received a copy of the paper by Kennedy and Christensen (1991) entitled "Coniacian and Santonian ammonites from Bornholm, Denmark". Some of the information contained in this paper was already known to the author, via Walter Christensen and is referred to in the text as Christensen (personal communication). However, not all the information contained in the paper was available and a short discussion of this new data is given below.

The age of the Arnager Limestone Formation:

Kennedy and Christensen (1991) give the following ages for the formation based on the various fossil groups; Middle Coniacian (ammonites), Early Coniacian (inoceramid bivalves) and Coniacian on foraminifera (Solakius and Larsson, 1985).

Foraminiferal evidence, this thesis, suggests that the Arnager Limestone is of Middle?-Coniacian age, which accords well with the above ammonite dates. Kennedy and Christensen (1991) suggest that discrepancies between ages given by various fossil groups may be due to differing concepts of the Coniacian substages.

The age of the Bavnodde Greensand Formation:

Ammonites from the Bavnodde Greensand Formation were generally found to indicate a Santonian age or were imprecisely dated. The presence of *Scaphites* (*Scaphites*) *Klieslingswaldensis ficheri* Reidel, 1931 indicates an Early Santonian to earliest Campanian age. This species was erroneously referred to as exclusively Campanian in earlier work (Christensen, 1985).

Belemnite evidence previously suggested the the formation was late Early to early Middle Santonian in age (Christensen, 1971). New studies in progress suggest that the formation maybe of Late Coniacian to Early Santonian age.

Inoceramid bivalve evidence now suggests that the Bavnodde Greensand exposures on the coast are of Early Santonian age, whilst exposure at Jydegaard is possibly of latest Coniacian age.

Foraminiferal evidence, this thesis, suggests that the Bavnodde Greensand is of Early? to Middle Santonian age. It would seem that the occurrence of *Vaginulinopsis scalariformis (sensu stricto)* in the lower part of the Bavnodde Greensand exposure accords well with an Early Santonian age (Assemblage Biozone five). It is unclear from Kennedy and Christensen (1991) whether the whole of the Bavnodde Greensand succession has been examined, as this work appears to be concentrated on the basal part of the succession. A Middle Santonian age for Assemblage Biozone six may still be applicable to the upper part of the succession.

The presence of the foraminiferid *Cibicides ex gr. beaumontianus* at the base of the succession (on the coast) indicates that the base of the formation is no older than Santonian on foraminiferal evidence. This conflicts with the proposed Late Coniacian age given by inoceramids. Again though, it should be noted that there is not close agreement between the microfossil groups with ammonites indicating that the Bavnodde Greensand is no older than Santonian. Two of the localities mentioned by Kennedy and Christensen (1991) at Risenholm and Jydegaard have not sampled in this study and may be worth sampling in future to provide a measure of clarification.

Reference:

Kennedy, W.J. and Christensen, W.K. 1991 Coniacian and Santonian ammonites from Bornholm, Denmark. *Bull. Geol. Soc. Denm.*, 38:203-226.


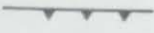


















Other papers cited are listed in the references.

GEOLOGICAL MAP (MESOZOIC FORMATIONS)

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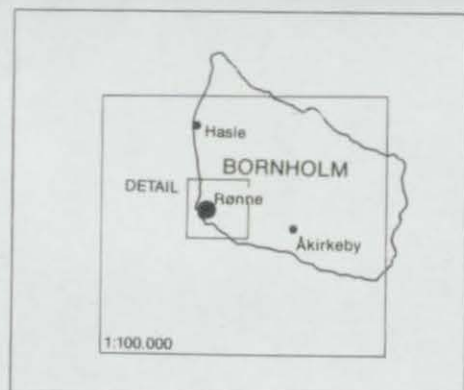
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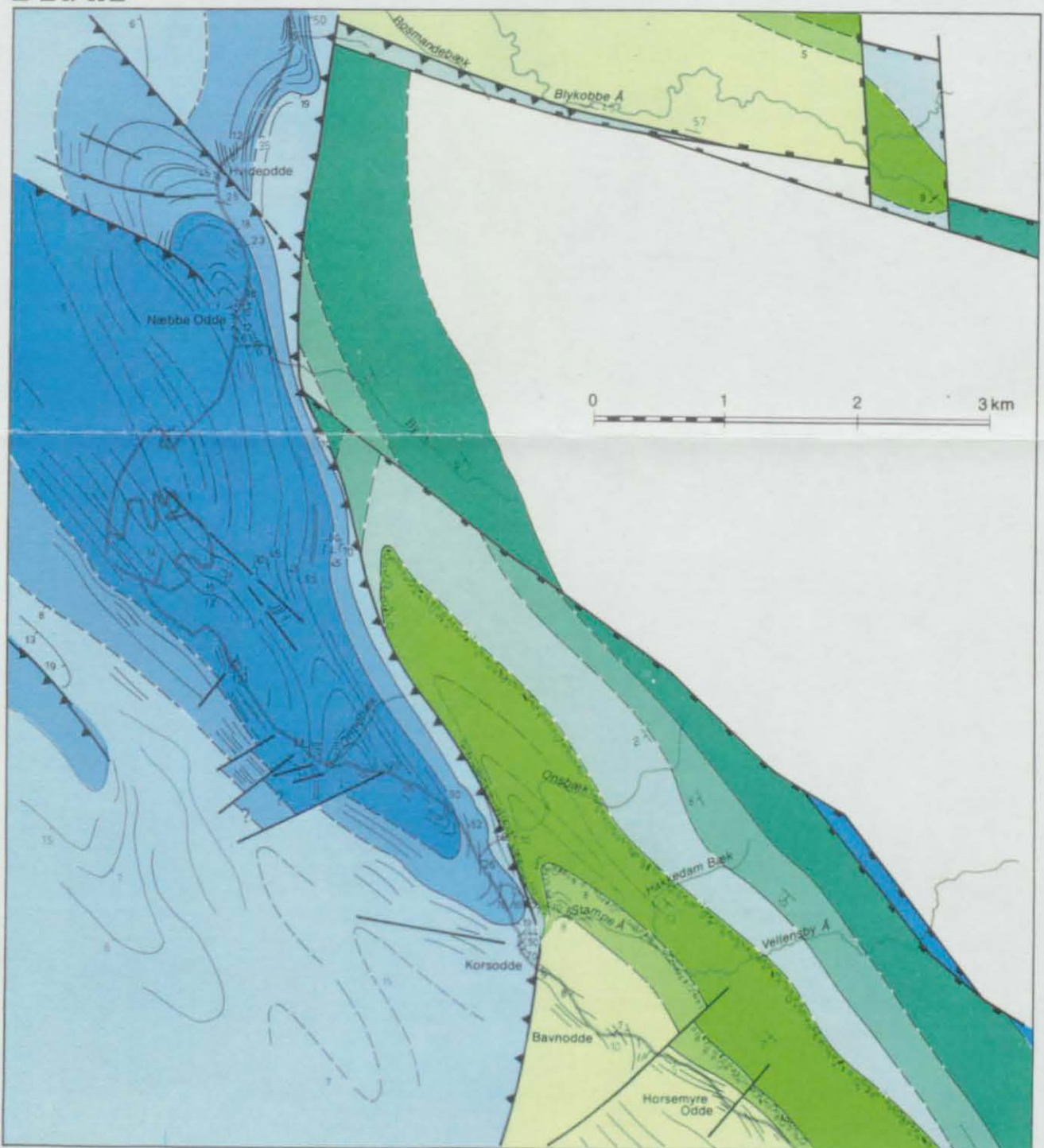
MESOZOICUM	FORMATION	
	 Bavnodde Greensand	 Reverse Faults
Upper	 Arnager Limestone	 Normal Faults
	 Arnager Greensand	 Faults of Transcurrent / unknown character
CRETACEOUS	 Jydegård	 Angular Unconformity
Lower	 Robbedale	 Formation Boundaries
	 Rabekke	 Strata Boundaries
Middle	 Bagå	 Strike/dip
JURASSIC	 Hasle	 Phosphatic Conglomerates
Lower	 Renne	 Unknown
TRIASSIC	Upper  Kågeröd	 Coastline

Uncertain geological features are represented by dashed lines.

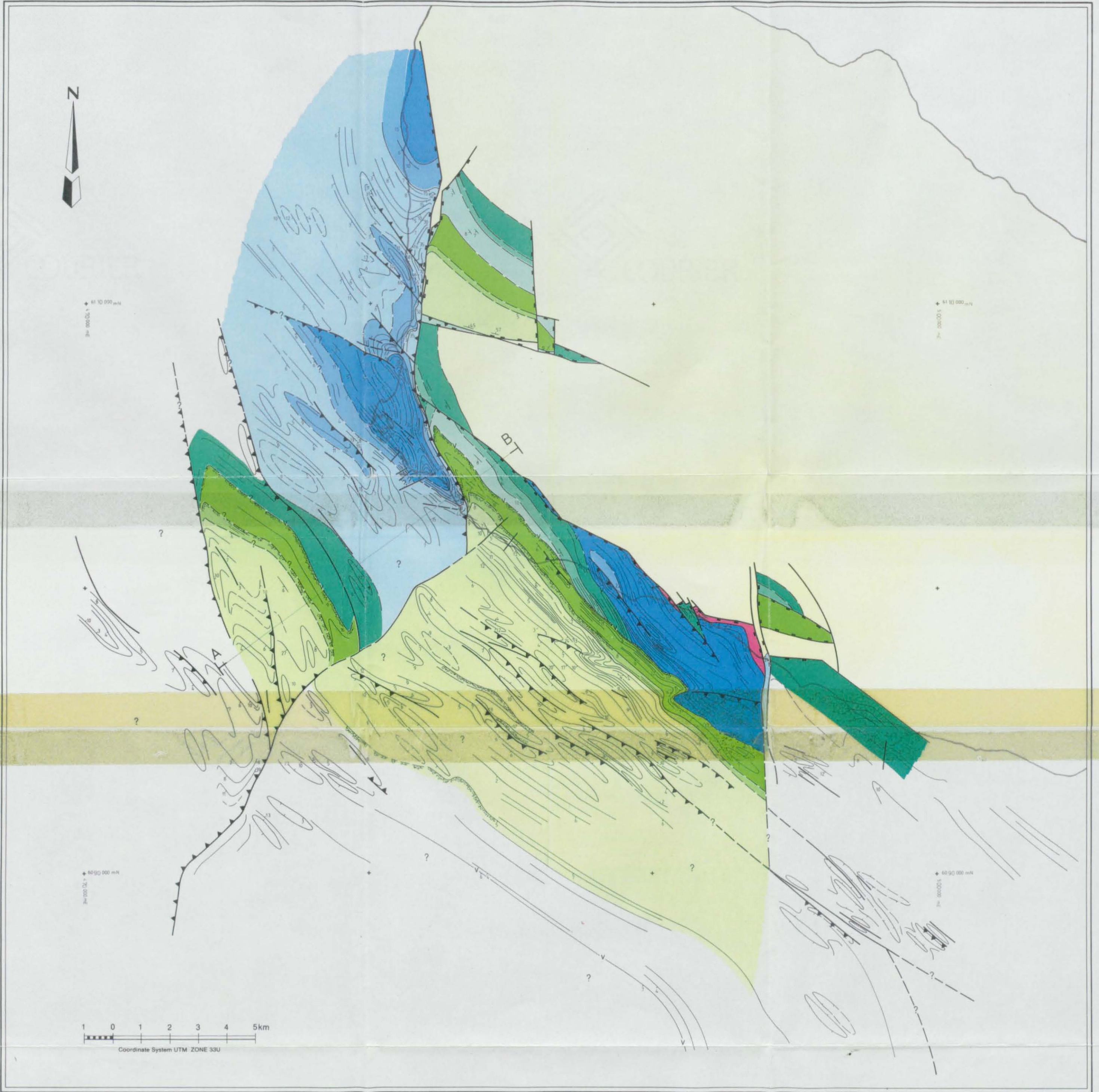
GEOGRAPHIC OVERVIEW



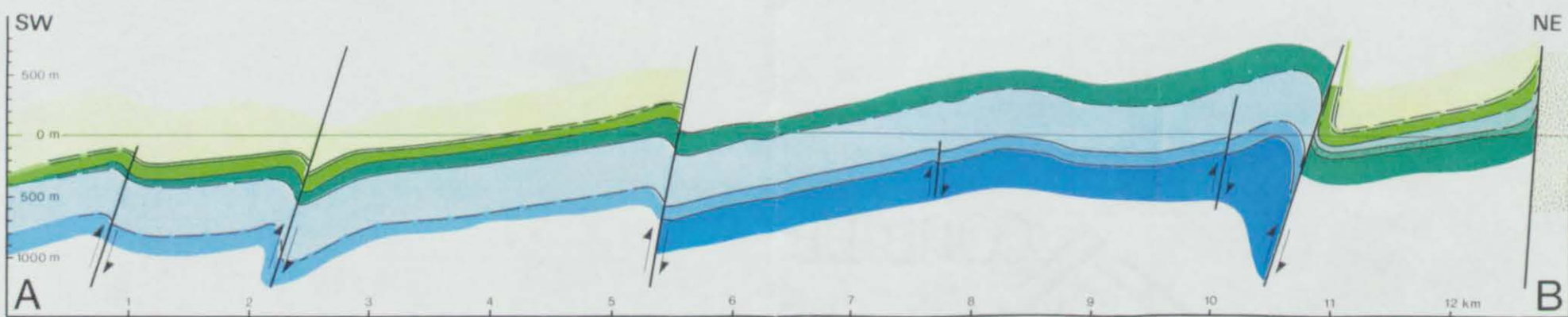
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CROSS-SECTION A-B



A Cross-section showing the structure along the Eastern part of the Rønne Graben. Vertical and horizontal scales are equal.

Enclosure two :

Correlation of Upper Cretaceous sections from the Bornholm and southern Sweden area

main sources of data : Chatzilemmannouil (1982); Christensen (1984)

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