MID JURASSIC TO EARLIEST CRETACEOUS
(CALLOVIAN - RYAZANIAN)
RADIOLARIA
OF THE NORTH SEA BASIN

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ΓΟΝΕΙΣ ΜΟΥ

ΕΝ ΟΙΔΑ ΟΤΙ ΟΥΔΕΝ ΟΙΔΑ

ΣΩΚΡΑΤΗΣ (470 - 399 Π. Χ.)

ABSTRACT

The North Sea is a series of interconnecting sedimentary basins, located on the northwest margin of the Eurasian tectonic plate. The complex geological setting and sedimentation patterns of the North Sea Basin have been reviewed as an introduction to this study.

Eleven wells/exposures from this area, spanning the Mid Jurassic (Callovian) to Earliest Cretaceous (Ryazanian) time interval, have been examined for radiolaria. The inclusion of 2 more wells from the Norwegian and Barents Seas has been used for comparative purposes and contributed to the taxonomic understanding of the less well-preserved North Sea radiolarians.

Previous work on radiolarians from around the world for the studied interval has been recorded and a database/list has been produced.

The state of preservation of the radiolarian assemblages has been discussed and Electron Microprobe analyses have been performed. In some instances the siliceous radiolarian skeletons have been replaced by other minerals, most commonly calcite or pyrite.

A total of 129 species/morphotypes from 392 samples has been described and illustrated with scanning electron and light microscope micrographs. The occurrence of these taxa in previous studies in the literature is reviewed to aid interpretation of the North Sea assemblages, which exhibit some affinity with other Boreal assemblages.

By employing careful processing techniques and taking into account the commonly poor preservation of radiolarians, their biostratigraphic value has been demonstrated by means of the Unitary Associations method. The ranges of 52 taxa have been used for computer treatment with the BioGraph program, from which 18 Unitary Associations have been established. These were grouped into 5 zones which were correlated to the standard ammonite zones:

Biozone 1 ?early Callovian to mid Kimmeridgian
» 2 mid Kimmeridgian to Early Volgian
» 3 Early Volgian to Mid Volgian
» 4 Mid Volgian to latest Mid Volgian
» 5 latest Mid Volgian to Late Ryazanian

The application of radiolaria to stratigraphic problems in the North Sea Basin is reviewed and suggestions made for future work.

ΠΕΡΙΛΗΨΗ

Η Βόρεια Θάλασσα αποτελείται από μια σειρά αλληλοσυνδεόμενων ιζηματογενών λεκανών και βρίσκεται στο βορειοδυτικό περιθώριο της Ευρασιατικής πλάκας. Στην εισαγωγή αυτής της μελέτης εξετάζεται η γεωλογική δομή και ακολουθεί μια επισκόπηση της ιστορίας ιζηματογένεσης της λεκάνης της Βόρειας Θάλασσας.

Από αυτήν την περιοχή έχει εξεταστεί για Ραδιολάρια το υλικό 8 γεωτρήσεων και 3 επιφανειακών τομών που καλύπτουν το διάστημα Μέσο Ιουρασικό (Καλλόβιο) - Κατώτατο Κρητιδικό (Ρυαζάνιο). Ακόμα, το υλικό από 2 γεωτρήσεις από τη Θάλασσα της Νορβηγίας και τη Θάλασσα του Βάρεντς έχει εξεταστεί για συγκριτικούς σκοπούς και την καλύτερη κατανόηση της ταξινόμησης των φτωχά διατηρημένων Ραδιολαρίων της Βόρειας Θάλασσας.

Για το συγκεκριμένο διάστημα έχουν καταγραφεί οι προηγούμενες μελέτες που αφορούν τα Ραδιολάρια και έχει συνταχθεί μια βάση δεδομένων υπό τη μορφή λίστας.

Συζητείται επίσης η κατάσταση διατήρησης των συγκεντρώσεων Ραδιολαρίων και έχουν λάβει χώρα αναλύσεις των στοιχείων των κελυφών (Electron Microprobe Analyses). Οι παραπάνω αναλύσεις έδειξαν ότι ένα ποσοστό των σκελετών των Ραδιολαρίων έχει υποστεί αντικατάσταση από άλλα στοιχεία, συνήθως ασβεστίτη ή πυρίτη.

Ενα σύνολο 129 ειδών/μορφοτύπων από 392 δείγματα περιγράφονται και απεικονίζονται με τη χρήση Ηλεκτρονικού Μικροσκοπίου Σαρώσεως (SEM) καθώς και Μικροσκοπίου Διαθλωμένου Φωτός. Η παρουσία αυτών των ειδών/μορφοτύπων σε προηγούμενες μελέτες επανεξετάζεται ώστε να συνδράμει στην ερμηνεία των συγκεντρώσεων της Βόρειας Θάλασσας, οι οποίες εν τέλει παρουσιάζουν κάποιες ομοιότητες με άλλες Αρκτικές συγκεντρώσεις.

Η βιοστρωματογραφία των Ραδιολαρίων έχει εξεταστεί, χρησιμοποιώντας τη μέθοδο Ενωτικών Συγκεντρώσεων (Unitary Associations), ακολουθώντας προηγουμένως ειδικές μεθόδους επεξεργασίας και λαμβάνοντας υπόψη τη συχνά πτωχή κατάσταση διατήρησης των σκελετών. Πιο συγκεκριμένα, οι εξαπλώσεις 52 ειδών εισήχθησαν σε ηλεκτρονικό υπολογιστή για επεξεργασία με το πρόγραμμα BioGraph, το οποίο έδειξε την παρουσία 18 Ενωτικών Συγκεντρώσεων. Αυτές ομαδοποιήθηκαν στις ακόλουθες 5 ζώνες οι οποίες είναι άμεσα συσχετίσιμες με τις πρότυπες βιοζώνες αμμωνιτών:

Βιοζώνη 1 : ?κάτω Καλλοβιο έως μέσο Κιμμερίδιο
Βιοζώνη 2 : μέσο Κιμμερίδιο έως Κάτω Βόλγιο
Βιοζώνη 3 : Κάτω Βόλγιο έως Μέσο Βόλγιο
Βιοζώνη 4 : Μέσο Βόλγιο έως ανώτατο Μέσο Βόλγιο
Βιοζώνη 5 : ανώτατο Μέσο Βόλγιο έως Ανω Ρυαζάνιο

Τέλος, αναθεωρείται η χρήση των Ραδιολαρίων στην αντιμετώπιση και λύση στρωματογραφικών προβλημάτων της Βόρειας Θάλασσας και γίνονται υποδείξεις για μελλοντική έρευνα.

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THIS WORK IS DEDICATED TO THEM!

CHAPTER 1

INTRODUCTION

1.1 Radiolaria

Radiolaria are a diverse group of marine, holoplanktonic protists. They are widely distributed in the modem world oceans, throughout the water column, from the surface to depths of many hundreds of meters (Anderson, 1983; Casey, 1993).

The skeleton of living radiolarians, which is the most commonly recognised morphological feature, is composed of amorphous (opaline) silica. In the fossil record only the class Polycystine is present, which has a detailed evolutionary history from the Cambrian. The term Polycystine was first introduced by Ehrenberg (1838) and includes:
1) Spumellaria (skeletons having spherical symmetry, ellipsoidal, discoidal, spiral, etc.)
2) Nassellaria (non-spherical, bipolar and usually bilaterally symmetrical).

The term Radiolaria was coined by Müller (1858) and is now used formally and informally (Casey, 1993; see discussion by Zhamoida (1984) for the use of the terms Radiolaria and Polycystine).

The single-celled living Radiolaria can range in size from about 50μm to 2000μm, although they can also be found living in colonies. They are distinguished from related classes (e.g. Foraminifera) by the presence of an organic wall, called the capsular wall, which encloses a mass of cytoplasm containing one or more nuclei (Anderson, 1980).

Many papers have been published about the living Radiolaria, their nature, biology, ecology, skeleton, distribution and evolution, by Deflandre, J. Cachon & M. Cachon, Petrushevskaya, Anderson and Casey to mention but a few. See Anderson (1983) for an overview of radiolarian biology, and Casey (1993) for a concise review of Radiolaria.

1.2 Application of Radiolaria in Geological & Environmental Sciences

Below follows a brief summary of some of the applications of radiolaria and their usefulness in geological and environmental sciences.

1) Ecology, Palaeoceanography, Palaeogeography.

i) Radiolaria, being planktonic organisms, have their abundance and geographic distribution defined by the character of the host watermass (Anderson, 1983) and its parameters, including: sea temperature, salinity, available nutrients, pressure, light penetration, etc.. Thus, the group can provide indications of marine conditions in the past (e.g. Casey *et al.,* 1989; etc.).

ii) Radiolaria are useful in defining palaeogeographic changes in the ocean basins (e.g. for

Mesozoic, Baumgartner, 1992, 1993).
iii) Radiolaria have recently been used in recognising displaced terranes (e.g. Circum-Pacific area, Pessagno and his colleagues for the Mesozoic).
iv) They are indicators of oceanic upwelling and climate and productivity changes, etc..

Aitchison (1993) gave brief examples of the application of radiolaria in understanding the tectonic evolution of orogenic zones worldwide.

2) Biostratigraphy.

Since the 1970's various workers have demonstrated that radiolaria are extremely useful in dating marine onshore and offshore sections, as additional help for other microfossil groups or where other microfossil groups are absent. Successful zonal schemes have been produced for the Palaeozoic (e.g. Nazarov and other workers), Mesozoic (Baumgartner, Pessagno, etc.) or Cenozoic (Sanfilippo, Nigrini, etc.), for DSDP and ODP Sites or for onshore sequences. These schemes can be of great use for commercial geologists and micropalaeontologists involved in the hydrocarbon industry.

1.3 Micropalaeontology in the North Sea Basin

Since the 1960's when the first gas and oil discoveries in the North Sea were announced, the hydrocarbon industry has demonstrated the usefulness of micropalaeontology for exploration purposes (e.g. correlation, age assignment, identification of unconformities, lithostratigraphic characterisation, etc.). A variety of microfossil groups have been used for the Mesozoic and Cenozoic of the North Sea Basin (Fig. 1.1).

AUTHOR(S)	DATE	SUBJECT
Bown	1987	Upper Triassic - Lower Jurassic nannofossils, zonation, evolution
Nagy	1980a, b	Lower - Middle Jurassic foraminifera
Nagy & Johansen	1991	Lower - Middle Jurassic foraminifera
Copestake & Johnson	1989	Lower Jurassic foraminifera, zonation
Bown *et al.*	1988	Jurassic nannofossil zonation
Dyer & Copestake	1989	Upper Jurassic - Lower Cretaceous radiolaria, zonation
Woollam & Riding	1983	Jurassic dinoflagellate zonation
Jenkins & Murray (eds.)	1989	Jurassic, Cretaceous & Cenozoic foraminifera
Parker (ed.)	1993	Various papers (proceedings of conference)
Burnhill & Ramsay	1981	Lower Cretaceous foraminifera, zonation
Banner *et al.*	1992	Lower Cretaceous foraminifera, informal zonation
Jakubowski	1987	Lower Cretaceous nannofossil zonation
Mortimer	1987	Upper Cretaceous nannofossil zonation
Gradstein *et al.*	1988	Tertiary foraminifera
Gradstein & Kaminski	1989	Tertiary foraminifera
Gradstein *et al.*	1992	Tertiary foraminifera
King	1983	Tertiary & Quaternary zonation
Varol	1989a, b	Palaeocene nannofossils
Charnock & Jones	1990	Cenozoic agglutinated foraminifera

Table 1.1 Important selected publications on micropalaeontology (especially biostratigraphy) for the Mesozoic and Cenozoic of the North Sea Basin.

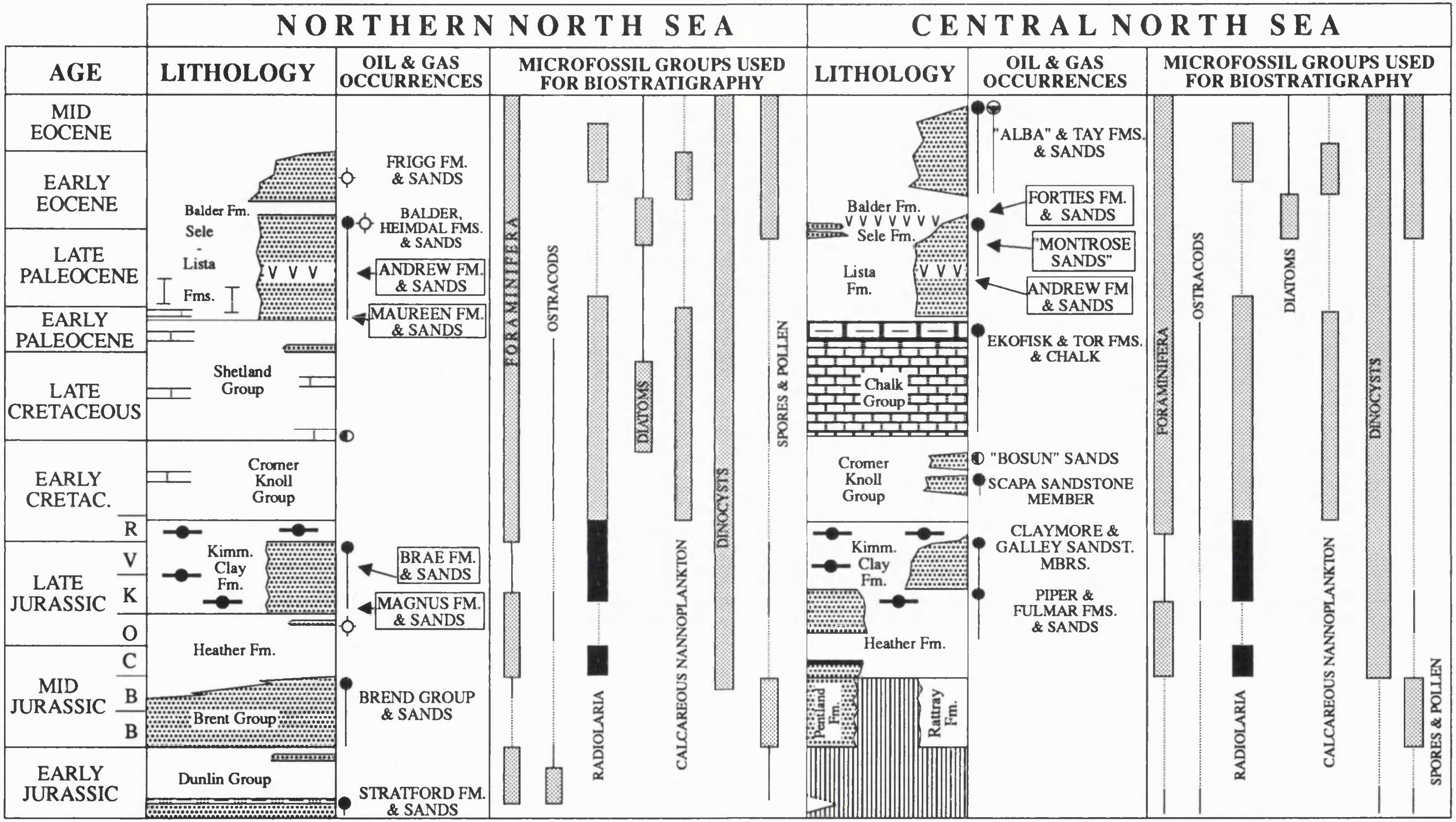
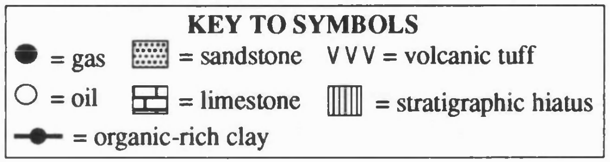


Fig. 1.1 Generalised lithostratigraphy, distribution of reservoirs, and microfossil groups used for zonation and correlation in the Jurassic - Eocene of the North Sea Basin (redrawn from Copestake, 1993, Figs. 4.18 & 4.19). Radiolarian interval studied here is shown in black.



However, in comparison to their usefulness, not much has been published as far as taxomonic and biostratigraphic studies are concerned. Important, selected publications dealing with Mesozoic and Cenozoic North Sea micropalaeontology (especially biostratigraphy) are given on Table 1.1.

1. Micropalaeontologists lack formal research background therefore taxonomic "lumping" is common.
2. Scarcity of published work for the area; existing zonations for other areas cannot be applied to the basin (possible faunal provincialism).
3. Usually poor preservation and the need for careful processing techniques.
4. Over-reliance on palynology.

Table 1.2 Reasons why radiolaria have not been used for biostratigraphic studies in the North Sea Basin (taken from Dyer & Copestake, 1989).

Radiolarian research for the North Sea area is discussed on Chapter 2. Dyer & Copestake (1989, p. 216-217) gave the advantages of including radiolaria in a zonation scheme for the Upper Jurassic to Lower Cretaceous of the North Sea Basin as well as the reasons why the group had not received the attention it deserves for biostratigraphic studies (Tables 1.2 & 1.3).

1. Their geographic distribution is less facies-controlled than other microfossils (especially for the Kimmeridge Clay Fm.). Consequently, radiolaria are present in sediments lacking other fossils.
2. Present in deep wells (in graben axes) where palynomorphs are absent due to high thermal maturity and/or diamond bit drilling.
3. Recognising transgressions and regressions (palaeoenvironmental indicators).
4. Preservation in sediments where few other microfossils are found (replacement of SiO_2 by FeS_2)

Table 1.3 Advantages of including radiolaria in a zonation scheme for the North Sea Basin (taken from Dyer & Copestake, 1989).

Copestake (1993) recently published a review of the application of micropalaeontology to hydrocarbon exploration for the North Sea Basin. See also Cox (1990) for a review of Jurassic micropalaeontology.

1.4 Objectives of the study

The main objectives of the present study were:

i) A detailed taxonomic survey of the recovered radiolaria assemblages.

ii) The biostratigraphical application of these assemblages, employing the Unitary Associations method, and the correlation of wells/sites studied.

The inclusion of two wells, one from the Norwegian Sea and another from the Barents Sea (kindly provided by IKU) has greatly helped towards understanding the taxonomy of the less well-preserved North Sea material and for comparative purposes. These assemblages are also included in the taxonomic part and, because of their similarity with the North Sea ones, have been also used for the proposed zonation scheme.

Secondary aims of the project were:

i) To record and discuss the preservation of the radiolaria.

ii) To investigate and employ the best possible techniques for extraction from the host lithology.

1.5 Problems encountered in this study

The main problems associated with the study were:

1) The nature of preservation, low diversity and often low abundance of the radiolarian assemblages.

2) The scarcity of published work on North Sea Jurassic radiolarians (this is also due to reasons of confidentiality).

3) Nature of available samples (usually ditch cuttings).

1.6 Chapter layout

Chapter 2 provides a review of previous work on radiolarians around the world for the studied interval (Callovian to Earliest Cretaceous). The relevant publications are listed in the Appendix 1. A review of previous work for the group in the North Sea Basin is also included.

The complex geological evolution of the North Sea Basin is described in Chapter 3 and this is followed (Chapter 4) by discussion of the sedimentation patterns and lithostratigraphy for the area, with the latter more specifically for the wells studied.

Studied well sites are described (with well logs) and the onshore locality at Eathie Haven, Cromarty (Chapter 5).

The preparation techniques and methods of study employed are given in Chapter 6, followed (Chapter 7) by a discussion of i) silica diagenesis, ii) preservation of recovered faunas, and iii) the Electron Microprobe analyses performed.

The systematic palaeontology of the radiolaria found is described, with illustrations, in Chapter 8 and their biostratigraphical distribution analysed in Chapter 9.

A general discussion, conclusions and suggestions for future work are summarised in Chapter 10.

1.7 Stratigraphic terminology

The North Sea Boreal terminology of Rawson *et al.* (1978), Cope *et al.* (1980) and Rawson & Riley (1982) has been followed in the present study (see Fig. 5.5 and Fig. 9.7).

Three stage names have been developed by earlier workers for the terminal Jurassic stage.

i) Tithonian: for the Tethyan areas;

ii) Portlandian: for the sub-Boreal area of northern France and southern Britain; and

iii) Volgian: for Boreal areas.

The term Volgian is widely used by oil companies in the northern North Sea and is followed here.

Kimmeridgian has two different usages:

i) *sensu anglico*: used in the UK sub-Boreal terminology, and corresponds to *baylei-fittoni* ammonite zones of Cope *et al.* (1980).

ii) *sensu gallico*: used in the North Sea Boreal terminology, for the *baylei-autissiodorensis* ammonite zones of Cope *et al.* (1980); this corresponds to the Early Kimmeridgian *sensu anglico*.

In the present study Kimmeridgian *sensu gallico* has been used.

CHAPTER 2

PREVIOUS WORK ON MID JURASSIC TO EARLIEST CRETACEOUS RADIOLARIANS

2.1 Introduction

In this chapter a brief summary of the history of Mesozoic (Jurassic to Earliest Cretaceous) radiolarian research is given. This is followed by the database/list of publications on Mid Jurassic to earliest Cretaceous radiolarians around the world. Finally, the chapter closes with a discussion of the work on this fossil group in the North Sea Basin.

2.2 History of Research

Radiolaria were first described by Meyen (1834) from the Atlantic Ocean. However, the microscopists Ehrenberg and Haeckel were the first to extensively study radiolaria. Ehrenberg (1854, 1875) studied the group from marine onshore and offshore samples and described Cenozoic forms. Haeckel (1881, 1887) undertook a broad work to describe all radiolarians which had been collected during the Challenger expedition. His results were published in a long monograph in 1887. Ehrenberg and Haeckel were responsible for the erection of the first taxonomic framework for radiolarian classification.

Pioneers in the study of Jurassic to Early Cretaceous radiolarians at the last part of the 19th Century were Rüst (1885a, 1888, 1898), Cayeux (1896), Wisniowski (1889), Vinassa de Regny (1898a,b; 1899), Parona (1890) and Neviani (1900), who all reported and described radiolarians from localities around the European Alps. However, according to Dumitrica & De Wever (1991), Karrer (1867) should be considered as the first worker to describe Late Jurassic radiolarians (having mistaken two radiolaria species as foraminifera).

By the beginning of this century Squinabol (1912, 1914a,b), Fischli (1916), Hojnos (1916), and Heitzer (1930a,b) contributed work in Europe while Hinde (1900a) and Tan Sin Hok (1927) studied faunas from the Indian Ocean. Khabakov (1932, 1937) continued the study of radiolaria in Russia. No other comprehensive report dealing with Late Jurassic to Early Cretaceous radiolaria was published in the following years until the 1950's and 1960's (with works by Lipman, Aliev, Zhamoida). In 1954 Campbell wrote the Anglo-American treatise on radiolarians.

From the 1970's onwards the interest in Mesozoic radiolaria increased rapidly (Fig. 2.1) and the excellent work of Baumgartner, De Wever, Dumitrica, Pessagno and others has created a new interest in the study of Mesozoic radiolaria.

Fig. 2.2 shows the recorded occurrences of Mid Jurassic to Earliest Cretaceous

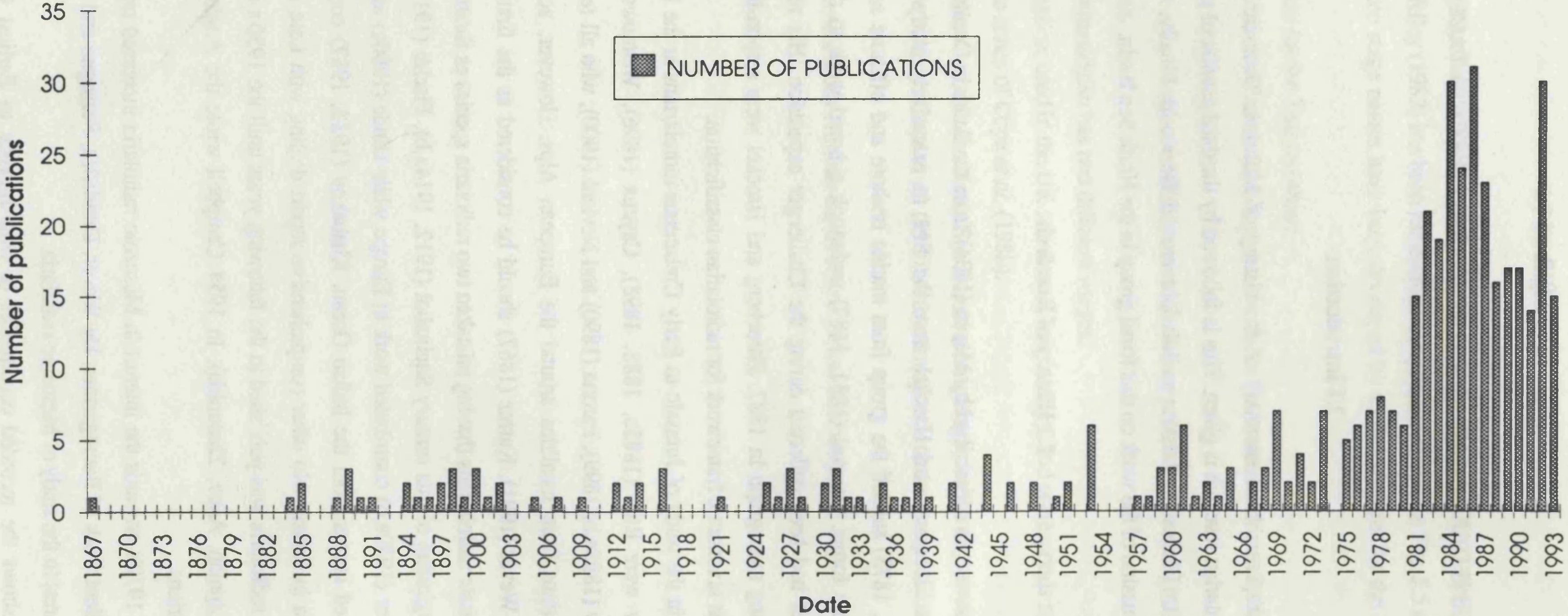
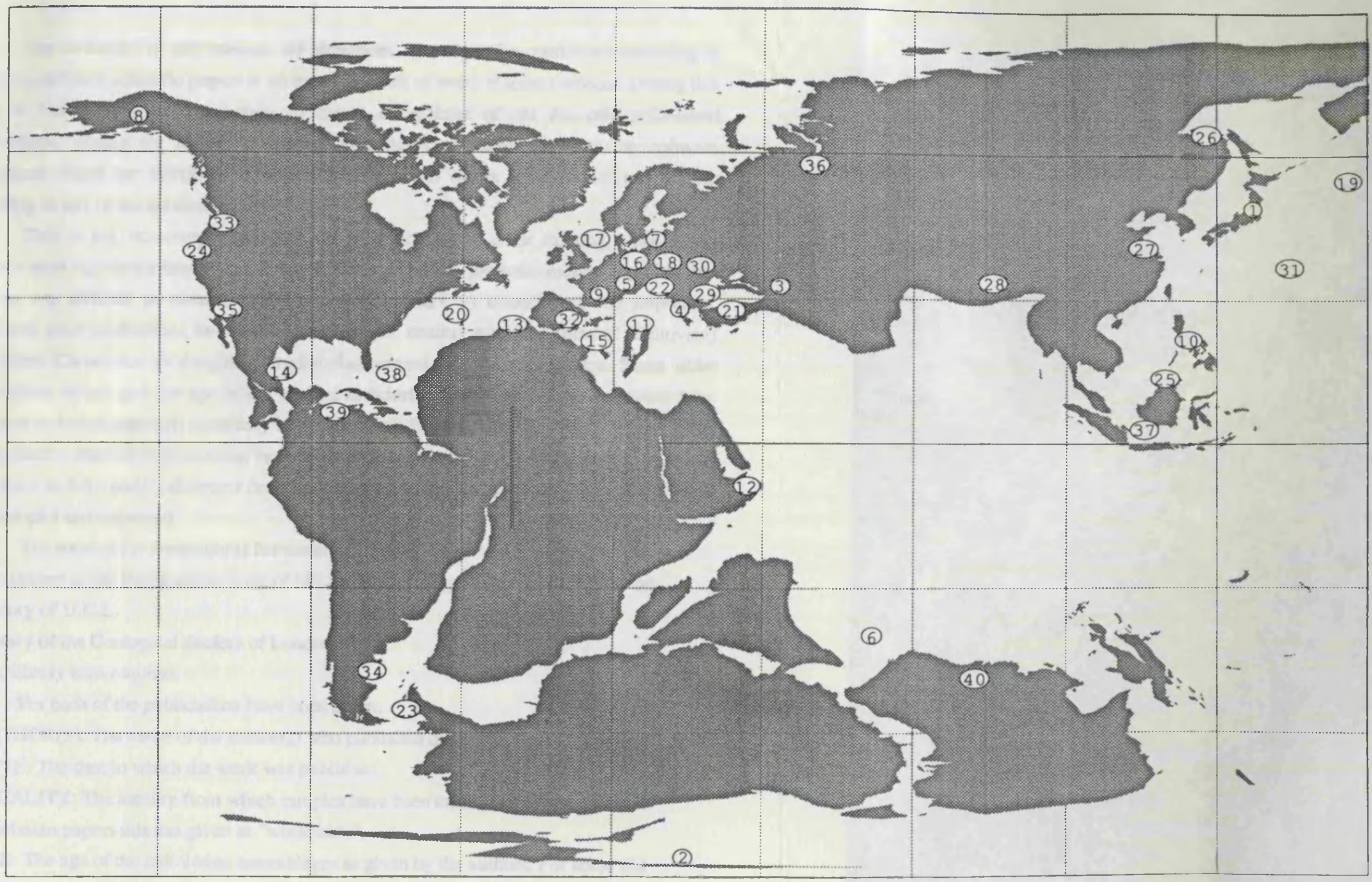


Fig. 2.1 Quantity of Mid Jurassic - Earliest Cretaceous radiolarian publications (data from database).



1=Japan
2=New Zealand
3=Azerbaidzhan
4=Greece
5=Switzerland
6=Indian Ocean
7=Poland (Carpathians)
8=Alaska
9=France
10=Philippines
11=Italy
12=Oman
13=Morocco
14=Costa Rica
15=Sicily
16=Austria, Germany (Alps)
17=North Sea
18=Hungary, Slovakia
19=N.W. Pacific
20=Atlantic Ocean
21=Turkey
22=Yugoslavia (Slovenia)
23=Antarctica
24=California
25=Sabah (Malaysia)
26=Kamchatca (Russia)
27=China
28=Tibet
29=Bulgaria
30=Russia (Carpathians)
31=W. Pacific
32=Spain
33=N. America (Oregon)
34=Argentina
35=Mexico
36=Siberia (Russia)
37=Indonesia
38=Bahama Basin (Atlantic Ocean)
39=Venezuela
40=Australia

Fig. 2.2 Recorded occurrences of Mid Jurassic - Earliest Cretaceous radiolarians. Palaeocontinental reconstruction (Atlas computing package by Cambridge Paleomap Services) for 150 Ma.

radiolarians (data from the database of publications).

2.3 Database/List of publications

The collection of any relevant old references, as well as the continuous recording of recently published scientific papers is an important task of every research worker. During this study it has been judged necessary to create a database of all the collected/viewed publications, mainly for reference reasons. This has been achieved using the software "Microsoft Word for Windows" (Tables feature) which offers easy access and sorting according to any of the columns created.

This is not, however, a complete list of all the publications existing, since recent journals need significant time to reach the libraries and some journals, mainly Japanese and Russian are difficult to obtain. The database (Appendix 1) contains all the important, commonly used publications from radiolarian workers, dealing with Mid Jurassic (Callovian) to Earliest Cretaceous (Valanginian) radiolarian assemblages/biostratigraphy. Some older publications which give the age of the studied radiolarian faunas as Early Cretaceous have also been included, although these may be younger than Early Cretaceous. Excluded are: i) the papers purely devoted to processing techniques and methods of study (these can be found on Tables 6.1 & 6.5), and ii) abstracts from various conferences. In the future, this database will be developed and improved.

The sources for creating this list were:

1) The library of the Postgraduate Unit of Micropalaeontology and the D.M.S. Watson Library of U.C.L.
2) Library of the Geological Society of London.
3) Interlibrary loan requests.

For each of the publications have been given:

a) AUTHOR(S): The name of the author(s) who published the paper.
b) DATE: The date in which the work was published.
c) LOCALITY: The locality from which samples have been examined. In some general radiolarian papers this has given as "worldwide".
d) AGE: The age of the radiolarian assemblages as given by the authors. For some old publications a question mark precedes this.
e) TAXONOMY: The taxonomic content is given. The following abbreviations have been used:

M = when the publication has a taxonomic part and no new species have been reported.

N = when new genera/species have been described.

Publications with no taxonomic part have this space blank.

f) ILLUSTRATIONS: The type of illustrations of each publication is given (if any). The following abbreviations have been used:

D = hand-drawn illustrations.

SEM = scanning electron microscope photographs.

LM = transmitted light photographs.

TS = thin section illustrations.

g) BIOSTRATIGRAPHY: Here is noted (with "Yes") any publication in which i) radiolarian zonations have been produced/proposed, or ii) previous zonations have been summarised.

h) COMMENTS: Some useful comments on the contents of the publication are given.

The database/list of publications can be found in Appendix 1.

2.4 Previous work on Radiolaria from the North Sea Basin

Fossil radiolaria have not been extensively studied in the North Sea Basin. At the end of the last century Sollas (1873a, p. 272; 1873b, p. 93; 1873c, p. 78) first reported the presence of radiolaria -"polycystina"- in Mesozoic rocks in the UK but he did not examine them. He was followed by M. D. Wallich (1883), Jones (1886), Hill & Jukes-Browne (1895) to mention but the most important; these studies seem to concentrate on assemblages from the Chalk (Upper Cretaceous). Other publications (Table 2.1) were dealing with Palaeozoic (e.g. Hinde 1890, 1893, 1899a; Hinde & Fox, 1895) or Cenozoic (Shrubsole, 1889 report of radiolaria from the London Clay) faunas. In the early part of this century Hill (1912) published a general paper on rocks containing radiolaria, and there then followed a long period of inactivity with the exception of Pulfrey (1932) on Palaeozoic faunas.

Waterston (1951) mentioned the existence of radiolaria in the Kimmeridgian black shales of Eathie, Cromarty in Scotland (studied here). Downie (1956, p. 490) noticed the presence of pyritised radiolaria in thin sections and in palynological preparations of the Upper Kimmeridge Clay from onshore localities, and pointed out that radiolaria were never common.

PALAEOZOIC	MESOZOIC	CENOZOIC-RECENT
Hinde (1890a, 1893, 1899)	Sollas (1873a,b,c)	Stokes (1862)
Hinde & Fox (1895)	Wallich, M. D. (1883)	Wallich, G. C. (1869)
Fox (1896, 1899)	Jones (1886)	McDonald (1869, 1871)
Fox & Teall (1893)	Grimes (1895)	Ponton (1871)
Peach (1892)	Hill & Jukes-Browne (1895)	Norman (1876)
Smith (1900)	Holmes (1900)	Jones (1886)
Dixon & Vaughan (1911)	Waterston (1951)	Shrubsole (1889)
Pulfrey (1932)	Downie (1956)	Murrey & Irvine (1892)
Holdsworth (1964, 1966a,b,c 1967, 1969)	Dyer & Copestake (1989)	Fowley (1898, 1904, 1905)
	Partington *et al.* (1993)	Robinson (1905)

Table 2.1 Publications of fossil and Recent radiolaria in the North Sea Basin.

In the 1960's Holdsworth (1964; 1966a,b,c; 1967; 1969) undertook an extensive study of Palaeozoic radiolaria from onshore localities.

The first attempt to devise a biostratigraphic scheme was that of Dyer & Copestake (1989) where 13 radiolarian events have been recognised and 21 taxa have been briefly described. Recently, Partington *et al.* (1993) published a zonation for the Jurassic of the North Sea including seven radiolarian zones for the Kimmeridgian to Ryazanian interval.

Table 2.1 shows the publications dealing with, or briefly mentioning, radiolaria from the North Sea Basin.

CHAPTER 3

OUTLINE OF THE GEOLOGICAL EVOLUTION OF THE NORTH SEA BASIN

3.1 Introduction

During the last two decades various workers have documented the geological history and sedimentation patterns of the North Sea Basin and its surrounding areas. At the same time many papers have been published, e.g. the Conference for Petroleum Geology and Geology of the North Sea and N. W. Atlantic held at Bergen/Norway in 1973 (proceedings by Whiteman *et al.* (eds.), 1975), the Bloomsbury Conference of the Institute of Petroleum (Woodland (ed.), 1975), the Norwegian Petroleum Society's Mesozoic Northern North Sea Symposium (Finstad & Selley (eds.), 1977), the Institute of Petroleum's Lancaster Gate Conference (Illing & Hobson (eds.), 1981), and meetings of the Petroleum Group of the Geological Society of London (e.g. Parker (ed.), 1993). Thus, the tectonic history and evolution of the North Sea is relatively well-known and in the following pages a summary only is given. Emphasis will, however, be given to the Jurassic geology and basin evolution of the North Sea grabens. Selected important publications for the geology of the area are given in Table 3.1.

3.2 Structural setting of the North Sea Basin

The North Sea Basin is located on the northwest margin of the Eurasian tectonic plate. The borders of the basin are:

a) to the west the area of the British Isles (Caledonides),

b) to the south the northern limit of the Alpine foreland (structural highs of Brabant Massif, Rhenish Massif and Bohemian High - Leckie, 1982),

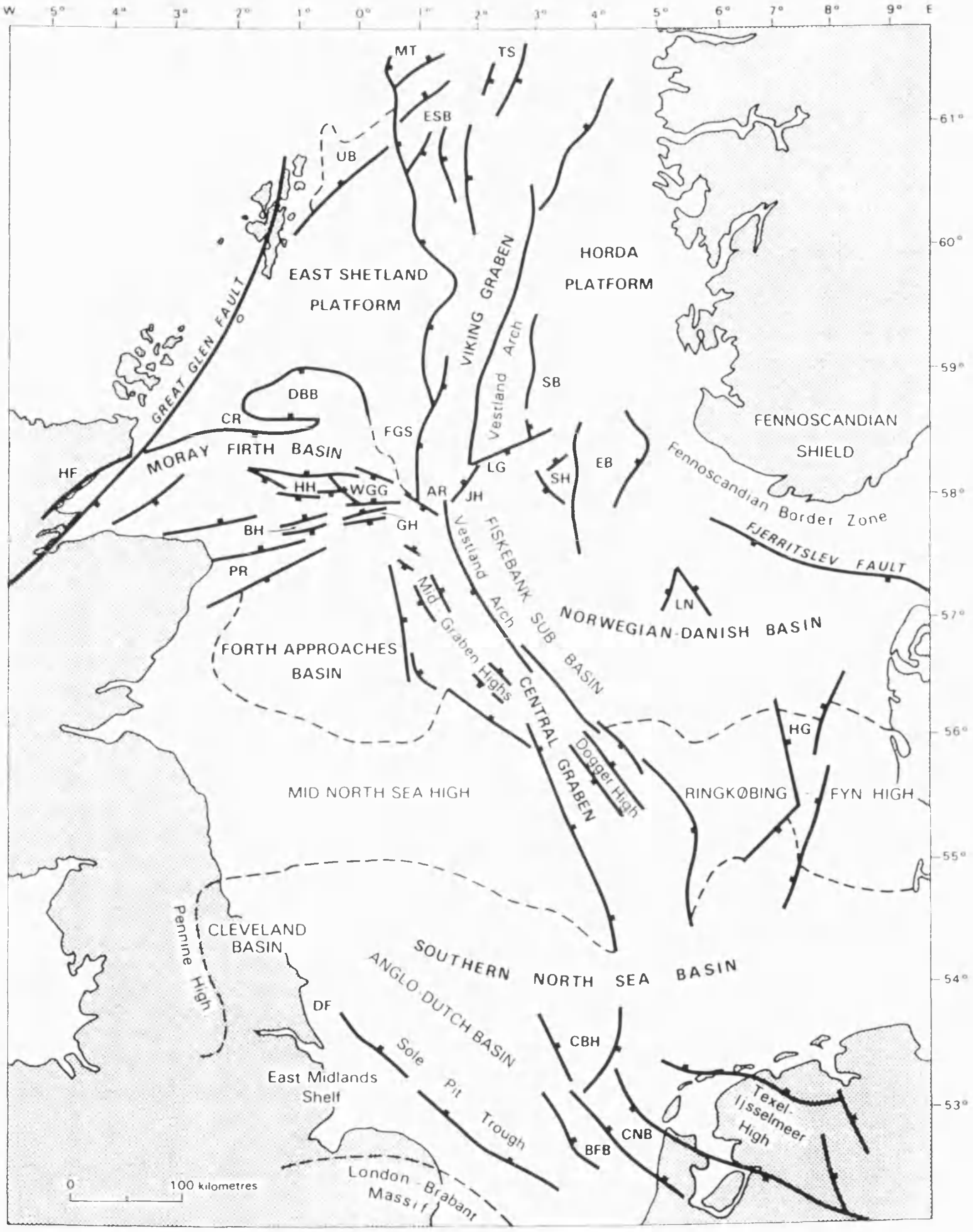
c) to the east Fennoscandia (old Pre-Cambrian craton) and the Danish Peninsula, and

d) to the north the edge of the Atlantic continental margin (at approximately 62°N latitude, northeast of the Shetland Islands - Glennie, 1989).

The North Sea is a series of interconnecting sedimentary basins. These form a major tectono-sedimentary system of the N. W. European continental shelf. The basic structural element of the basin is the trilete graben system which consists of the Viking Graben (north of the Northern Permian Basin), the Central Graben (which cuts both the Northern and Southern Permian Basins) and the Moray Firth Basin. They all meet at about 58°N latitude in the vicinity of the Forties Field (Fig. 3.1).

AUTHOR/EDITOR	DATE	DEALING WITH
Woodland (ed.)	1975	Petroleum & Continental Shelf of N.W. Europe (proceedings)
Whiteman *et al.* (eds.)	1975	Geology of N. Sea & N. E. Atlantic (proceedings)
Finstad & Selley (eds.)	1977	Mesozoic Northern N. Sea (proceedings)
Hallam & Sellwood	1976	Mesozoic sedimentation & tectonics
Ziegler, P. A.	1978	Tectonics & basin development of N. W. Europe
Cope *et al.*	1980	Correlation of Jurassic rocks in the British Isles
Skarpnes *et al.*	1980	Jurassic setting in the N. Sea
Norwegian Petrol. Soc.	1981	Geology of N. Sea (proceedings)
Illing & Hobson (eds.)	1981	Petroleum Geology of N. W. Europe (proceedings)
Leckie	1982	Lithology & Subsidence
Ziegler, P. A.	1982	Faults & Grabens in western & central Europe
Rawson & Riley	1982	Jurassic & Cretaceous events & Cimmerian phase
Chesher & Lawson	1983	Geology of Moray Firth
Turner *et al.*	1984	Stratigraphy & sedimentation of Outer Moray Firth
Beach	1984	Evolution of Witch Ground Graben
Dunning (ed)	1985	Geological structure of United Kingdom & adjacent areas
Brooks & Glennie (eds)	1987	Petroleum Geology of N. W. Europe
Badley *et al.*	1988	Evolution of Northern Viking Graben
Hellinger *et al.*	1988	Mesozoic extension in the Central Graben (part I)
Sclater & Shorey	1988	Mesozoic extension in the Central Graben (part II)
Richards *et al.*	1988	Palaeogeographic reconctruction of the Middle Jurassic of N. Sea
Glennie (ed.)	1989	Petroleum Geology of N. Sea
Thorne & Watts	1989	Quantitative analysis of N. Sea subsidence
Ziegler, P. A.	1990	Geological Atlas of western & central Europe
Blundell & Gibbs (eds.)	1990	Evolution of the N. Sea rifts
Boldy & Brealey	1990	Jurassic tectonism in the Outer Moray Firth
Cope *et al.*	1992	Atlas of Palaeogeography & Lithofacies of N. Sea
Parker (ed.)	1993	Petroleum Geology of N. W. Europe (proceedings)

Table 3.1 Selected important publications for the geology and evolution of the North Sea Basin.



AR	Andrew Ridge	ESB	East Shetland Basin	MT	Magnus Trough
BFB	Broad Fourteens Basin	FGS	Fladen Ground Spur	PR	Peterhead Ridge
BH	Buchan Horst	GH	Glenn Horst	SB	Stord Basin
CBH	Cleaver Bank High	HF	Helmsdale Fault	SH	Sele High
CNB	Central Netherlands Basin	HG	Horn Graben	TS	Tampen Spur
CR	Caithness Ridge	HH	Halibut Horst	UB	Unst Basin
DBB	Dutch Bank Basin	JH	Jaeren High	WGG	Witch Ground Graben
DF	Dowsing Fault	LG	Ling Graben		
EB	Egersund Basin	LN	Lista Nose		

Fig. 3.1 Tectonic setting of the N. Sea Basin (from Brown, 1989, Fig. 8.1).

Deeper below the surface lie two major east-west trending basins initiated in Permian times. These are the Southern Permian Basin and the smaller Northern Permian Basin, separated by the Mid North Sea High and Ringkøbing-Fyn High. Results of drilling and seismic research have revealed the presence of an older sedimentary basin (Carboniferous in age, Glennie (1989)) beneath the floor of the Southern Permian Basin.

Other major features on the North Sea are the East Shetland and Horda Platforms (Fig. 3.1) separated by the Viking Graben, the Forth Approaches and Norwegian-Danish Basins lying to the west and east of the Central Graben respectively, the Horn-Bamble-Oslo and North German system of grabens.

3.3 Structural evolution of the North Sea area

The North Sea area has undergone a complex geological evolution during its Cambrian to Recent history. Plate movements (extension and compression in different directions, at different times) resulted in the present day structural geometry (Glennie, 1989). The most

ERA			TECTONIC STAGE
CENOZOIC	QUATERNARY		POST-RIFTING
	TERTIARY	NEOGENE	
		PALAEOGENE	
MESOZOIC	CRETACEOUS		RIFTING, TAPHROGENIC
	JURASSIC		
	TRIASSIC		PERMO-TRIASSIC INTRACRATONIC
PALAEOZOIC	PERMIAN		
	CARBONIFEROUS		VARISCAN GEOSYNCLINAL
	DEVONIAN		
	SILURIAN		CALEDONIAN GEOSYNCLINAL
	ORDOVICIAN		
	CAMBRIAN		

Table 3.2 The 5 stages of the tectonic history of the North Sea area as distinguished by P. A. Ziegler (1975).

important events are summarised below (and listed on Table 3.2) in chronological order.

In the late Proterozoic and early Palaeozoic the North Sea area was occupying separated continental fragments in different parts of the Iapetus Ocean (which existed between the Laurentia and Scandinavia cratons) and the Tornquist Sea (crossing eastern Europe from the Black Sea to the Skagerrak (Shurawlew, 1965; Bush *et al.*, 1974) (Fig. 3.2). At the end of Silurian occurred the Caledonian Orogeny (Gee & Wilson, 1974, etc.) which had major effects for N. W. European geological history. These first events are described as the Caledonian Geosynclinal Stage by P. A. Ziegler (1975) (Table 3.2) and generally agreed by others (W. H. Ziegler 1975, etc.).

The Variscan Geosynclinal Stage of P. A. Ziegler (1975) is marked by extensive rifting (e.g. the Devonian movements along the Great Glen Fault (Glennie, 1989)) and the Variscan Orogeny during the late Carboniferous. The Variscan geosyncline was extended from west to east, from the south of England across southern Germany. By that time the Proto-Tethys Ocean had been closed and the Pangean supercontinent had been developed (Fig. 3.2).

During the early Permian a phase of crustal tension started (Permo-Triassic Intracratonic Stage of P. A. Ziegler, 1975). The existing Southern and Northern Permian Basins started to subside together with the Moray Firth. Major rifting occurred along the Arctic-North Atlantic Rift Zone (Haller, 1970; Hallam, 1971a) giving birth to the north - south trending Viking and Central Graben system (Fig. 3.2).

By Triassic times block-faulting established the system of horsts and grabens which were affected by rapid subsidence which continued throughout the Jurassic. Three deformation phases took place in Jurassic times, recognised through much of the North Sea area as unconformities, disconformities and transgressive-regressive cycles (P. A. Ziegler, 1975). In the Mid Jurassic domal uplift associated with volcanism and widespread erosion took place, known as the mid-Cimmerian orogenic phase, followed by the Late Jurassic-Earliest Cretaceous strike-slip movements and fault block rotation (late Cimmerian phase of P. A. Ziegler). The opening of the Central Atlantic probably occurred at that time (Table 3.3).

During the Cretaceous rifting movements (sea floor spreading) continued in the Arctic-North Atlantic. All these events are termed as "the Rifting, Taphrogenic Stage" by Ziegler.

A last phase of rifting (Laramide phase) occurred during the Palaeocene, marking the beginning of a new episode of subsidence, the Post-Rifting Stage of Ziegler, which continues to the present day.

3.4 The Central Graben

3.4.1 Tectonic setting of the Central Graben

The Central Graben is the broad, southern arm of the trilete graben system of the

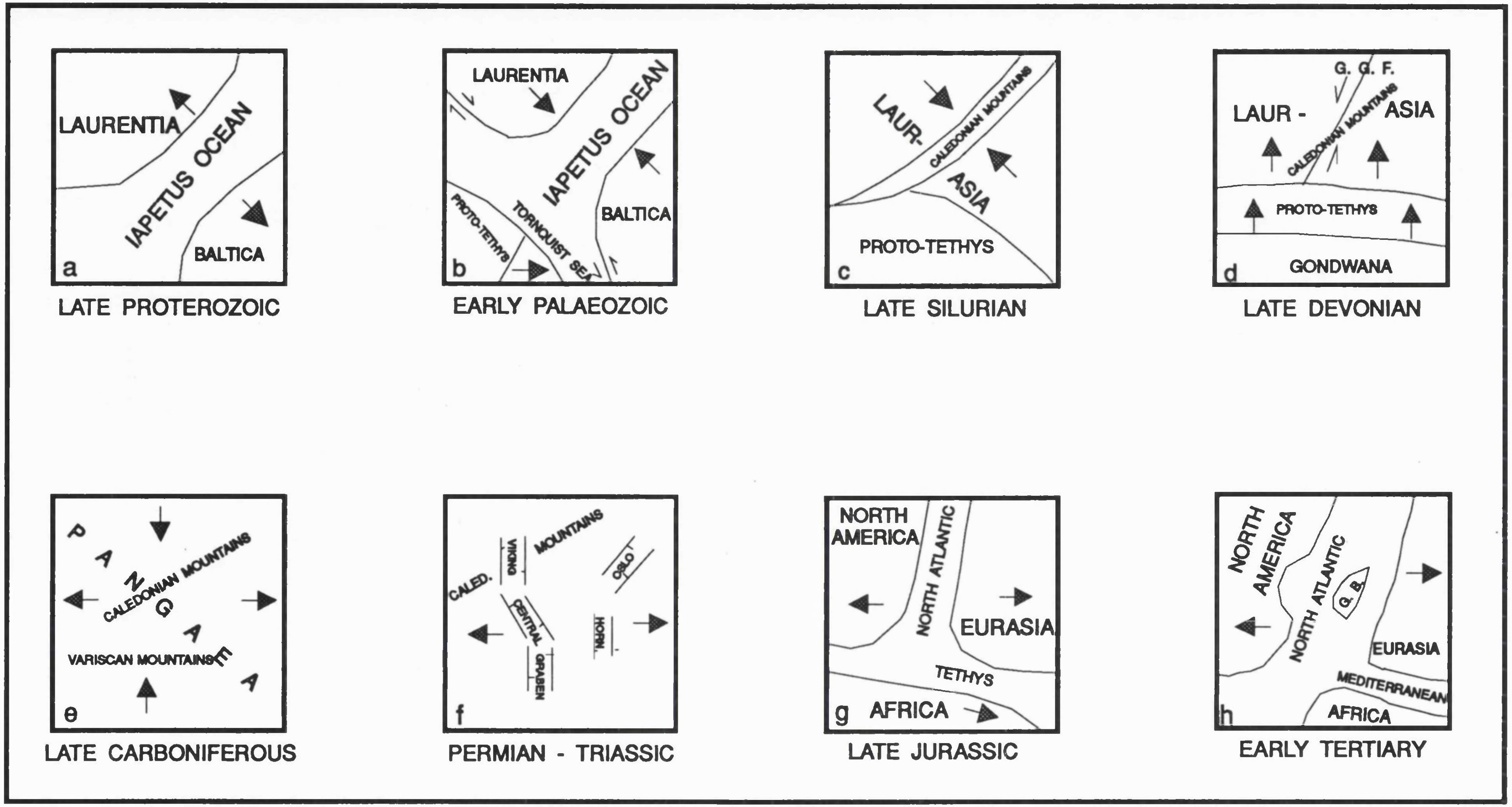


Fig. 3.2 Plate movements that affected the geological history of the North Sea Basin (not in scale) (redrawn from Glennie, 1989; Fig. 2.5).
Abbreviations: G.G.F. = Great Glen Fault
G.B. = Great Britain

			REGIONAL EVENTS		NORTH SEA				
Ma		PERIODS	TETHYS-RELATED	ATLANTIC-RELATED	NORTHERN	MORAY FIRTH	CENTRAL	SOUTHERN	Ma
0									0
	CENOZOIC	Miocene		SPREADING OF PRESENT MID ATLANTIC RIDGE	REGIONAL SUBSIDENCE CENTRED OVER GRABEN SYSTEM				
		Oligocene	ALPINE OROGENY					Zechstein diapirism	
		Eocene		Plateau basalts	Doming of West Shetlands	Uplift of Moray Firth & Scottish Highlands			
		Palaeocene	PLATE COLLISION				Renewed faulting in Central Graben; Inversion of Danish Embayment	Inversion of NW - SE trending sub-basins	
	CRETACEOUS	Late	Gradual closure of Tethys; Rotation of Iberia	SPREADING OF ROCKALL TROUGH EXTENDING NORTH TO NORWAY - GREENLAND SEA	LATE RIFTING PHASE				
100		Early		SEA - FLOOR SPREADING IBERIA - NEWFOUNDLAND	Doming in N. Viking	Rapid subsidence of Inner Moray Firth	SUBSIDENCE in CENTRAL GRABEN; Extrusives in Danish Embayment	Zechstein diapirism	100
	JURASSIC	Late		ONSET OF SEA - FLOOR SPREADING IN CENTRAL ATLANTIC	ROTATIONAL FAULTING IN VIKING GRABEN		DOMAL COLLAPSE & MAIN PHASE OF GRABEN FORMATION	Indefatigable erosion Rapid Sole Pit subsidence	
		Mid	SEA-FLOOR SPREADING IN TETHYS			Volcanic activity in the east	DOMING & LIMITED VOLCANIC ACTIVITY	RIFT & WRENCH TECTONICS	
200		Early							200
	TRIASSIC		RIFTING PHASE	RIFTING IN CENTRAL ATLANTIC	MAIN RIFTING PHASE		Earliest Zechstein diapirism		
	PERMIAN	Late			DEVELOPMENT OF NW EUROPEAN BASIN/GRABEN SYSTEM Zechstein flooding of sub-sea level basins				
		Early	LATE HERCYNIAN WRENCH TECTONICS		E - W Scottish & Scanian dyke swarms: volcanics	SUBSIDENCE OF MORAY FIRTH	COMMENCEMENT OF SUBSIDENCE IN SOUTHERN & NORTHERN PERMIAN BASINS		
300	CARBONIFEROUS	Stephanian	EARLY COLLAPSE OF VARISCAN				Extrusion of L. Rotliegend volcanics		300
		Westphalian	FOLD BELT IN EUROPE	Rifting in Norway - Greenland Sea	RIFTING IN NORTH BRITISH ISLES		Right - lateral faulting: inversion of Sole Pit Basin		
		Namurian	VARISCAN OROGENY	INITIATION OF N. ATLANTIC FRACTURE PATTERN	Renewed uplift of Scottish Highlands			VARISCAN FOREDEEP	
		Dinantian	PLATE COLLISION						
	DEVONIAN	Late	STEP-WISE CLOSURE OF PROTO-TETHYS	Probable strike-slip movement of the Great Glen Fault & extension in N. Atlantic		Volcanics in Orcadian Basin	Marine Limestones in Auk & Argyll	BACK - ARK RIFTING	
		Mid							
400		Early			Granites in Scottish Highlands	Subsidence in Orcadian Basin	Volcanics in S. Scotland	Granites in Lake District	400
						CALEDONIAN	OROGENY		

Table 3.3 Events affecting the geological evolution of the North Sea Basin (redrawn from Glennie, 1989; Table 2.1).

North Sea region which has its origin as far back as the Early Triassic. The Graben can be divided into two parts:

i) the northern section, which generally trends NNW-SSE, and

ii) the southern section with a N-S direction.

The change in trend occurs where the graben meets the Ringkøbing-Fyn High (Fig. 3.1).

The Central Graben ends south of the Central Highs. To the north it meets the Viking Graben and Moray Firth Basin where Mid Jurassic volcanics occur. According to Johnson & Dingwall (1981) and McQuillin *et al.* (1982) the Central Graben continues north, linking up with the Witch Ground and Buchan Grabens.

To the east the northern section of the graben (where four of the wells studied occur) is bounded by the Vestland Arch, a complex of asymmetric, rotated fault blocks (Brown, 1989) and to the west by the late Palaeozoic Forth Approaches Basin. Narrow, prominent and discontinuous "highs" such as the Mid-Graben Highs and Dogger High occur parallel to the graben axis (Fig. 3.1). The major structural elements of the northern part of Central Graben are illustrated in Fig. 3.3.

3.4.2 Structural evolution of the Central Graben

The principal structure of the Central Graben formed as a result of the Hercynian Orogeny which in turn influenced the orientation of the later Mesozoic graben. The rift system of the northern section of the graben formed during the Triassic, overprinting the final phases of downwarping and subsidence of the Northern Permian Basin. The important role of listric faults in the evolution of the graben is discussed by Gibbs (1984).

During the Early Jurassic rifting continued throughout the graben, until Mid Jurassic times when a phase of regional upwarping focused on the graben and resulted in erosion of Lower Jurassic and some Triassic sediments from all but the deepest troughs (P. A. Ziegler, 1981; Eynon, 1981). This was associated with Bajocian-Bathonian alkaline volcanism (Howitt *et al.*, 1975) restricted to the junction between the three major grabens. After these events fault-controlled subsidence and rifting recommenced in the Early Oxfordian and continued throughout the Late Jurassic with large movements occurring along individual faults. These fault-bounded depressions accommodated the thick sequences of the Kimmeridge Clay Formation (Brown, 1989). By that time the Central Graben was a number of interconnected subsiding troughs. The active rifting phase ceased along most faults by the end of the Early Cretaceous and was replaced by downwarping subsidence which continued into the Tertiary. The end of the Cretaceous marks the cessation of minor rifting and the transfer of crustal extension west of the British Isles.

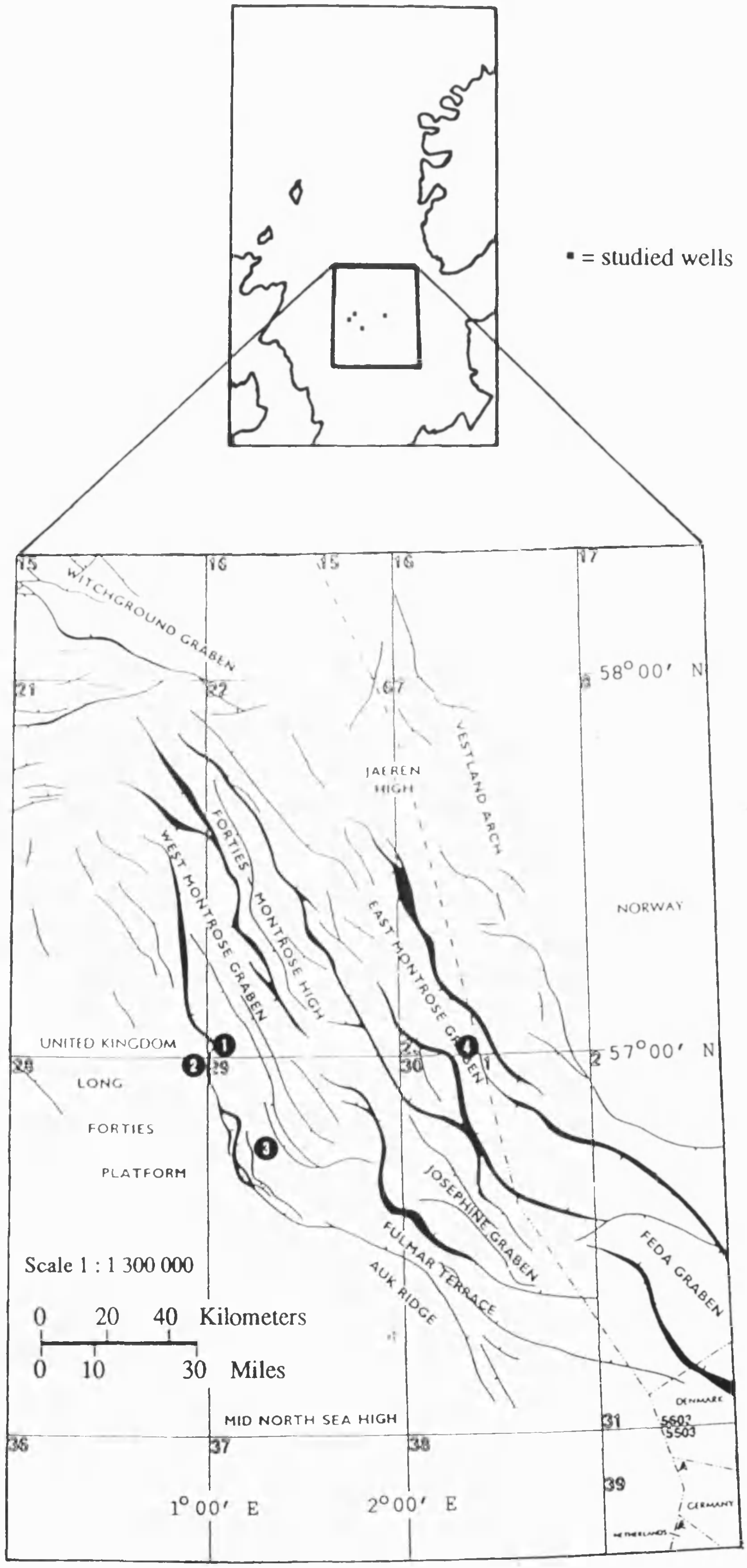


Fig. 3.3 Structural elements of the northern part of the Central Graben (from SPT) and location of wells studied (SPT refers to Simon Petroleum Technology proprietary reports (*pers. comm*)).
❶ = well 22/21-2, ❷ = well 28/5-1, ❸ = well 29/12-1, ❹ = 23/27-4.

All these main events are listed in chronological order in Table 3.4.

ERA				TECTONIC STAGE
CENOZOIC	TERTIARY			* continuation of downwarping
MESOZOIC	CRETACEOUS	Late		* all rifting ceased * fault-controlled subsidence replaced by graben-centred downwarping
		Aptian-Albian		
		Early		* active rifting mainly ceased
	JURASSIC	Late	Volgian	* large movements occur along individual faults & accummulation of Kimmeridge Clay Formation
			Kimmeridgian	
			Oxfordian	* recommencement of most active rifting phase & fault-controlled subsidence
		Mid		* Bajocian - Bathonian alkaline volcanism * regional upwarping
		Early		* rifting
	TRIASSIC			* formation of rift system

Table 3.4 The main events in the evolution of the Central Graben.

3.5 The Viking Graben

3.5.1 Tectonic setting of the Viking Graben

The Viking Graben is the northerly trending arm of the North Sea triple rift system. Its limits are:

a) to the east - (i) the Vestland Arch, which separates it from the Stord Basin, and (ii) further north the Horda Platform;

b) to the west - the Fladen Ground Spur and the large East Shetland Platform;

c) to the south - the NW-SE trending Andrew Ridge (Hamar *et al.*, 1983) where it meets the Central Graben and Outer Moray Firth (region of the Forties Field); and

d) to the north - the Viking Graben loses its identity at around 62°N latitude, beyond the Magnus Trough and Tampen Spur (Fig. 3.1).

The graben has a N-S to NNE-SSW trend and it can be broadly divided into the North and South Viking Graben. The former includes an intermediate area of Mesozoic sedimentation, the East Shetland Basin. Wells for this study are from the latter area which, according to Brown (1989, p. 238) "has an asymmetric, broadly half-grabenal form in east-west section with the major basin-margin faults on the western margin". The halokinetic movements of the

Zechstein salt influence the general structure at Jurassic level in the South Viking Graben (P. A. Ziegler, 1975; Brown, 1989). The major structural elements of the South Viking Graben and the important oil and hydrocarbon reservoirs are illustrated on Fig. 3.4.

3.5.2 Structural evolution of the South Viking Graben

A summary of the regional structural framework of the South Viking Graben follows and focuses on the Palaeozoic rocks, the Mesozoic to Late Cretaceous crustal extension and the Late Cretaceous to Tertiary basin subsidence (Table 3.5).

ERA	EVENT
CENOZOIC	* basin subsidence
MESOZOIC	* crustal extension
PALAEOZOIC	* major structures obtain NNE-SSW orientation

Table 3.5 Three major events for the evolution of the South Viking Graben.

The orientation of the individual sedimentary basins between the Moray Firth Basin and Horda Platform indicates a complex tectonic history for the South Viking Graben. The Precambrian and Palaeozoic rocks of the onshore areas close to the graben (Norwegian mainland, Shetland Isles and also the Scottish mainland) add important information to the interpretation of the pre-Permian structure in the vicinity of the graben. The Caledonian structures of Scotland are mainly characterised by large thrust sheets in a WNW direction, in contrast to the ESE direction of those in Norway. This suggests that the now-adjacent areas originated on opposite margins of the Iapetus Ocean (Fig. 3.2). Donato & Tully (1981) interpreted gravity data from the North Sea region and deduced the existence of continental crust beneath the Mesozoic sedimentary basins of the South Viking Graben. This basement has undergone deformation during the Caledonian events together with all major structures on both sides of the graben to obtain a common NNE-SSW and NE-SW trend.

Triassic time saw the formation of the North Sea Graben system. A progressive extension within the continental crust of the North Sea region continued intensively in Triassic to Early Jurassic time. This was a function of the initial phase of break-up of the Laurasian

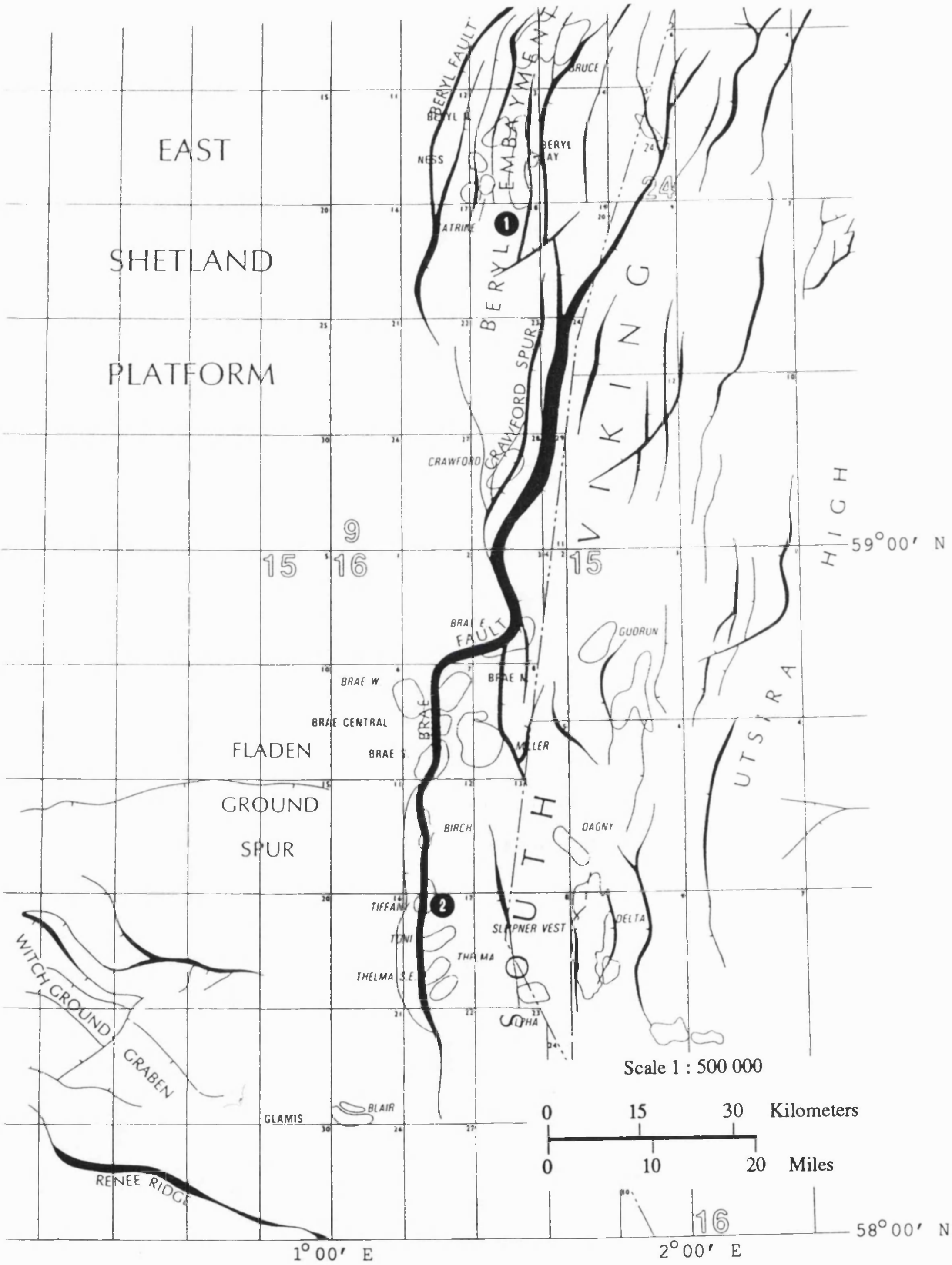


Fig. 3.4 Structural elements of the South Viking Graben, the main oil and hydrocarbon reservoirs (from SPT), and location of wells studied.
➊ = well 9/18A-4, ➋ = well 16/17-5.

megacontinent (Fig. 3.2). South of the graben, the establishment of a volcanic centre in the early Mid Jurassic resulted in uplift and erosion of older sediments (P. A. Ziegler 1982). These volcanics are mainly Bajocian in age (Dixon *et al.*, 1981) and volcanic activity ceased by the end of the Bathonian. In Mid to Late Jurassic times the extensional faulting within the continental crust of the North Sea resulted in rapid subsidence in the South Viking Graben. Riley & Davies (1993) postulated that rifting was initiated in the Brae area (well 16/17-5) in the early Callovian.

Regional downwarping characterised the subsidence history of the North Sea from the Late Cretaceous onwards. This is usually associated with the postulated deep cooling and contraction of mantle material which had risen to high crustal levels during the peak of Jurassic crustal extension (McKenzie, 1978).

3.6 The Moray Firth Basin

3.6.1 Tectonic setting of the Moray Firth Basin

The Moray Firth Basin is a complex system of Mesozoic fault-controlled sub-basins which exhibit an overall E-W trend from the junction zone with the Viking and Central Grabens in the vicinity of the Forties Field (Fig. 3.1). The basin has been considered as being the third arm of a trilete Mesozoic rift system of the North Sea (Whiteman *et al.*, 1975; Woodhall & Knox, 1979; P. A. Ziegler, 1981).

The basin may be divided - on the basis of structural style and stratigraphy - into the Inner and Outer Moray Firth areas, along a structural boundary that mainly follows the zero Bouguer anomaly across the north-south axis of the central part of Quadrant 13 (Barr, 1985).

In the Inner Moray Firth the orientation of faults is caledonide (NE and ENE). The Wick, South Wick, Beatrice and Lossiemouth Faults trend obliquely to the Great Glen Fault forming a zone of en-echelon extensional faults. The limits of the Moray Firth Basin are:

a) to the west - the Great Glen and Helmsdale Faults at the Scottish coast, where an onshore outcropping sequence is Kimmeridgian to Mid Volgian in age (Lam & Porter, 1977) (Helmsdale-Brora inlier and Eathie Haven, Cromarty);

b) to the north - the Caithness Ridge, in particular the Wick Fault which trends broadly east;

c) to the south - the east-trending Grampian Massif and Banff Fault, both of which had a major influence in the Mesozoic history of the basin.

In the Outer Moray Firth the faults possess a broadly W-E orientation. The limits of the basin are:

a) to the north - the Caithness Ridge and further east the Dutch Bank, a large embayment in the East Shetland Platform;

b) to the south - the Peterhead Ridge, a NE-SW trending basement high, and the Buchan and Glen Horst to the southeast; and

c) to the east - the Fladen Ground Spur, a structural high which separates the basin from the South Viking Graben.

The most notable features of the basin are the Halibut Horst and the Witch Ground Graben. The former trends NW-SE and its eastward termination, at the East Halibut Faults, forms the southern margin of the Witch Ground Graben. The latter is well-defined by WNW-ESE faults (Piper and Piper Spur Faults) and according to McQuillin *et al.* (1982) can be regarded as a northward continuation of the Central Graben. A detailed structural framework map for the Moray Firth is given on Fig. 3.5.

3.6.2 Structural evolution of the Moray Firth Basin

The structural evolution of the basin is complicated and has its origin as far back as the Caledonian Orogeny. However, attention will be given below to the Jurassic - Early Cretaceous phase.

A major Devonian basin underlies the area, believed to have been initiated by transtensional movement along the Great Glen Fault (McQuillin *et al.*, 1982; Rogers *et al.*, 1989) which itself had a complex history and played a significant role in the evolution of the basin.

The general structural framework for the Outer Moray Firth was initiated by an extensional regime in late Carboniferous to early Permian times (Whiteman *et al.*, 1975). As mentioned in previous pages, the Triassic saw the establishment of the trilete graben system of the North Sea area. This pattern of rifting for the Inner Moray Firth continued into the Jurassic and Early Cretaceous. McQuillin *et al.* (1982) described right-lateral movement on the Great Glen Fault associated with extension between the Wick and Banff Faults. This movement had as a result the reactivation of the Beatrice, Lossiemouth and Banff Faults. Barr (1985) modelled the extension of the basin between its major bounding faults and suggested 7 to 8% post-Triassic extension. Underhill (1991) postulated that the Inner Moray Firth had developed as a purely extensional basin in Late Oxfordian to early Kimmeridgian times.

The early part of the Mid Jurassic was a tectonically quiet period during which the basin subsided uniformly, in contrast to the Late Jurassic which was the most active phase of fault-controlled subsidence. Pre-Callovian uplift associated with basic alkaline volcanism and deposition of volcanics occurred east of the Halibut Horst. Andrews & Brown (1987) emphasized changes in the subsidence pattern in the Oxfordian; at that time the Helmsdale

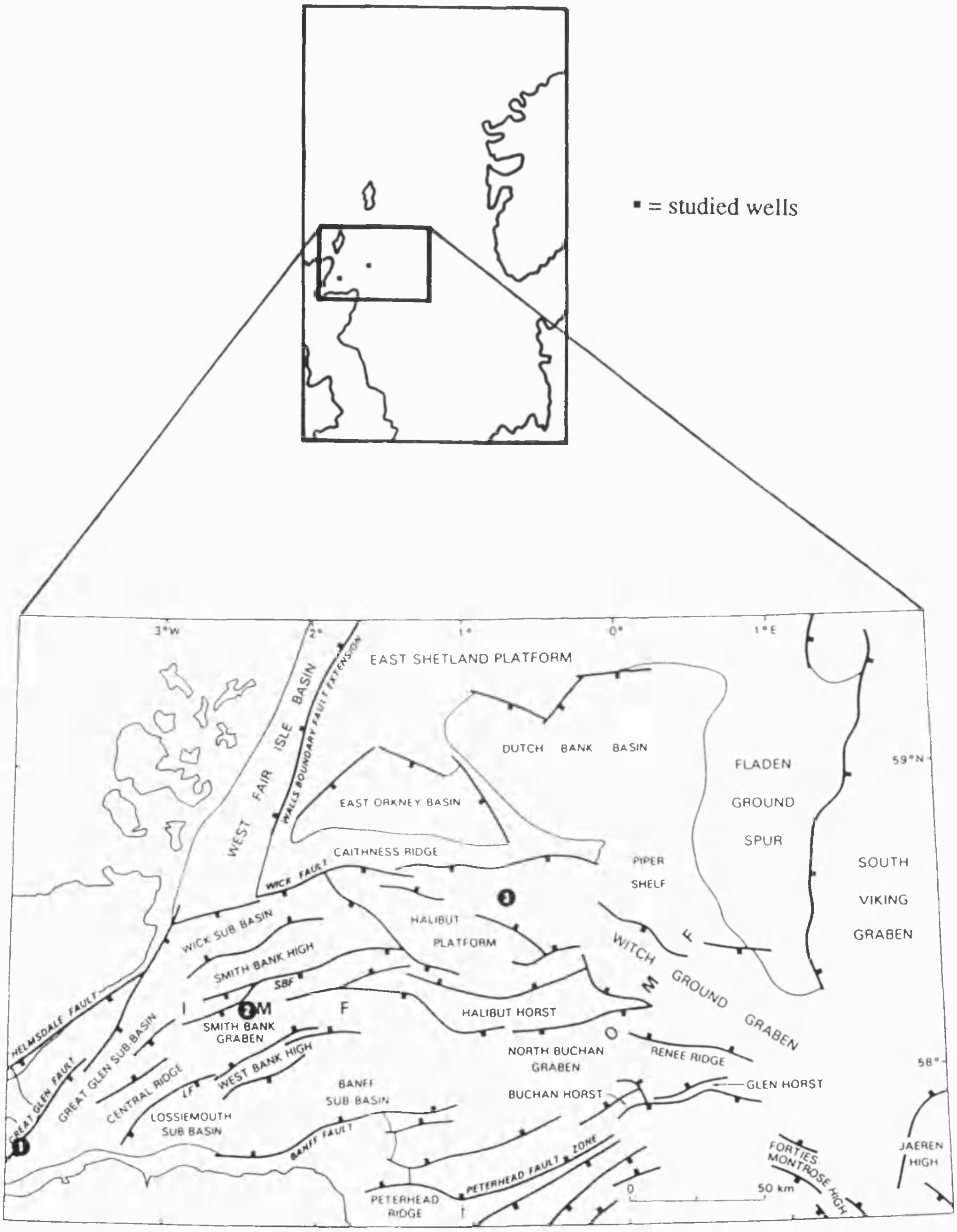


Fig. 3.5 Structural elements of the Moray Firth Basin (from Andrews & Brown, 1987, Fig. 1) and location of wells/exposure studied.
➊ = Eathie Haven, ➋ = 12/28-1, ➌ = 14/18-1.
Abbreviations. IMF = Inner Moray Firth
OMF = Outer Moray Firth
SBF = Smith Bank Fault
LF = Lossiemouth Fault

Fault was reactivated.

ERA				EVENT
CENOZOIC	QUATERNARY			* continuation of downwarping in the Outer Moray Firth
	TERTIARY	NEOGENE		
		PALAEOGENE	OLIGOCENE	
			EOCENE	
			PALAEOCENE	* uplift of Scottish Mainland & Shetland Platform, erosion in the Inner Moray Firth
MESOZOIC	CRETACEOUS		UPPER	* regional downwarping occurs in Outer Moray Firth progressively reducing towards the Inner Moray Firth
			LOWER	* reduced rates of fault controlled subsidence
	JURASSIC		UPPER	* intense subsidence in the Outer Moray Firth * changes in subsidence pattern
			MIDDLE	* volcanism & uplift in eastern the Moray Firth
			LOWER	
	TRIASSIC			* commencement of uniform subsidence * establishment of pattern rift for N. Sea & Moray Firth Basin
PALAEOZOIC	PERMIAN			* extensional regime initiates structural framework in the Outer Moray Firth
	CARBONIFEROUS			
	DEVONIAN			* transtensional movement along the Great Glen Fault initiates Devonian basin
	SILURIAN			
	ORDOVICIAN			* Caledonian movements, faults obtain WSW-ENE caledonian trend
	CAMBRIAN			

Table 3.6 Major events in the evolution of the Moray Firth Basin.

From the Oxfordian to Volgian the Outer Moray Firth underwent intense subsidence and the Halibut and Glenn Horsts became defined as structurally high areas on which erosion occurred. This subsidence was an important part of the development of the Witch Ground Graben (Woodhall & Knox, 1979), the final major structural feature to form. The axis of the Witch Ground Graben trends WNW-ESE while the NE-SW faults cut obliquely across the Halibut Horst and Renee Ridge. Beach (1984) supported the "perpendicular-to-its-axis" opening direction of the graben, parallel to the general opening direction of the Moray Firth area.

In the Early Cretaceous fault-controlled subsidence of the basin continued at reduced rate and was replaced by regional downwarping in the Outer Moray Firth at the end of the Late Cretaceous. This downwarping was most intense in areas of previous subsidence (Witch Ground Graben and Buchan Graben). Thermal recovery of a thinned lithosphere underneath the rifted zones of the North Sea is believed to be the reason for the downwarping, which was reduced progressively towards the Inner Moray Firth from the junction with the Viking and Central Grabens.

Cenozoic uplift of the Scottish Mainland and Shetland Platform resulted in erosion of the western part of the basin. The regional downwarping of the major rifted areas of the Outer Moray Firth continued into the Eocene and Oligocene.

Table 3.6 shows the major events for the evolution of the basin.

CHAPTER 4

SEDIMENTATION PATTERNS & LITHOSTRATIGRAPHY OF THE NORTH SEA BASIN

4.1 Introduction

In this chapter a description is given of the post-Caledonian sedimentary development of the North Sea Basin. A description of the Palaeozoic, Mesozoic and Cenozoic sedimentation patterns will first be given followed by a detailed discussion of the sedimentation and lithostratigraphy of the Jurassic for the three main North Sea grabens where the studied wells occur. Finally, the Humber Group and its formations will be described with emphasis on the Kimmeridge Clay Formation.

4.2 Outline of post-Carboniferous sedimentation patterns

The North Sea Basin, which, as mentioned earlier, has been developed at the N.W. margin of the Eurasian tectonic plate, exhibits a continuous Carboniferous to Recent record of sedimentation which varies from epeirogenic to deltaic and marine (Leckie, 1982). This record will be described below.

a) **Devonian.** By the end of Silurian, with the closure of the Iapetus Ocean, the formation of the Laurasian megacontinent occurred and the uplift of a major mountain range (Caledonian mountains) (Fig. 3.2, Chapter 3) passing through the north Britain. Barrell (1916) postulated that erosion of the mountains in a vegetation-free continental climate had as a result widespread deposition of fluvial sediments. Marine Devonian sediments persisted in the southern North Sea where the Proto-Tethys Sea was situated. A major terrestrial basin with Old Red Sandstone occupied much of the northern North Sea area (Glennie, 1989, Fig. 2.12; P. A. Ziegler, 1990). The deposition and deformation of the Old Red Sandstone sediments have been discussed by P. A. Ziegler (1982).

b) **Carboniferous.** While relatively arid conditions dominated the Late Devonian, with the slow northerly drift of the Laurasian megacontinent the Carboniferous sedimentation seems to have occurred in a more humid climate, where equatorial conditions allowed the deposition of Coal Measure swamp sediments (Leckie, 1982). These are very important for the hydrocarbon industry (as a source for southern North Sea and Dutch-German gas reservoirs). The erosion of the Caledonian Highland continued to the north of the area with shallow marine conditions prevailling in the southern North Sea by the end of the period (maps C3 -C7 of Cope *et al.*, 1992).

c) **Permian.** During the early Permian (Roetliegendes) in the southern Permian Basin dune sands were deposited (Glennie, 1972) which graded northwards into sabkha evaporites and shales (Leckie, 1982). The widespread marine incursion of the Zechstein sea followed, which probably came from the north (W. H. Ziegler, 1975). By this time a huge thickness of halite was deposited over much of the North Sea, with shelf carbonates on the margins of the basin. Zechstein shoal-carbonates and evaporites occur also in the Moray Firth Basin and northern Viking Graben (W. H. Ziegler, 1975). Stable tectonic conditions persisted in the Late Permian with minor igneous activity. Jaritz (1973) postulated the significant influence of the diapirism of those Zechstein evaporites for post-Triassic sedimentation. Latest Permian time saw the deposition of thick clastics (derived from the Massif Central in France) on top of the Zechstein in the southern North Sea. According to W. H. Ziegler (1975) these clastics probably extended as far north as the South Viking Graben.

d) Triassic. During Triassic times faulting and rift development occurred (Whittaker, 1985; P. A. Ziegler, 1987; etc) with regional subsidence of the area and: i) deposition of thick continental muds and clastics in the north (Scandinavian Shield, London-Brabant Massif and Scottish Caledonian Highlands the sources), and ii) marine sedimentation in the south. The Mid-North Sea High and Ringkøbing-Fyn High marked the northern limit (maps Tr2 & Tr3a of Warrington & Ivimey-Cook, 1992) of the various evaporitic pan systems.

e) Jurassic. The early Cimmerian phase (P. A. Ziegler, 1975) initiated a change from the Triassic sedimentary patterns to the new Jurassic phase of marine to deltaic sedimentation across N. W. Europe (Rusitzka, 1967; Bradshaw *et al.*, 1992). With the widespread marine transgression in the Early Jurassic deltaic-sand complexes were deposited in the N. Sea basin and especially in the north (W. H. Ziegler, 1975). This phase lasted through to the Bajocian and Bathonian when uplift associated with volcanism occurred in the central North Sea. Thick volcanic beds are preserved locally. The marine sedimentation continued with shales interbedded with sands in the northern North Sea and limestones in the southern North Sea. The older sands as well as those younger ones on the basin margins are paralic. Towards the end of the Jurassic deep-sea sands and boulder beds (onshore Inner Moray Firth basin) were deposited along the rift margins. Shale sequences of the Upper Jurassic Heather and Kimmeridge Clay Formations (with commercially important sand units) of over 1km in thickness can be preserved in the Central Graben and the axial portion of the Viking Graben. At the Jurassic-Cretaceous boundary another major rifting phase (late Cimmerian) occurred (P. A. Ziegler, 1975; Rawson & Riley, 1982). The erosional effect of this disruptive phase was so intense that channels were cut as deep as the Zechstein in parts of the central North Sea.

f) Cretaceous. In the Early Cretaceous the irregular Cimmerian surface infilled with sands and clays. This was followed by a major change in the sedimentary pattern of the area which took place across the Albian/Cenomanian boundary (Hancock & Rawson, 1992). Just before the Albian a widespread transgression occurred. During this tectonic quiet period chalk and marls were deposited over much of the area, which by the Late Cretaceous was covered by a sea more extensive than in any other part of the Mesozoic (maps K4a & b of Hancock & Rawson, 1992).

g) Tertiary. The deposition of chalk ended with the intense Laramide tectonic phase of the Maastrichtian and Palaeocene. Erosion then occurred over the Central and South Viking Graben, removing the chalk and causing extensive mélanges of chalk boulders to be shed off fault scarps in the deepest parts of the grabens creating the reservoirs of Danian Chalk Fields (W. H. Ziegler, 1975). The early Tertiary was characterised by volcanic activity and widespread ash bands at the Palaeocene-Eocene boundary. In the Eocene, sands and shales were deposited in the north of the basin, derived from the NW. Finally, from the Late Eocene onwards the basin was filled by a monotonous sequence of marine shales which sealed it (W. H. Ziegler, 1975; Leckie, 1982).

4.3 The North Sea as a failed rift system

Selley (1981) supported the idea that the North Sea, in general, shows a classic sequence of facies for a failed rift basin which is favourable for the generation and entrapment of hydrocarbon accumulations.

i) The N. Sea rift floor lay above sea level, receiving continental clastics (reservoir rocks: Rotliegend and Triassic sandstones). Gas was sourced from basement Carboniferous Coal Measures.

ii) The subsiding basin reached sea level and marine conditions prevailed. This time evaporites formed which later acted as cap rocks (Zechstein).

iii) Widespread transgression occurred and organic-rich marine clays were deposited with stagnant bottom conditions (see Kimmeridge Clay Formation discussion). At the same time paralic and deep water, commercially important, sands (reservoirs) were also deposited.

iv) After the rift system "ended", the deposition of open-marine sediments followed. These are significant because a) of the role they play as cover that further buries the source strata in order to mature and expel the hydrocarbons, and b) they contain reservoirs, trapping migrating oil (Chalk).

4.4 Jurassic and Lower Cretaceous Lithostratigraphy

4.4.1 Introduction

The importance of hydrocarbon discoveries in the North Sea Basin has led geologists to work for a formal lithostratigraphic nomenclature for the basin, based on the study of the geological successions illustrated by well logs. In 1974 Rhys published his results for the southern UK North Sea, followed by the work of Deegan & Scull (1977) for the central and northern North Sea. Other lithostratigraphic schemes for the Mesozoic of the basin have been published by Michelsen (1978), the Nederlandse Aardolie Maatschappij B. V. & Rijks Geologische Dienst (1980), Vollset & Dore (1984), Jensen *et al.* (1986) and recently Richards *et al.* (1993). Table 4.1 shows these main publications. Lithostratigraphy for the studied wells has been done by Simon Petroleum Technology using the lithostratigraphic schemes published before 1993, and these will be followed here.

The next pages are devoted to the lithostratigraphy of the North Sea Jurassic with emphasis on the UK sector. A brief description of the Lower to Middle Jurassic will be given first, followed by a detailed discussion of Upper Jurassic lithostratigraphy (Fig. 4.1) and facies of all the three main grabens.

AUTHOR	DATE	AREA
Rhys	1974	UK southern N. Sea
Deegan & Scull	1977	UK central & northern N. Sea
Michelsen	1978	eastern Norwegian-Danish Basin
NAM & RGD	1980	Dutch southern N. Sea
Vollset & Dore	1984	Norwegian N. Sea
Jensen *et al.*	1986	Danish Central N. Sea
Richards *et al.*	1993	UK central & northern N. Sea

Table 4.1 Main publications on Jurassic lithostratigraphical schemes for the North Sea Basin.

4.4.2 Lower Jurassic

4.4.2.1 Central Graben

Lower Jurassic sediments are absent in the central UK sector due to the doming and widespread erosion which, according to Eynon (1981), was initiated during late Toarcian time. However, Smith (1987) referred to the presence of late Toarcian strata locally appearing on the Clyde Field (UK block 30/17b). Brown (1989) did not reject the posibility of finding Lower Jurassic sediments in fault-bounded "lows" (Dunlin Group equivalent). Richards *et al.* (1993) postulated the presence of Lower Jurassic strata (possibly of Sinemurian age, Fjerritslev Formation) in the area.

In the eastern sector of the UK Central Graben, as well as in the Norwegian part, Lower Jurassic sediments are present, with the Gassum Formation (sands) overlain by the marine shales of the Fjerritslev Formation (Fig. 4.2) (Michelsen, 1978; Bertelsen, 1978). These deposits tend to be preserved only in downfaulted "lows" (Brown, 1989).

In the southern North Sea the Lower Jurassic sediments are far better preserved.

As far as volcanicity is concerned only local tuffaceous beds occur, being the precursors of the later Mid Jurassic activity (Deegan & Scull, 1977).

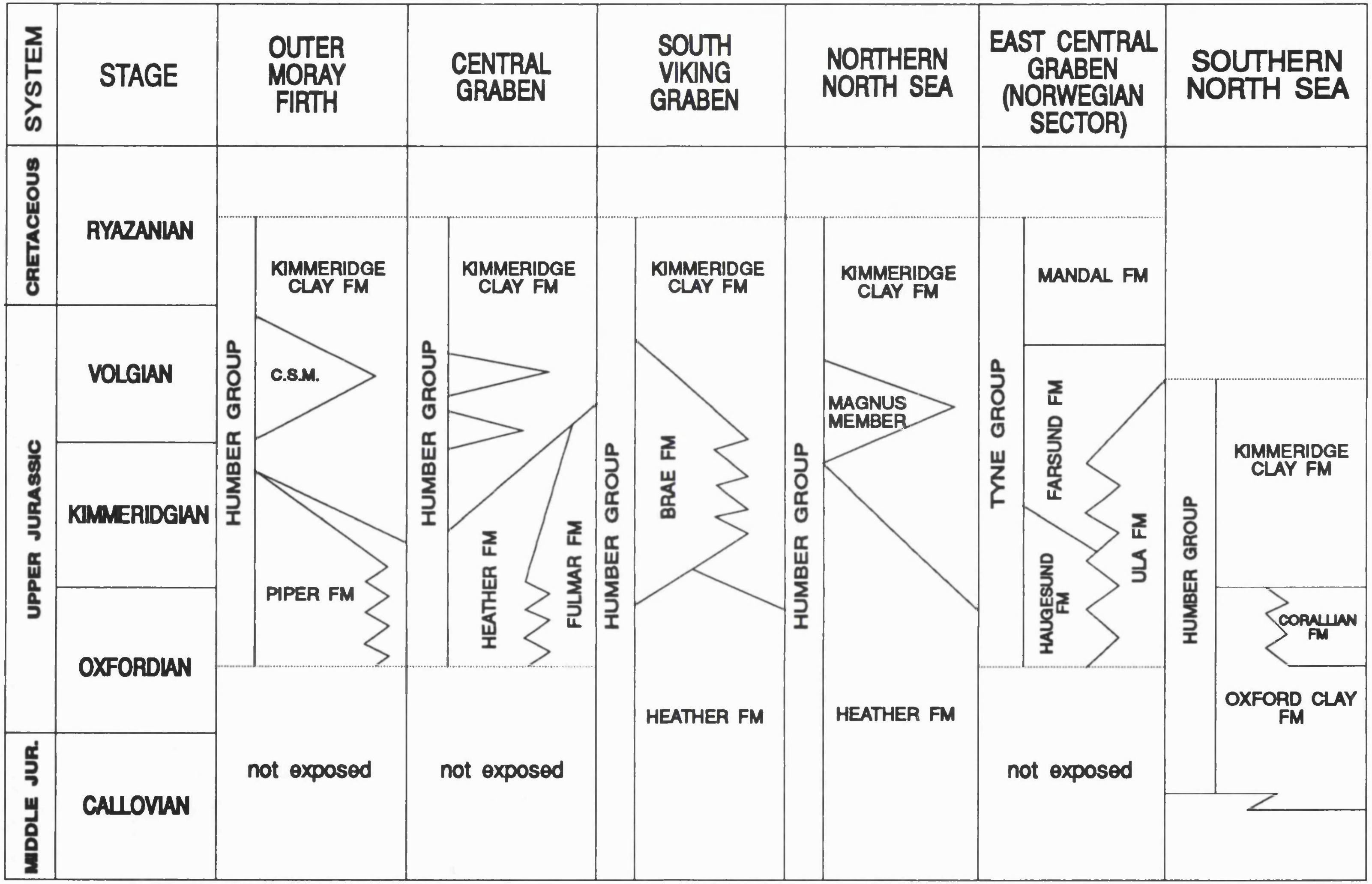


Fig. 4.1 Generalised lithostratigraphy for the Callovian to Ryazanian interval of the North Sea Basin (modified from Johnson & Stewart (1985) with data from Rhys (1974), Cope *et al.* (1980), Vollset & Dore (1984). Abbreviation: C.S.M. = Claymore Sandstone Member.

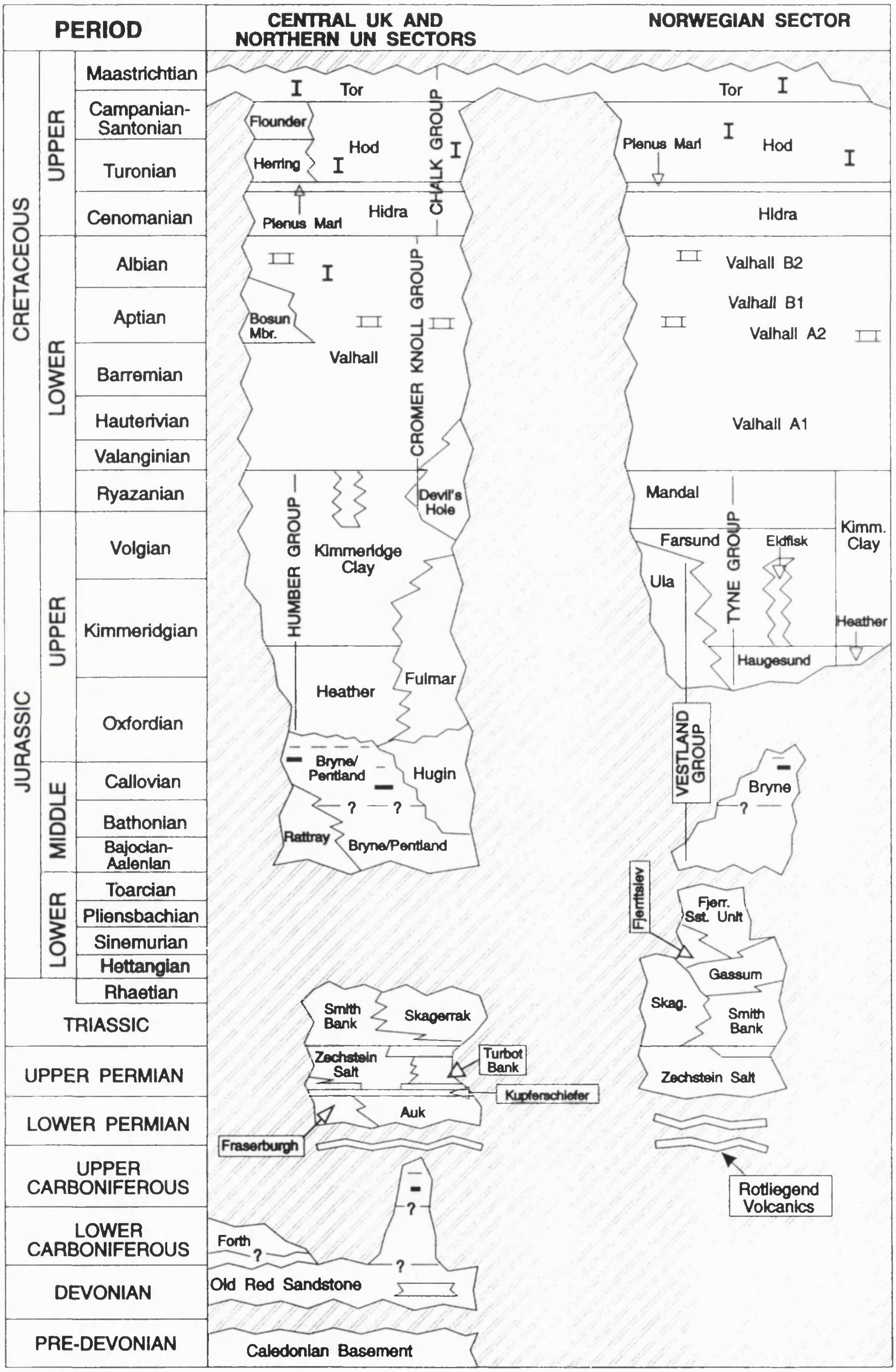


Fig. 4.2 Palaeozoic and Mesozoic lithostratigraphy of the Central Graben (redrawn after SPT).

4.4.2.2 South Viking Graben & Beryl Embayment area

The oldest Jurassic deposits in the South Viking Graben are the Rhaetian to Sinemurian (Late Triassic - Early Jurassic) age sands of the Statfjord Formation (Skagerrak Formation according to Richards *et al.*, 1993). These indicate a transition from continental to fluvio-deltaic and marginal marine conditions (Deegan & Scull, 1977; Brown, 1989). The rest of the Lower Jurassic sequence consists of the (?)marine shales of the Dunlin Group and the Drake Formation in the Beryl Embayment area and South Viking Graben respectively (Fig. 4.3). Thin sands (Cook Formation), commercially important as reservoirs, occur in the Pliensbachian in the South Viking Graben. However, sediments of this age are pr esent in the South Viking Graben in places (SPT and Richards *et al.*, 1993). There is a broad gradation in finding Early Jurassic sediments from south to north in the basin. This, again, can be linked with the later updoming at the junction of the three main North Sea grabens.

4.4.2.3 Moray Firth Basin

In the Moray Firth Basin the Jurassic succession is relatively complete. Onshore, the Earliest Jurassic sediments are those of the Dunrobin Bay Formation (Group, according to Richards *et al.*, 1993) (Hettangian to mid Pliensbachian in this part of the basin). Then a break in sedimentation follows until the Bathonian (Fig. 4.4).

Offshore, in the Inner Moray Firth the Lower Jurassic is represented by the Fleet (shales) and Orrin (sands) Formations. The first rests conformably on a thin Cherty Rock limestone of Triassic age. In the Outer Moray Firth strata of this age are absent (owing, again, to the Mid Jurassic updoming and following erosion) (Fig. 4.5).

4.4.3 Middle Jurassic

4.4.3.1 Central Graben

In the eastern UK and Norwegian sectors the Middle Jurassic sediments are assigned to the Bryne Formation (Bathonian to Callovian) which has been interpreted by Vollset & Dore (1984) as fluvio-deltaic. The volcanic activity of the Middle Jurassic was the culmination of igneous activity which had occurred intermittently since the Permian (Woodhall & Knox, 1979). The result was the deposition of basaltic lavas and tuffs (Fall *et al.*, 1982) (Rattray Formation) (Fig. 4.2), especially in the Piper to Forties Field area (intersection of three main grabens). Richards *et al.* (1993) have described these volcanics as the Rattray Volcanics Member of the Pentland Formation. The non-marine coal-bearing strata of the Pentland Formation are characteristic of Callovian and older sedimentation in the Central Graben (well 29/12-1 from depth 9350' and deeper). In addition, there are non-marine

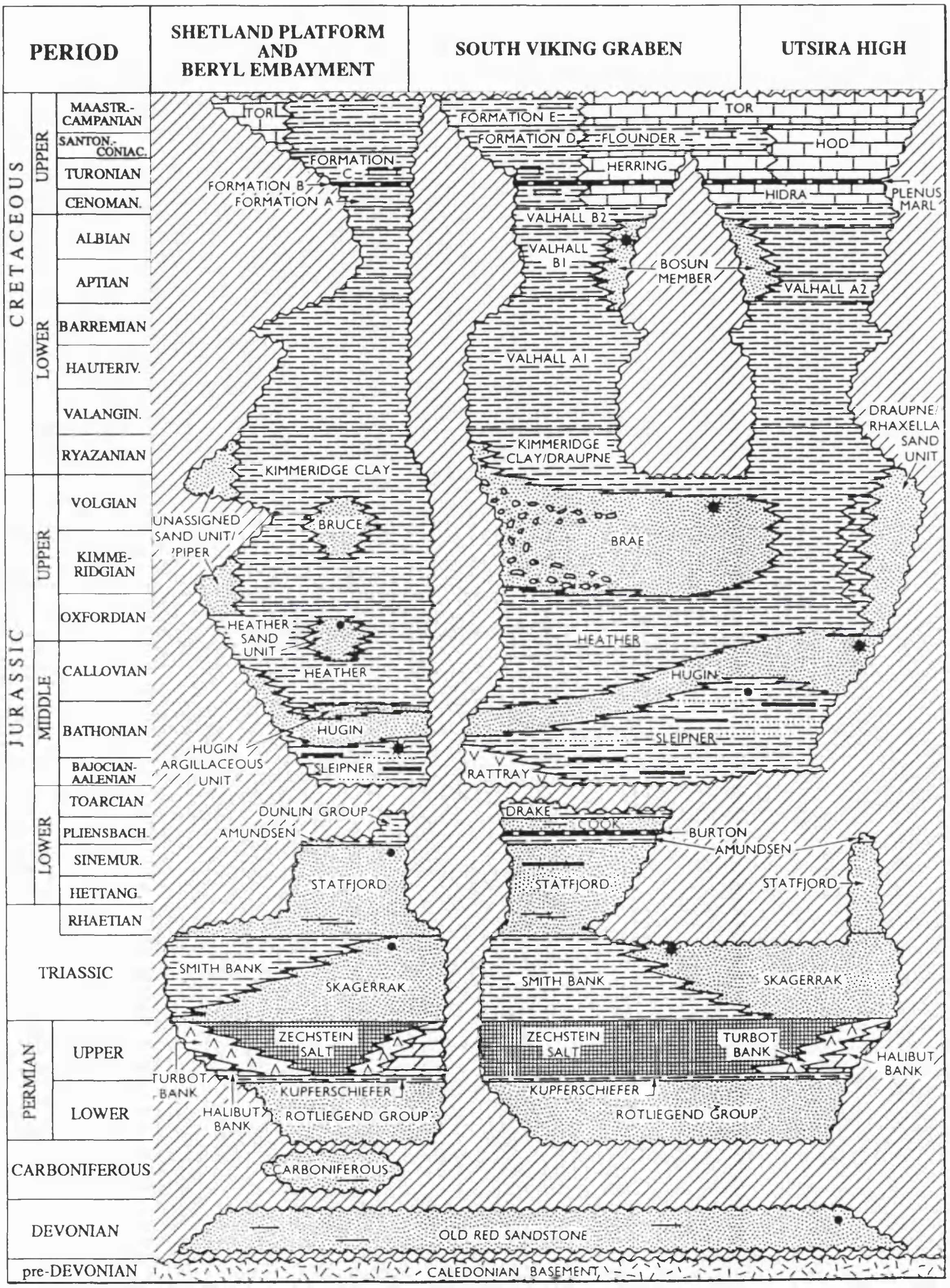


Fig. 4.3 Palaeozoic and Mesozoic lithostratigraphy and important oil occurrences of the South Viking Graben and adjacent areas (redrawn after SPT).

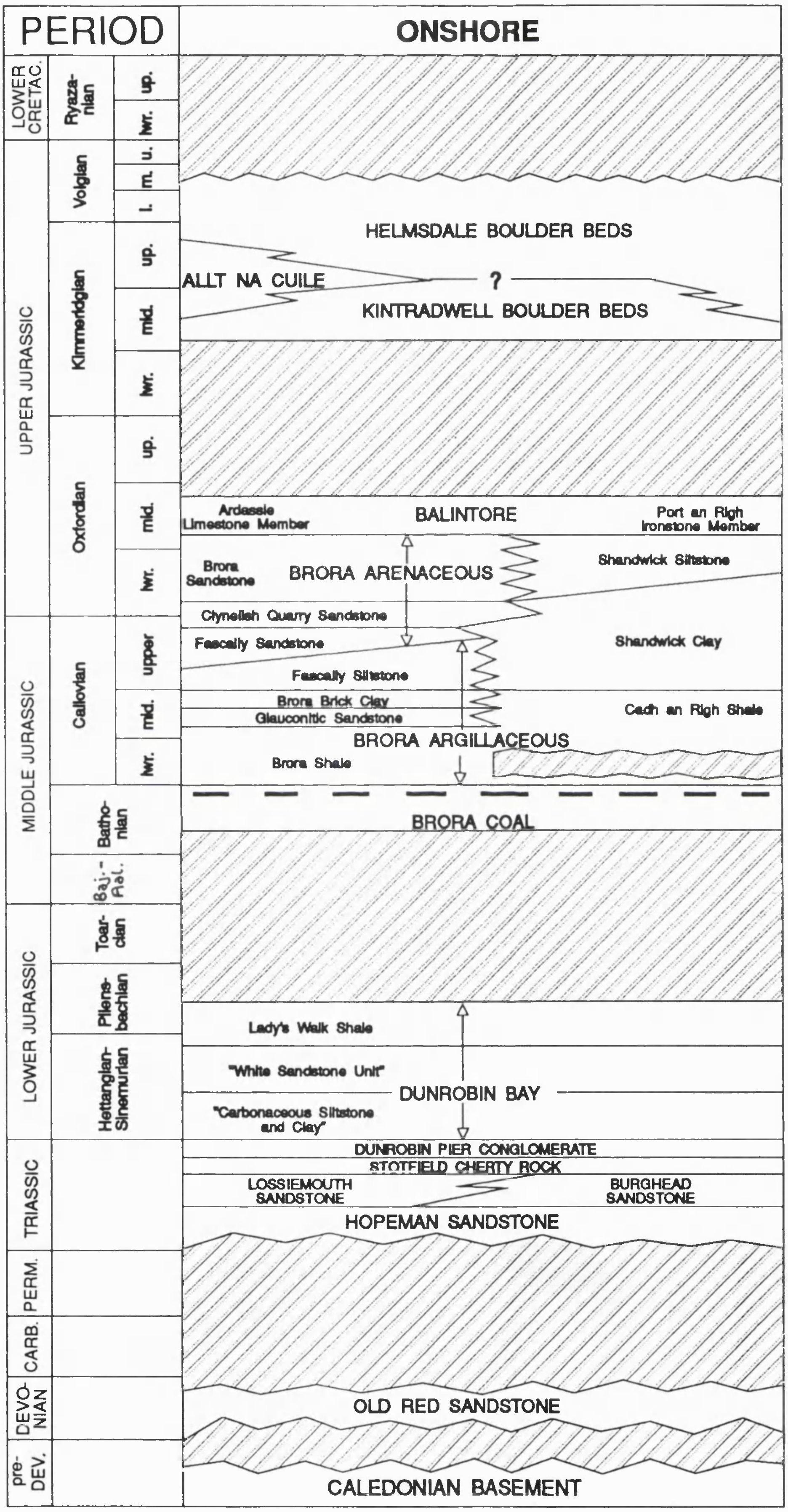


Fig. 4.4 Onshore Moray Firth Basin lithostratigraphy for the Palaeozoic to Early Cretaceous interval (redrawn after SPT).

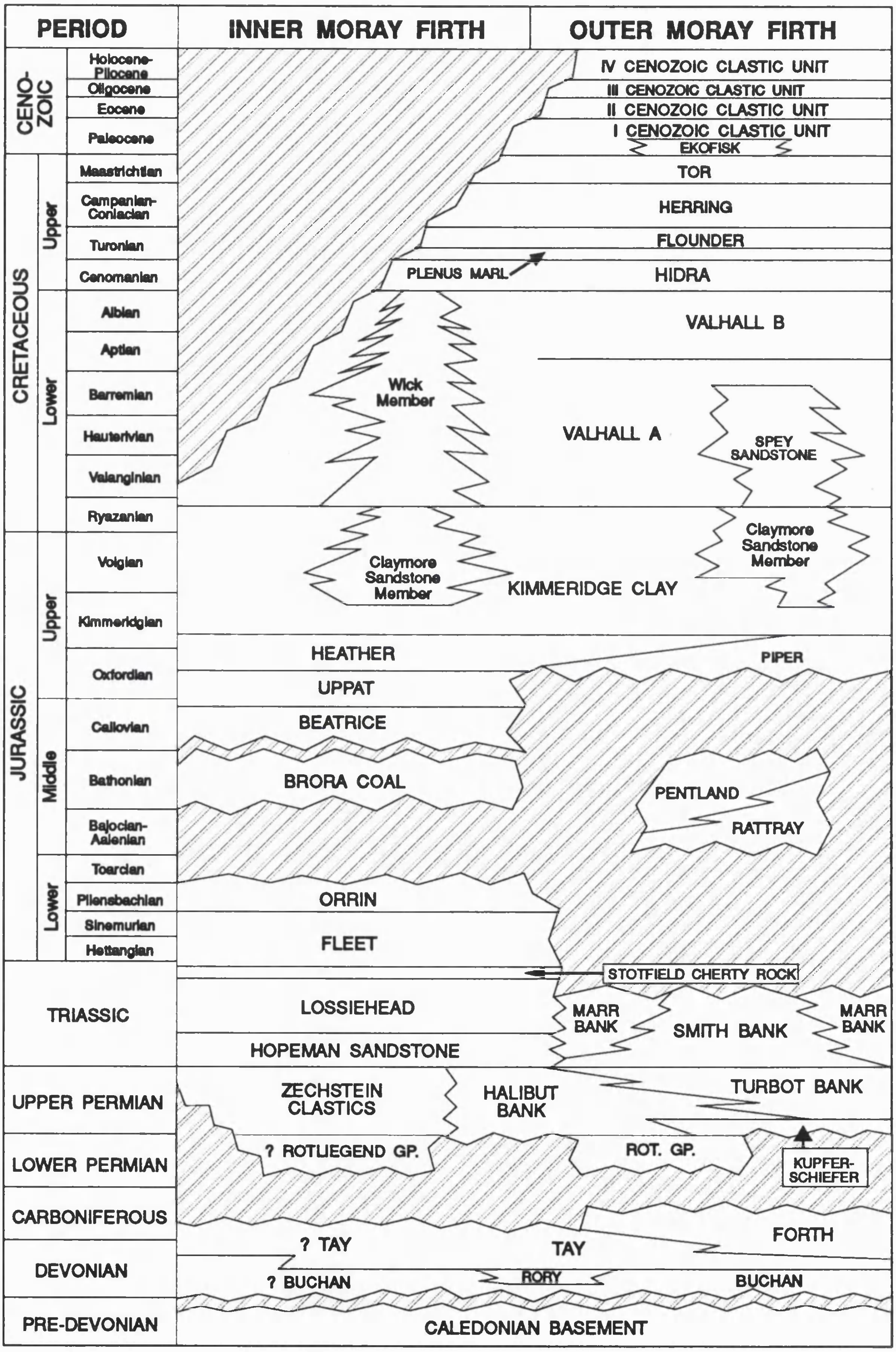


Fig. 4.5 Offshore Moray Firth Basin lithostratigraphy (modified after SPT).

to paralic sands of uncertain age in the graben (Brown, 1989). All the above-mentioned deposits are named the Fladen Group (Deegan & Scull, 1977) and are present in structurally low basin areas. Open marine conditions were not established in the graben during the Middle Jurassic.

4.4.3.2 South Viking Graben & Beryl Embayment area

Open marine conditions existed in the North Viking Graben from the Bathonian (Callomon, 1975, 1979). In the South Viking Graben, however, sedimentation started in the Aalenian in a non-marine/deltaic environment. The extrusion of volcanics (which are restricted to the south) was followed by rapid subsidence. The Rattray Formation (Rattray Volcanics Member of the Pentland Formation according to Richards *et al.*, 1993) in this area is overlain by the sand-dominated deltaic to paralic sequence of the Hugin Formation (Fig. 4.3) of Bajocian to Callovian age (in the basin margins). In the Brae Field these sands are derived in part from the south (Bowen, 1975) (main source the central domal high). At the same time the Shetland Platform was emergent, providing sediments to the adjacent areas and the North Viking Graben (Richards *et al.*, 1988).

The oldest Middle Jurassic marine strata in the studied areas are the shales of the Heather Formation, which continue into the Upper Jurassic. These are overlain the Hugin Formation as can be seen in well 9/18A-4, depth 11470' and deposition was initiated in earliest Callovian times or slightly earlier (in well 16/17-5 the boundary is in the Lower Oxfordian). The more extensive marine deposition that occurred during Callovian times is likely to have resulted from subsidence rates exceeding sedimentation rates.

4.4.3.3 Moray Firth Basin

1) Onshore. Generally, the Middle Jurassic as well as the Lower Jurassic (previously discussed) onshore sediments exhibit a transgression-regression-transgression sequence. After the mid Pliensbachian to Early Bathonian hiatus the Brora Coal Formation was deposited (Fig. 4.4), according to Hurst (1981) in an alluvial plain environment with estuarine conditions. This was followed by the Brora Argillaceous and Brora Arenaceous Formations, both recording the return to fully marine conditions (Brown, 1989).

2) Offshore. In the Inner Moray Firth Basin the Beatrice Oil Field (UK block 11/30) provides much of the information for Middle Jurassic stratigraphy (Linsley *et al.*, 1980). Sedimentation resumed in the Bathonian with the Brora Coal Formation (muds, sands and peat) which has the same time duration as onshore and is overlain by shallow marine sandstones of the Beatrice Formation (Callovian in age) and Uppat Formation (Callovian to Oxfordian in age) (Fig. 4.5). Andrews & Brown (1987) have given a detailed stratigraphic

evolution for the basin and they have distinguished two seismic stratigraphic packages, the lower one having an upper limit at their "intra-Oxfordian event".

Further east, the Middle Jurassic strata rest unconformably on Triassic continental sediments. As in the northern Central Graben these are assigned to the Rattray Formation (volcanics) and the Pentland Formation (Rattray Volcanics Member and Pentland Formation of Richards *et al.*, 1993). The former can reach thicknesses up to 3km in places (southern part of Quadrant 15, Woodhall & Knox, 1979). The accumulation of volcanics and sedimentary rocks in the Outer Moray Firth ceased in the Late Bathonian to Callovian.

4.4.4 Upper Jurassic

4.4.4.1 Central Graben

The Upper Jurassic sediments in the Central Graben are more widely preserved than older Jurassic units and several units represent deposition that continued into the Cretaceous.

The main control on sedimentation for the first part of the Upper Jurassic (Oxfordian to early Kimmeridgian) was the differential subsidence due to faulting, uplift, and subsidence over and around active salt domes (Gibbs, 1984; Johnson *et al.*, 1986; Smith, 1987). The Oxfordian was a period of worldwide sea level rise (Haq *et al.*, 1987). By that time the marine sediments of the Heather Formation (silty claystones) started to be deposited in the basinal areas, unconformably on the Bryne/Pentland Formations (Fig. 4.2). The Heather Formation is called the Haugesund Formation in the Norwegian sector. Simultaneously, shallow marine sands were accumulated in both margins of the graben, the Fulmar Formation on the western side (present in wells 28/5-1 and 29/12-1) and the Ula Formation on the eastern side (present in well 23/27-4). This deposition was controlled by synchronous movements on faults (Brown, 1989).

Hamar *et al.* (1983) supported the concept that these sands originated through sub-aerial erosion of the Auk Platform and Vestland Arch. Armstrong *et al.* (1987) have interpreted them as sublittoral sheets and ridges which were storm emplaced (Bailey *et al.*, 1981; Spencer *et al.*, 1986; Johnson *et al.*, 1986) and intensely bioturbated (Johnson & Stewart, 1985). Bradshaw *et al.* (1992) postulated that the Fulmar sands represent submarine reworking from the Auk Platform (with a similar model valid for the Ula Formation).

The continued tectonism caused progressive subsidence of the graben in Kimmeridgian times. The shales of the Heather Formation passed laterally and vertically into organic-rich muds of the Kimmeridge Clay Formation. As far as nomenclature is concerned the Kimmeridge Clay Formation is termed the Farsund and Mandal Formations in the Norwegian sector (Vollset & Dore, 1984), both belong to the Tyne Group (Fig. 4.2). A very thick sequence of Kimmeridge Clay occurs, often exceeding 1km thickness (Leckie, 1982).

In the Middle Volgian and later, falling sea level (Haq *et al.*, 1987) may be responsible for the break in sedimentation on the graben-margin areas (Fig. 5.5, wells 28/5-1 and 22/21-2). This marked the end of deposition of the Fulmar and Ula sands (the former persisted to the Upper Volgian in some parts of the basin). In contrast, sedimentation continued uninterrupted in the basinal areas during the Middle Volgian to Upper Ryazanian.

By the end of the Ryazanian the stagnant conditions (of the Kimmeridge Clay) were replaced by open-marine well-oxygenated waters, with the "flushing" effect of the southward transgression of the Boreal Sea (Rawson & Riley, 1982; Bradshaw *et al.*, 1992). The deposition of organically rich muds gave way to the calcareous muds and carbonates of the Cromel Knoll Group. The boundary at the top of the Kimmeridge Clay Formation, an unconformity or disconformity, is considered the upper lithostratigraphic limit of the Jurassic, although the chronostratigraphical Jurassic/Cretaceous boundary falls within the Kimmeridge Clay Formation.

4.4.4.2 South Viking Graben & Beryl Embayment area

Increased subsidence rates and regional eustatic rise in sea level during the Late Jurassic (Haq *et al.*, 1987) had as a result the continuation of marine conditions and deposition of the Kimmeridge Clay (or Draupne Formation in the Norwegian sector) (Fig. 4.3) and important clastic units along the western margin of the area. In the Beryl Embayment area these units are termed Bruce Formation (Marcum *et al.*, 1978) (Bruce Sandstone Member according to Richards *et al.*, 1993) (not recorded in well 9/18A-4).

The transition from the Heather to the Kimmeridge Clay Formation is documented on well logs by an upward increase in gamma-ray response and decrease in sonic velocity. This usually occurs in the Upper Oxfordian. In well 9/18A-4 it can be observed at 10850' depth and in 16/17-5 at 14150'. Recently, Richards *et al.* (1993) supported the concept that the boundary cannot be defined purely on the wireline-log character and suggested that the base of the Kimmeridge Clay Formation be taken at the wireline-log marker immediately underlying the *S. crystallinum* FDO biomarker.

Harris & Fowler (1987) discussed the facies distribution in the South Viking Graben. Here, a thick sequence of sandstones and conglomerates (Brae Formation), mainly derived from the Shetland Platform (Bradshaw *et al.*, 1992), was deposited in Oxfordian to Volgian times (in 16/17-5 thickness reaches 1300'). The deposition was controlled by the western basin margin fault zone. Harms *et al.* (1981) suggested the accumulation of this formation on a fan surface by fluvially dominated processes (fan-delta model). In contrast, Stow *et al.* (1982) agreed with a submarine fan model as discussed in Surlyk (1978a) for fault-controlled shallow, small basin fans. These sands act as reservoirs and together with the Kimmeridge Clay (deeply buried and mature, source rock) give significant oil fields (Brae Oil Field).

The upper limit of the Jurassic is as discussed for the Central Graben.

4.4.4.3 Moray Firth Basin

1) Onshore. Here the deposition of Upper Jurassic sediments was probably affected by the movements of the Helmsdale Fault. The Brora Arenaceous Formation is overlain by the Mid Oxfordian age Balintore Formation (calcareous sandstones, representing deep water offshore facies according to Sykes, 1975).

Upper Oxfordian to lower Kimmeridgian sediments appear to be absent (Fig. 4.4), followed by deposits of mid Kimmeridgian to Volgian age. These crop out along the coast of East Sutherland and in a narrow strip at Eathie Haven, Cromarty (Fig. 4.7 and later discussion for the area). They consist of:

- The Alt na Cuille sandstones (gravity flow deposits (Neves & Selley, 1975)), and
- The Kintradwell and Helmsdale Boulder Beds (coarse breccias and conglomerates, interbedded with dark marine shales (Pickering, 1984)). Their origin has been discussed as early as 1873 by Judd. The latest idea is that they represent submarine fan deposits (Crowell, 1961; Linsley, 1972; Neves & Selley, 1975; Pickering, 1984; Wignall & Pickering, 1993).

A general model of the area and the formation of the Boulder Beds is given on Fig 4.6.

2) Offshore. The fault controlled subsidence during Oxfordian to Volgian times had as a result the deepening of the existing sea.

In the Inner Moray Firth the Upper Jurassic sediments were deposited on an open marine shelf (Andrews & Brown, 1987). These are the Heather and Kimmeridge Clay Formation and sands which accumulated on the downthrown sides of the already active faults (Great Glen and Beatrice Faults). According to the work of Underhill (1991) the Great Glen fault had no significant influence on Jurassic deposition in the area. The Kimmeridge Clay deposition commenced at around mid Kimmeridgian times and continued until the Ryazanian.

Further to the east the sediments can be divided into two main sequences:

a) The Upper Oxfordian to lower Kimmeridgian Heather and Piper Formations. The Piper Sandstone Formation (Williams *et al.*, 1975; Maher, 1980; Harker *et al.*, 1987) indicates deep water conditions. These sands rest unconformably on Triassic sediments or Middle Jurassic volcanics (Fig. 4.5) and act as hydrocarbon reservoirs in the Piper and Tartar Oil Fields (Brooks, 1977).

b) The overlying dark, organic-rich muds of the Kimmeridge Clay Formation, which locally contain significant marine gravity flow sandstone units of Volgian age (recently defined by Richards *et al.*, 1993; e.g. Burns Sandstone Member, etc.). By that time uplift along major faults had increased the supply of clastics from the "highs" (e.g. Halibut Horst (Bradshaw *et al.*, 1992)). Thus the deposition of sands (Claymore Sandstone Member, Turner *et al.*, 1987) (present in 12/28-1 from depth 5790' and upwards but not studied) occurred close to the source areas or muds (Claymore Sandstone Member equivalent, SPT) (observed

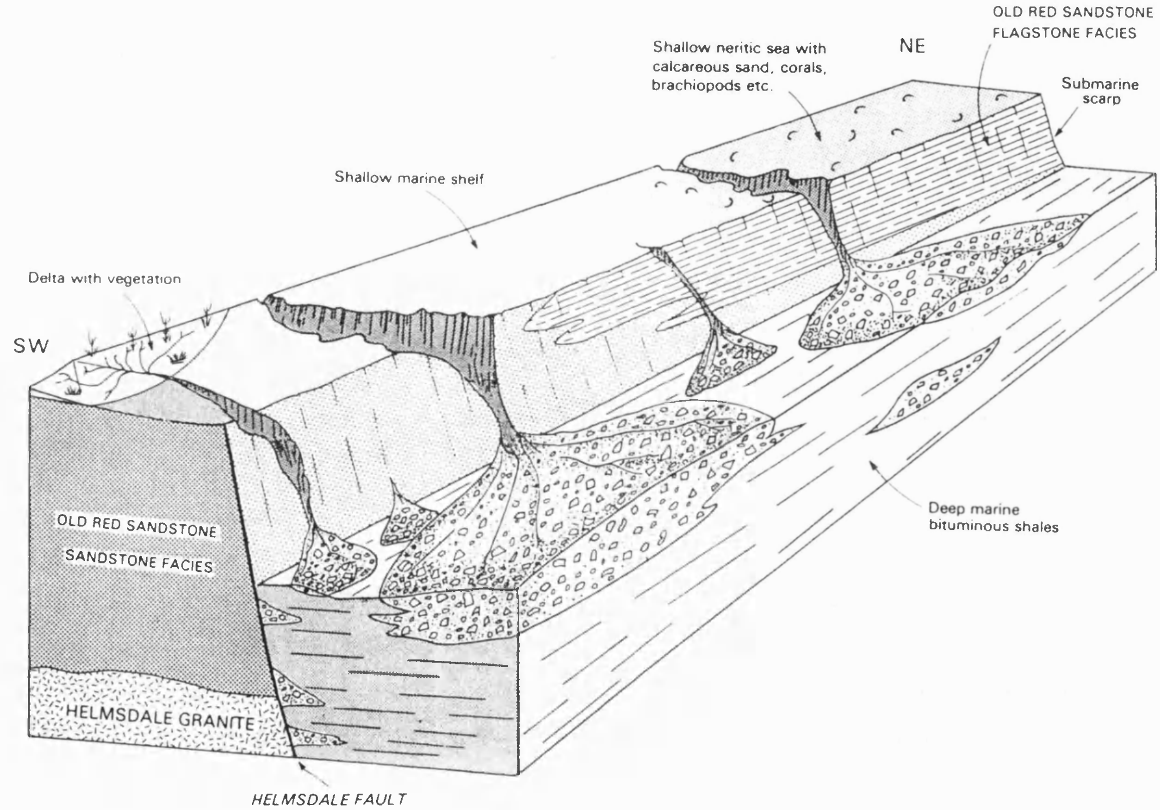


Fig. 4.6 General model for the formation of the Boulder Beds (from Johnstone & Mykora, 1989, Fig. 43).

in 14/18-2, interval 7800' to 8070') further from source (SPT). As in the rest of the North Sea grabens, the Kimmeridge Clay Formation is succeeded by the Cromer Knoll Group (Valhall Formation, in 14/18-2 from depth 7620' and upwards).

4.4.5 Lower Cretaceous

The Lower Cretaceous sediments are well-developed in the North Sea Basin. An unconformity ("Late Cimmerian") between Jurassic and Cretaceous strata occurs over the marginal (as in 28/5-1 where the Kimmeridge Clay Formation is overlain by the Upper Cretaceous Tor Formation) and intra-basinal "highs" (Brown, 1989). However, in the graben axes sedimentation continued uninterrupted and the system boundary, as mentioned earlier, falls within the Kimmeridge Clay Formation. Calcareous mudstones and sandstones (locally developed) of the Cromer Knoll Group are present throughout the North Sea Basin for the Early Cretaceous (Figs. 4.2, 4.3 & 4.5). Shallow water calcareous mustones and shales of the Valhall Formation, which gradually grade to deeper water shales in the Viking Graben (W. H. Ziegler, 1975), overlie the Kimmeridge Clay Formation. The Valhall Formation is present in all wells (except in 28/5-1) studied (in well 22/21-2 four samples did not yield radiolaria).

4.5 Lithostratigraphy in wells studied

4.5.1 The Humber Group

The Humber Group was first named by Rhys (1974) from the southern North Sea and it is dominantly Callovian to Ryazanian in age. In the central and northern North Sea it generally consists of marine mudstones and shales interbedded with sandstone units. According to Richards *et al.* (1993) the group can be subdivided into six formations (some locally restricted) named: Kimmeridge Clay, Heather, Brae, Piper, Fulmar and Emerald. In the southern North Sea the group includes two marine shale formations (Kimmeridge Clay and Oxford Clay) which are separated by a limestone formation (Corallian) (Rhys, 1974) (Fig. 4.1).

Below is a description of the formations present in the studied intervals of the wells.

Radiolarian assemblages have been recovered from the marine mudstones and shales of the Kimmeridge Clay and Heather Formations as well as the Claymore Sandstone Member equivalent of the former. In contrast, all the sandstone formations were found to yield no radiolarians.

4.5.2 Kimmeridge Clay Formation

Introduction. The term was first defined and applied to strata in the southern North Sea by

Rhys (1974). Hodson (1975) named it the Magnus Formation. Later, Deegan & Scull (1977) extended its use in the central and northern North Sea and included it in the "radioactive member" ("Hot Shale") of the "Kimmeridge Clay Formation" of Bowen (1975). The formation is regarded as the principal source rock for the North Sea oil (Barnard & Cooper, 1981; Brown & Deegan, 1981).

Type Section. Kimmeridge Bay, Dorset (no formal definition has been published).

Well type section. UK well 47/15-1 (southern North Sea) from depth 2908' (885m) to 3015' (919m).

Lithology. Organically-rich, non-calcareous, dark grey-brown to black claystones and shales with thin interbeds of sandstone and siltstone laterally passing into thicker units (Claymore Sandstone Member or Claymore Sandstone Member equivalent, SPT) or limestones and dolomites. In the Moray Firth Basin when the formation is complete (as in 14/18-1) it can be subdivided into three gamma ray log units, an upper and lower "hot" (highly radioactive) unit, separated by an interval of "cooler" shale (Claymore Sandstone Member equivalent).

Boundaries. The formation rests conformably on silty claystones of the Heather Formation (as in 12/28-1, 22/21-2, 16/17-5 and 9/18A-4) or sandstones of the ?Piper, Fulmar and Ula Formations (as in 14/18-2, 28/5-1 & 29/12-1, 23/27-4 respectively). The upper boundary is an unconformity ("Late Cimmerian Unconformity") with Lower Cretaceous strata (calcareous claystones and limestones of lighter colour, Valhall Formation) or exceptionally with Upper Cretaceous (Tor Formation of the Chalk Group, in 28/5-1).

Distribution. It is widely distributed over the North Sea Basin (Deegan & Scull, 1977; Brown & Deegan, 1981; Richards *et al.* 1993) and present in all wells studied here.

Age. Kimmeridgian to Late Ryazanian.

Depositional Environment. A discussion follows later in this chapter.

4.5.3 Heather Formation

Introduction. The term was first introduced by Hodson (1975) and later defined by Deegan & Scull (1977) who included it in the "Brent Shale" and the "non-radioactive member" of the "Kimmeridge Clay Formation" of Bowen (1975). Andrews & Brown (1987) used the informal name Renne Mudstone for it in the Outer Moray Firth Basin.

Well type section. UK 221/21-1A (northern North Sea) from 9218' (2811m) to 9317' (2842m).

Lithology. The formation consists of grey to dark grey, weakly calcareous, micromicaceous silty claystones and shales with thin stringers of hard limestone and dolomite and fine grained sandstone. The "flat" gamma ray is interrupted by peaks indicating the presence of cemented sandstone or carbonate beds (this can be observed in 22/21-2, 9/18A-4 and 12/28-1).

Boundaries. In the Moray Firth the formation usually rests conformably on the Uppat

Formation (12/28-1 records the passage from the shales to the spiculite sandstone of the Alness Member (Uppat Formation)). In the Central Graben the Heather Formation unconformably overlies the sandstones of the Bryne Formation, showing a decrease in gamma ray response. In the Viking Graben the lower boundary is unconformable on the Hugin Formation.

The upper boundary in all studied wells (except in 29/12-1) is the contact with the Kimmeridge Clay Formation, marked by an upward change to darker, highly organic, non-calcareous shales and increase in gamma ray response. In 29/12-1 it is overlain by the Fulmar Formation sands.

Distribution. It is preserved over most of the northern North Sea and basinal parts of the central North Sea (Brown & Deegan, 1981). In the studied wells it is present in 12/28-1, 22/21-2 (where it reaches a great thickness of 1600+'), 16/17-5, 9/18A-4 and questionably in 29/12-1.

Age. Bathonian to Kimmeridgian.

Depositional Environment. Fully marine (Brown & Deegan, 1981).

4.5.4 Claymore Sandstone Member equivalent

Introduction. This is an informal term used by Simon Petroleum Technology for a predominantly shaly sequence which produces a lower gamma ray reading than the surrounding Kimmeridge Clay Formation. It is considered to be the shale equivalent of the Claymore Sandstone Member (SPT).

Lithology. The interval consists of claystones and shales, which appear similar in composition to the "hot" shales of the Kimmeridge Clay Formation seen above and below the interval. The Claymore Sandstone Member equivalent tend to be slightly more silty and sandy. Thin interbeds of limestone may occur sporadically.

Boundaries. The upper and lower limits of the interval are conformable passages to the Kimmeridge Clay Formation and are easy to distinguish by the change in gamma ray reading response.

Distribution. Moray Firth Basin, present in well 14/18-2 with 270' thickness.

Age. Volgian.

Depositional Environment. The environment is considered to have been similar to that of the Claymore Sandstone Member of Turner *et al.* (1987). It may represent distal deposits of mass gravity flows.

4.5.5 Fulmar Formation

Introduction. The term was first used by Johnson & Stewart (1985) to describe sandstones forming the main reservoirs in the UK Fulmar and Clyde Fields. It has been redefined by

Richards *et al.* (1993) to include some Upper Jurassic sandstones in the Central Graben.

Well type section. UK 30/16-6 from 10326' (3147.5m) to 11230' (3423m).

Lithology. It consists of grey, fine to medium sorted sandstones. Occasional, subordinate interbedded claystones may occur, as well as glauconite.

Boundaries. The formation rests unconformably on sequences of pre-Jurassic age (as in 28/5-1) or it can be seen to overlie the Heather Formation (in 29/12-1). The upper boundary is a conformable passage to the highly radioactive claystones of the Kimmeridge Clay Formation, marked by a sharp upward increase in gamma ray response (not definition of Richards *et al.*, 1993).

Distribution. UK sector of Central Graben (wells 28/5-1 & 29/12-1).

Age. Oxfordian to Mid Volgian.

Depositional Environment. Mainly shallow marine.

4.5.6 Brae Formation

Introduction. Harms *et al.* (1981) first discussed the sedimentation history the Brae Oil Field and introduced the term. The formation defined by Turner *et al.* (1987) and applies to a heterolithic coarse clastic unit within the Kimmeridge Clay Formation in the South Viking Graben.

Well type section. UK 16/7a-8 from 12071' (3679.5m) to 14008' (4271m).

Lithology. The formation consists of predominantly clastic sediments, conglomerates and greyish turbiditic sandstones with thinly bedded mudstones.

Boundaries. The lower boundary is either conformable on Humber Group sediments (well 16/17-5, depth 13760') or unconformable on older deposits. The upper boundary is commonly conformable with the Kimmeridge Clay Formation. Both boundaries can be easily picked on the well log by the high gamma ray reading response on the formations above and below.

Distribution. Widespread in the South Viking Graben; in well 16/17-5 reaches a thickness of 1312' (400m).

Age. Oxfordian to Volgian.

Depositional Environment. A discussion is given in p. 45.

4.5.7 Ula Formation

Introduction. The name was first introduced by Bailey *et al.* (1981). Vollset & Dore (1984) formalised the name for the sequence which forms the main reservoir in the Ula and Gyda Fields of the Norwegian Central Graben sector. The formation belongs to the Vestland Group of Vollset & Dore (1984).

Well type section. N7/12-2 from 11084' (3379m) to 11586' (3532m) (Vollset & Dore, 1984).

Lithology. The formation consists of fine to medium grained, grey sandstones, rarely interbedded with silty claystones.

Boundaries. It overlies non-marine sandstones and claystones of the Bryne Formation, while it is generally overlain by the Kimmeridge Clay Formation (as seen in 23/27-4) or the equivalent Norwegian Farsund and Mandal Formations. This upper boundary is easily distinguished by an upward increase in gamma ray response.

Distribution. Present in the eastern flanking "highs" of the Central Graben. In 23/27-4 it reaches a thickness of 842' (257m).

Age. Oxfordian to Volgian.

Depositional Environment. Generally shallow marine (Vollset & Dore, 1984).

4.6 Kimmeridge Clay Formation; onshore exposures

The formation takes its name from Kimmeridge Bay in Dorset (southern England) and is regarded as the most organic-rich shale in the British stratigraphic sequence (Morris, 1980). Taking into account the amount of organic carbon and kerogen and the containing faunas, the onshore Kimmeridge Clay can be divided (Cox & Gallois, 1981; etc.) into alternating beds of:

i) organic-poor mudstones,

ii) laminated organic-rich shales ("bituminous shales"),

iii) laminated highly organic-rich shales ("oil shales"), and

iv) thin coccolith limestones (occuring in the upper part of the sequence).

Such facies have been also reported from Northern France (Oschmann, 1988), Norwegian shelf (Birkelund *et al.*, 1978) and Greenland (Surlyk, 1977; Callomon & Birkelund, 1982). Similar bituminous, anoxic shales of Volgian age have also been observed and extensively drilled for hydrocarbons in the Western Siberian Basin (Kontorovich, 1971). Doré (1991) discussed the distribution of organic-rich shales in North Western Europe and the Arctic (Table 4.2).

In offshore wells, the high radioactivity of the formation has been studied by Bjørlykke *et al.* (1975) and is attributed to the uranium content which has been adsorbed by the organic matter on the stagnant sea bottom.

Radiolarian assemblages have been reported and studied from the following Kimmeridge Clay outcrops: a) Eathie (Waterston, 1951; Gregory, 1986, 1991; this study) and b) Skye and Helmsdale (Gregory, 1991) but not from the Dorset type section (Lord & Bown, 1987). However, stratigraphical investigations concerning the Kimmeridge Clay have been extensively published (Cope, 1967, 1968, 1978; Gallois & Cox, 1974; etc.) as well as microplankton and palynological studies (Downie, 1956; Gitmez, 1970; Ioannides *et al.* 1976; Gallois & Cox, 1976; Gallois & Medd, 1979; Tyson, 1989; etc.). All these studies are based on onshore material.

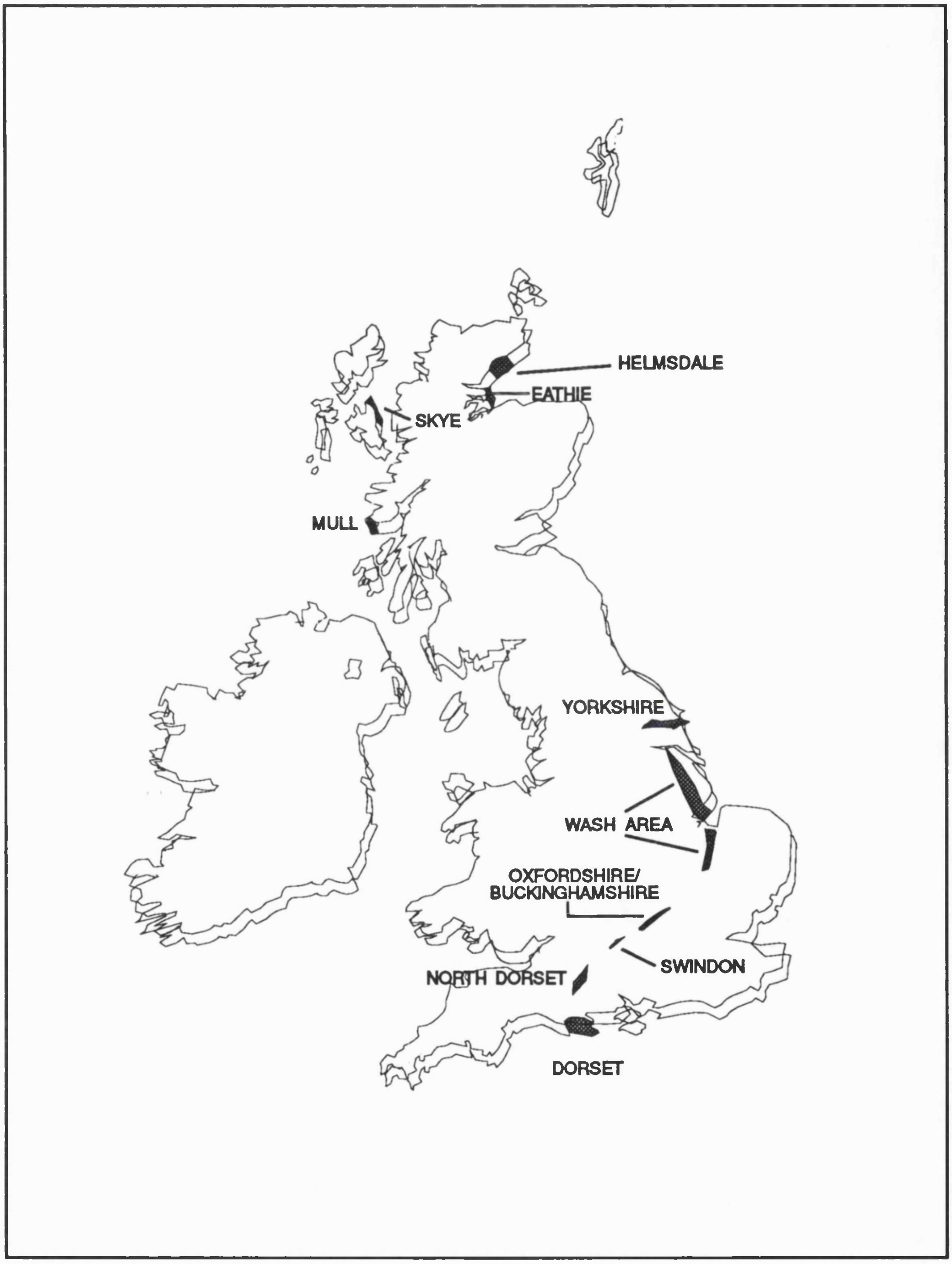


Fig. 4.7 The Kimmeridgian Clay outcrop in the UK (based on Gallois & Medd, 1979; Cope *et al.*, 1980).

LOCATION	NAME OF LITHOSTRATIGRAPHIC UNIT	AGE RANGE	AUTHORITY
Great Britain (incl. UK N. Sea sector)	**Kimmeridge Clay Fm.**	Kimmeridgian - Tithonian	e.g. Richards *et al.* (1993)
Central North Sea (Norwegian sector)	Mandal Fm. Farsund Fm.	Tithonian - Berriasian Kimmeridgian - Tithonian	Vollset & Dore (1984)
Egersund Sub-Basin	Tau Fm.	Kimmeridgian - Tithonian	Vollset & Dore (1984)
Northern North Sea (Norwegian sector)	Draupne Fm.	Oxfordian - Berriasian	Vollset & Dore (1984)
East Greenland Rift	Hareelv & Bjernberg Fms.	Oxfordian - Kimmeridgian	Surlyk (1978b)
Haltenbanken (Mid-Norway)	Spekk Fm.	Oxfordian - Berriasian	Dalland *et al.* (1988)
Andoya (Lofotens)	Ratjonna Mbr. of Dragneset Fm.	?Kimmeridgian - Tithonian	Dalland (1979)
Western Barents Sea	**Hekkingen Fm.**	Oxfordian - Berriasian	Dalland *et al.* (1988)
Svalbard	Agardhfjellet Mbr. of Janusfjellet Fm.	Callovian - Tithonian	e.g. Steel & Worsley (1984)
Sverdrup Basin	Ringnes Fm.	Oxfordian - Kimmeridgian	Embry (1989)
North Alaska	Upper Kingak Fm. (parts)	Oxfordian - Kimmeridgian	Embry (1989)
Eastern Barents Sea	Unnamed	Kimmeridgian - Tithonian	Doré (1991)
Timan-Pechora Basin	Unnamed	Tithonian	Ulmishek (1982)
West Siberia	Bazhenov Fm.	Tithonian - Berriasian	e.g. Braduchan (1986)

Table 4.2 Late Jurassic - Earliest Cretaceous organic shales in N. W. Europe and the Arctic (from Dore, 1991; Table 2). Formations in bold are studied here.

4.6.1 Depositional Environment

A number of published papers deal with the depositional environment of the Kimmeridge Clay Formation. All are based on onshore sequences. The most commonly accepted idea is that Kimmeridge Clay sedimentation has been affected by periodically fluctuating low oxic and anoxic conditions (Hallam, 1975; Gallois, 1976; Gallois & Medd, 1979; Tyson *et al.*, 1979; Aigner, 1980; Morris, 1980; Oschmann, 1985, 1988, 1992). Disagreements, however, do exist and are mainly focused on i) the nature of the marine environment, and ii) origin, extent and duration of the anoxic conditions prevailing at that time (Oschmann, 1988).

Hallam (1967, 1975), Gallois (1976) and Aigner (1980) postulated a relatively shallow marine environment on a broad continental shelf, in contrast to Tyson *et al.* (1979) who favour a marine environment of several hundred metres depth. Oschmann (1988, p. 233) stated that the Kimmeridge Clay "presumably was deposited below wave base in several tens of metres depth, in a quiet environment with weak relief".

As far as the anoxic environment is concerned two general models have been proposed. Tyson *et al.* (1979), Demaison & Moore (1980) and Parrish & Curtis (1982) prefer a "silled basin model" (Fig. 4.8). According to this model, anoxia was favoured in a to-some-degree land-locked basin with shallow and narrow connection to adjacent seas. This resulted in restricted water circulation and stagnant bottom conditions (similar to the present-day Black Sea). Oschmann (1988, p. 236) rejected that model and proposed a new one, the "North Atlantic water passage model". The main concept is a wind-driven water current and counter current system in the North Atlantic and Arctic Ocean causing anoxic bottom conditions (Fig. 4.9).

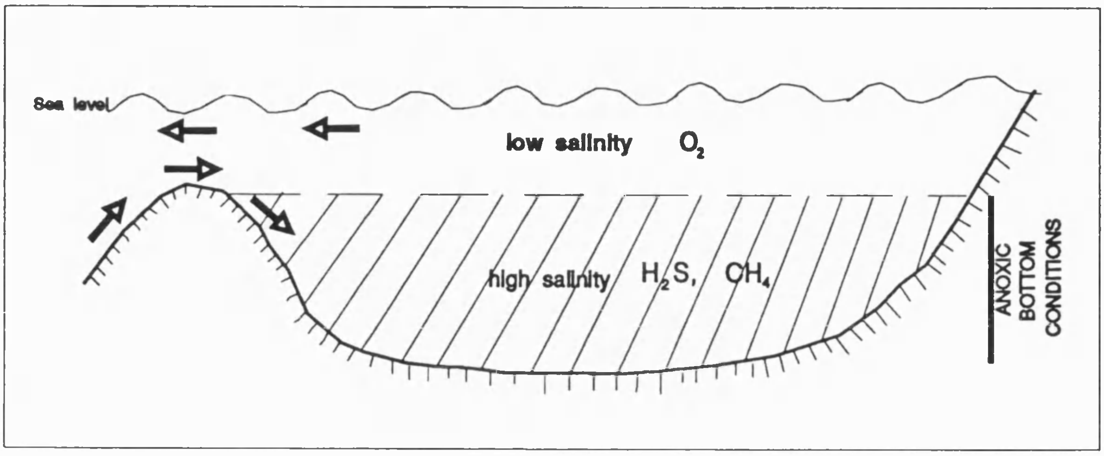


Fig. 4.8 The silled basin model of Demaison & Moore (1980) (redrawn from Oschmann, 1988, Fig. 22).

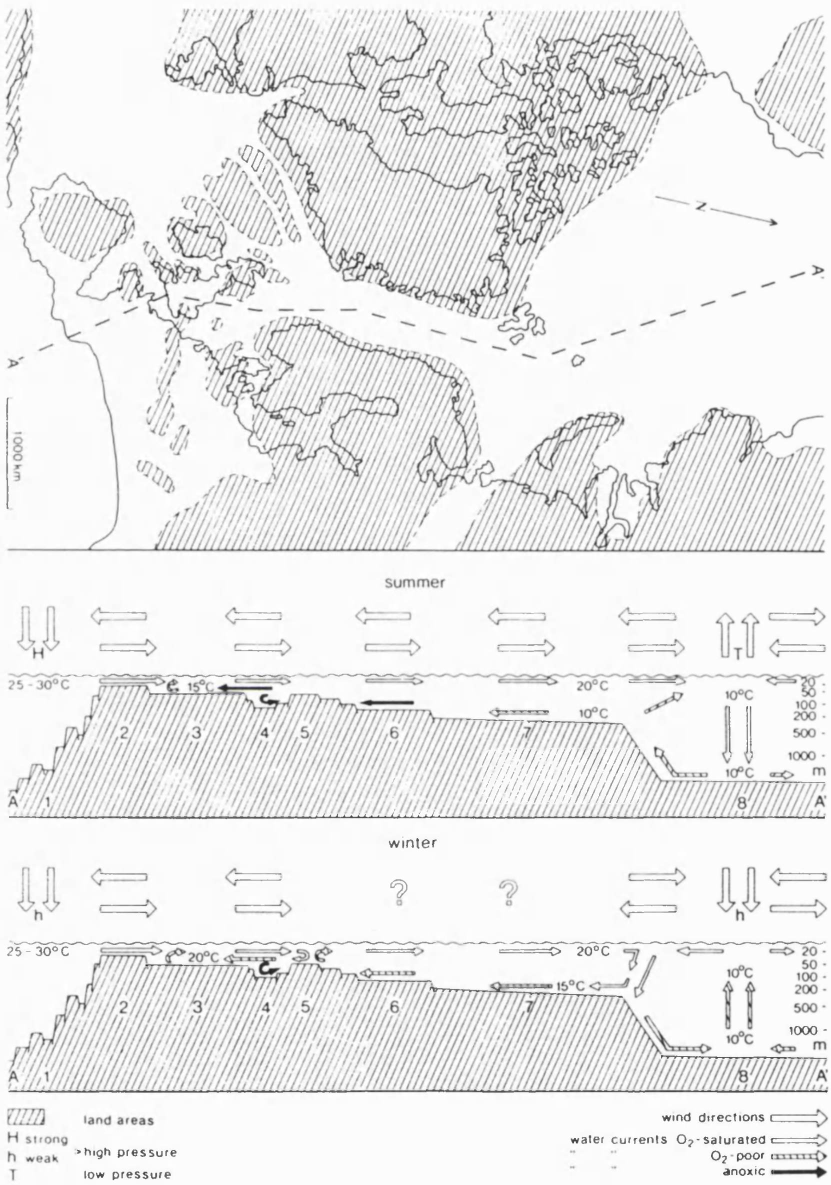


Fig. 4.9 The North Atlantic water passage model of Oschmann (1988) (from Oschmann, 1988; Fig. 27). Areas: 1 = Tethys, 2 = French Shelf, 3 = English Shelf, 4 = Central & Viking Grabens, 5 = Norwegian Sea, 6 = Møre & Vøring Basins, 7 = Barents Sea, 8 = Arctic Ocean.

CHAPTER 5

STUDIED SITES: EATHIE HAVEN, CROMARTY AND OFFSHORE WELLS

5.1 Introduction

The first part of the chapter deals with the onshore exposure sampled at Eathie Haven, Cromarty, and the second part with commercial well sites in the North Sea.

5.2 Eathie Haven, Cromarty, Location

A small, narrow strip - the southernmost of the Upper Jurassic onshore exposures of NE Scotland - of Kimmeridgian strata occurs adjacent to the Great Glen Fault at Eathie Haven, 3 miles (5 km) south of the village of Cromarty (Rosshire).

In detail, the Eathie Haven exposure lies in a small sandy bay by the Boat Hard, at the abandoned Eathie fishing station (Fig. 5.1), under the slopes of the Hill of Eathie. Access to the rocks is about 20 minutes walk from the secondary road. The succession is covered by the waters of the Moray Firth and it is only possible at low tide to observe and examine the sediments. The sequence on the landward side has been downfaulted against the pre-Mesozoic metamorphic rocks of the hill which consist of Moine Gneiss. The Old Red Sandstone is also present (Fig. 5.1). The contact is to the west of the shore section.

5.3 Previous work on Eathie Haven, Cromarty

The previous work for the area has, generally, concentrated on the geology (description and discussion of rocks) and stratigraphy/palaeontology (study of ammonites and other invertebrates). Waterston (1951, p. 48) pointed out that the study of the microfauna requires further investigation.

As early as 1827 Murchison mentioned the geological interest of the area and recorded the sandstone dykes which are present in Eathie Haven. Miller (1854, 1857, 1859) (who lived in the nearby village of Cromarty) observed the rocks, described various plant fossils and collected ammonites (his collection of ammonites is still housed in Edinburgh). He assigned the rocks to the Liassic series. Judd (1873) described the sequence at Eathie and gave a list of fossils, but he correlated the rocks with the Middle and Lower Kimmeridgian of England. In the beginning of this century, Seward & Bancroft (1913) described new species of plants from Eathie. Buckman (1922) studied the ammonites and postulated an Early Kimmeridgian age for the beds. Lee (1925) described the Mesozoic rocks of Sutherland and Ross (including Eathie) and identified various species of ammonites. He placed the sequence

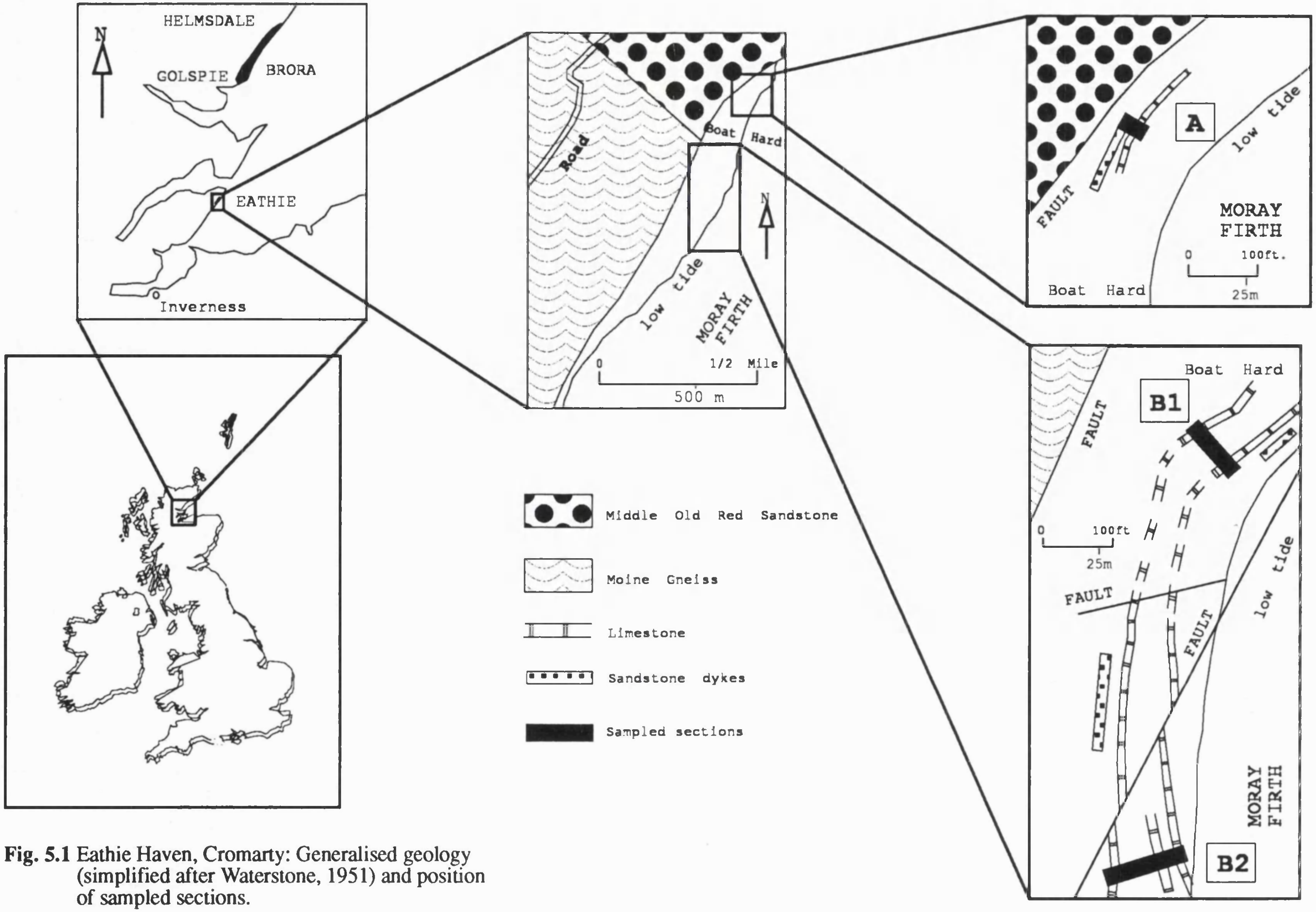


Fig. 5.1 Eathie Haven, Cromarty: Generalised geology (simplified after Waterstone, 1951) and position of sampled sections.

in the *Rasenia cymodoce* zone and the lower part of the *"Rasenia" mutabilis* zone. Later, Lee & Pringle (1932) published a synopsis of Lee's (1925) conclusions. Waterston (1950) gave his concept for the sandstone dyke injections and a year later (1951) published a detailed study of the stratigraphy and palaeontology, giving a faunal list and mentioning the presence of "two genera of cyrtoid radiolaria" (p. 47). The study of Eathie's ammonites was continued by B. Ziegler (1962a,b). A brief review of the geology of the area can be found in the latest edition (Johnstone & Mykora, 1989) of the BGS (British Geological Survey) "The Northern Highlands of Scotland". In 1992 Gregory described a new foraminiferal species from the area and postulated a deep water environment from the presence of radiolaria and agglutinated foraminifera. Finally, Wignall & Pickering (1993) published a paper on the Kimmeridgian outcrops of NE Scotland including Eathie Haven (ammonite biostratigraphy and palaeoecology).

5.4 Sedimentology and sampling

Black shales of about 150 feet thickness are exposed by the shore. The main marker beds are two limestone bands. The first is heavily recrystallised, about 2 feet (0.6 m) thick, light olive grey in colour (5 Y 6/1) (all colour code numbers referred to Rock Colour Chart by Geological Society of America, 1979), weathering to moderate yellow brown (10 YR 5/4) (Photographs 5.1 & 5.2; see end of chapter). The second limestone (50 feet (15 m) above the first) is thinner, medium dark grey in colour (N 4), weathering to olive grey (5 Y 3/2) (Photographs 5.2, 5.3 & 5.4). The contact of Jurassic with the Palaeozoic is vertical, and the dip of the sediments decreases from 90º to 60º at the "first limestone" and 20º at the "second limestone" (Waterston, 1951). Base of Jurassic sequence not observed by present author because covered by beach sediment and vegetation.

The shales are olive black (5 Y 2/1) to dark grey (N 3) in colour, fairly coarse grained and well-laminated (Photographs 3 & 4). The organic carbon content is 12% (Wignall & Pickering, 1993).

Sandstones also occur in the succession, including dykes, oblique intrusions and sills (Waterston, 1950). According to various workers (Bailey & Wier, 1932; Waterston, 1950; Wignall & Pickering, 1993) they have been intruded after the deposition of the Kimmeridgian beds with a possible origin in the underlying, unexposed Late Oxfordian sediments (Wignall & Pickering, 1993, p. 325).

Small faults interrupt the beds (Fig. 5.1).

During the fieldwork, three different sections were sampled, named A, B1 and B2 (Figs. 5.1 & 5.2). The section A is exposed north of the Boat Hard and is heavily disrupted by faulting. Only a narrow bed of limestone is present here, which according to Waterston (1951, p. 38) is the northerly extension of the "first limestone". Section B1 is exposed just south of the Boat Hard while B2 reveals the complete succession (Photograph 5.6). Here, an intermediate limestone bed (Photograph 5.5) of dark bluish grey colour (5 B 3/1), weathering to olive grey (5 Y 3/2), occurs and wedges out northwards.

The three sections and the distribution of samples, which have been collected at about every 10 to 20 feet (3 to 6 m), are given on Fig. 5.2.

5.5 Age of the sequence

The age of the exposure has been known since the early works (Lee, 1925; Waterston, 1951; etc) using ammonites which are common throughout the sequence. The Eathie Haven exposure is believed to span the *cymodoce* to *mutabilis* ammonite zones which indicates a mid Kimmeridgian age (in the North Sea Boreal terminology of Cope *et al.*, 1980).

Waterston (1951) postulated that the "second limestone" and the black shales above belong to the *mutabilis* zone, while the *cymodoce* zone of Salfeld (1913) falls in the remaining lower strata.

Birkelund *et al.* (1983) placed the *cymodoce-mutabilis* boundary between the "first" and the "second limestone" bands (Fig. 5.2). However, Wignall & Pickering (1993) identified *Rasenia (Rasenioides) lepidula* occurring in shales up to 3 metres below the "first limestone" which suggests that the zonal boundary should be placed there. An ammonite identified as *Rasenia (Rasenioides)* cf. *lepidula* in sample 10503 (collected 2.5m below the "first limestone") implies, although with some doubt, that the boundary can be placed somewhere between samples 10503 and 10504 which agrees with Wignall & Pickering (1993).

5.6 Palaeoenvironment

As far as the palaeoenvironment is concerned, Waterston (1951) commented on the mixed Boreal (amoeboceratids) and mediterranean (Tethyan) (aulacostephanitids) ammonite assemblages recorded from Eathie. Ammonites which have been identified from some collected samples are given on Table 5.1.

MacDonald (1985) working on fault-margin sedimentation at Brora (onshore exposure, 17 miles (28km) from Eathie) and offshore postulated a relatively shallow and above wave base basin for the *cymodoce* to *mutabilis* zone with oxic, relatively high-energy bottom conditions.

Tyson (1989) in his work on the palynofacies of the Kimmeridgian rocks from the Moray Firth Basin and onshore Brora exposure concluded that bottom water became progressively more oxygen deficient during the *mutabilis* zone and a general deepening of the basin followed.

Wignall & Pickering (1993) using the Oxygen Related Biofacies scheme (ORB) of

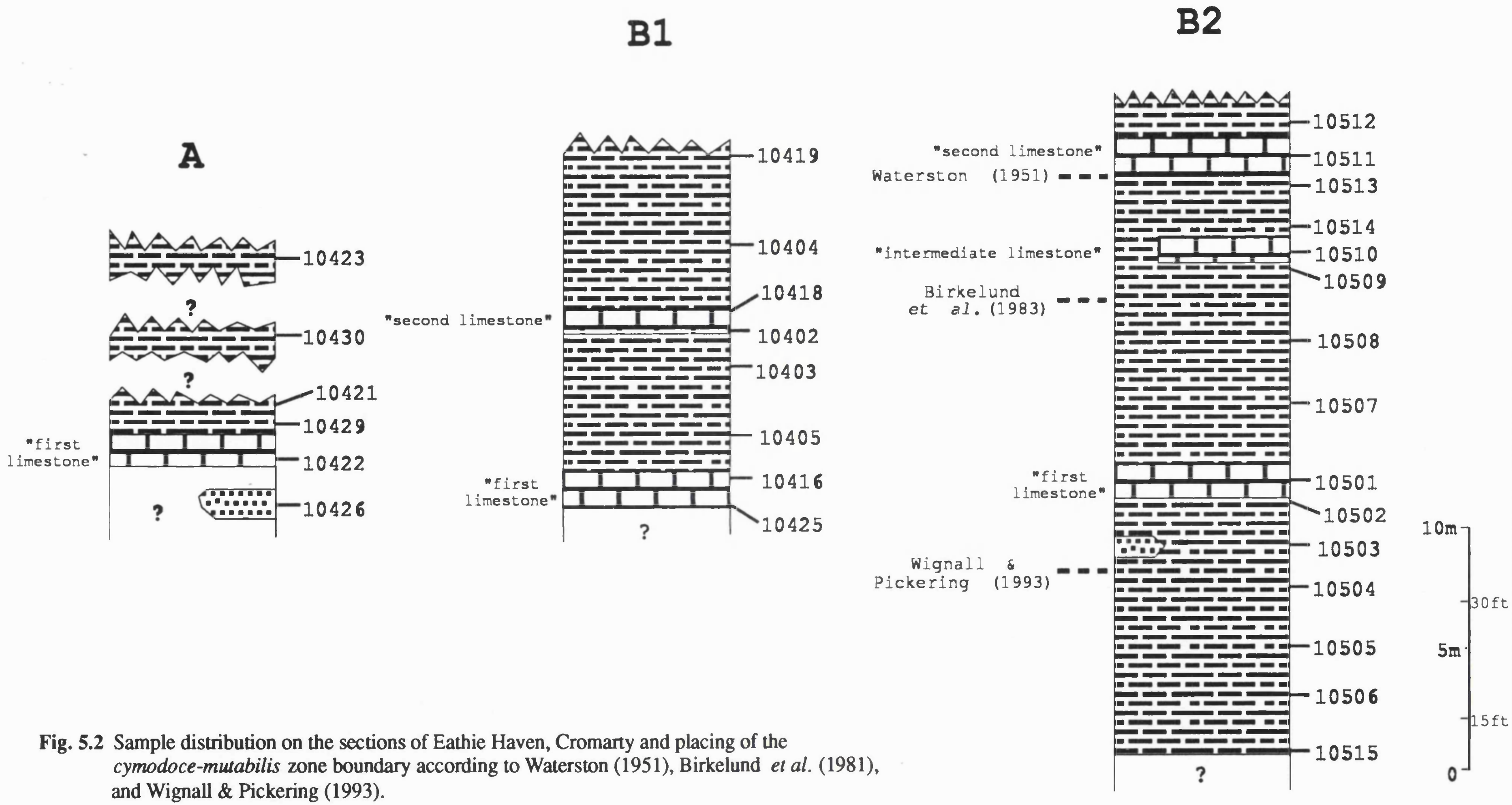


Fig. 5.2 Sample distribution on the sections of Eathie Haven, Cromarty and placing of the *cymodoce-mutabilis* zone boundary according to Waterston (1951), Birkelund *et al.* (1981), and Wignall & Pickering (1993).

SAMPLE	ROCK TYPE	AMMONITES IDENTIFIED
10421	black shale	*Rasenia (Rasenioides)* cf. *askeptus* *Amoeboceras (Amoebites) rasenense*
10405	black shale	*Amoeboceras (Amoebites) rasenense* *Rasenia* sp. indet ? cf. *evoluta*
10418	limestone	*Amoeboceras (Amoebites) rasenense* *Amoeboceras (Amoebites)* cf. *cricki*
10404	black shale	*Amoeboceras (Amoebites) rasenense* *Rasenia (Rasenioides)* cf. *lepidula*
10419	black shale	*Amoeboceras (Amoebites) rasenense* *Amoeboceras (Amoebites)* cf. *rasenense* *Amoeboceras (Amoebites)* cf. *kitchini*
10503	black shale	*Rasenia* sp. idet. *Rasenia (Rasenioides)* cf. *lepidula*
10507	black shale	*Rasenia (Rasenioides) askeptus*
10509	black shale	*Amoeboceras (Amoebites) kitchini*
10510	limestone	*Amoeboceras (Amoebites)* sp. indet.
10513	black shale	*Amoeboceras (Amoebites)* sp. indet. *Rasenia* sp. indet.
10511	limestone	*Rasenia (Rasenioides) askeptus*

Table 5.1 Ammonites identified by Dr. S. Brealey from samples of the Eathie Haven exposure.

Wignall & Hallam (1991) interpreted and classified the palaeoenvironment. This scheme is based on a gradient of faunal diversity (invertebrate fossils such as ammonites, belemnites and bivalves) and sedimentological characteristics which are related to an interpreted oxygen gradient (Figs. 2 & 3 of Wignall & Pickering, 1993).

The same authors postulated a decline in bottom-water oxygenation (the main feature of the Kimmeridge Clay Formation) towards the top of the sequence which may be due to deepening upwards. This deepening could well be associated with the increase in radiolarian abundance and diversity, as observed in sample 10512 from the top of the sequence (Fig. 5.3) indicating more open marine contact with "oceanic" waters.

5.7 Exploration wells studied

5.7.1 Introduction

This part contains a brief description of the studied wells in the North Sea area as well as of the "comparison" wells from the Norwegian and Barents Seas. The locations of all

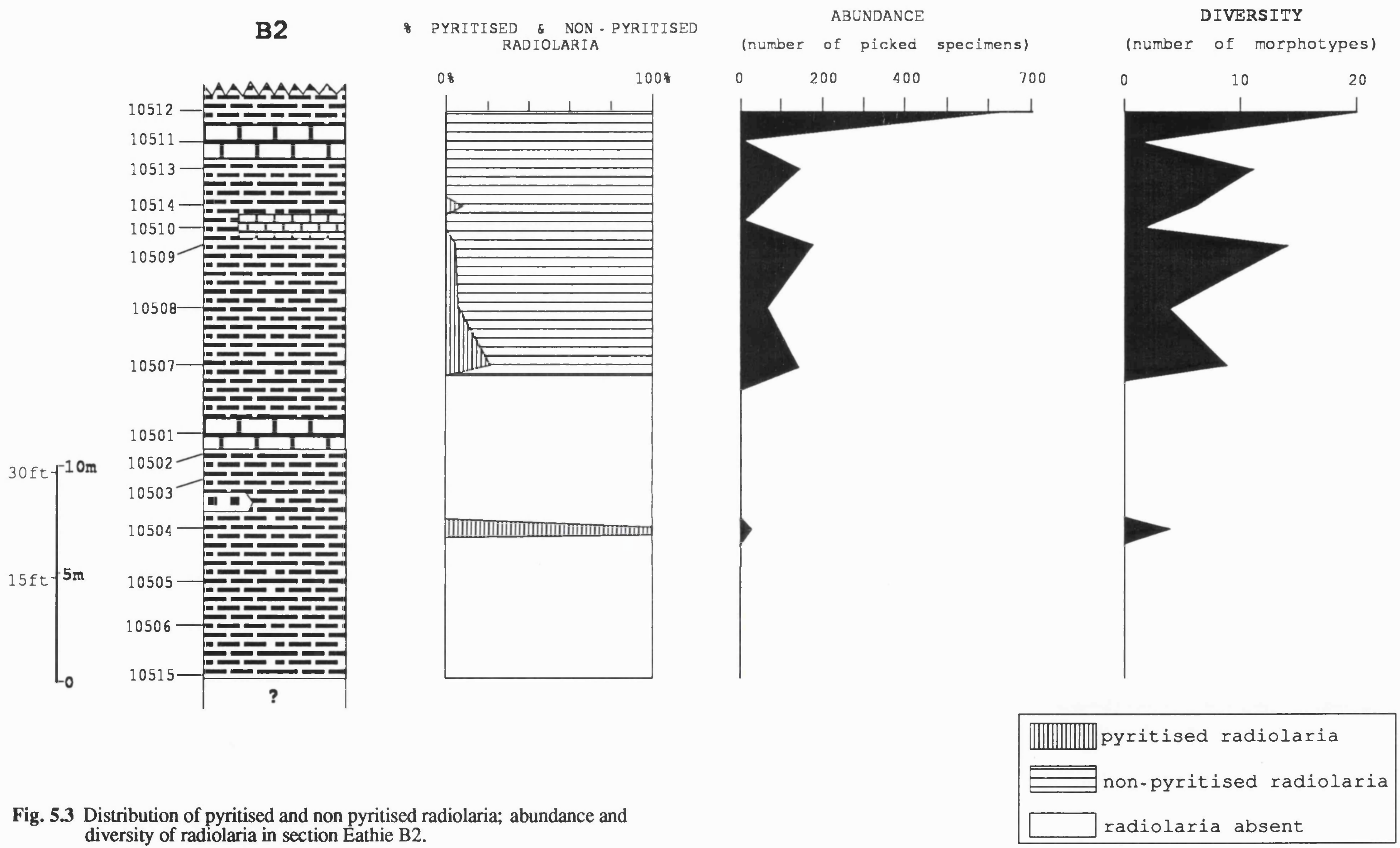


Fig. 5.3 Distribution of pyritised and non pyritised radiolaria; abundance and diversity of radiolaria in section Eathie B2.

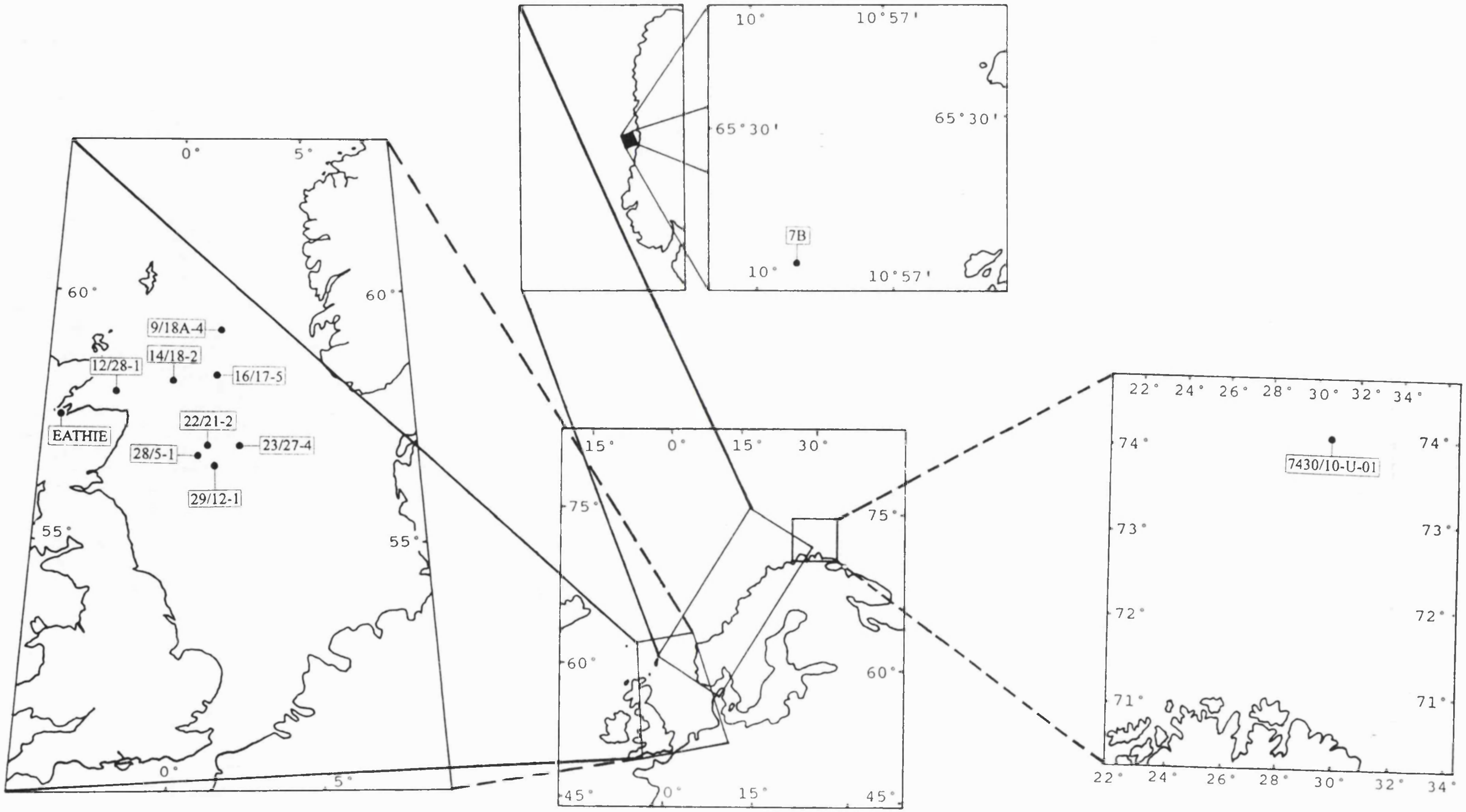


Fig. 5.4 Location maps of wells/exposure studied.

the wells are shown in Fig. 5.4. General information on the studied wells and the co-ordinates of the onshore sampled exposures are shown in Table 5.2. The latter have been calculated from the Ordnance Survey map, sheet NH 66/76 (Invergordon).

Finally, Fig. 5.5 shows the intervals analysed for the studied wells.

5.7.2 Well 23/27-4 (Fig. 5.6)

The upper part of the well consists of Upper Cretaceous limestones which have not been sampled. These are unconformably underlain by a thin bed of Valanginian claystone (Valhall Formation) which is firm, subfissile, variably coloured (generally medium dark grey and greyish red) and slightly silty.

The next 866' (264m) (Kimmeridge Clay Formation) are composed of silty claystone, firm, dark grey to greyish black in colour, slightly to moderately silty and non-calcareous. Occasionally, thin stringers of dolomite, limestone and sandstone occur with the latter becoming more common in the lower part.

Finally, the remaining lower part of the well consists of disaggregated light grey to light olive grey sandstone of the Ula Formation.

5.7.3 Well 28/5-1 (Fig. 5.7)

The upper part consists of Upper Cretaceous chalky limestone (Tor Formation) which was not sampled and is unconformably underlain by 310' (94.5m) of Kimmeridge Clay Formation. This consists of soft to firm, greyish black, slightly silty and non-calcareous claystone. Traces of sandstone occur in the lower part of the claystone. The remaining 107' (32.6m) of Upper Jurassic sequence (Fulmar Formation) consists of disaggregated, light grey to light olive grey, well-sorted and non-calcareous sandstone. Here, abundant opaque *Rhaxella* spicules occur. Thin beds of claystone also occur. Finally, the lower part of the sequence is unconformably underlain by Triassic age anhydrite.

5.7.4 Well 29/12-1 (Fig. 5.8)

A thin bed of Late Hauterivian age limestone (Valhall Unit A1) unconformably overlies the Kimmeridge Clay Formation. The latter is 823' (250.8m) thick and consists of soft to firm, dark grey to olive black (on top) and dark grey to yellowish brown (on the base), weakly calcareous silty claystone. Occasional disaggregated, light grey, moderately sorted sandstones and beds of dolomite and dolomitic limestone occur as common subordinate lithologies.

A sandstone of 450' (137.2m) thickness (Fulmar Formation) underlies the

WELL or EXPOSURE	CO-ORDINATES	OPERATOR	DATE SPUDED	TOTAL DEPTH	DATUM ELEVATION	INTERVAL STUDIED
Eathie A	57° 38′ 48" N 04° 02′ 38" W		1990			
Eathie B1	57° 38′ 42" N 04° 02′ 41" W		1990			
Eathie B2	57° 38′ 31" N 04° 02′ 50" W		1992			
23/27-4	57° 09′ 36.5" N 02° 18′ 30.3" E	Ranger Oil (UK)	1978	12199′ (3718.3m)	77′ (23.5m)	10160′ - 11300′ (3096.8m - 3444.2m)
28/5-1	56° 55′ 16.4" N 00° 48′ 22.7" E	Transocean	1977	9800′ (2987m)	79′ (24.1m)	6400′ - 6810′ (1962.9m - 2075.7m)
29/12-1	56° 37′ 53.5" N 01° 23′ 55.2" E	Amoco (UK)	1980	10485′ (3195.8m)	85′ (25.9m)	7950′ - 9400′ (2423.2m -2865.1m)
22/21-2	57° 10′ 04.9" N 01° 02′ 49.6" E	Shell (UK)	1973	14719′ (4486.4m)	78′ (23.8m)	11600′ - 13320′ (3535.7m - 4059.9m)
12/28-1	58° 06′ 56.3" N 02° 28′ 23.2" W	Tenneco	1982	12097′ (3687.2m)	77′ (23.5m)	5800′ - 6400′ (1767.8m - 1950.7m)
14/18-2	58° 28′ 09.4" N 00° 03′ 26.6" W	Occidental	1978	8752′ (2667.6m)	83′ (25.3m)	7620′ - 8440′ (2322.6m - 2572.5m)
16/17-5	58° 24′ 08.3" N 01° 18′ 10.1" E	Phillips	1977	15350′ (4678.7m)	85′ (25.9m)	12000′ - 14310′ (3657.6m - 4361.7m)
9/18A-4	59° 26′ 36.7" N 01° 33′ 20.1" E	Conoco	1979	13613′ (4149.2m)	80′ (24.4m)	10760′ - 11400′ (3279.6m - 3474.7m)
7B	65° 06.0′ N 10° 17.3′ E	IKU	1978	92.52′ (28.20m)		37.72′ - 92.52′ (11.50m - 28.20m)
7430/10-U-01	74° 12′ 47.8" N 30° 14′ 44.2" E	IKU	1988	221.78′ (67.60m)		143.37′ - 221.78′ (43.71m - 67.60m)

Table 5.2 General information on wells/exposures studied.

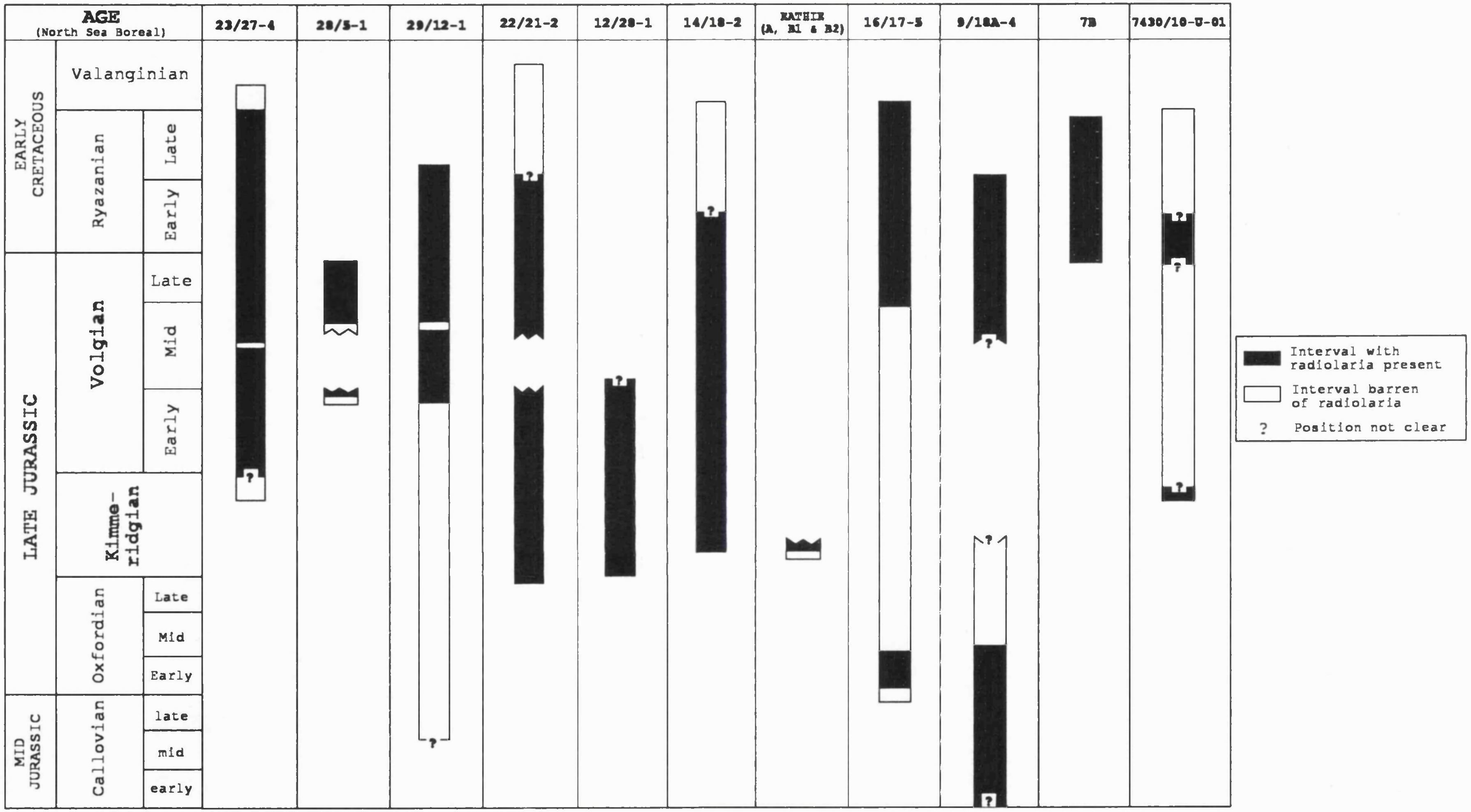


Fig. 5.5 Well/exposure intervals analysed in this study (age terminology after Rawson *et al.* (1978), Cope *et al.* (1980) and Rawson & Riley (1982).

Kimmeridge Clay. This is light grey and well-sorted and includes thin dolomite beds as traces in the form of thin stringers or nodules. At the base of the formation a light grey to light olive grey, micromicaceous silty claystone occurs.

The next 169' (51.5m) are questionably assigned to the Heather Formation. Silty claystone with sandstone as a subordinate lithology and traces of limestone constitute this part of the section, which unconformably overlies the silty claystone, sandstone and coal beds of the Bryne Formation (Middle Jurassic).

5.7.5 Well 22/21-2 (Fig. 5.9)

The first interval of the well studied consists of soft to firm, medium dark grey claystone and firm to hard, yellowish grey limestone of the Valhall Unit A1 Formation. This is conformably underlain by 1344' (409.6m) of the Kimmeridge Clay Formation. The boundary can be easily picked from the gamma ray response. Firm, blocky, greyish black, non-calcareous claystone with beds of hard, brownish grey to brownish black dolomite constitute the upper and middle parts of the formation. In the lower part a slightly silty, dark grey to brownish black claystone with common, thin dolomitic layers is present.

The remaining 363' (110.6m) of the sequence consist of silty claystone with common beds of dolomite. These are assigned to the Heather Formation.

5.7.6 Well 12/28-1 (Fig. 5.10)

The studied interval includes mainly the lower part of the Kimmeridge Clay Formation. This is a claystone/shale, moderately soft, dark brown to greyish black and locally silty. A few thin beds of soft limestone and hard dolomite occasionally occur. The remaining 158' (48.2m) are assigned to the Heather Formation and consist of medium grey, locally silty claystone/shale.

5.7.7 Well 14/18-2 (Fig. 5.11)

The upper part of the well studied is assigned to the Valhall Unit A Formation and consists of soft, light/dark grey, locally silty calcareous shale. The Kimmeridge Clay Formation is 720' (219.5m) thick in this well and can be divided into three parts according to lithology. The upper 172' (52.4m) are soft, greyish black weakly to non-calcareous shale with a thin bed of hard, dark grey limestone. Then follows the Claymore Sandstone Member equivalent (277' (84.4m)) (discussion in Chapter 4) which is a silty shale with limestone beds. The remaining part (271' (82.6m)) of the Kimmeridge Clay is a soft to hard, black, locally silty shale.

Finally, the lower part of the well studied is a soft, medium to very coarse, locally pebbly sandstone with a coal/lignite bed on its base. This is questionably assigned to the Piper Formation.

5.7.8 Well 16/17-5 (Fig. 5.12)

The upper part of the well studied (433' (132m)) is a dark grey to greyish black, laminated, silty mudstone with beds of very fine and coarse sandstones. These are assigned to the Kimmeridge Clay Formation. There follows below a very thick (1312' (400m)) unit of very fine and coarse sandstones (as the main lithology) occasionally with thin beds of mudstone (greyish black, laminated). This part corresponds to the Brae Formation.

The Kimmeridge Clay Formation lithology reappears (of Late Oxfordian age) for 382' (116.4m) thickness as a brownish grey to dark grey silty mudstone. A few beds of fine, siliceous cemented sandstone are also present.

The remaining 173' (52.7m) are assigned to the Heather Formation, which conformably overlies the Hugin Formation in this well, and consists of silty mudstone and a limestone bed.

5.7.9 Well 9/18A-4 (Fig. 5.13)

The Kimmeridge Clay Formation in this well conformably underlies the Valhall (Unit A1) Formation (calcareous mudstone and limestone) and consists of brownish black, silty, very carbonaceous mudstone (118' (36m)). The remaining studied 623' (189.9m) of the section are assigned to the Heather Formation (conformably overlying in this case the Hugin Formation) which is a dark grey to greyish black, silty, micaceous mudstone. A few dolomite, limestone and sandstone beds are also present.

5.7.10 Well 7B (Fig. 5.14)

In this well, the studied interval (56.5' (17.2m)) is a black, organic-rich mudstone which is very homogeneous, lacking sedimentary structures and bioturbation. This is sharply overlain by a light grey limestone, containing several large intraclasts of a similar lithology. A calcareous grey claystone and finally, another limestone bed occur.

5.7.11 Well 7430/10-U-01 (Fig. 5.15)

In the upper part of the well, grey marls occur (partly assigned to the Knurr Formation). The rest of the section studied is assigned to the Hekkingen Formation (Århus,

1991) and consists of: i) a 2' (0.6m) thick, fine-grained, glauconitic, calcite cemented sandstone, present at around 147.6', ii) a very thin mudpebble conglomerate (at 156.8'), and iii) black shales (68' (20.7m)).

5.8 Well logs

For each studied well a log is provided in the next pages. These include the following information:

AGE, which is based on foraminifers and palynomorphs examined by SPT (for the North Sea wells) and IKU (for the Norwegian and Barents Sea).

LITHOSTRATIGRAPHIC UNIT. Given here are the formations which occur in the wells. A detailed discussion of the relevant formations can be found in Chapter 4.

LITHOLOGICAL DESCRIPTION. In this column is a concise description for the different lithologies present in the well.

LITHOLOGY. In this column is given a schematic representation of the lithology, using standard lithological symbols.

SAMPLING DEPTHS. Depth of samples studied in this work.

GAMMA RAY, RESISTIVITY. The gamma ray and resistivity log response is given when available.

DEPTH. Finally, the general depth is given, acting as a scale.

WELL 23/27-4

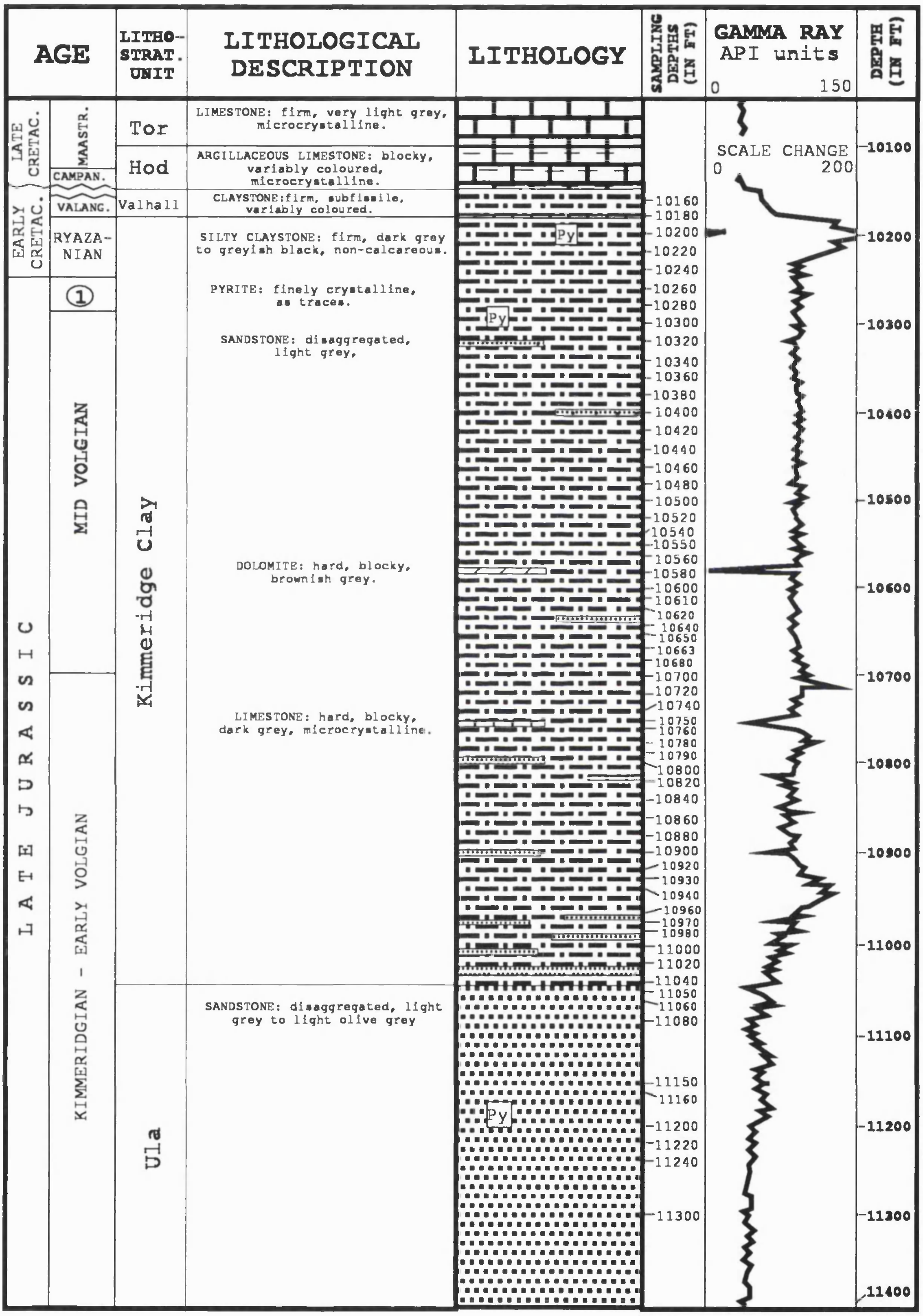


Fig. 5.6 Log of well 23/27-4.

KEY

① LATEST MID VOLGIAN - LATE VOLGIAN

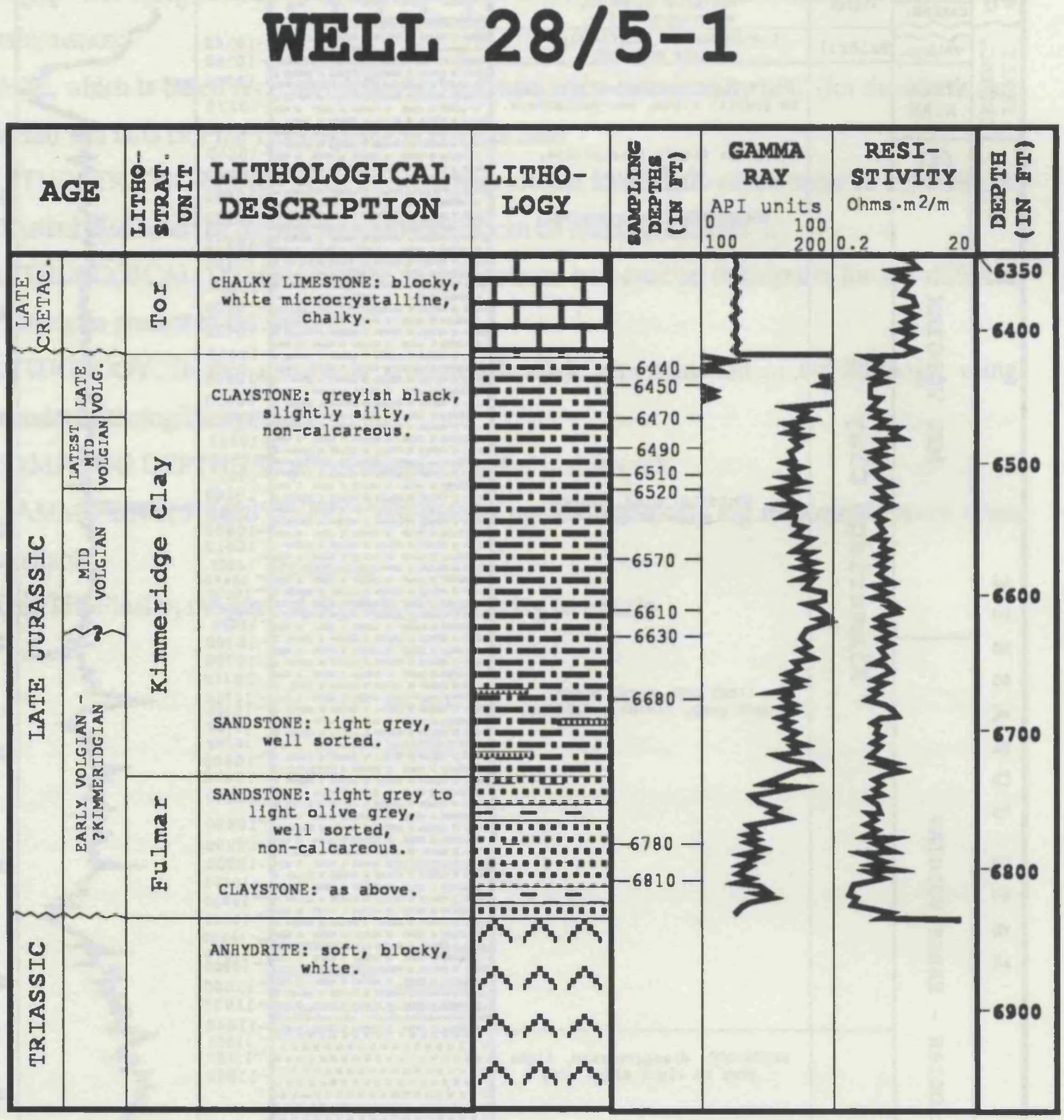


Fig. 5.7 Log of well 28/5-1.

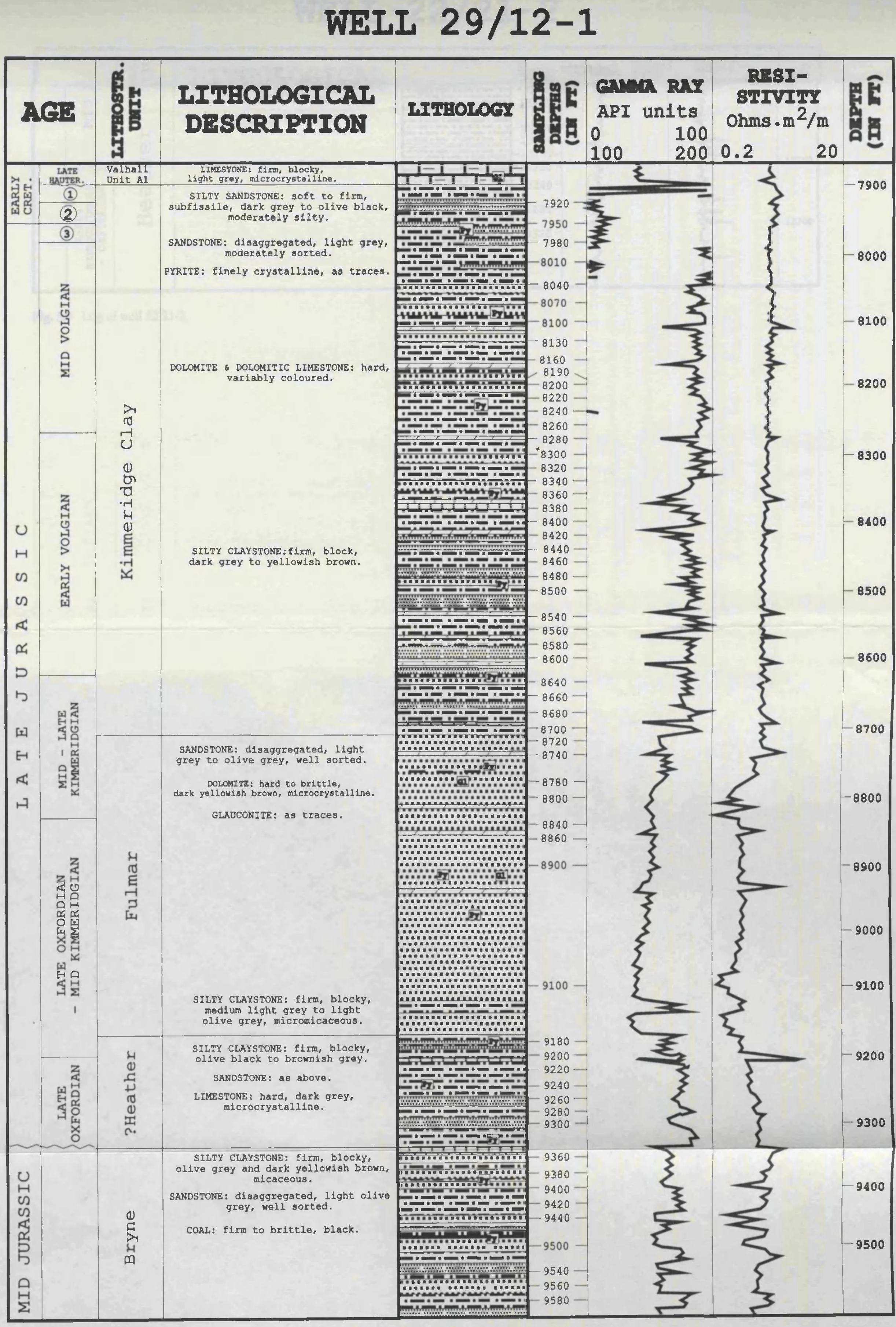


Fig. 5.8 Log of well 29/12-1.

KEY

1. LATE RYAZANIAN
2. EARLY RYAZANIAN
3. LATEST MID VOLGIAN

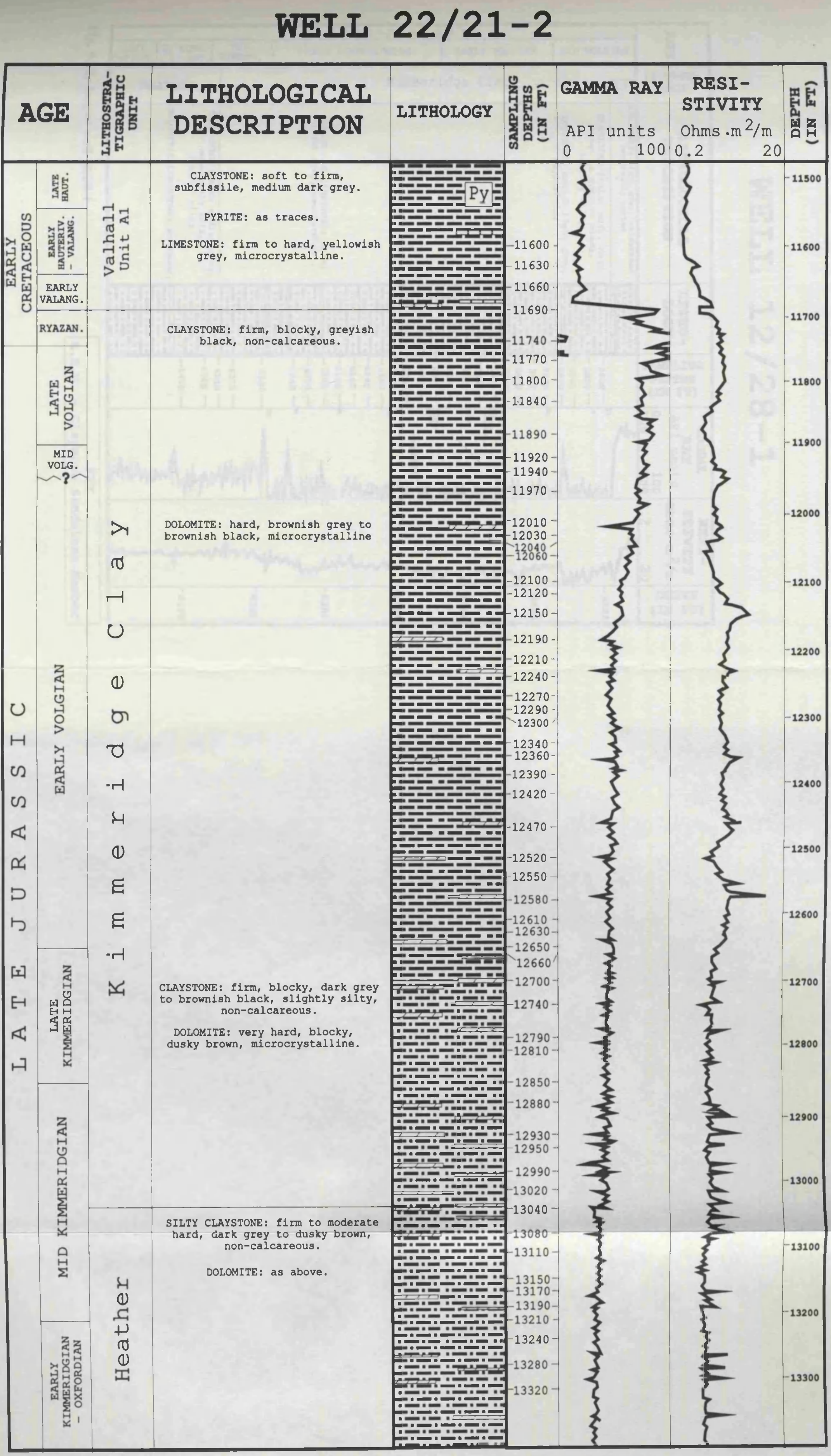


Fig. 5.9 Log of well 22/21-2.

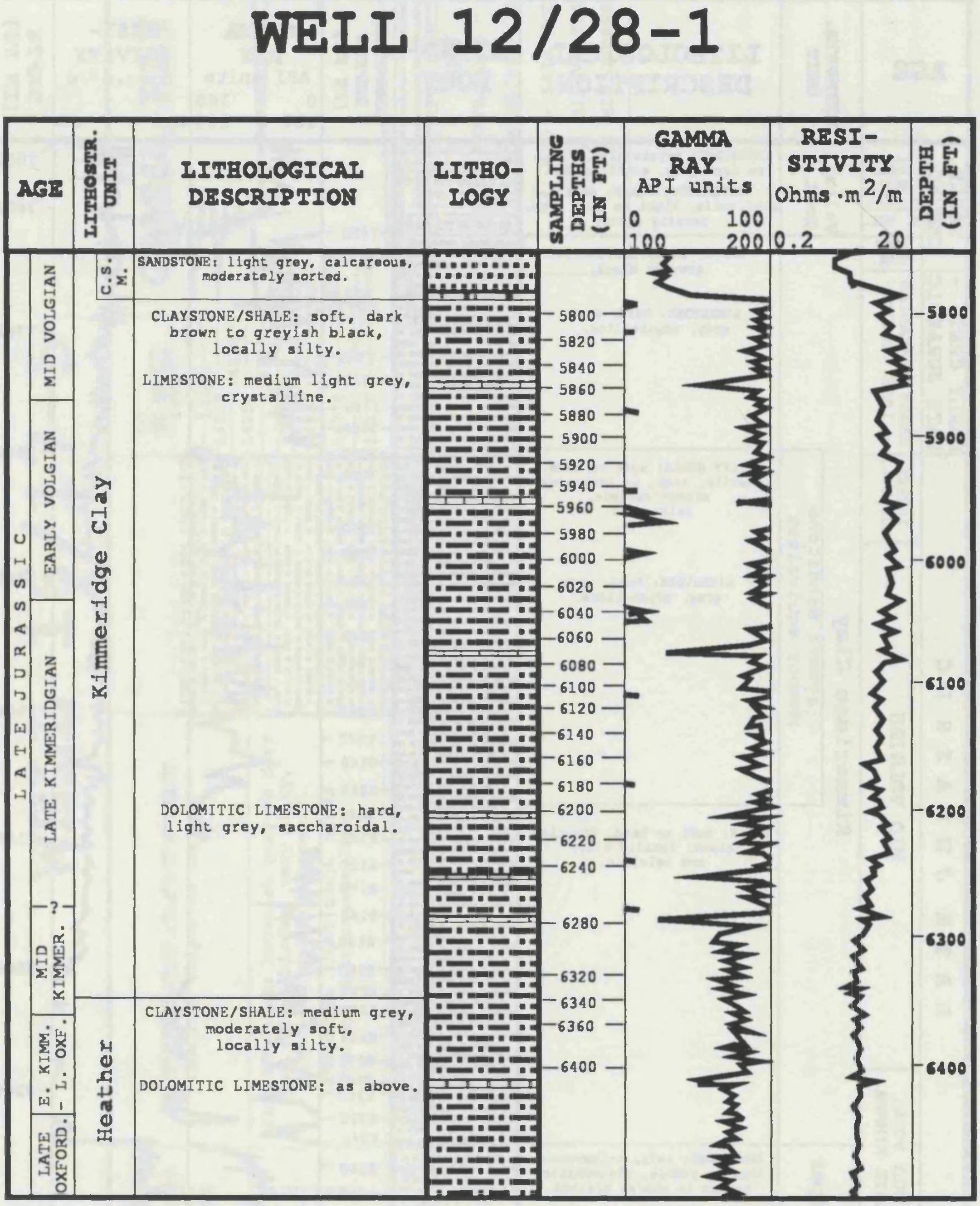


Fig. 5.10. Log of well 12/28-1.

KEY
C.S.M. = Claymore Sandstone Member

WELL 14/18-2

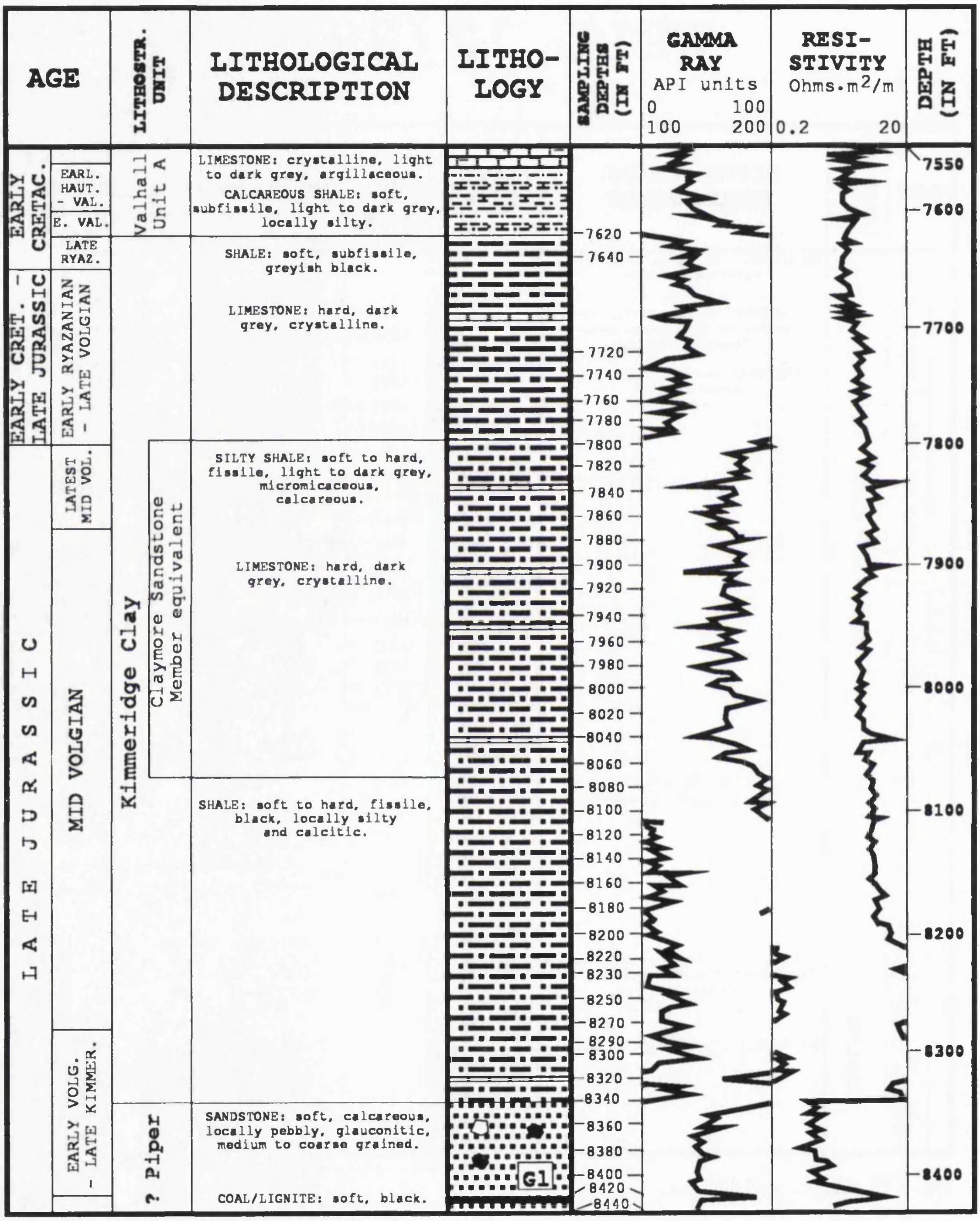


Fig. 5.11 Log of well 14/18-2.

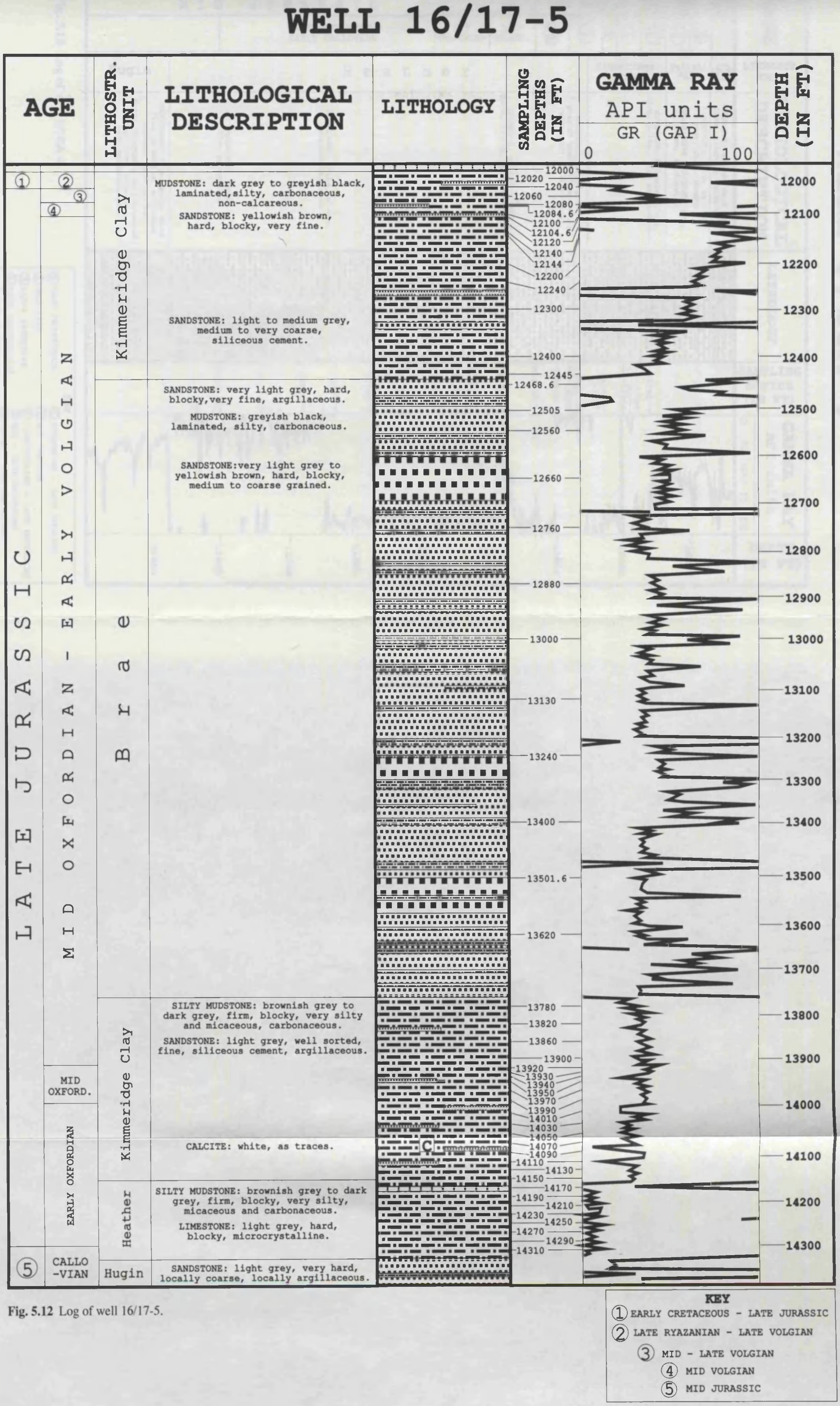


Fig. 5.12 Log of well 16/17-5.

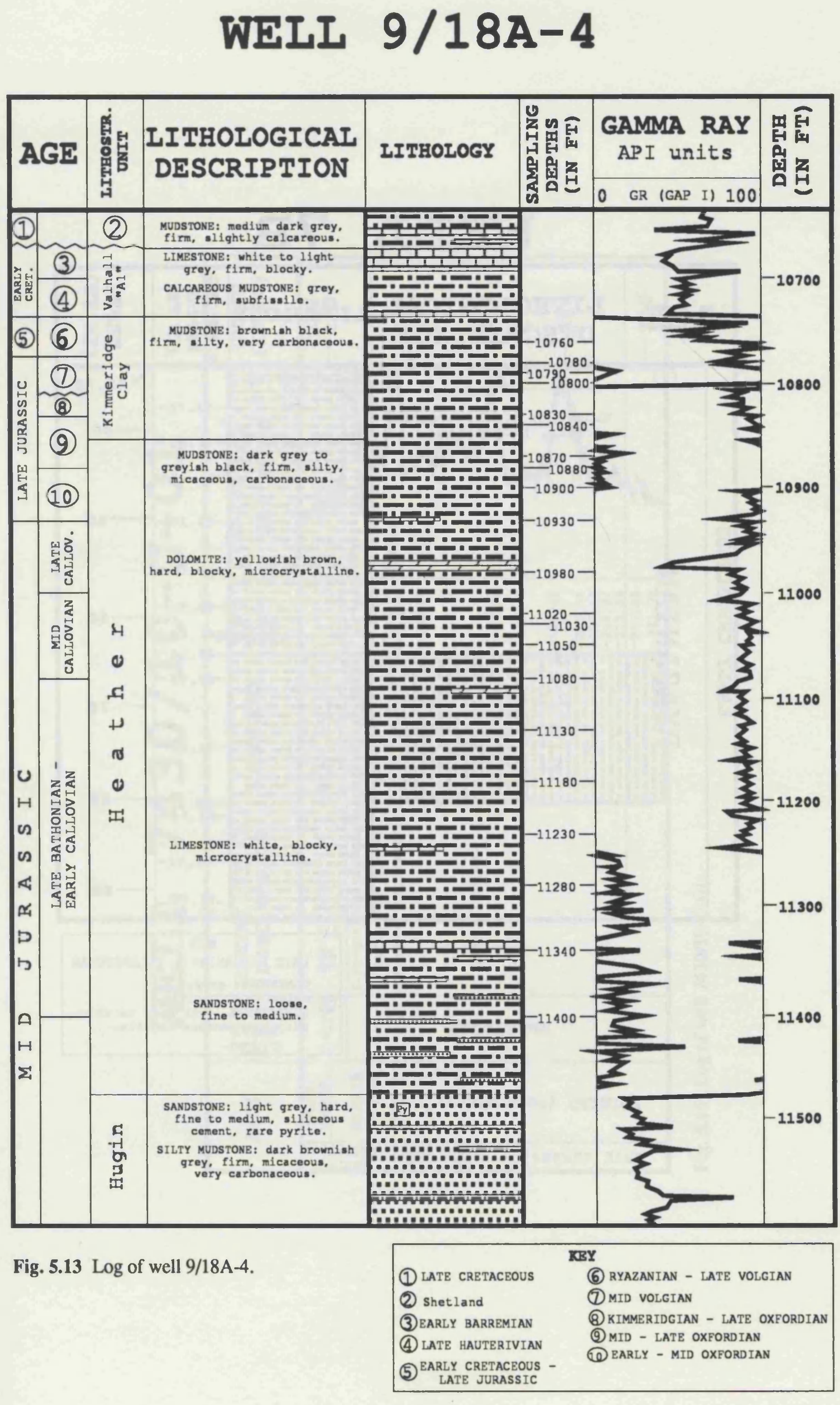
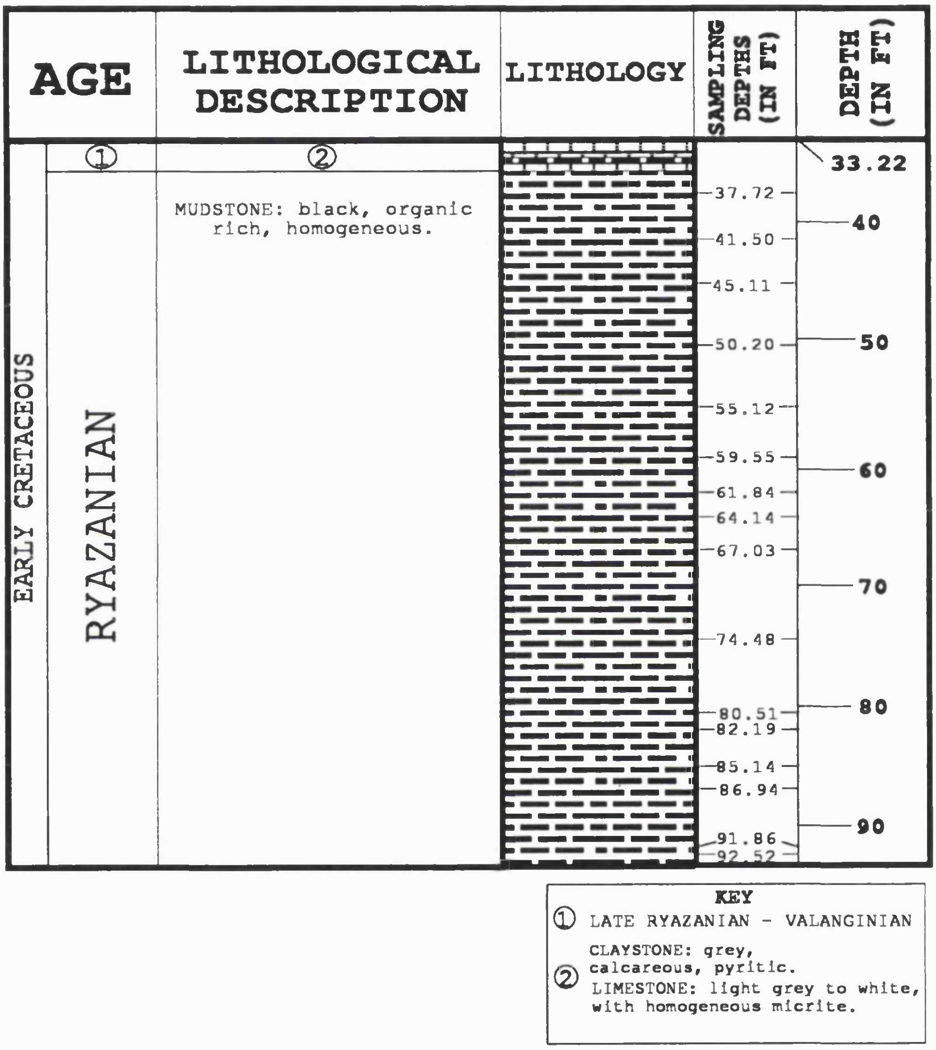


Fig. 5.13 Log of well 9/18A-4.

WELL 7B


AGE
LITHOLOGICAL DESCRIPTION
LITHOLOGY
SAMPLING DEPTHS (IN FT)
DEPTH (IN FT)
①
②
EARLY CRETACEOUS
RYAZANIAN
MUDSTONE: black, organic rich, homogeneous.
33.22
37.72
41.50
45.11
50.20
55.12
59.55
61.84
64.14
67.03
74.48
80.51
82.19
85.14
86.94
91.86
92.52
40
50
60
70
80
90
KEY
① LATE RYAZANIAN - VALANGINIAN
② CLAYSTONE: grey, calcareous, pyritic.
LIMESTONE: light grey to white, with homogeneous micrite.

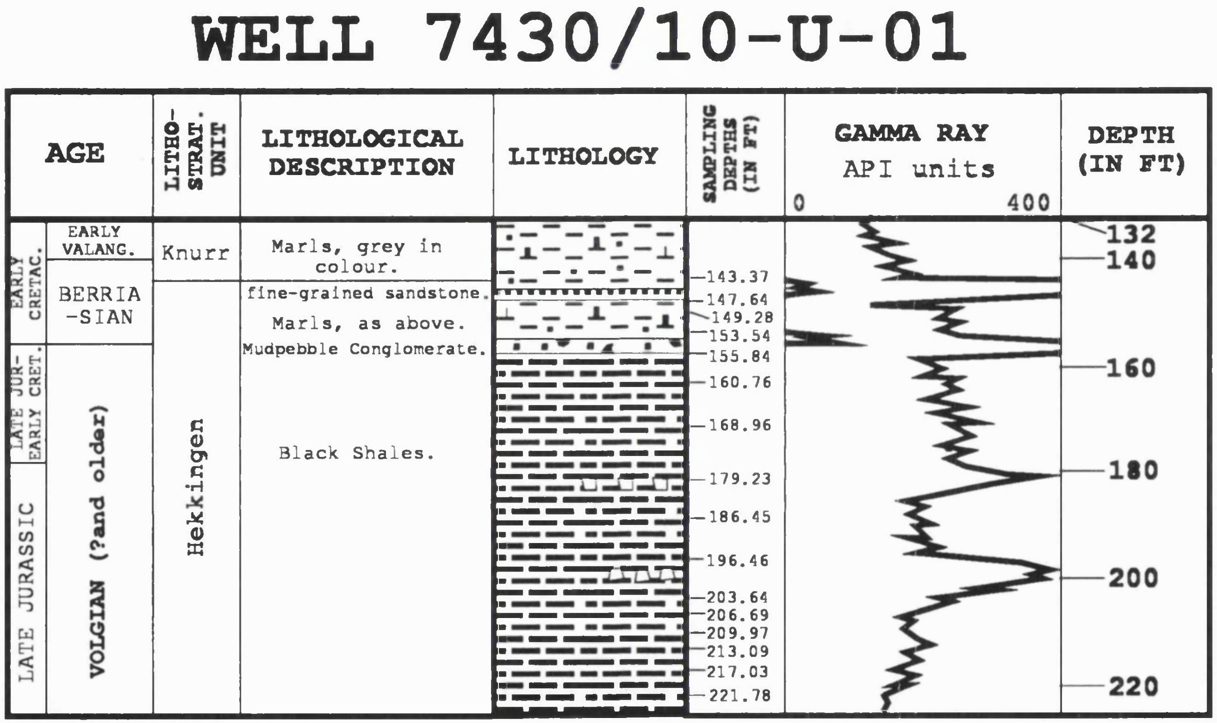
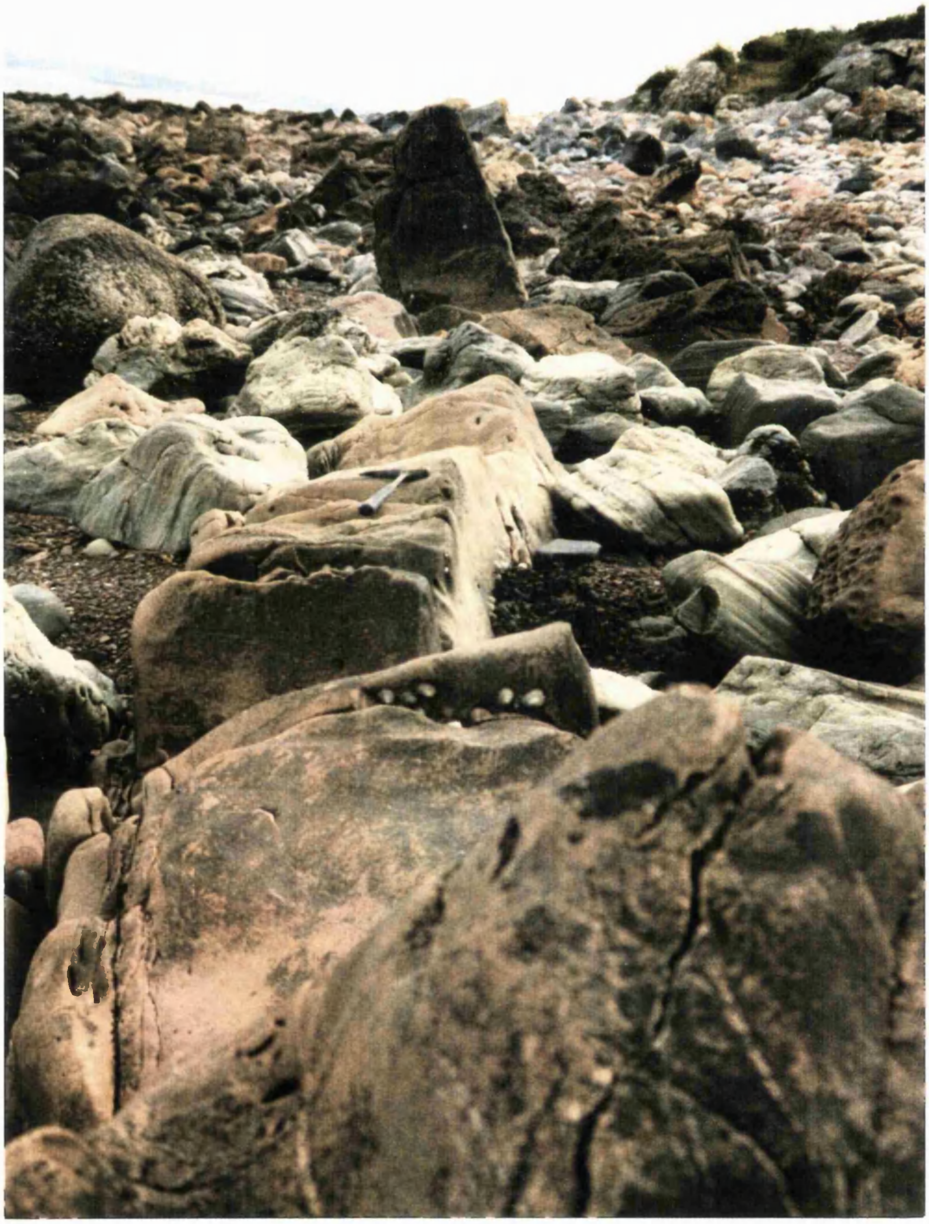


Fig. 5.15 Log of well 7430/10-U-01.



Photograph 5.1 The first limestone bed in section Eathie B2 (younger section to the left).

Photograph 5.2 The section Eathie B1 (①= first limestone bed; ② = second limestone bed).

Photograph 5.3 The second limestone bed in section Eathie B2.

Photograph 5.4 The second limestone bed in section Eathie B1.

Photograph 5.5 The intermediate and second limestone beds in section Eathie B2 (second limestone bed on the top left of the photograph).

Photograph 5.6 The complete succession (section Eathie B2) as seen from the Hill of Eathie.

CHAPTER 6

PROCESSING TECHNIQUES & METHODS OF STUDY

6.1 Introduction

Sample preparation techniques are an important part of every radiolarian research project. Good and successful results for radiolarian taxonomic and biostratigraphic studies require careful and appropriate methods. Careful processing techniques are required especially for North Sea material where Kimmeridge Clay radiolarians can be badly preserved and recrystallised (Dyer & Copestake, 1989).

In the next pages a review is given of i) those extraction methods that have been applied for Jurassic North Sea radiolarians, and ii) the methods of study have been used here. Finally, a discussion of the results closes the chapter.

6.2 Review of Processing Techniques

In the last two decades the significant increase in research on Mesozoic radiolaria has demanded the establishment, improvement and publication of new processing techniques for extraction of radiolarian tests from sediments. The early techniques used were simple (and usually involved mechanical action) and mainly applicable to well-preserved Cenozoic material. Grayson (1956) first noticed that calcified microfossils can be converted to fluorite with the use of Hydrofluoric acid (HF). In the early seventies, Dumitrica (1970) first used Hydrofluoric acid to extract Mesozoic radiolaria from cherts but he gave no details for his technique. Two years later, Pessagno & Newport (1972) published an HF method with very good results when applied to chert samples. The silica of the radiolarian test is significantly less soluble in comparison to the silica matrix. Although, HF is extremely dangerous to work with, the excellent results make its use obligatory especially for chert and silicified limestone samples. This technique can be modified by varying the concentration of acid and length of reaction, according to the degree of lithification of samples. Yao (1972) described a technique for extraction from manganese carbonate rocks. Pessagno (1977a) followed by De Wever *et al.* (1979), Baumgartner *et al.* (1981) and Sanfilippo & Riedel (1985) gave good summaries of processing methods that they had used. The description of every technique that has been published is considered unnecessary here, however, Table 6.1 shows the most important relevant publications. It should be noted that i) rock type, and ii) radiolarian test preservation dictate the most appropriate method.

TYPE OF PRESERVATION / ROCK TYPE	SILICEOUS RADIOLARIA	PYRITISED, CALCIFIED OR NOT SPECIFIED BY AUTHOR RADIOLARIA
SILICEOUS	-Schwarz (1924) * -Campbell (1954) -Dumitrica (1970) -Pessagno & Newport (1972) -Holdsworth *et al.* (1978) -De Wever *et al.* (1979) -Baumgartner *et al.* (1981) -Sanfilippo & Riedel (1985)	-De Wever *et al.* (1979) -Ozvoldova (1978)
CALCAREOUS	-Yao (1972) -Pessagno (1977a) -Sakai (1978) -De Wever *et al.* (1979) -Brasier (1980) -Sanfilippo & Riedel (1985)	-Bourdon (1962) -Ozvoldova (1978) -Pessagno (1977a) -De Wever *et al.* (1979)
ARGILLACEOUS	-Camp & Hanna (1937) * -Burma (1965) -Frizzer & Middour (1951) -Pessagno (1977a) -De Wever *et al.* (1979) -Brasier (1980) -Sanfilippo & Riedel (1985)	-Baumgartner *et al.* (1981) -Baumgartner (1992)

Table 6.1 Selected important publications dealing or mentioning processing techniques (* indicates outdated method).

6.3 Processing Techniques applied on North Sea samples

Below are the processing techniques that have been used here for extraction of radiolaria from a) samples from offshore well localities, and b) samples from the onshore exposure. A description of eight different methods (named A to H) tested by Simon Petroleum Technology on Kimmeridge Clay samples is shown on Table 6.2 and their recorded results are

METHOD	STEP
A **Hexane**	1. Break sample into small pieces. 2. Heat for 10min in oven at 100° C. 3. Allow to cool & place in pyrex beaker. 4. Add Hexane to cover & soak for 15min. Pour off Hexane. 5. Add water & allow 15min to soak (stir regularly). 6. If disintegrated wash, sieve & dry. If not repeat 2 - 5.
B **Sodium carbonate**	1. As above. 2. As above. 3. As above. 7. Add Sodium carbonate (washing soda) solution to cover sample. 8. Boil gently for 15min with stirring (or until disintegrated). 9. If disintegrated wash, sieve & dry, if not repeat 8.
C **Hexane**	As method A but omit step 2 (do not heat initially).
D **Hexane & 20% NaOH**	1. As previously. 4. As previously (leave sample for a while before start next step). 10. Add sufficient 20% NaOH Solution. Boil gently & stir until disintegrated. Then wash & dry.
E **Turpentine**	1. As previously. 3. As previously. 11. Add Turpentine to cover, soak for 1 hour then pour off Turpentine. 12. Cover sample with hot water, soak for 30min. 13. If disintegrated wash, sieve & dry. If not repeat 12 (with boiling).
F **15% solution Sodium hypochlorite**	1. As previously. 3. As previously. 14. Add 15% aq solution of Sodium hypochlorite to cover sample. Soak for 1 hour. 15. If disintegrated wash, sieve & dry. If not repeat 14.
G **10% solution Sodium Hexameta-phosphate ("Calgon")**	1. As previously. 3. As previously. 16. Add 10% aq solution hexametaphosphate. Soak for 3 hours. 17. If disintegrated wash, sieve & dry. If not continue 16.
H **Quaternary-O (detergent used in N. America)**	1. As previously. 18. Place sample in metal beaker. 19. Add solution of Quaternary-O (dissolve 2lbs of Q-O in 5 gallons warm water). 20. Boil for 30min (or more). 21. If disintegrated wash, sieve and dry.

Table 6.2 Brief description of 8 different preparation techniques (named A to H) tested on Kimmeridge Clay samples by Simon Petroleum Technology (information kindly provided by M. A. Charnock).

documented on Table 6.3. Method B (boiling in Sodium carbonate) gave the best result.

METHOD	RESULTS			REMARKS
	Reaction		Disintegration Change in sample	
A	no		some	small residue
B	vigorous		yes	very small residue
C	no		no	
D	*step 4*	no	no	
	step 10	vigorous	no	
E	*step 11*	no	no	
	step 12	vigorous	no	
F	no		no	
G	no		no	
H	vigorous		no	sample same size but very clean

Table 6.3 Effectiveness of Simon Petroleum Technology methods A to H (Table 6.2).

6.3.1 Samples from offshore wells

Samples analysed were mainly mudstones, claystones and sandstones, processed with an improved Method B as follows:

1. Dry sample in the oven if wet.
2. Place it in plastic beaker and cover with solution of washing soda (Sodium carbonate, Na_2CO_3) and water and leave overnight.
3. Boil gently for 10 to 15 minutes.
4. Sieve and wash with gently flowing cold water through a 63μm sieve to remove clay and separate the fine fraction (to ensure that fragile radiolaria were not destroyed by repeated boilings).
5. Place remaining sample in hot water and boil again in the same solution as before.
6. Repeat step 4 and 5 until most of the clay has been removed, and then dry.

Few samples were also treated by boiling in solution of calgon (Sodium hexametaphosphate) giving the same results.

Ditch cutting samples from the well 16/17-5 had been already processed with Hydrogen peroxide (H_2O_2) by Simon Petroleum Technology; HF treatment was applied (using 5% to 10% HF) to these samples.

6.3.2 Samples from the onshore exposures

Black shales and limestone samples were collected from the onshore exposure of Eathie Haven (Chapter 5). Black shales have been processed with Method B (boiling in Sodium carbonate and water) giving very good results. They were also treated with different concentrations of HF with 3% acid to give good results but not comparable to Method B. Limestones were processed in three different ways. The techniques and their results are described below.

A) Method for obtaining pyritised radiolaria from calcareous rocks (Pessagno, 1977a):

1. Crush the limestone into small pieces.
2. Place the pieces into a plastic beaker and apply HCl (30% and 10% HCl has been used). Leave until rock disintegrates.
3. Decant the acid washing with a gentle spray of water through a 63µm sieve.
4. In order to remove the excess clay apply 5% to 10% HF for a few minutes.
5. Pour off acid (as in 3) and dry.

Remarks. This technique gave no radiolarians.

B) Method for obtaining calcified radiolaria from calcareous rocks (modified from Pessagno, 1977a):

1. Crush the limestone into small pieces (to accelerate disintegration).
2. Place in a plastic beaker and cover with HF. Leave until sample disintegrates.
3. Decant the acid by adding and pouring off water and sieve through a 63µm. Dry in the oven.

Remarks. Different concentrations of HF have been tested (64%, 40%, 14%, 5% and 1%). The most dilute Hydrofluoric acid (1%) gave specimens of radiolarians, although these were poorly preserved. De Wever *et al.* (1990) used extremely diluted HF. The bad recrystallisation of radiolaria is thought to be the reason for the poor recovery from limestone samples.

C) Method for obtaining siliceous radiolaria from calcareous rocks (Pessagno, 1977a):

1. After limestone crushed into small pieces, place in plastic beaker.
2. 10% HCL applied and sample left until rock disintegrated.
3. Decant as previously and dry.

Remarks. This method gave no radiolarians.

6.4 Note for the use of Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) has proven to be mainly ineffective in processing rock samples from the North Sea Basin.

Samples of black shales (e.g. Eathie Haven sample 10512) processed with 10 volume peroxide gave poorly preserved radiolaria in comparison with Method B (boiling in Sodium carbonate and water). When non-pyritised specimens (opaque and translucent) were left overnight or for a shorter duration in drops of weak H_2O_2 they were found to have undergone significant corrosion or had been destroyed completely. It is known (Baumgartner *et al.*, 1981, p. 1052) that peroxide corrodes pyritised radiolaria. Since microprobe analyses (see Chapter

7) on various specimens has shown that non-pyritised radiolaria in this study have some pyrite preserved in their test, the use of peroxide should be avoided when possible. The action of peroxide on pyrite produces sulphuric acid (H_2SO_4) which may be detrimental to any calcified/siliceous radiolaria.

6.5 Aqua Regia experiment

A solution of Aqua Regia (75% concentrated HNO_3 and 25% concentrated HCl) has

SOLUTION USED	TIME	RESULT
Aqua Regia (75% HNO_3 & 25% HCl)	15sec	none
Aqua Regia (75% HNO_3 & 25% HCl)	10sec	none
50% H_2O & 50% Aqua Regia	5sec	none
95% H_2O & 5% Aqua Regia	1-3sec	very few "hollow" rad tests left
97%-99% H_2O & 1%-3% Aqua Regia	1-3sec	few "hollow" rad tests left test surface as previously

Table 6.4 Results of Aqua Regia experiment.

been used to etch the surface of poorly preserved pyritised radiolaria specimens. This was carried out in order to ascertain whether an outer layer of pyrite could be dissolved away leaving an inner layer on which the radiolarian test morphology was preserved. Results using different concentrations varying from 100% to weak (1 to 3%) Aqua Regia are shown on Table 6.4. Positive results as far as the test preservation is concerned were not obtained, although the weakest solution left specimens with a residual outer mould, the inside having being dissolved away. This could suggest a different state of preservation for test surface and internal part of radiolarian test (see microprobe analyses, Chapter 7).

6.6 Methods of study

6.6.1 Introduction

Correct methods of study are as important as the processing techniques. They include picking, use of Scanning Electron Microscope and Transmitted Light Microscope, photography, measurement, and cleaning radiolaria tests. Table 6.5 shows the most significant publications that mention methods of study. It is not the aim of this chapter to describe them in detail. However, methods used and applied for the study of radiolarians from the North Sea Basin are discussed in the following pages.

<table>
<tr><th colspan="2">WORK</th><th>PUBLICATIONS</th></tr>
<tr><td colspan="2">Collecting Radiolaria in the field</td><td>-De Wever et al. (1979)
-Baumgartner et al. (1981)
-Sanfilippo & Riedel (1985)
-Cordey & Krauss (1990)
-Haslett & Robinson (1991)</td></tr>
<tr><td colspan="2">Picking Radiolaria</td><td>-Camp & Hanna (1937)
-Frizzel & Middour (1951)
-Burma (1965)
-De Wever et al. (1979)
-De Wever (1980)</td></tr>
<tr><td colspan="2">Mounting - Strew slides & techniques for transmitted light photography</td><td>-Camp & Hanna (1937)
-Campbell (1954)
-Zhamoida (1960b)
-Burma (1965)
-Sakai (1978)
-De Wever et al. (1979)
-Boltovskoy et al. (1983)</td></tr>
<tr><td colspan="2">Scanning Electron Microscopy</td><td>-Pfefferkorn (1970)
-Russ & Kabaya (1970)
-McCandless et al. (1971)
-Lane (1972)
-Clanton & Ladle (1975)
-Pessagno (1976, 1977a)
-Baumgartner (1980)
-De Wever (1980)
-Baumgartner et al. (1981)
-MacLeod & Carter (1984)</td></tr>
<tr><td colspan="2">Computer applications</td><td>-Guex & Davaud (1982, 1984)
-Kojima & Mizutani (1982)
-Baumgartner (1984b)
-Riedel (1988)
-Vrielynck & De Wever (1988)
-De Wever et al. (1989)
-Takemura et al. (1989)
-De Wever & Vrielynck (1991)
-Sanfilippo et al. (1991)
-Yang (1991)
-Guex (1991)</td></tr>
<tr><td colspan="2">Observation of internal structure</td><td>-Kennedy (1978)
-Baumgartner (1980)
-Nomura (1983)</td></tr>
<tr><td rowspan="3">Cleaning Radiolarian Fossils (preserved as SiO_2)</td><td>from encrusting iron oxides</td><td>-De Wever et al. (1979)
-Sanfilippo & Riedel (1985)</td></tr>
<tr><td>from superficial clay</td><td>-Burma (1965)
-Boltovskoy (1977, 1981)
-De Wever et al. (1979)
-Boltovskoy et al. (1983)
-Sanfilippo & Riedel (1985)</td></tr>
<tr><td>from colloidal silica</td><td>-De Wever et al. (1979)</td></tr>
</table>

Table 6.5 Important publications concerning methods of study for radiolarians (or they can be applied for radiolarians).

6.6.2 Picking

Dried residues were sieved into the following fractions i) 63 to 150µm, ii) 150 to 250µm, iii) 250 to 500µm, and iv) over 500µm. Each fraction was scattered as evenly as possible across a black picking tray with 20 scored rectangles. Attempts were made to pick the same amount of sample for each depth, although this was proven to be difficult owing to limited quantities in some cases. An average of 3 to 4 picking trays for each fraction was picked under a WILD M5 binocular stereomicroscope having 20x oculars and 6x, 12x, 25x and 50x objectives. A very fine (000) brush occasionally moistened in water was used for picking. Samples that gave no radiolarians after the completion of picking of 4 trays or after one hour continuous picking, were declared barren. Fig. 6.1 gives the distribution of barren samples at each well/exposure. Specimens were then, mounted on multicell faunal slides of 32 or 64 cells. At the first stages of this project paper glue solution was used to secure the specimens but the excess glue hinders good SEM results. Glue, however, can be quite easily removed with drops of acetone before SEM study.

As mentioned in the introduction, North Sea radiolaria are generally small in size. The importance of the fine fraction (<150µm) is shown on Table 6.6 and significant percentages

WELL	Number of samples	Fraction >250µm		Fraction >150µm		Fraction <150µm	
		absolute number recovered	%	absolute number recovered	%	absolute number recovered	%
22/21-2	57	241	5.3	2442	54.5	1800	40.2
29/12-1	58	2	0.8	95	37.1	159	62.1
23/27-4	61	111	2	3539	65.3	1773	32.7
28/5-1	12	3	4.4	21	30.4	45	65.2
9/18A-4	21	0	0	87	35.7	157	64.3
16/17-5	54	3	0.6	247	50.6	238	48.8
14/18-2	40	15	0.4	1286	32.2	2693	67.4
12/28-1	28	11	1.4	448	58.4	308	40.2

Table 6.6 Absolute numbers and percentages of picked specimens for each fraction (in North Sea studied wells).

of radiolaria occur in the finest fraction. Dyer & Copestake (1989, p.223) also emphasize the importance of the fine fraction. The high percentages of radiolaria in fraction 150 to 250µm are due mainly to the influxes of large *Archaeocenosphaera*(?) specimens.

6.6.3 Estimation of Preservation State

In a few recent publications on Mesozoic radiolaria, workers have attempted to determine and record the preservation state for each sample studied. A good example is that of

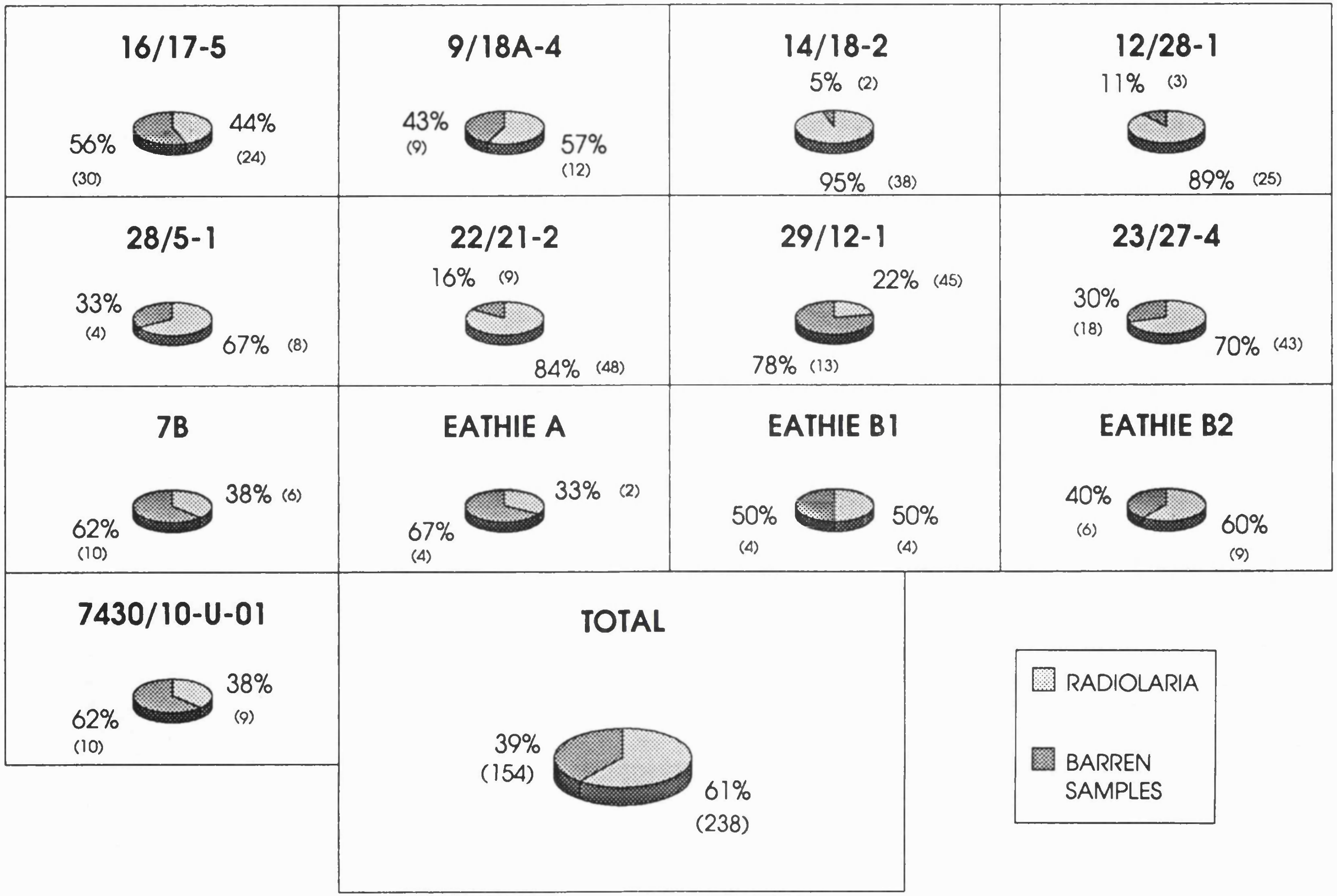


Fig. 6.1 Distribution of samples with radiolaria and barren samples in the wells/exposures studied.

Baumgartner (1992).

As mentioned earlier, North Sea Jurassic radiolaria can be badly preserved, so for this study it was judged useful to estimate and record the state of preservation for picked samples in order to recognise horizons of "good" preservation. This has been done as follows:

G (good) = Over 50% of the radiolaria specimens picked were identifiable to species level, with few broken or partly broken and partially recrystallized.

M (moderate) = 20 to 50% of the picked specimens were identified with a significant number to be found broken.

P (poor) = Only 5 to 20% of the radiolaria recovered could be identified to species level. The majority of the specimens have been found to be broken, flattened/compressed and/or badly recrystallized.

VP (very poor) = In these samples a very small number of specimens (less than 5%) identifiable. Almost all radiolaria recovered broken.

6.6.4 Transmitted Light Microscopy

Most Mesozoic radiolarian specimens are not preserved as opaline silica but have their tests replaced by pyrite, calcite, chalcedony (SiO_2) or limonite (Pessagno, 1977a), which are often unsuitable for observation by transmitted light microscope. However, when preservation permits (this depends upon the degree of calcification of the specimen itself), the use of transmitted light photomicroscopes gives important information for the internal structure of the radiolarian test. Details of internal test structures and features such as the number of segments of the nassellarian test, thickness of test wall and other measurements cannot be easily defined using the reflected light microscope or SEM.

In this study the use of transmitted light was limited, as the majority of radiolarians are either pyritised or non-pyritised (opaque), but it proved to be extremely useful for at least two cases: 1) the classification and description of *Tricolocapsa* morphotypes, and 2) identification of two same-sized *Archaeocenosphaera*(?) morphotypes with distinctively different sizes of pore frame.

6.6.4.1 Preparation of slides for Transmitted Light Microscopy

Smear slides have been prepared from the <63µm residue when samples were washed after the first or second boiling. Using a pipette the <63µm suspension was spread on to a labelled glass slide (1.0 to 1.2mm thick plain). The slides were then placed on a hot plate to allow water to evaporate leaving a thin residue film and covered with a thin cover slip (22 x 50mm, thickness no.1) using a mounting medium. For this study Norland Optical Adhesive 61 (RI=1.56mm) was used, which contains no solvent and is cured by exposure to long wave ultraviolet light (320 to 400nm). Other mounting media which can be used are: 1) Canada Balsam (for restoration of radiolaria strew slides mounted in Canada Balsam see Brunner & Blueford, 1986), 2) Glycerine jelly, 3) Petropoxy 154, 4) DPX, and 5) "Entellan New", a synthetic medium (Yao *et al.*, 1980; Matsuoka, 1982a; Yao, 1984).

It is important to take into account the refractive index (RI) of the mounting medium. Specimens may become invisible or unclear if their refractive index is similar to that of the mounting medium.

A Zeiss Photomicroscope with 10x, 20x and 40x objectives was used for the routine study of all smear slides prepared but no radiolaria were found.

Single non-pyritised specimens (translucent under the stereoscopic microscope) permitting transmitted light through their tests were placed on glass slides. Any water was allowed to evaporate completely and the specimens then covered as previously with a mounting medium. A slight excess of the adhesive substance allows orientation of the specimen by gently moving the cover slip.

6.6.5 The Scanning Electron Microscope

Since its development in 1968, the scanning electron microscope has become an essential tool for micropalaeontological studies. Detailed observations of the surface and small features of the radiolarian test as well as illustrations with good depth of focus are best carried out using the SEM. Pessagno (1977a, p. 110) stated "several light photomicrographs required to achieve results which in the end are usually inferior to those provided by a single SEM micrograph". For this study a Jeol T200 and, later, a Zeiss DSM940 scanning electron microscopes were used.

6.6.5.1 Preparation of SEM stubs

Radiolarian specimens were cleaned and mounted in rows (Fig. 6.2) on the surface of a small square piece of photographic film (with emulsion side up) which was secured onto an aluminum stub with double sided adhesive tape. A line was always drawn on the top of the square of film to assist orientation in the SEM chamber. At the edges of the film conductive colloidal silver was applied to aid conductivity of electrons. The stub was coated in a "sputter-coater" with a thin layer of gold (approximately 4 minutes coating has been given to each stub) in an Argon atmosphere, to prevent the charging (Baumgartner, 1992) but not so thick as to obscure surface details.

Important techniques for fixing and orientating specimens for SEM study were published and discussed by Pessagno (1976), De Wever (1980), and Baumgartner *et al.* (1981). MacLeod & Carter (1984) invented a method for obtaining consistent orientation of specimens used in biometric studies (Table 6.5). In order to remove radiolaria from the stub a slightly wet picking brush is required. Gold or gold palladium coating can be removed from the test surface with Aqua Regia if necessary (Pessagno, 1977c).

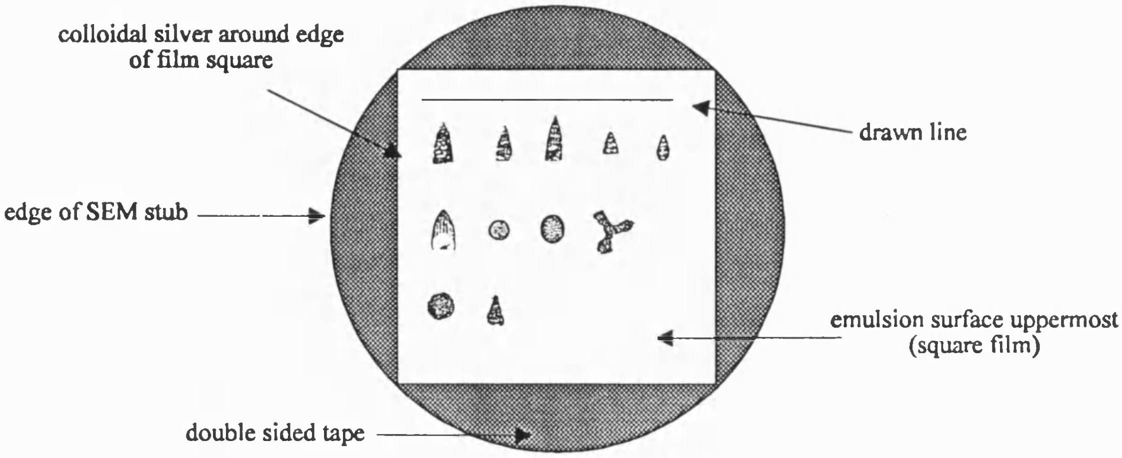


Fig. 6.2 A Scanning Electron Microscope Stub.

6.6.6 Photography

Low ASA films (50 or occasionally 25 ASA) were used for both SEM and transmitted light photography in order to achieve high resolution when enlarged. The use of a green filter on the photomicroscope gives a sharper (better contrast) negative. A photographic record of contact sheets was kept throughout the study. All negatives are stored in the Postgraduate Unit of Micropalaeontology, University College London and their catalogue numbers follow the pattern: UCL-3745 (film number)/10 (frame number).

6.6.6.1 Stereophotography

Stereophotographs have been previously successfully applied to the studies of ostracods, conodonts and foraminifera. Stürmer (1952, 1966) first suggested the use of stereopairs for radiolaria studies. Pessagno (1976) illustrated stereopairs of the internal structure of *Praeconocaryomma*.

For this study stereopair photographs were taken for species difficult to identify and gave useful information for shapes, architectural details or size relationships (Boltovskoy *et al.*, 1983). The angle of separation was 5 to 7° and the prints later mounted pallalel to each other at a distance of approximately 2 inches and viewed through a stereo-viewer.

6.6.7 Measurements

Measurements were taken of all well-preserved specimens in order to show dimensional variations within morphotypes. They were carried out using:

1) An ocular micrometer in the eyepiece of the stereoscopic microscope or transmitted light microscope. The graticule divisions were calculated as in Allman & Lawrence (1972, p. 132).

2) The scale bar on the scanning electron micrographs.

3) The measurement cursors on the DSM 940 Scanning Electron Microscope.

Remarks. The ocular micrometer has been applied for measuring relatively large species. Features such as the diameter of *Archaeocenosphaera*(?), length and width of "large" nassellarians were easily measured.

Caution should be taken when measuring with the bar scale of the SEM micrographs. Dimensions of tilted specimens may differ significantly from true ones.

Finally, the measurement cursors on the SEM give, doubtlessly, accurate results, especially for the pore size of *Archaeocenosphaera*(?) species or small segments of *Tricolocapsa*. All the specimens used for scanning electron photography were measured.

6.7 Conclusions

1) The best results for extraction of radiolarians from the claystones and mudstones of the Kimmeridge Clay and other argillaceous rocks were achieved using the method of boiling in a solution of washing soda (Sodium carbonate, Na_2CO_3). This method requires patience and persistence until most of the clays have been removed. Baumgartner (1992, p. 301) suggested that samples processed with detergents can give residue assemblages close to the originally deposited ones.

2) The Hydrofluoric acid (HF) method gave good results when used but for its success a prerequisite is samples containing well-preserved and not badly recrystallised radiolaria (Pessagno 1977c, p. 919). In a recent publication, Blome & Reed (1993) showed how acid (HF) processing can influence results of radiolarian studies.

3) Treatment with Hydrogen peroxide (H_2O_2) was abandoned since when used it corroded or completely destroyed pyritised and non-pyritised radiolaria.

4) The use of the transmitted light microscope when possible (owing to preservation factors) was valuable for some taxonomic problems.

CHAPTER 7

SILICA DIAGENESIS, PRESERVATION OF FOSSIL RADIOLARIANS & ELECTRON MICROPROBE ANALYSES.

7.1 Introduction

The chapter contains a brief review of silica diagenesis, which plays a major role in the preservation of radiolarians in Mesozoic sediments. Then follows a part on the preservation of North Sea Jurassic radiolarian assemblages. Finally, the results of Electron Microprobe analyses of North Sea sample material are presented and discussed.

7.2 Silica Diagenesis

Today the entire ocean is undersaturated with respect to silica (including biogenic silica) (Berner, 1971; Kastner, 1981; etc). So, if a small siliceous organism (radiolaria, diatom) is left long enough in the marine water it will dissolve. Thus, the thanatocoenoses of radiolarians which are preserved in rocks obviously do not represent the biocoenoses (Calvert, 1974). The biogenic opaline silica (opal-A, nomenclature after Jones & Segnit, 1971) after being deposited in sediment experiences crystallographic changes. This has been observed in many DSDP sites, the Monterey Formation in California (which has been extensively studied), as well as in laboratory experiments (Kastner, 1981). Kastner & Gieskes (1983) postulated that the pathways and rates of silica diagenetic evolution are controlled by i) the nature of the initial silica, and ii) the various physico-chemical factors such as temperature, pressure, pH and pore fluid chemistry affecting it after deposition.

Biogenic silica (opal-A) which constitutes the radiolarian and diatom tests is highly unstable and changes to metastable opal-CT during burial diagenesis, as recognised by

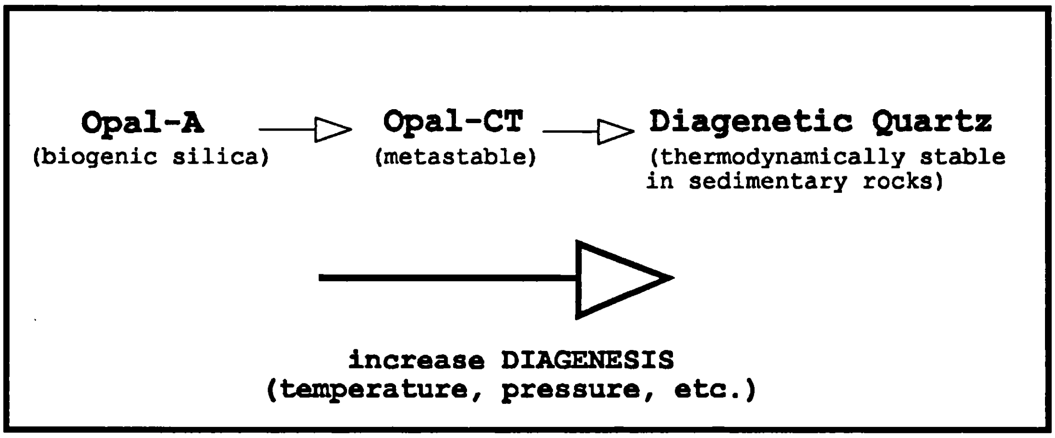


Fig. 7.1 Typical diagenetic sequence of silica minerals (data from Isaacs *et al.*, 1983).

various workers (Murata & Larson, 1975; Hein *et al.*, 1978; etc.) (Fig. 7.1). The initial phase changes do not usually affect the fine morphological features of the radiolarians which are still well-preserved after this stage (Kakuwa, 1984). Where opal-CT changes to quartz, radiolarians are found to be partly preserved and may be destroyed by the later stage growth of quartz crystals (Kakuwa, 1984). Siever (1979) estimated the time required for the formation of diagenetic quartz from opal-A under deep-sea conditions at 40 to 100 Ma.

7.3 Preservation of fossil Radiolarians

Diagenesis is directly affected by burial rate and tectonic events.

It is generally accepted (Renz, 1974; Baumgartner *et al.*, 1980; Baumgartner, 1984a; etc.) that radiolarian skeletons are very prone to selective dissolution before and after their burial in the sediments. Riech & von Rad (1979) postulated the geologically preserved siliceous plankton to be only the 2% of the original total deposited in the oceans. Some radiolarian morphotypes are likely be more affected by diagenesis and consequently selectively lost from the original assemblages (Baumgartner *et al.*, 1980, p. 33). Factors such as the nature of test and the diagenetic environment also control the preservation of radiolarian morphotypes (Baumgartner *et al.*, 1980, p. 33).

Kakuwa (1984) concluded that the following factors are important for the preservation of resistant siliceous skeletons: abundance of carbonate, rate of sedimentation, duration of deposition, and existence of easily soluble siliceous skeletal materials.

Vitukhin (1991) after studying radiolarian skeletons from Cenozoic sections concluded that the radiolarian shells in terrigenous rocks (siltstones, claystones) are undergoing "filling of the inner parts of the shells by silica with destroying of all inner and rounding of the outer morphological structures" (Vitukhin 1991, p. 92). Thus, only general features are preserved.

Fossil radiolarian tests and especially pre-Cenozoic ones are not composed of opaline silica but have been diagenetically altered (as discussed earlier). Radiolarian tests can also be replaced by smectite, pyrite, limonite or calcite (Pessagno *et al.*, 1984). With these chemical replacements preservational changes occur, the external structure may be completely or partly lost and more often the internal structure obscured (by intragranular fillings).

Limestones, radiolarites and cherts can yield well-preserved radiolarian assemblages, according to Pessagno (1977c), in contrast to shales, mudstones and other silty rocks, where sedimentary compaction frequently destroys the more fragile tests. However, according to De Wever (1985) after field observations in Tethyan areas, rocks rich in clays generally yield better preserved radiolarians. This is because: i) clays form a protective cover around the radiolarian test, and ii) "slow the opal-A to opal-CT transformation so the structure of the opal-CT is better organised and much less subject to subsequent dissolution" (De Wever, 1985, p. 450). Blome (1984) and Blome & Albert (1985) discussed the presence of better preserved, more abundant and diverse radiolarian faunas from carbonate concretions in comparison to those extracted from the surrounding, host rock.

Finally, Kakuwa (1984) after studying Palaeozoic, Mesozoic and Cenozoic quartz cherts determined six preservational grades for siliceous skeletons (Fig. 7.2) based on the state of i) preservation of pores, ii) visibility of pore structures, and iii) intergranular cement fillings.

	PRESERVATION OF PORE STRUCTURE		
CEMENTATION	Well Preserved Not Filled **(WPNF)**	Partly Preserved Not Filled **(PPNF)**	Not Preserved Not Filled **(NPNF)**
	Well Preserved Filled **(WPF)**	Partly Preserved Filled **(PPF)**	Not Preserved Not Filled **(NPF)**

Fig. 7.2 Preservation grade of siliceous skeletons (redrawn after Kakuwa. 1984; Table 1).

A summary for radiolarian preservation, siliceous sediments and silica diagenesis is given by De Wever *et al.* (1993).

7.4 Preservation of Mid Jurassic to Earliest Cretaceous North Sea Basin Radiolarians

7.4.1 Introduction

Investigations of both the distribution of pyritised and non-pyritised radiolarians throughout the sections and of the mineral composition of individual fossil tests following diagenesis are discussed below.

7.4.2 Stratigraphical distribution of pyritised and non-pyritised radiolaria, using the reflected light microscope

7.4.2.1 Methods

During the picking of well and field sample material for radiolarians the following types of radiolarian preservation were distinguished when observed with a reflected light microscope:

TYPE 1 - dark yellowish in colour when viewed with the reflected light microscope and appear opaque, not allowing study under the transmitted light microscope.

TYPE 2 - light yellowish to white in colour under the reflected light microscope and can be studied with the transmitted light microscope, although very often the inner structure is not preserved. Sometimes dark spots (?pyrite) may be present on the test surface.

TYPE 3 - black to dark grey in colour, opaque and unsuitable for transmitted light microscopy.

TYPE 4 - pale yellowish in colour and appear hyaline with the reflected light microscope. These forms are very rare.

Radiolarian tests from the Norwegian Sea (well 7B) are milky white in colour, they can be easily studied with the transmitted light microscope, and are better preserved in comparison to specimens from the North Sea Basin and the Barents Sea. The majority of the identifiable radiolarian specimens from the latter areas fall into the PPF type of Kakuwa (1984). The type NPF of Kakuwa is also common (specimens occur as internal casts, Pl. 10, Fig. 13).

Electron Microprobe analyses have been performed on the four types of preservation. The results and a discussion follow on p. 116.

7.4.2.2 Results

The distribution of pyritised and non-pyritised radiolarians in the well sites in relation to ages is given in Figs. 7.3 to 7.12 (see end of chapter). Additionally, the percentages of pyritised and non-pyritised radiolaria can be found in the range charts at the end of Chapter 9 (Tables 9.2 to 9.14).

7.4.2.3 Conclusions

The following general conclusions can be drawn from the distribution of the pyritised and non-pyritised radiolarians:

1). The Ryazanian to Late Volgian radiolarian faunas are pyritised (Fig. 7.4, well 23/2-4; Fig. 7.12, well 7430/10-U-1), non-pyritised (Fig. 7.7, well 14/18-2) or more often composed of both pyritised and non-pyritised radiolaria (Fig. 7.3, well 22/21-2; Fig. 7.5, well 28/5-1; Fig. 7.6, well 29/12-1; Fig. 7.9, well 16/17-5; Fig. 7.10, well 9/18A-4; and Fig. 7.11, well 7B).

2). The Mid to Early Volgian faunas are mainly non-pyritised. Exceptions are the radiolarians from well 9/18A-4 (Fig. 7.10), well 28/5-1 (Fig. 7.5) and the Mid Volgian assemblages of well 23/27-4 (Fig. 7.4).

3). The oldest recovered radiolarians (earliest Oxfordian and Callovian) appear to be exclusively preserved as pyrite (Fig. 7.9, well 16/17-5, and Fig. 7.10, well 9/18A-4).

7.4.3 Electron Microprobe analyses

The chemical composition of constituent minerals and oxides from/in specimens from the North Sea Basin was determined with the Electron Microprobe analyses.

7.4.3.1 Materials & Methods

Radiolarian specimens were hand picked, cut in cross-section with a small razor where needed for analysis of the internal composition, cleaned and placed onto a stub (as discussed for the SEM preparation, p. 107). Specimens were mounted on a special plastic adhesive sellotape and coated with carbon, instead of gold which was used for SEM photography.

The following specimens were analyzed:

Specimen 1: Spumellarian specimen (Type 3) which has been picked broken. Under reflected light microscope external surface looks pyritised. Specimen was picked from sample 10930, well 9/18A-4 (late Callovian).

Specimen 2: Nassellarian (Type 1) which is non-pyritised and dark, not allowing transmitted light photography. Specimen was picked from sample 10404, Eathie Haven (mid Kimmeridgian).

Specimen 3: Nassellarian specimen (Type 1) cut in cross section. Specimen was picked from sample 10404, Eathie Haven (mid Kimmeridgian).

Specimen 4: Specimen of *Archaeocenosphaera*(?) sp. indet (Type 2) non-pyritised which allows transmitted light photography (cut in cross-section). Specimen was recovered from sample 12650, well 22/21-2 (Early Volgian).

Specimen 5: *Rhaxella* sponge spicule (Type 4), hyaline under reflected light microscope. Recovered from sample 8040, well 29/12-1 (Mid Volgian).

Specimen 6: *Praeconocaryomma* sp. A (Type 4), hyaline enough to be examined with a transmitted light microscope. Sample 6450, well 28/5-1 (Late Volgian).

Specimen 7: *Praeconocaryomma hexagona* (Rüst) specimen (Type 3) which appears to be pyritised externally and cut in cross-section. Inner section appears pyritised under reflected light microscope. Sample 10520, well 23/27-4 (Mid Volgian).

The analyses were performed using a JEOL SUPERPROBE 733 analyzer at 15.00kV connected with a Link AN-10000/55S. The ZAF/4-FCS program was used for the Stoichiometry (elemental & oxides results). For each specimen a SEM photograph was taken, usually using the back-scatter mode of the microscope (Fig. 7.13).

7.4.3.2 Results

Specimen 1. Analyses from this specimen:

a) SAMPLE 1 CORE, the inner small area (Figs. 7.13.1 & 7.13.2). This was found to consist (Fig. 7.14) mainly of silica (Si) and a smaller amount of secondary deposits (Al), as well as traces of pyrite (Fe & S elements on Fig. 7.14).

b) SAMPLE 1 MID, the bright area on Fig. 7.13.2 which consists entirely of barite ($BaSO_4$) (Fig. 7.15).

c) SAMPLE 1 EDGE, the wall (surface) of the radiolarian test which proved to be almost pure pyrite (Fig. 7.16).

Specimen 2. Analyses from this specimen:

a) SAMPLE 2 SURFACE, generally the test surface which is composed of calcite, silica, traces of pyrite and the usual secondary mineral deposits (Al, Mg, K elements) (Fig. 7.17).

b) SAMPLE 2 BRIGHT AREA, the bright areas on Fig. 7.13.4, are sphalerite (ZnS) (Fig. 7.18) and cannot be distinguished with a reflected light microscope (compare Figs. 7.13.3 & 7.13.4).

Specimen 3. Analyses from this specimen (Fig. 7.13.5):

a) SAMPLE 3 EDGE, the wall of test (dark area of Fig. 7.13.5) which proved to consist of silica, calcite, traces of pyrite and secondary mineral deposits (Fig. 7.19).

b) SAMPLE 3 CORE, the inside filling of the test which is almost pure calcite (Fig. 7.19).

Specimen 4 (Fig. 7.13.6).

SAMPLE 4 CORE, the bright area on Fig. 7.13.6, which is the inside filling of the skeleton and almost entirely consists of calcite (Ca) with a very small amount of pyrite (Fe) (Fig. 7.20).

Specimen 5 (Fig. 7.13.7).

SAMPLE 5 SURFACE, analysis of the surface, which was found to consist almost entirely of calcite with traces of silica (Fig. 7.21).

Specimen 6 (Fig. 7.13.8).

SAMPLE 6 SURFACE, the test surface was scanned and found to consist mostly of silica. Very small amounts of calcite (Ca) as well as secondary mineral deposits have also been detected (Fig. 7.22).

Specimen 7 (Fig. 7.13.9). Analyses from this specimen:

a) SAMPLE 7 CORE, the inside of the test, which consists of calcite, magnesium (Mg) and small amount of pyrite (Fig. 7.23).

b) SAMPLE 7 SURFACE, a general scan of the test surface showed that it consists of silica (Si), pyrite (Fe & S elements on Fig. 7.24) as well as secondary mineral deposits (clays Al, K).

c) SAMPLE 7 BRIGHT AREA, the bright areas on Fig. 7.13.9. This consists almost entirely of pyrite (Fig. 7.25).

7.4.3.3 Conclusions

All graphical results can be found at the end of the chapter (Fig. 7.14 to Fig. 7.25). The following summarized conclusions can be drawn from the analyses:

1) The replacement of silica by calcite, pyrite or sphalerite has not usually occurred totally.
2) No significant difference in the composition of the internal part of tests of Type 1 and Type 2 has been detected.
3) The "pyritised" Radiolaria (Type 3) do not necessarily have their tests completely replaced by pyrite, although under a reflected light microscope this looks to be the case. It is possible that this replacement may be more intense in older tests (comparison of Callovian age Specimen 1, S1 EDGE analysis and Mid Volgian Specimen 7, S7 SURFACE analysis), however, significant conclusions cannot be drawn here on the basis of the analysis of a single specimen.
4) There is no correlation between the appearance of the non-pyritised tests in reflected light (classed here as Types 1, 2 and 4) and their chemical composition as determined by the Electron Microprobe analyses.

7.4.4 Discussion

A) Barite.

Specimen 1 was picked broken, thus the barite ($BaSO_4$) which was detected (SAMPLE1 MID) obviously derived from the clay-rich sediment (Heather Formation).

Compton *et al.* (1992) (ODP Leg 123) reported barite to be abundant in several samples from Sites 261 and 765 from sediments rich in radiolarian tests which were altered to quartz. The barite suggested that "the narrow, restricted basin of the Indian Ocean had highly productive surface waters (as postulated by Schmitz, 1987), a result of upwelling or fluvial nutrient influxes" (Compton *et al.*, 1992, p. 789).

The South Viking Graben in Callovian times was also a narrow, restricted basin with fluvial nutrient influxes from the Shetland Platform in the west and Scandinavian Landmass and Utsira High in the east (map J8 of Bradshaw *et al.*, 1992 and Chapter 4). However, the South Viking Graben is not directly comparable with the above restricted basin in the Indian Ocean. Callovian sediments analysed in this study did not yield rich radiolarian assemblages and the majority of specimens appear to be preserved as pyrite (Specimen 1).

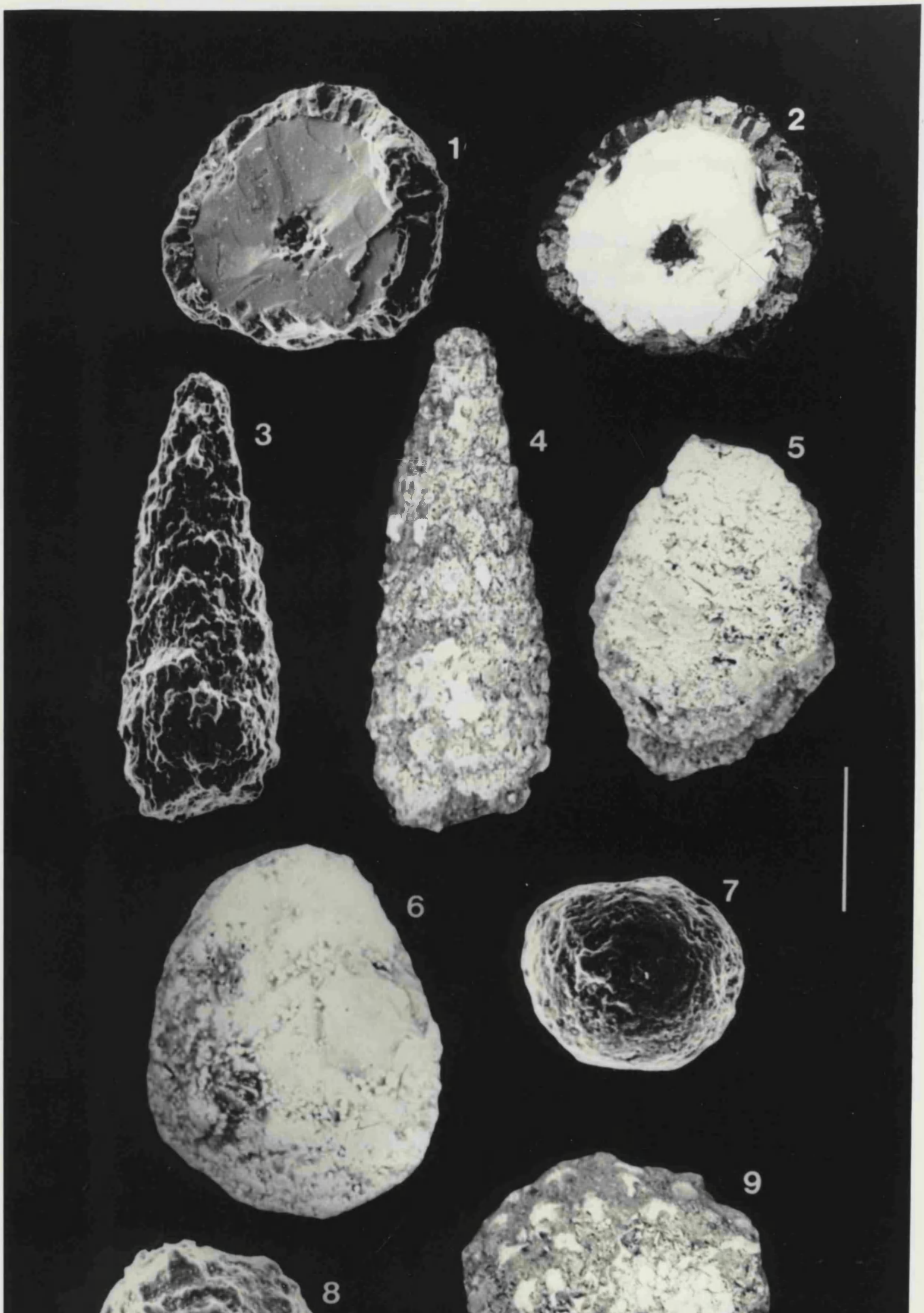
B) Pyrite.

Pyrite has been reported from many kinds of rocks of pre-Cambrian to Holocene age

Fig. 7.13 Specimens used for Electron Microprobe analyses

Length of scale in right = number of μm cited for each illustration.

1. Specimen 1, sc. 86.
2. Specimen 1, back-scatter SEM photograph, sc. 86.
3. Specimen 2, sc. 106.
4. Specimen 2, back-scatter SEM photograph, sc. 94.
5. Specimen 3, back-scatter SEM photograph, sc. 71.
6. Specimen 4, back-scatter SEM photograph, sc. 71.
7. Specimen 5, sc. 86.
8. Specimen 6, sc. 86.
9. Specimen 7, back-scatter SEM photograph, sc. 86.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from all over the world (Love & Amstutz, 1966) and under favourable conditions is formed in fresh water, brackish and marine environments.

From recent experiments, considerations of seawater circulation and supply of organic matter suggest that pyritisation should be strongly facies dependant. This also applies to Jurassic shales (Hudson & Palframan, 1969).

The organic matter degradation by sulphate-reducing bacteria produces H_2S ($2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO_3^-$) which reacts with iron to form iron sulphide which later converts into pyrite (Berner, 1970, 1984; Tissot & Welde, 1978). The requirements for the formation of pyrite have given by Berner (1984) as:

a) enough metabolizable organic matter (high content of organic matter existed in the Kimmeridge Clay Formation),

b) presence of dissolved sulphate (marine environment source),

c) reactive iron, and

d) elemental sulphur (seawater sulphate source).

Hudson (1982) emphasized the idea that the presence of pyrite in clay sediments does not necessarily imply a stagnant "euxinic" environment. Pyritised fossils have been found in sediments yielding trace fossils or benthic fauna.

Individual framboids of pyrite, which may range approximately 50-80µm in size, have been found present in many samples from the offshore North Sea Basin. Pyrite overgrowths (termed by Hudson, 1982 as "overpyrite") often occur on the test surface of radiolarian specimens (Pl. 4, Fig. 4). Brett & Speyer (1990, Fig. 2) on their "pyrite taphofacies model" postulated that disseminated framboidal pyrite is favoured by the following conditions:

a) anoxic sediment,

b) anaerobic overlying water, and

c) increasing sedimentation.

However, the pyritic replacement of the radiolarian tests may also have occurred later in the diagenetic history of the sediment after the sediment compaction (when silica can be replaced by pyrite or other minerals, Pessagno *et al.*, 1984). It is not possible to distinguish whether a radiolarian fauna has been pyritised immediately after its burial in the sediment or by later replacement of silica by pyrite.

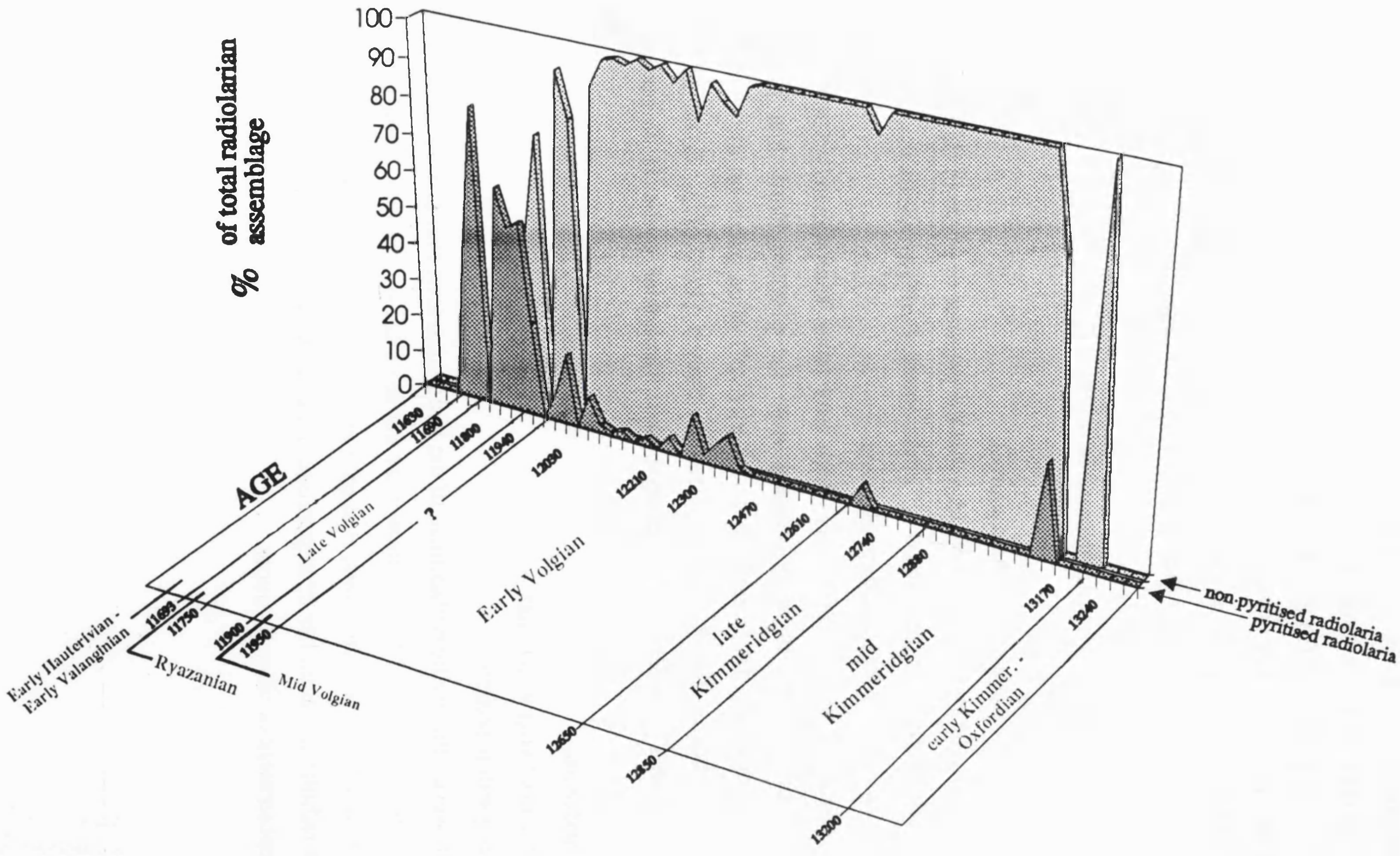


Fig. 7.3 Percentages of pyritised and non-pyritised radiolaria in well 22/21-2.

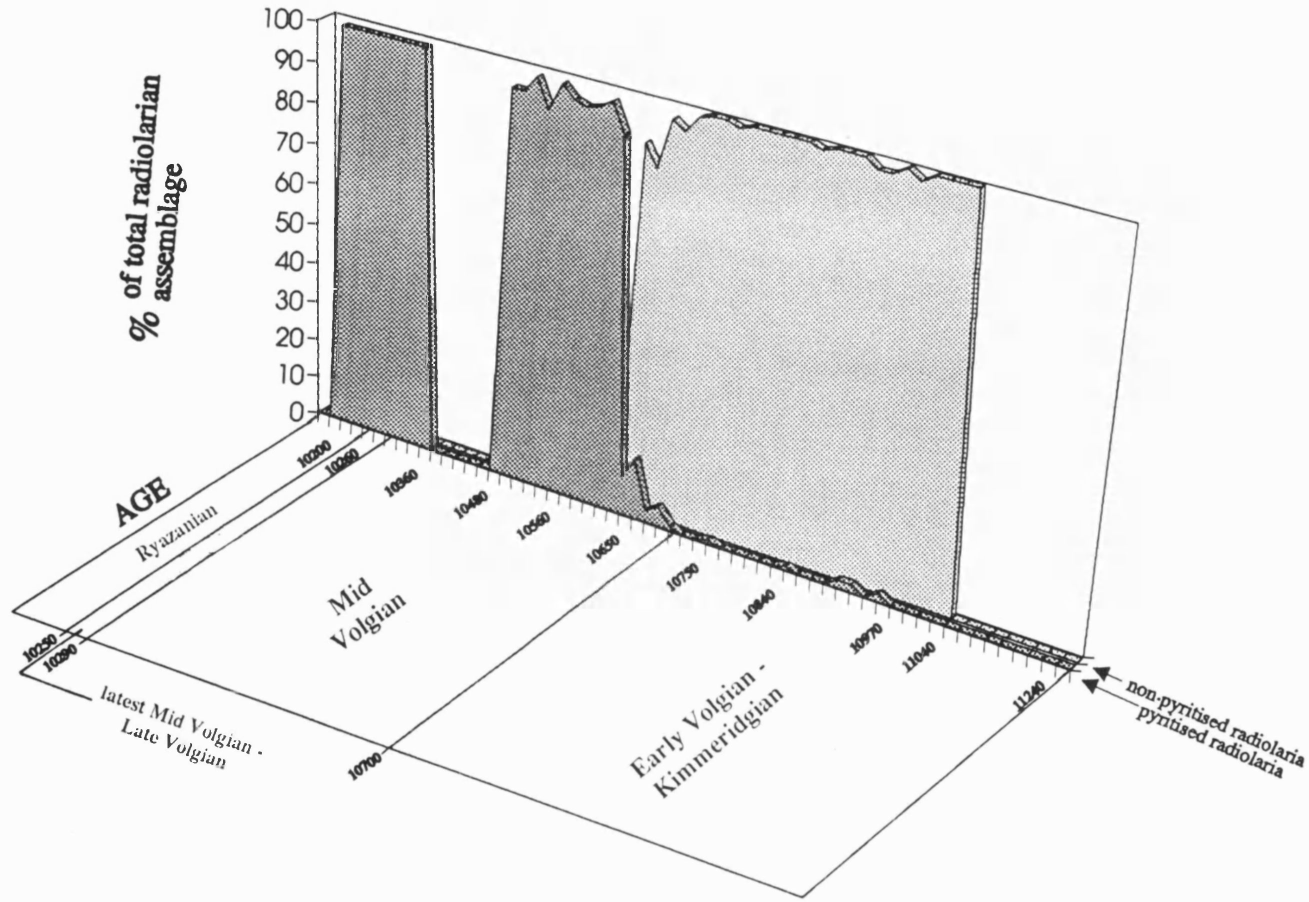


Fig. 7.4 Percentages of pyritised and non-pyritised radiolaria in well 23/27-4.

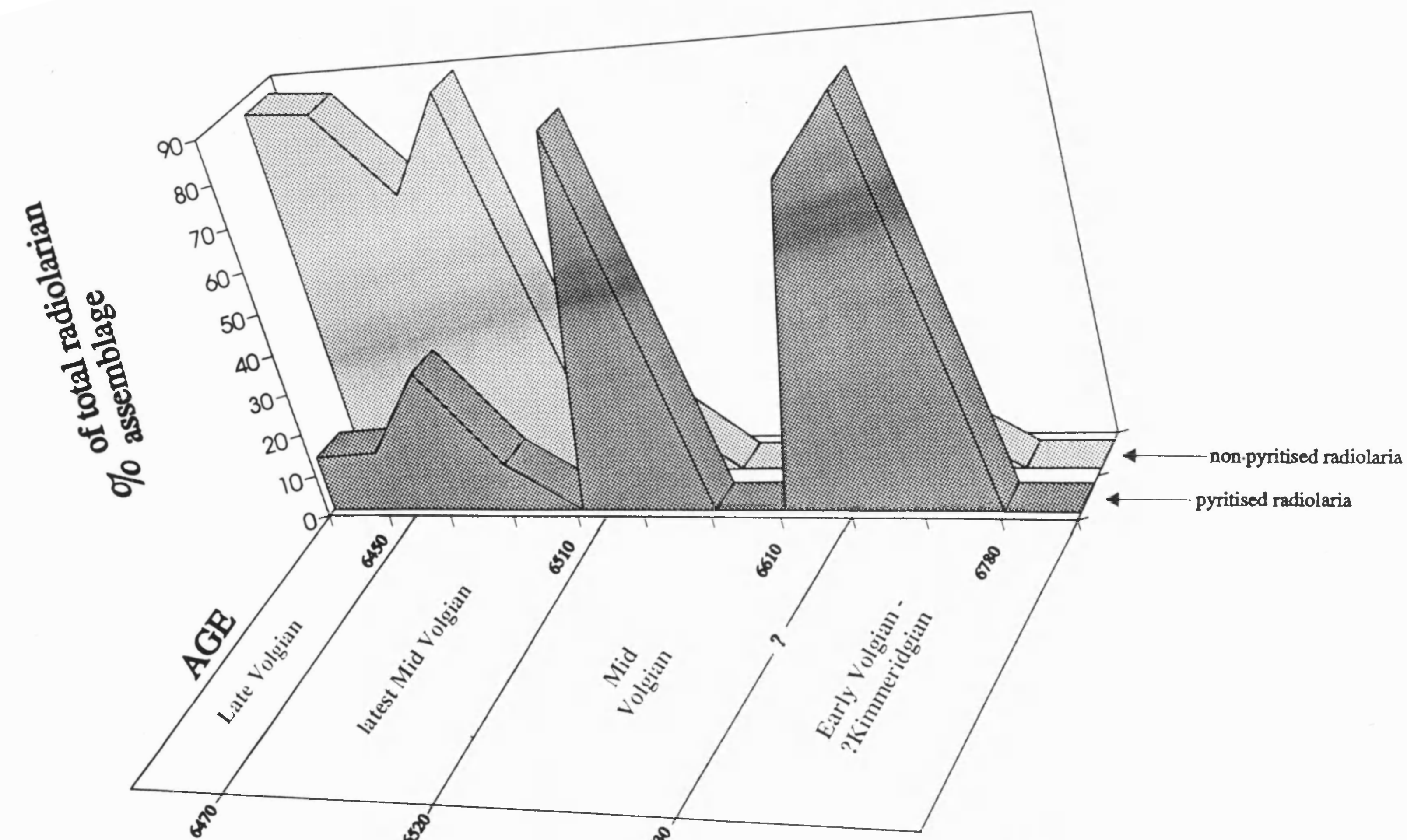


Fig. 7.5 Percentages of pyritised and non-pyritised radiolaria in well 28/5-1.

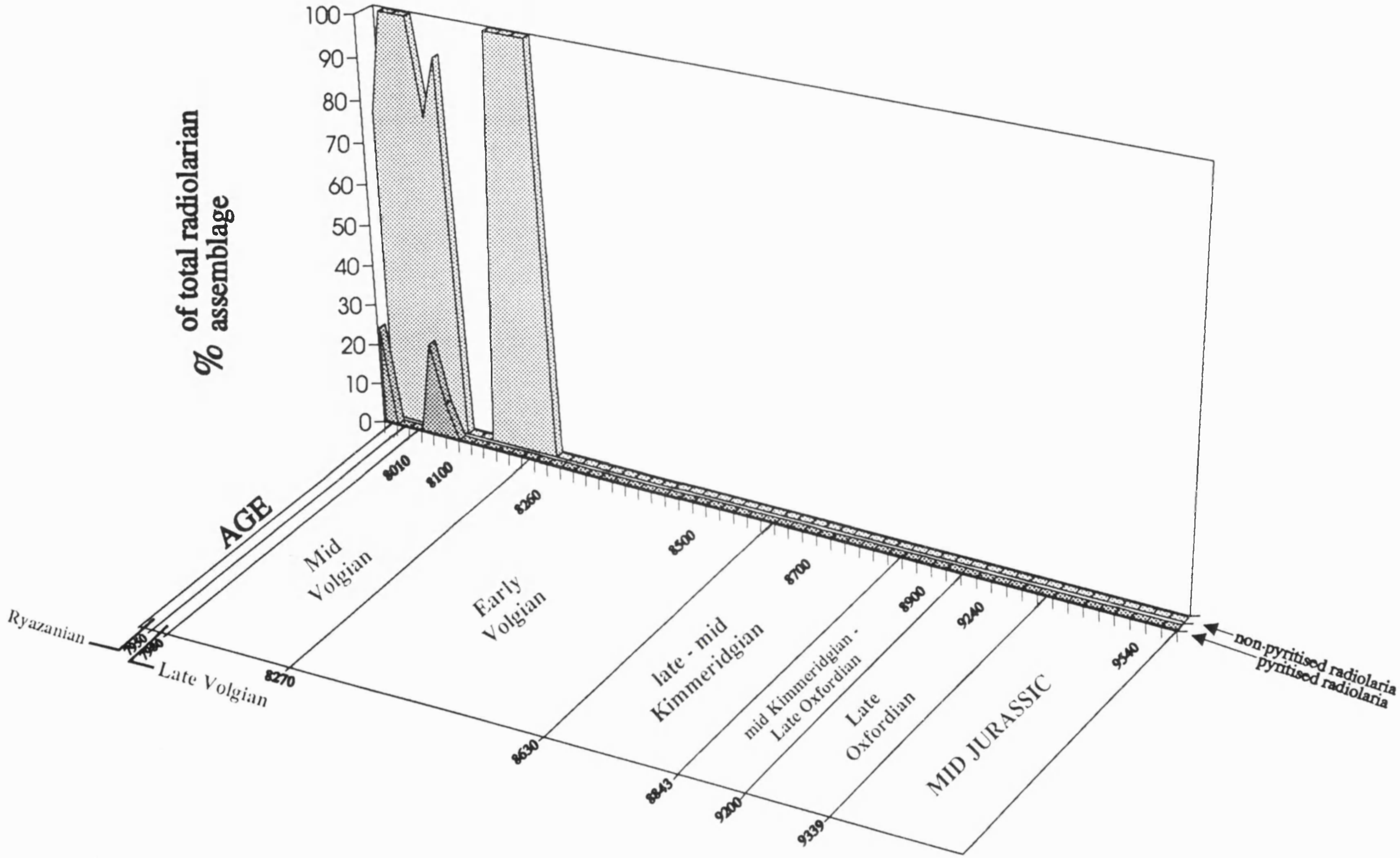


Fig. 7.6 Percentages of pyritised and non-pyritised radiolaria in well 29/12-1.

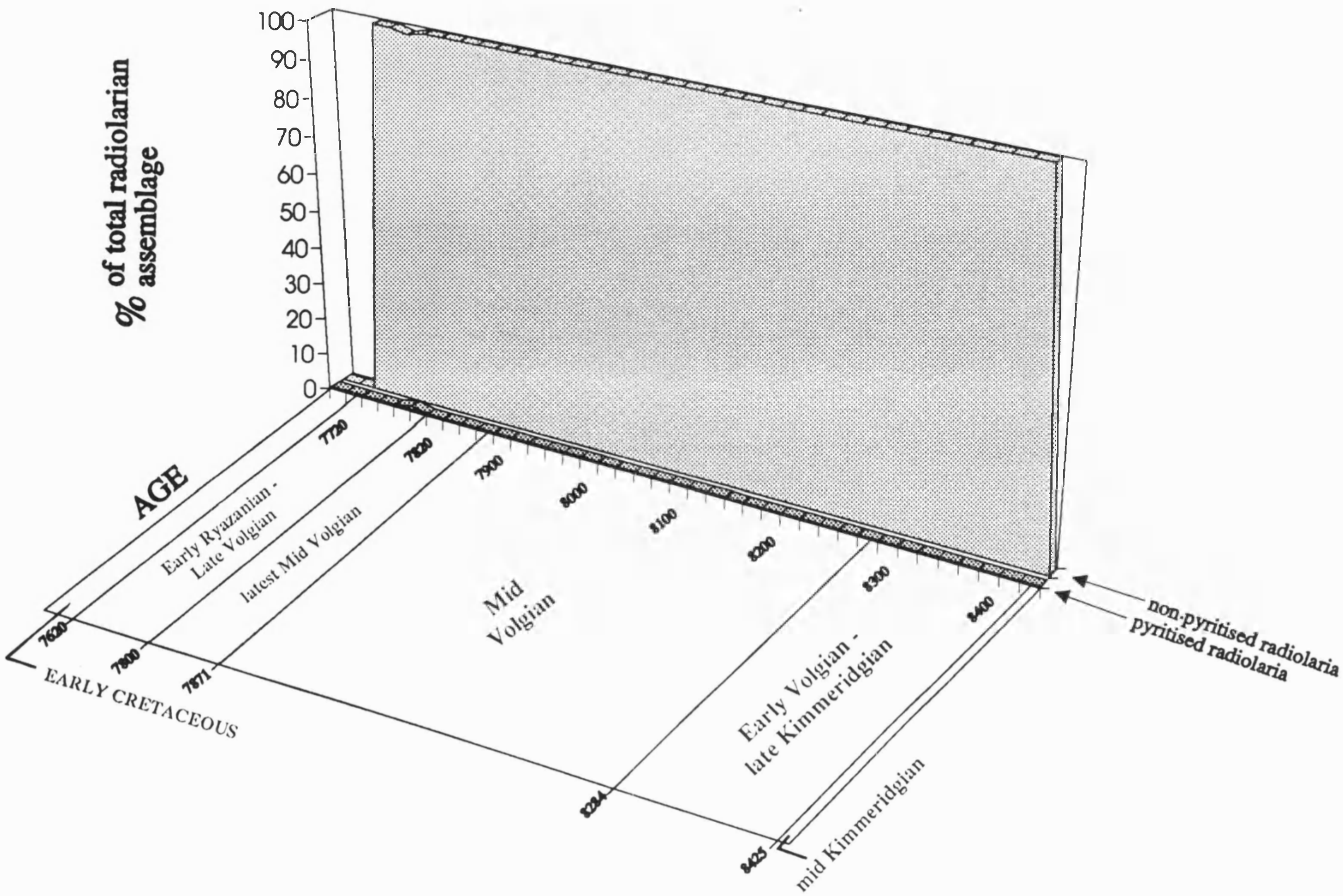


Fig. 7.7 Percentages of pyritised and non-pyritised radiolaria in well 14/18-2.

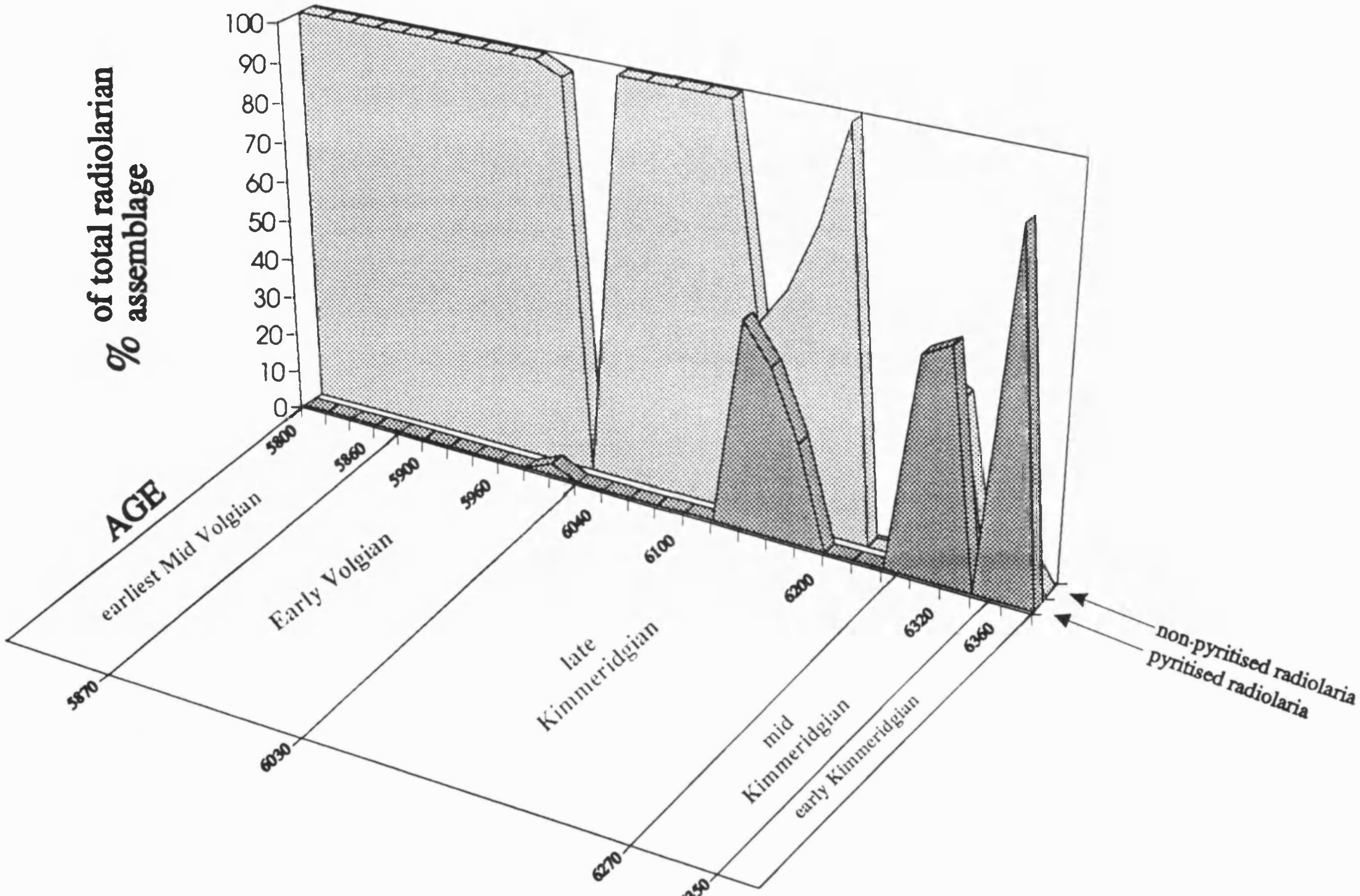


Fig. 7.8 Percentages of pyritised and non-pyritised radiolaria in well 12/28-1.

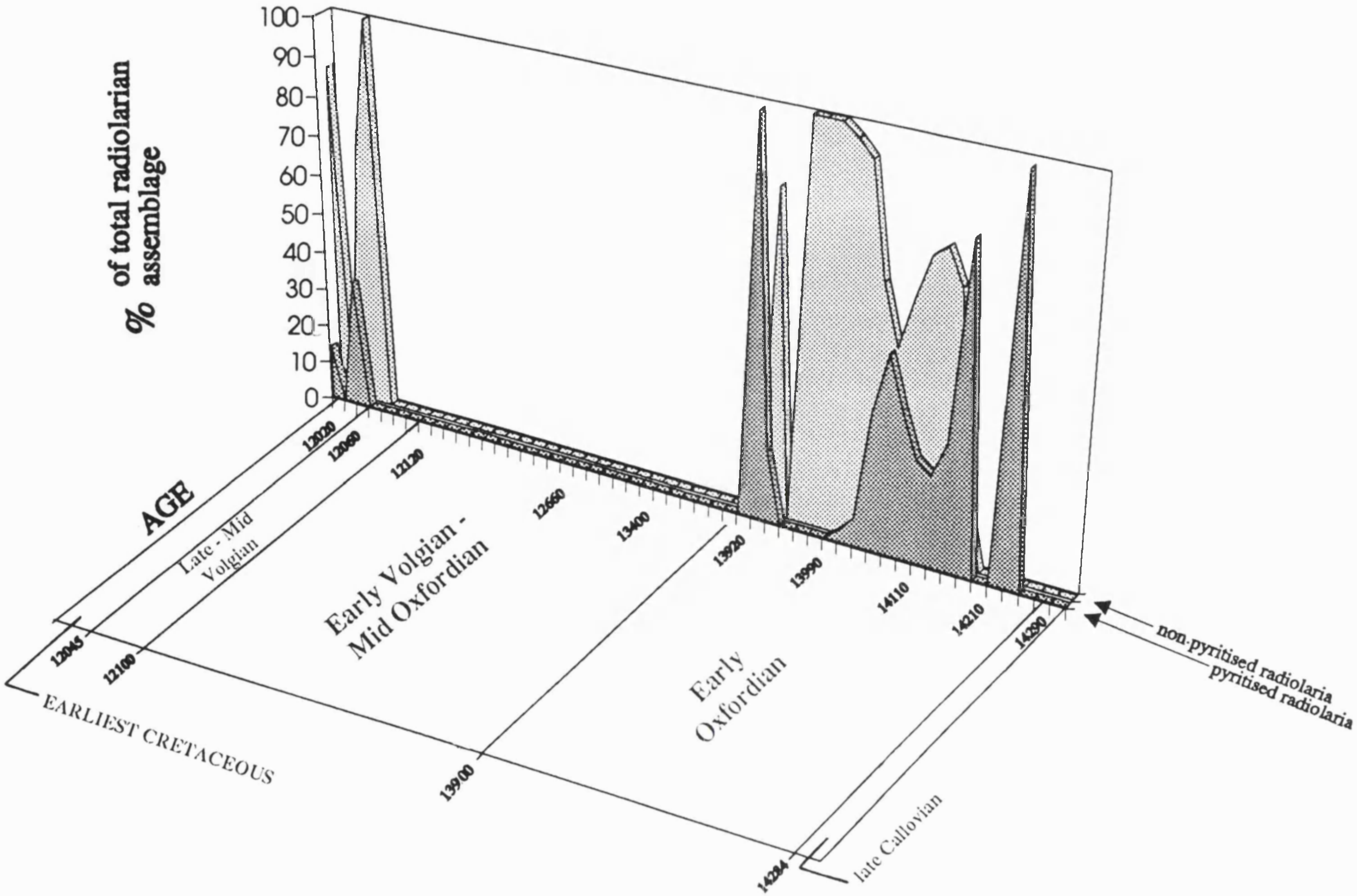


Fig. 7.9 Percentages of pyritised and non-pyritised radiolaria in well 16/17-5.

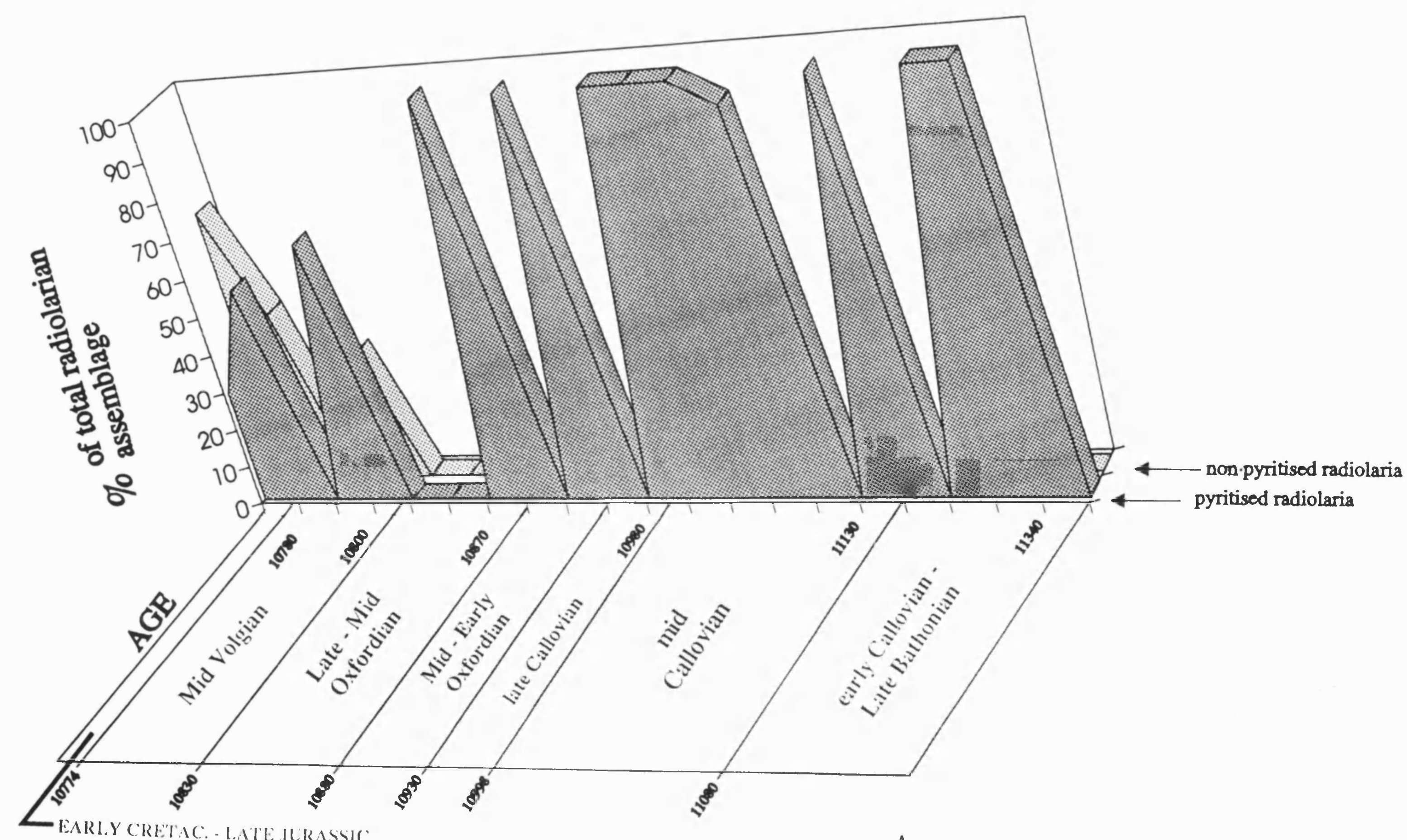


Fig. 7.10 Percentages of pyritised and non-pyritised radiolaria in well 9/18A-4.

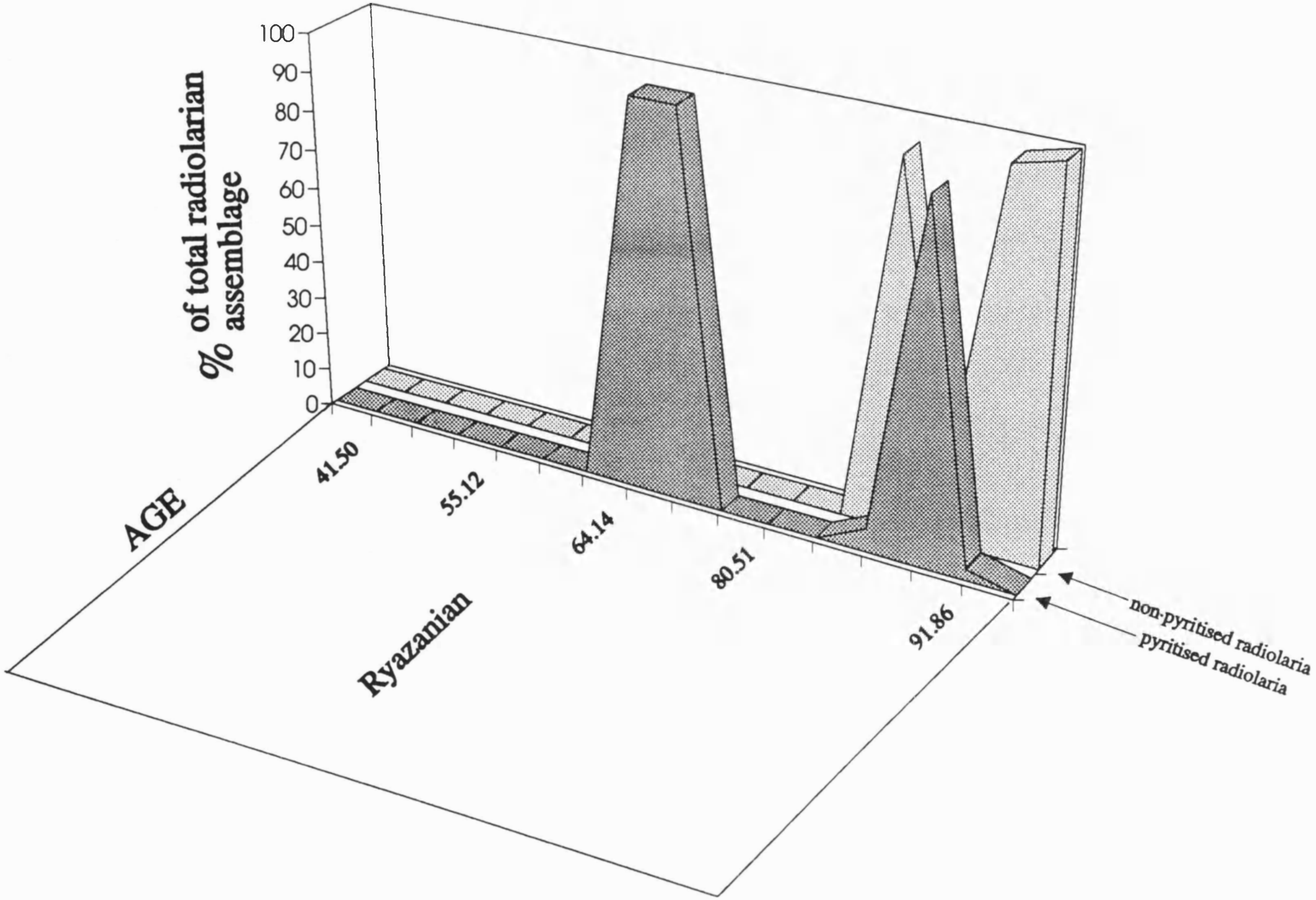


Fig. 7.11 Percentages of pyritised and non-pyritised radiolaria in well 7B.

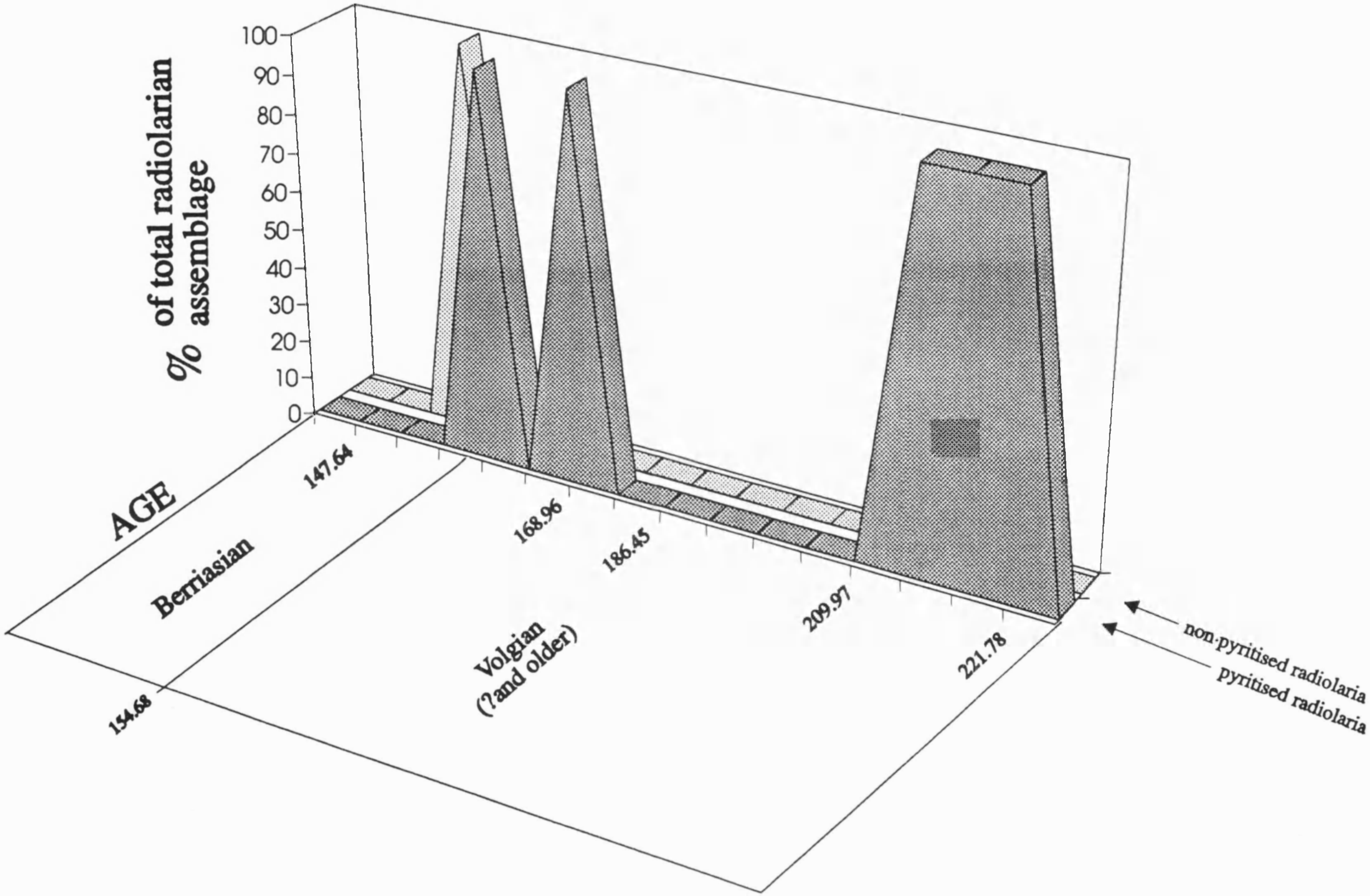
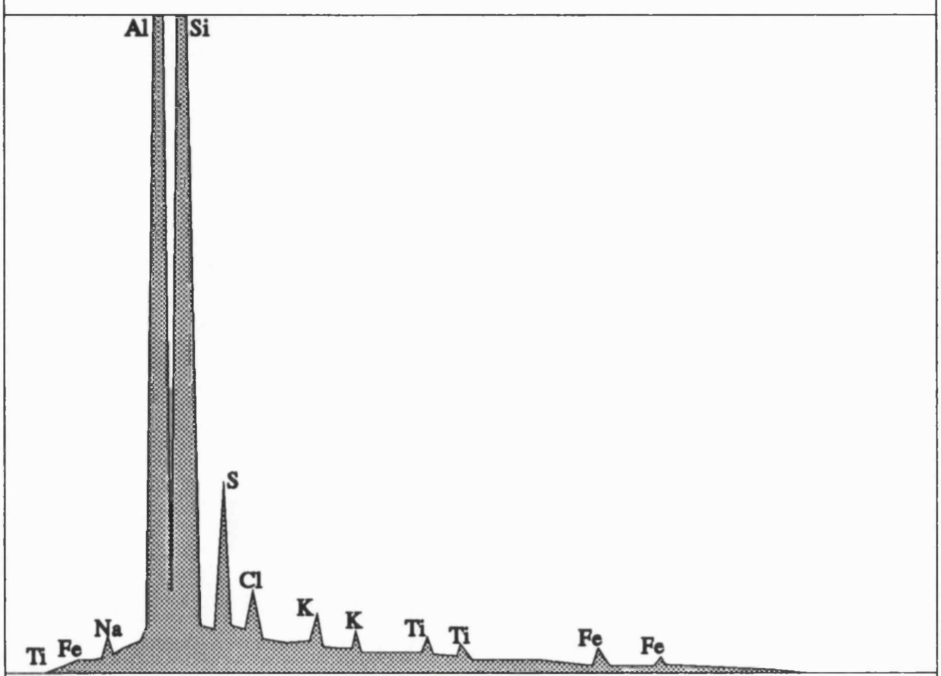


Fig. 7.12 Percentages of pyritised and non-pyritised radiolaria in well 7430/10-U-01.

X-RAY : 0 - 10 keV

Live: 100s Preset: 100s Remaining: 0s

Real: 119s 16% Dead



<-.1 5.20 keV 10.1 >

FS= 2K ch 512= 59 cts

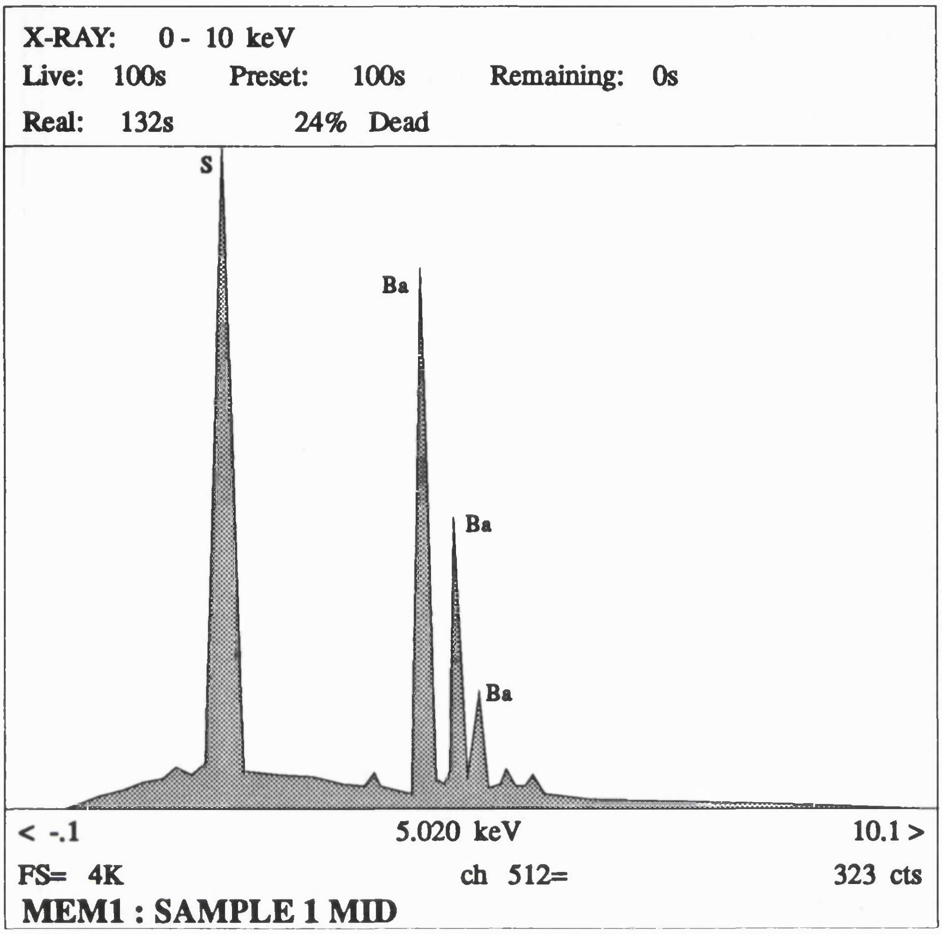
SAMPLE 1 CORE

Spectrum: SAMPLE 1 CORE

Last elmt by STOICHIOMETRY

ELMT	ZAF	%ELMT	ATOM.%		%OXIDE	FORMULA
SiK : 1	.852	16.257	17.341	Si1O2	34.777	2.770
TiK : 1	.827	.356	.223	Ti1O2	.594	.036
AlK : 1	.961	14.618	16.235	Al2O3	27.622	2.593
FeK : 1	.952	1.136	.610	Fe1O1	1.462	.097
MnK : 1	.807	.087	.047	Mn1O1	.112	.008
NiK : 1	.821	.000	.000	Ni1O1	.000	.000
CrK : 1	.828	.000	.000	Cr2O3	.000	.000
MgK : 1	1.012	.162	.200	Mg1O1	.269	.032
CaK : 1	.962	.216	.162	Ca1O1	.303	.026
K K : 1	.986	.388	.297	K2O1	.467	.047
NaK : 1	.946	.505	.658	Na2O1	.681	.105
S K : 1	.816	1.739	1.625	S1O1	2.606	.260
O K : 1	.000	33.429	62.602			10.000
TOTAL		68.893	100.000		68.893	5.974

Fig. 7.14 Results of analysis of Specimen 1 (SAMPLE 1 CORE).

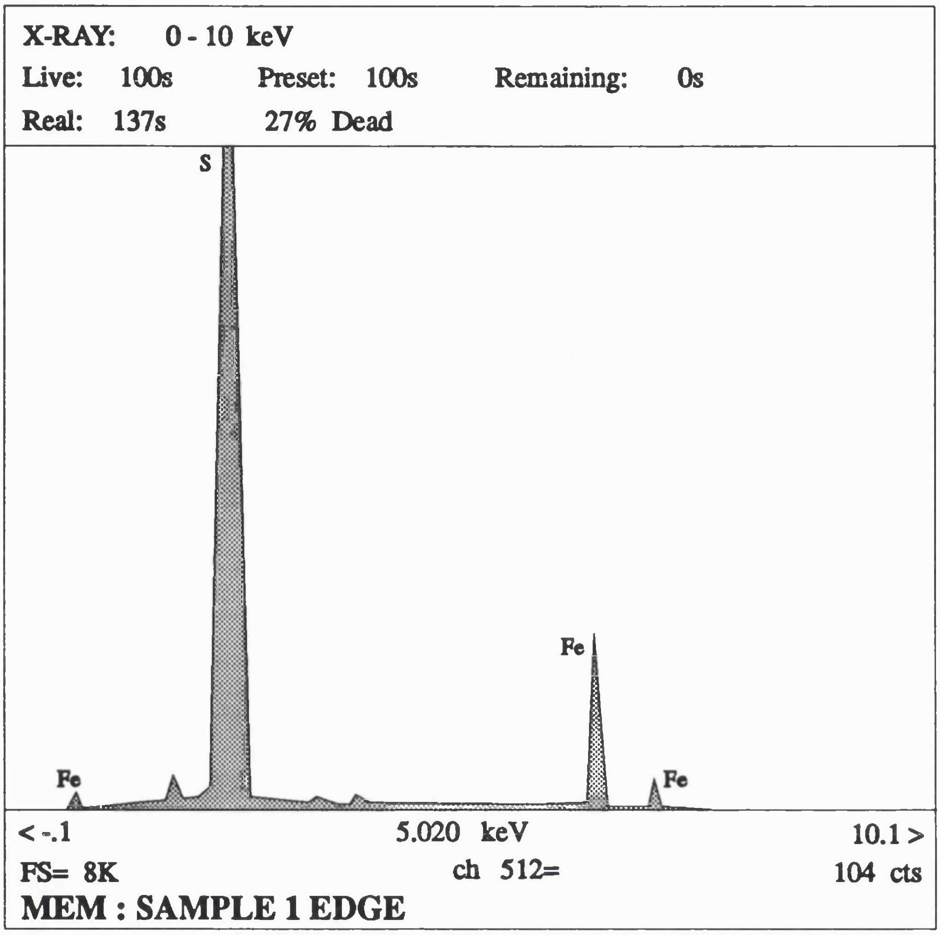


Spectrum: SAMPLE 1 MID

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	.835	.219	.484	Si1O2	.468	.097
AlK : 1	.672	.092	.211	Al2O3	.173	.043
TiK : 1	1.023	.164	.212	Ti1O2	.273	.043
FeK : 1	1.129	.037	.041	Fe1O1	.047	.008
MnK : 1	.945	.038	.043	Mn1O1	.049	.009
NiK : 1	1.020	.000	.000	Ni1O1	.000	.000
CrK : 1	.970	.000	.000	Cr2O3	.000	.000
CaK : 1	1.198	.001	.001	Ca1O1	.001	.000
MgK : 1	.662	.058	.147	Mg1O1	.096	.030
K K : 1	1.195	.062	.098	K2O1	.074	.020
NaK : 1	.680	.879	2.374	Na2O1	1.185	.479
BaL : 1	1.063	49.065	22.185	Ba1O1	54.781	4.472
S K : 1	.993	12.578	24.364	S1O1	18.856	4.911
ClK : 1	.987	.131	.230	Cl-O1	.101	.046
O K : 1	.000	12.782	49.611			10.000
TOTAL		76.105	100.000		76.105	10.157

Fig. 7.15 Results of analysis of Specimen 1 (SAMPLE 1 MID).

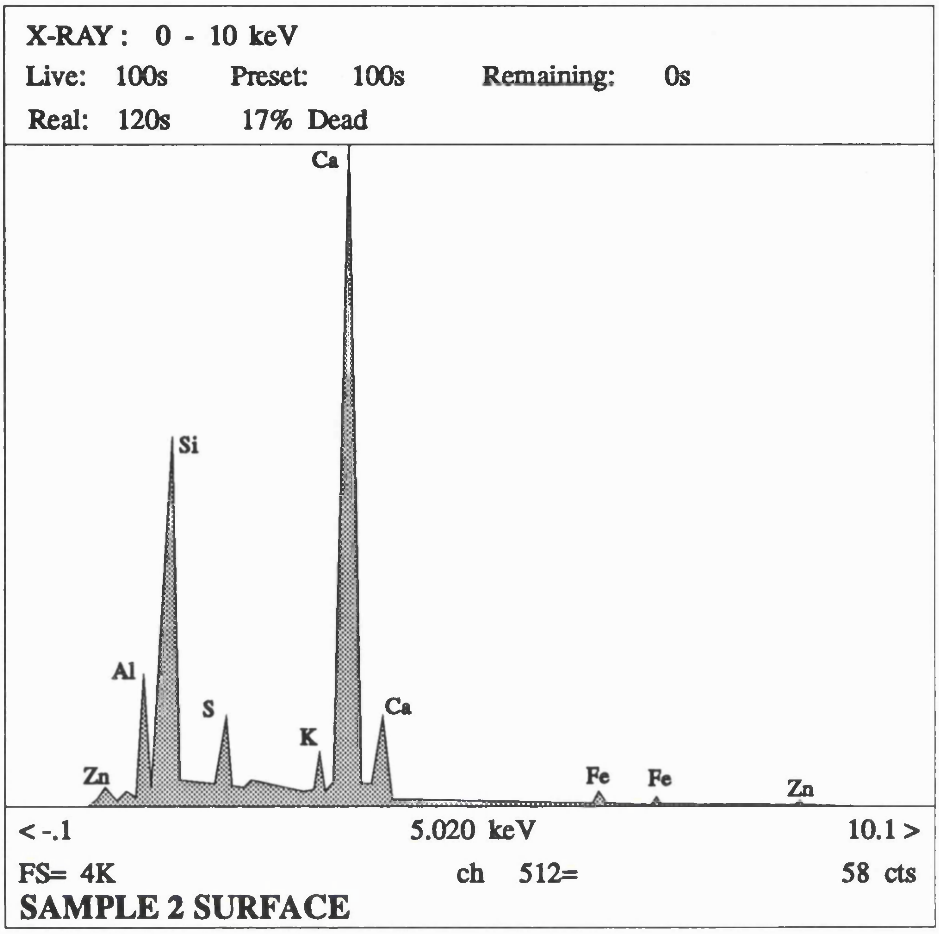


Spectrum: SAMPLE 1 EDGE

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	.937	.941	.803	Si1O2	2.012	.160
AlK : 1	.811	.169	.150	Al2O3	.319	.030
TiK : 1	.880	.037	.019	Ti1O2	.062	.004
FeK : 1	1.005	36.130	15.521	Fe1O1	46.480	3.091
MnK : 1	.850	.029	.012	Mn1O1	.037	.002
NiK : 1	.853	.051	.021	Ni1O1	.065	.004
CrK : 1	.925	.000	.000	Cr2O3	.000	.000
CaK : 1	.991	.173	.103	Ca1O1	.242	.021
MgK : 1	.783	.184	.181	Mg1O1	.305	.036
K K : 1	1.000	.269	.165	K2O1	.324	.033
NaK : 1	.658	.488	.509	Na2O1	.658	.101
BaK : 1	.916	.040	.007	Ba1O1	.045	.001
S K : 1	.979	43.030	32.203	S1O1	64.505	6.414
ClK : 1	.836	.140	.095	Cl-O1	.108	.019
O K : 1	.000	33.482	50.209			10.000
TOTAL		115.163	100.000		115.163	9.917

Fig. 7.16 Results of analysis of Specimen 1 (SAMPLE 1 EDGE).



Spectrum: SAMPLE 2 SURFACE

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM.%		% OXIDE	FORMULA
SiK : 1	.939	6.192	10.058	Si1O2	13.245	1.836
AlK : 1	.879	2.562	4.334	Al2O3	4.841	.791
TiK : 1	.798	.091	.087	Ti1O2	.152	.016
FeK : 1	.959	1.031	.843	Fe1O1	1.327	.154
MnK : 1	.807	.103	.086	Mn1O1	.133	.016
NiK : 1	.835	.000	.000	Ni1O1	.000	.000
CrK : 1	.819	.000	.000	Cr2O3	.000	.000
CaK : 1	1.006	19.774	22.514	Ca1O1	27.668	4.110
MgK : 1	.889	.347	.652	Mg1O1	.576	.119
K K : 1	1.107	.898	1.048	K2O1	1.081	.191
NaK : 1	.820	1.666	3.308	Na2O1	2.246	.604
BaL : 1	.828	.000	.000	Ba1O1	.000	.000
S K : 1	.929	1.340	1.907	S1O1	2.008	.348
ClK : 1	.956	.305	.393	Cl-O1	.236	.072
O K : 1	.000	19.205	54.773			10.000
TOTAL		53.514	100.000		53.514	8.257

Fig. 7.17 Results of analysis of Specimen 2 (SAMPLE 2 SURFACE).

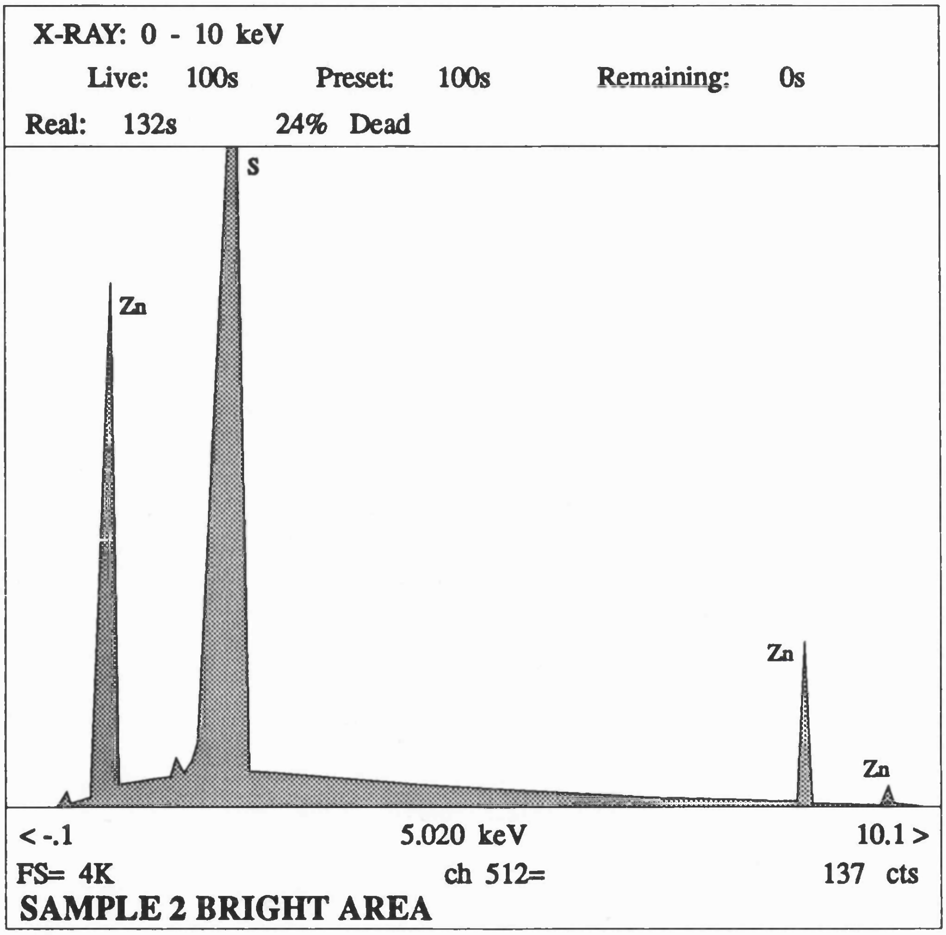
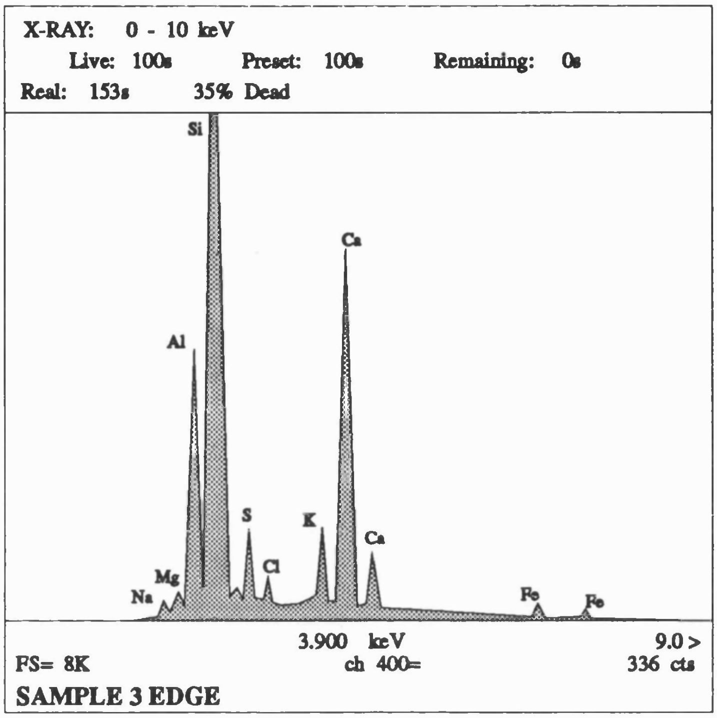


Fig. 7.18 Results of analysis of Specimen 2 (SAMPLE 2 BRIGHT AREA).



Spectrum: SAMPLE 3 EDGE

Last elmt by STOICHIOMETRY

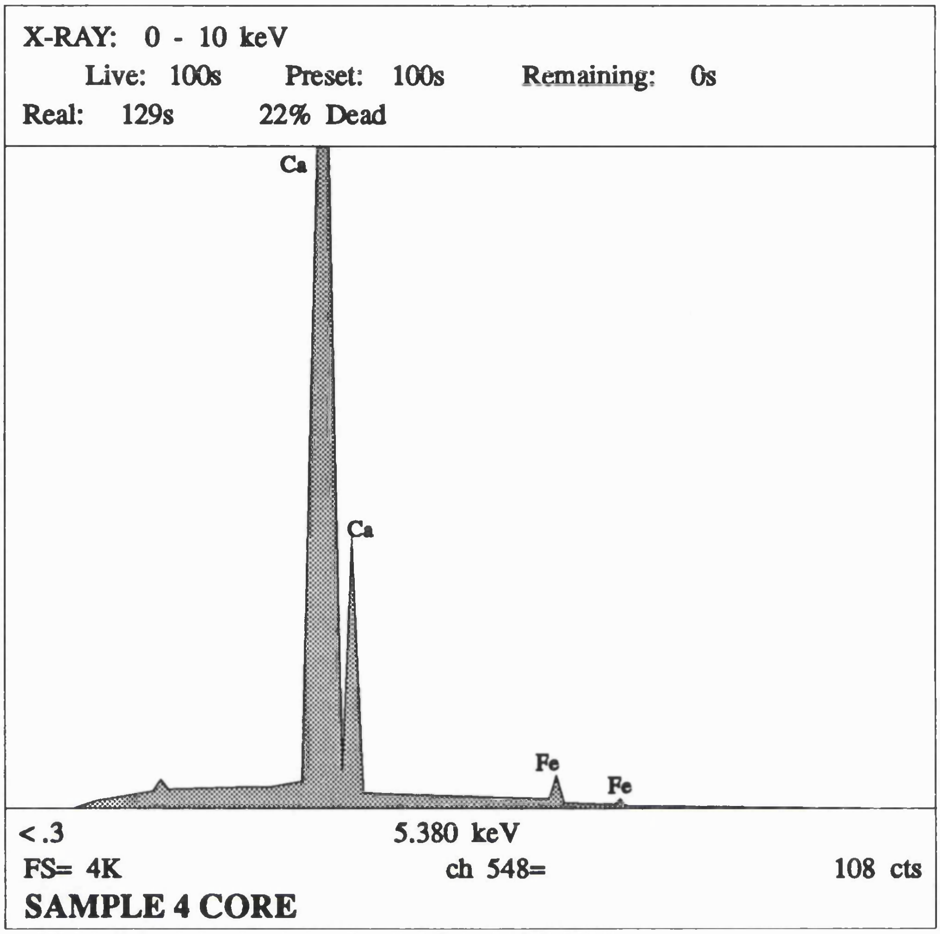
ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	.927	37.437	17.217	Si1O2	80.085	2.916
AlK : 1	.914	14.749	7.062	Al2O3	27.869	1.196
TiK : 1	.811	.106	.029	Ti1O2	.177	.005
FeK : 1	.954	3.395	.785	Fe1O1	4.368	.133
MnK : 1	.806	.000	.000	Mn1O1	.000	.000
NiK : 1	.827	.022	.005	Ni1O	.028	.001
CrK : 1	.822	.122	.030	Cr2O3	.178	.005
CaK : 1	.975	28.989	9.343	Ca1O1	40.561	1.582
MgK : 1	.943	1.202	.639	Mg1O1	1.993	.108
K K : 1	1.034	5.089	1.681	K2O1	6.131	.285
NaK : 1	.877	3.563	2.002	Na2O1	4.803	.339
BaL : 1	.841	.102	.010	Ba1O1	.114	.002
S K : 1	.867	3.918	1.579	S1O1	5.873	.267
ClK : 1	.901	1.581	.576	Cl-O1	1.224	.098
O K : 1	.000	73.129	59.043			10.000
TOTAL		173.404	100.000		173.404	6.937

Spectrum: SAMPLE 3 CORE

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	.976	.536	.690	Si1O2	1.148	.138
AlK : 1	.867	.074	.099	Al2O3	.140	.020
TiK : 1	.780	.000	.000	Ti1O2	.000	.000
FeK : 1	.964	1.013	.655	Fe1O1	1.304	.131
MnK : 1	.808	.073	.048	Mn1O1	.095	.010
NiK : 1	.846	.012	.008	Ni1O	.016	.002
CrK : 1	.814	.074	.051	Cr2O3	.108	.010
CaK : 1	1.050	52.097	46.939	Ca1O1	72.894	9.403
MgK : 1	.862	.028	.041	Mg1O1	.046	.008
K K : 1	1.269	.408	.377	K2O1	.491	.075
NaK : 1	.750	.166	.261	Na2O1	.224	.052
BaL : 1	.808	.000	.000	Ba1O1	.000	.000
S K : 1	1.023	.450	.507	S1O1	.675	.102
ClK : 1	1.060	.394	.401	Cl-O1	.305	.080
O K : 1	.000	22.119	49.922			10.000
TOTAL		77.445	100.000		77.445	10.031

Fig. 7.19 Results of analyses of Specimen 3 (SAMPLE 3 EDGE and SAMPLE 3 CORE).

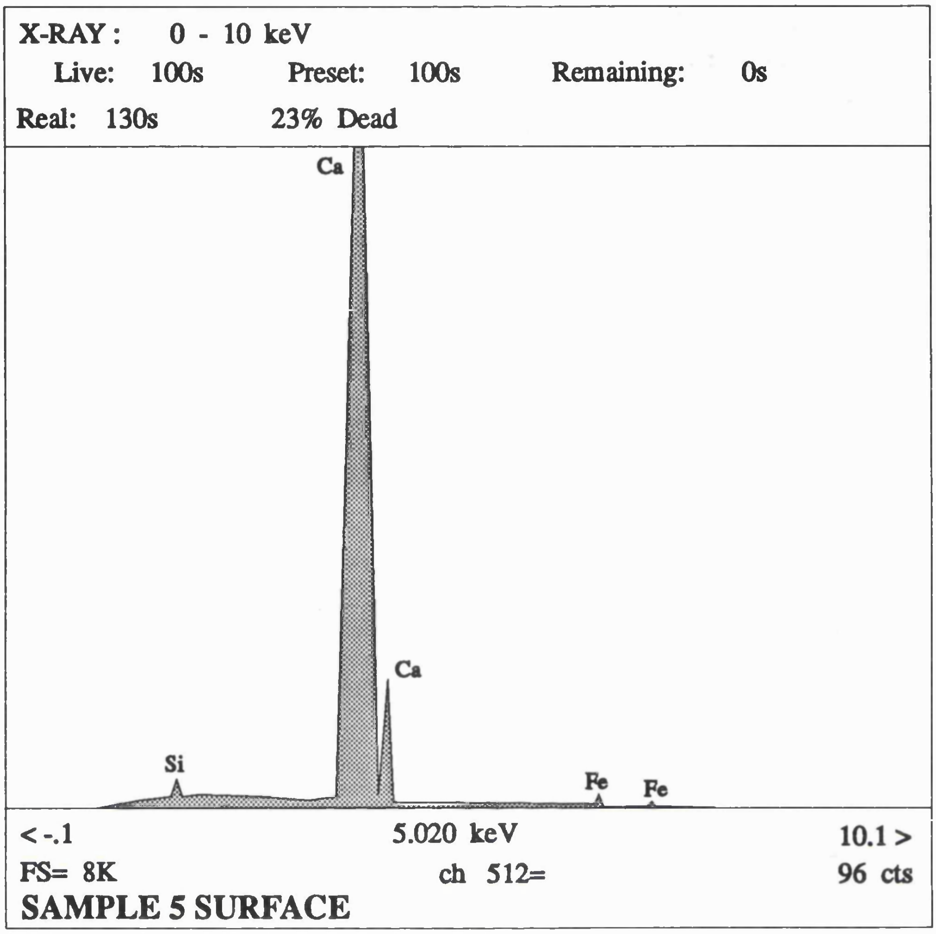


Spectrum: SAMPLE 4 CORE

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	.966	.085	.113	Si1O2	.181	.023
AlK : 1	.852	.026	.036	Al2O3	.049	.007
TiK : 1	.785	.093	.072	Ti1O2	.154	.014
FeK : 1	.969	2.975	1.994	Fe1O1	3.827	.398
MnK : 1	.812	.011	.007	Mn1O1	.014	.001
NiK : 1	.848	.235	.150	Ni1O1	.300	.030
CrK : 1	.820	.005	.004	Cr2O3	.007	.001
CaK : 1	1.057	50.184	46.868	Ca1O1	70.217	9.368
MgK : 1	.844	.206	.318	Mg1O1	.342	.064
K K : 1	1.279	.109	.105	K2O1	.132	.021
NaK : 1	.728	.086	.140	Na2O1	.116	.028
BaL : 1	.815	.000	.000	Ba1O1	.000	.000
S K : 1	1.022	.127	.149	S1O1	.191	.030
ClK : 1	1.063	.011	.012	Cl-O1	.009	.002
O K : 1	.000	21.386	50.033			10.000
TOTAL		75.539	100.000		75.539	9.987

Fig. 7.20 Results of analysis of Specimen 4 (SAMPLE 4 CORE).

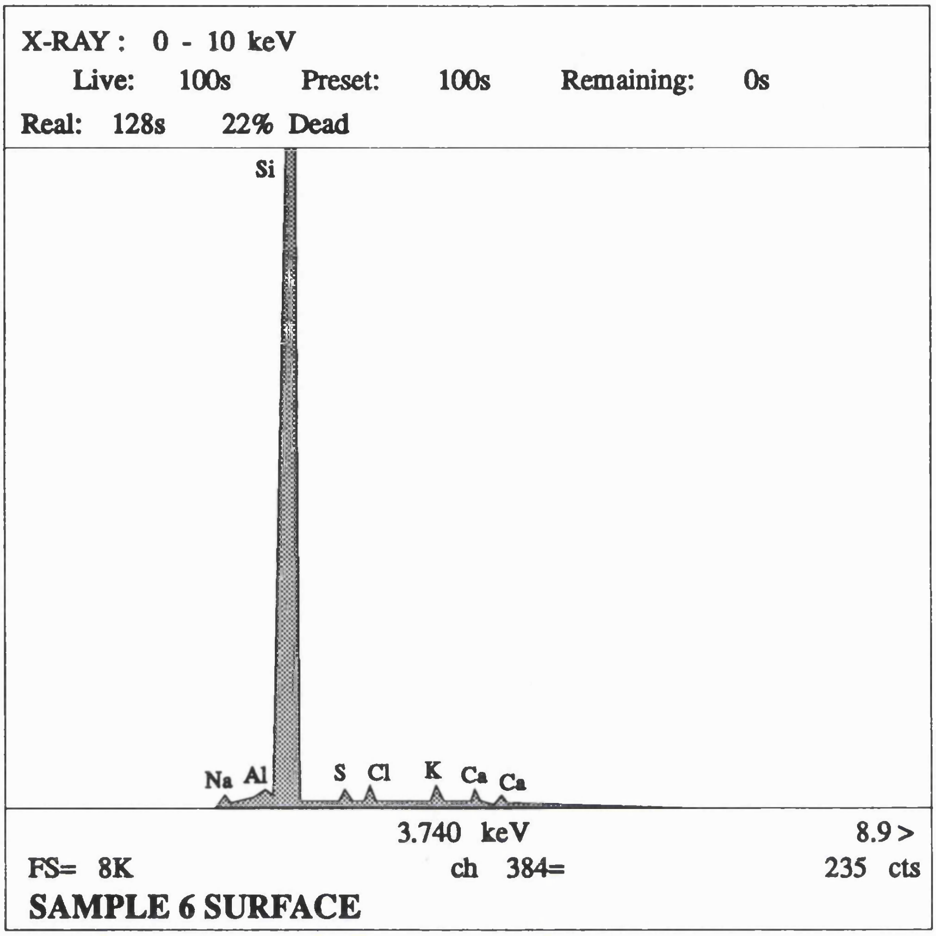


Spectrum: SAMPLE 5 SURFACE

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	.971	.789	1.064	Si1O2	1.689	.212
AlK : 1	.863	.268	.376	Al2O3	.506	.075
TiK : 1	.780	.000	.000	Ti1O2	.000	.000
FeK : 1	.964	.764	.518	Fe1O1	.983	.103
MnK : 1	.807	.146	.101	Mn1O1	.188	.020
NiK : 1	.845	.055	.036	Ni1O1	.071	.007
CrK : 1	.813	.000	.000	Cr2O3	.000	.000
CaK : 1	1.050	48.558	45.888	Ca1O1	67.943	9.142
MgK : 1	.861	.252	.393	Mg1O1	.419	.078
K K : 1	1.267	.268	.259	K2O1	.322	.052
NaK : 1	.754	.433	.713	Na2O1	.583	.142
BaL : 1	.809	.042	.012	Ba1O1	.047	.002
S K : 1	1.017	.165	.195	S1O1	.247	.039
ClK : 1	1.057	.234	.250	Cl-O1	.181	.050
O K : 1	.000	21.205	50.196			10.000
TOTAL		73.179	100.000		73.179	9.922

Fig. 7.21 Results of analysis of Specimen 5 (SAMPLE 5 SURFACE).

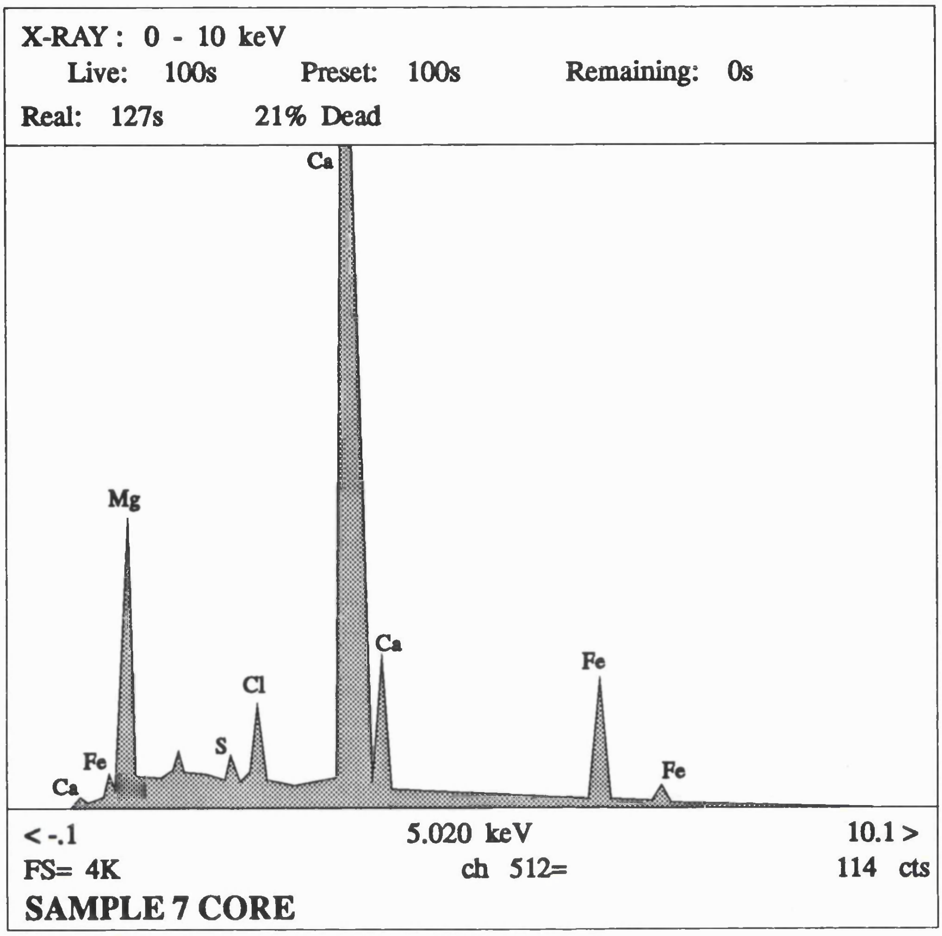


Spectrum: SAMPLE 6 SURFACE

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	1.022	42.775	32.206	Si1O2	91.504	4.902
AlK : 1	.970	.360	.282	Al2O3	.681	.043
TiK : 1	.818	.066	.029	Ti1O2	.110	.004
FeK : 1	.944	.021	.008	Fe1O1	.027	.001
MnK : 1	.800	.065	.025	Mn1O1	.084	.004
NiK : 1	.815	.043	.015	Ni1O1	.055	.002
CrK : 1	.817	.000	.000	Cr2O3	.000	.000
CaK : 1	.951	.637	.336	Ca1O1	.891	.051
MgK : 1	1.006	.008	.007	Mg1O1	.013	.001
K K : 1	.975	.505	.273	K2O1	.609	.042
NaK : 1	.940	.661	.608	Na2O1	.890	.092
BaL : 1	.848	.070	.011	Ba1O1	.078	.002
S K : 1	.795	.217	.143	S1O1	.325	.022
ClK : 1	.847	.593	.354	Cl-O1	.459	.054
O K : 1	.000	49.705	65.703			10.000
TOTAL		95.725	100.000		95.725	5.220

Fig. 7.22 Results of analysis of Specimen 6 (SAMPLE 6 SURFACE).

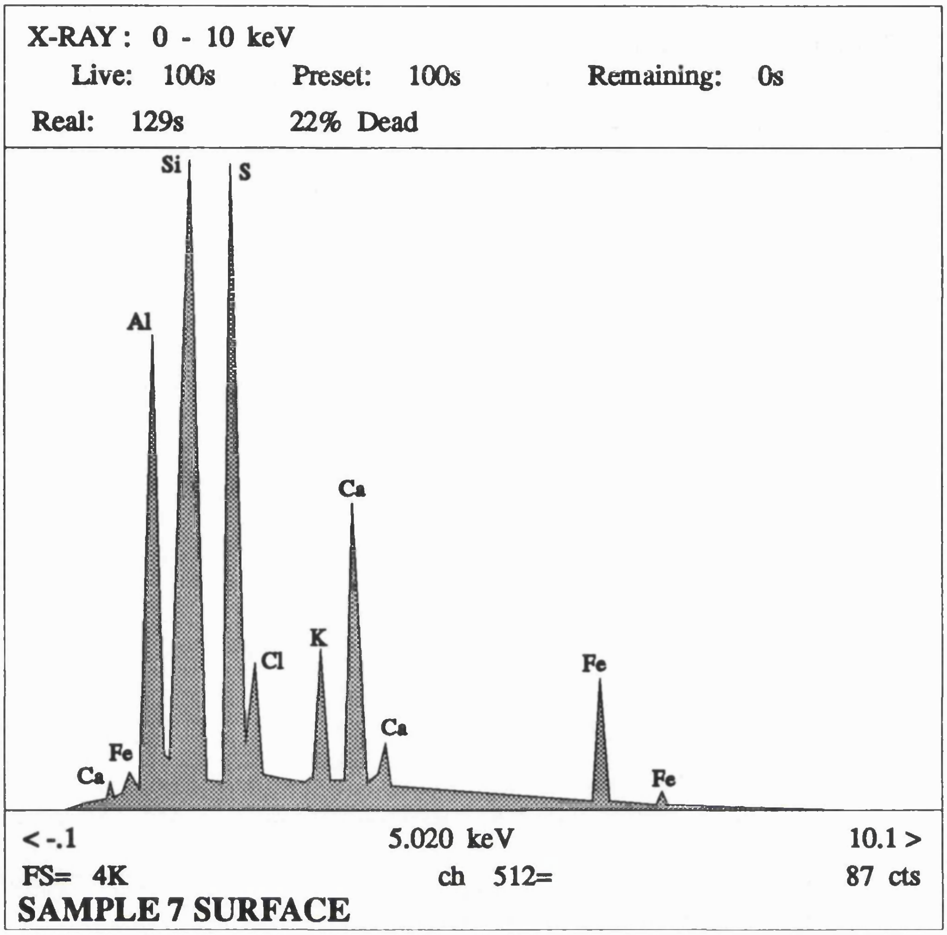


Spectrum: SAMPLE 7 CORE

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	.874	.575	.722	Si1O2	1.231	.149
AlK : 1	.746	.153	.200	Al2O3	.289	.041
TiK : 1	.822	.000	.000	Ti1O2	.000	.000
FeK : 1	.980	10.538	6.653	Fe1O1	13.557	1.375
MnK : 1	.825	.210	.135	Mn1O1	.271	.028
NiK : 1	.846	.000	.000	Ni1O1	.000	.000
CrK : 1	.852	.018	.012	Cr2O3	.027	.003
CaK : 1	1.035	28.108	24.729	Ca1O1	39.329	5.112
MgK : 1	.822	9.523	13.812	Mg1O1	15.790	2.855
K K : 1	1.137	.344	.310	K2O1	.414	.064
NaK : 1	.727	1.834	2.813	Na2O1	2.473	.582
BaL : 1	.854	.092	.024	Ba1O1	.103	.005
S K : 1	.956	.487	.536	S1O1	.730	.111
ClK : 1	.991	1.691	1.682	Cl-O1	1.310	.348
O K : 1	.000	21.949	48.372			10.000
TOTAL		75.523	100.000		75.523	10.673

Fig. 7.23 Results of analysis of Specimen 7 (SAMPLE 7 CORE).

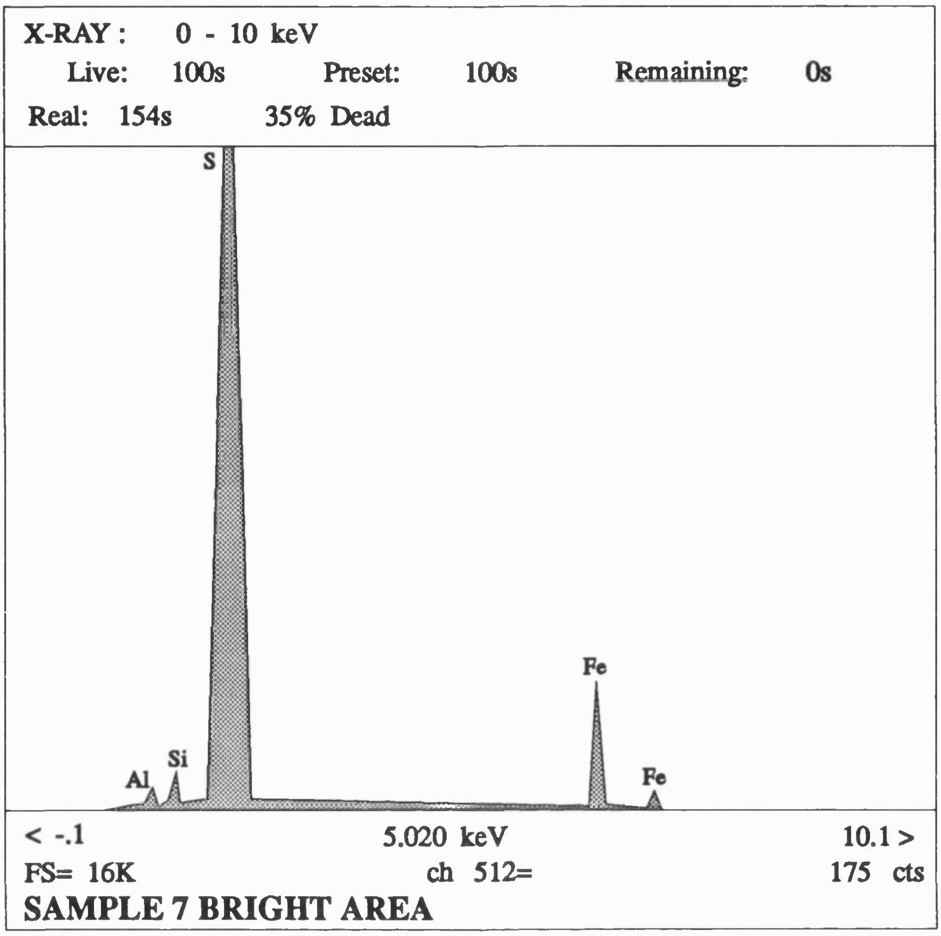


Spectrum: SPECIMEN 7 SURFACE

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	.901	12.341	10.986	Si1O2	26.401	1.968
AlK : 1	.882	9.384	8.679	Al2O3	17.731	1.558
TiK : 1	.835	.140	.073	Ti1O2	.234	.013
FeK : 1	.971	10.337	4.628	Fe1O1	13.299	.829
MnK : 1	.821	.072	.033	Mn1O1	.092	.006
NiK : 1	.835	.216	.092	Ni1O1	.275	.016
CrK : 1	.854	.037	.018	Cr2O3	.055	.003
CaK : 1	.974	7.340	4.579	Ca1O1	10.271	.820
MgK : 1	.895	.708	.728	Mg1O1	1.174	.130
K K : 1	1.010	2.648	1.693	K2O1	3.190	.303
NaK : 1	.805	1.434	1.560	Na2O1	1.993	.279
BaL : 1	.867	.120	.022	Ba1O1	.134	.004
S K : 1	.896	12.361	9.641	S1O1	18.530	1.727
ClK : 1	.876	2.021	1.425	Cl-O1	1.565	.255
O K : 1	.000	35.723	55.826			10.000
TOTAL		94.883	100.000		94.883	7.913

Fig. 7.24 Results of analysis of Specimen 7 (SAMPLE 7 SURFACE).



Spectrum: SAMPLE 7 BRIGHT AREA

Last elmt by STOICHIOMETRY

ELMT	ZAF	% ELMT	ATOM. %		% OXIDE	FORMULA
SiK : 1	.925	2.492	1.449	Si1O2	5.332	.287
AlK : 1	.807	1.909	1.159	Al2O3	3.607	.229
TiK : 1	.882	.013	.005	Ti1O2	.022	.001
FeK : 1	1.007	53.750	15.721	Fe1O1	69.149	3.11
MnK : 1	.851	.000	.000	Mn1O1	.000	.000
NiK : 1	.854	.318	.089	Ni1O1	.405	.018
CrK : 1	.928	.000	.000	Cr2O3	.000	.000
CaK : 1	.994	.569	.232	Ca1O1	.796	.046
MgK : 1	.778	.373	.251	Mg1O1	.619	.050
K K : 1	1.005	.658	.275	K2O1	.792	.054
NaK : 1	.654	.930	.661	Na2O1	1.254	.131
BaL : 1	.918	.000	.000	ba1o1	.000	.000
S K : 1	.971	57.488	29.291	S1O1	86.179	5.799
ClK : 1	.845	.774	.357	Cl-O1	.600	.071
O K : 1	.000	49.478	50.514			10.000
TOTAL		168.754	100.000		168.754	9.796

Fig. 7.25 Results of analysis of Specimen 7 (SAMPLE 7 BRIGHT AREA).

CHAPTER 8

SYSTEMATIC PALAEONTOLOGY

8.1 Introduction

In 1887 Haeckel proposed a classification for radiolaria stressing the shape and geometry of the test, not taking into account any phylogenetic relationships (the limited palaeontological data and primitive methods of study did not allow so). His scheme, with minor modifications, was followed until the 1950's (e.g. Campbell, 1954) or even the 1970's. Riedel (1967) first expressed strong criticism against Haeckel's classification and suggested that a fundamental revision should be made, a concept agreed by later Mesozoic radiolarian workers. The same worker proposed (1967, 1971) a systematic classification of Polycystine Cenozoic radiolaria on the basis of cephalic features. Empson-Morin (1981) in her work on Cretaceous radiolaria put into question the taxonomic value of the nassellarian cephalic skeletal features. She stated (p. 254) that they "represent an early stage of development in most di- to multicyrtoid nassellarians".

Pessagno (1977c), and Pessagno & Whalen (1982) postulated that the internal structure of the radiolarian test can greatly help towards a more phylogenetic classification of Mesozoic radiolaria. Important examples are the works of: Dumitrica (1970, 1978, 1982) on cryptocephalic and cryptothoracic nassellaria, Eptingiidae and Centrocubidae; Baumgartner (1980) on Hagiastridae; De Wever (in Baumgartner *et al.*, 1981) on Poulpinae; Pessagno & Whalen (1982) on shell structure of nassellarians; Takemura (1986) who proposed a new suprageneric classification using excellent preserved Middle Jurassic nassellarians according to their cephalic skeletal elements; Pessagno *et al.* (1986); Yang & Pessagno (1989); and Kito & De Wever (1990) on Hagiastridae. Since Mesozoic radiolarian faunas are not as well preserved as Cenozoic ones and information on internal structure is limited, problems exist for construction of a phylogenetic classification.

Discussion of the systematics and classification of Mesozoic radiolaria can be found in Pessagno (1977c), Baumgartner (1980) or Zhamoida (1984).

The taxonomy adopted in this study follows the generic classification of Haeckel (1881, 1887), Dumitrica (1970, 1978), Kozlova (in Petrushevskaya & Kozlova, 1972), Foreman (1973), Pessagno (1976, 1977a,b), Pessagno & Whalen (1982), Blome (1984), Takemura (1986), Pessagno & Yang (in Pessagno *et al.*, 1989), Pessagno *et al.* (1993). Open nomenclature has been used where forms are poorly/badly preserved or internal structure has not been observed.

8.2 Remarks on systematics

The genera in the taxonomic part of the present work have been alphabetically ordered, first the genera of the Suborder Spumellariina and then genera of the Suborder Nassellariina, and intervening classificatory levels are not generally used. The taxa have not been studied here on the suprageneric level but a brief note about each family is given within the remarks for every genus.

For each species/morphotype a number has been given which corresponds to the number under which they have been entered for the computer BioGraph program. Morphotypes having this number in **Bold** are those which have been used for the biozonation scheme.

The **Original** and **Emended Diagnoses** for the genera and the **Original Description** of species is given.

Synonymy lists from the published literature are included where applicable.

Dimensions of species/morphotypes have been measured as discussed in Chapter 6. For each photographed, measured, and illustrated specimen a catalogue number has been given (CK no). These numbers and their details can be found on Appendix 2. The abbreviations which have been used are listed below.

Abbreviations used for the dimensions (measured in μm)

(DA)	=	diameter of aperture.
(DC)	=	diameter of cephalis.
(DCC)	=	diameter of central cavity.
(DCC/TD)	=	ratio of diameter of central cavity to test diameter.
(DEP)	=	diameter of equatorial plane.
(DM)	=	diameter of "mammae".
(DPa)	=	diameter of abdominal pore frames.
(DPt)	=	diameter of thoracic pore frames.
(HA)	=	height of abdomen.
(HT)	=	height of thorax.
(LCC)	=	length of central cavity.
(LT)	=	length of test.
(MDP)	=	maximum diameter of pore frames.
(MW)	=	maximum width of test.
(NP)	=	number of projections on lateral view of diameter.
(NPL)	=	number of pore frames on lateral view of diameter.
(TD)	=	test diameter.
(TH)	=	total heigth of test.
(TT)	=	thickness of test.
(WC)	=	width of cephalis.
(WCC)	=	width of central cavity.
(WSB)	=	width of spines at their base
(WTH)	=	width of thorax.

The **Range** of genera/species is the composite range from the published literature or the one given by the original author.

The **Occurrence (literature)** is the composite localities occurrence for the genus/species which have been obtained from various publications.

Under **Occurrence (present work)** is given i) the biozone(s) and the Unitary Associations (only for those used in the biozonation scheme) in which the species/morphotypes are present, and ii) the studied wells/onshore exposure in which the species/morphotypes have been found present.

Open nomenclature has been used as follows:

cf. (proceeding a species name), when the determination is uncertain, owing to poor preservation of the material studied, where the morphotype closely resembles the species holotype.

(?) (following immediately after the genus name), "indicates that the identification of the genus is uncertain" (Bengtson 1988, p. 226), owing to preservational limitations on observation of all diagnostic features of the genus.

" " (enclosing a genus name), when a name is treated as *nomen dubium* (e.g. *Staurosphaera*) or when a new genus should be erected (absence of phylogenetic link between Cenozoic and Mesozoic forms) for the forms (e.g. *Cenodiscus*).

spp. indet., when species are indeterminate (owing to extremely poor preservation).

8.3 Taxonomic contents list

Class ACTINOPODA

Subclass RADIOLARIA

Order POLYCYSTIDA Ehrenberg 1838

Suborder SPUMELLARIINA Ehrenberg 1838

Genus ACAENIOTYLE Foreman

Acaeniotyle Foreman, 1973, p. 258.

Type species. *Xiphosphaera umblicata* Rüst 1898, p. 7, pl. 1, fig. 9.

Original Diagnosis. "Spherical or ellipsoidal shell with a surface of large porous nodes from which two or three spines extend" (Foreman 1973, p. 258).

Range. Upper Callovian to Campanian.

Occurrence. Worldwide.

Remarks. Although Foreman (1973) did not give any detail of the internal structure of the genus, it is clear from various publications & illustrations (e.g. Empson-Morin, 1981 (pl. 3, figs. 8A-D); Baumgartner, 1984a (pl. 1, fig. 4); Ozvoldova & Sykora, 1984 (pl. 1, fig. 2 & 5)) that it consists of a medullary shell which is connected to the cortical (outer) shell with bars.

Differs from *Xiphostylus* Pessagno & Yang in the nature of the test and in lacking latticed protrusions on the base of the spines. Also differs from *Spongoprunum* Haeckel by having polar spines exhibiting alternating ridges and grooves. *Protopsium* Pessagno & Poisson differs from this genus by possessing a compressed test and patagium-like mass supported by secondary spines. Finally, *Acaeniotyle* Foreman differs from *Archaeospongoprunum* Pessagno, by having a spherical to subspherical test instead of ellipsoidal or cylindrical. The genus is assigned to Family Actinommidae Haeckel, emend. Riedel

1. *Acaeniotyle*(?) sp. 1

(Pl. 1, Fig. 1, 2)

Description. Test almost spherical with its smallest dimension in the equatorial plane. Two three-bladed spines are preserved only on their bases. Test surface very nodose with large circular to subcircular pores of various size.

Dimensions (in μm). Average test diameter on equatorial plane (DEP), 177; average width of spines at their base (WSB), 32; maximum diameter of pore frames (MDP), 21.

specimen	Pl. Fig.	DEP	WSB	MDP
CK 1	1, 2	178	39	21
CK 2		175	25	20

Occurrence (present work). Biozone 5. Rare morphotype recovered from the Ryazanian of the Norwegian Sea (well 7B).

Remarks. The morphotype is questionably assigned to the genus owing preservational limitations on observation of the presence of the medullary shell. Differs from *A. umblicata* (Rüst) by having its largest test dimension in the polar plane and the test surface, although very nodose, lacking bumps.

Genus ARCHAEOCENOSPHAERA Pessagno & Yang

Achaeocenosphaera Pessagno & Yang, 1989, p. 203.

Type species. *Archaeocenosphaera ruesti* Pessagno & Yang 1989, p. 203, pl. 1, fig. 9; pl. 9, fig. 23.

Original Diagnosis. "Cortical shell spherical, lacking spines, consisting of two fused latticed layers. Latticed layers comprised of symmetrical polygonal pore frames. Outer latticed layer often quite thick" (Pessagno & Yang, 1989, p. 203)

Range. Palaeozoic?; Triassic to Cretaceous (Pessagno & Yang, 1989).

Occurrence. Tethyan and Boreal realms.

Remarks. Differs from *Cenosphaera* Ehrenberg by possessing thick cortical shell, consisting of two fused latticed layers and usually having symmetrical polygonal pore frames (Pessagno & Yang 1989, p. 203). It is related to *Triactoma* Rüst but differs from it by lacking three secondary spines. Pessagno & Yang (1989, p. 203) observed peaks of abundance in *Archaeocenosphaera* for the Jurassic of North America "often accompanied by a drop in both the abundance and diversity of other radiolarian taxa".

2. *Archaeocenosphaera*(?) sp. 1

(Pl. 1, Fig. 3-7; Pl. 19, Fig. 1)

1989 *Cenosphaera* sp. 2 Dyer & Copestake, p. 226, pl. 1, figs. 9 & 10.

(?) 1989 *Cenosphaera* sp. 1 Dyer & Copestake, p. 226, pl. 1, fig. 11.

Description. Test spherical (or approximately spherical when preservational factors taken into account), lacking spines. Test surface ornamented with a meshwork of polygonal pore frames, usually symmetrically arranged, of medium to large size compared with test size. Pore frames having pores filled with secondary deposits. Well-defined nodes at the junctions of the pore frames.

Dimensions (in μm). Minimum test diameter, 100; maximum test diameter, 230; size of pore frames, 10-20.

Occurrence (present work). Biozones 2 to 5. Unitary Associations 4 to 17. Few specimens recovered from the Upper Jurassic/Lower Cretaceous of the South Viking Graben (well 9/18A-4), though the morphotype becomes very abundant in the Middle Volgian to Kimmeridgian strata (*mutabilis* zone, onshore exposure) of the North Sea Basin (all studied wells except 28/5-1).

Remarks. Included here are all specimens for which there is clear indication of the size of the pore frames. The morphotype is questionably assigned to the genus. Recrystallization of specimens does not allow the identification of the two fused latticed layers of the cortical shell.

3. *Archaeocenosphaera*(?) sp. 2

(Pl. 1, Fig. 8)

Description. Test spherical to subspherical with very small polygonal pore frames (compared to test size) arranged asymmetrically and having circular to subcircular pores usually filled with secondary deposits.

Dimensions (in μm). Test diameter, 171; size of pore frames, 5.

Occurrence (present work). Biozone 5. Ryazanian of the Norwegian Sea (well 7B).

Remarks. Only one specimen has been recovered. Questionably assigned to the genus owing to preservational limitations on observation of two fused latticed layers comprising the cortical shell.

Differs from *Archaeocenosphaera*(?) sp. 1 by having significantly smaller size of pore frames. Differs also from "*Cenosphaera*" *boria* described and illustrated by Pessagno (1977b, pl. 3, figs. 13, 19) from the Berriasian to upper Valanginian of California, by having significantly smaller, irregularly arranged, pore frames and smaller test diameter (diameter of Pessagno's holotype = 348μm).

4. *Archaeocenosphaera*(?) sp. 3

(Pl. 1, Fig. 9, 12)

Description. Test spherical with various sizes of circular to subcircular pore frames having a large circular to subcircular pores.

Dimensions (in μm). Average test diameter (8 specimens measured), 158.

Occurrence (present work). Biozone 1. Fairly common in abundance from the Lower Oxfordian of the South Viking Graben (well 16/17-5).

Remarks. Questionably assigned to the genus for the same reason as the above morphotypes.

Differs from *Archaeocenosphaera*(?) sp. 1 by having circular to subcircular pore frames and by lacking a nodose test surface.

5. *Archaeocenosphaera*(?) sp. 4

(Pl. 1, Fig. 11)

Description. Morphotype with large spherical test with pitted surface. Test surface with small numerous hexagonal pore frames, arranged symmetrically and well-developed nodes at junctions that give an impression of tiny mammae.

Dimensions (in µm). Test diameter, 373.

Occurrence (present work). Biozone 3. Lower Volgian of the Central Graben (well 22/21-2).

Remarks. Only one specimen has been recovered. Questionably included in the genus for the same reasons as in previously described morphotypes. Differs from *Archaeocenosphaera*(?) sp. 2 by having regularly arranged pore frames and significantly larger test. Differs also from "*Cenosphaera*" *boria* Pessagno by having significantly smaller pore frames.

6. *Archaeocenosphaera*(?) sp. 5

(Pl. 1, Fig. 10, 13-15; Pl. 2, Fig. 1; Pl. 19, Fig. 2-4)

(?) 1971 *Stylosphaera* (?) *asperalla* Kozlova, n.sp.; pl. 1, fig. 3.

(?) 1973 *Stylosphaera asperalla* Kozlova; Kozlova, p. 57, pl. 18, fig. 3, 4.

Description. Test spherical to subspherical (probably owing to preservational factors), robust, lacking spines, with a meshwork of irregularly arranged polygonal to oval pore frames having well-developed nodes at each junction. On well-preserved specimens there are 10 to 14 pore frames on the circuit of one hemisphere.

Dimensions (in µm). Test diameter (TD), 241-286 (mean, 264); number of pore frames on lateral view of diameter (NPL), 12-13; maximum diameter of pore frames, (MDP), 16-23 (mean, 19).

specimen	Pl. Fig.	TD	NPL	MDP
CK 29	19, 2	261	13	18
CK 30		257		18
CK 26	1, 13-15	241		22
CK 31		260	12	18
CK 35	1, 10	286		23
6280 12/28-1		276	12	16

Occurrence (present work). Biozone 2. Unitary Associations 4 to 6. Common morphotype in the middle/upper Kimmeridgian of the North Sea Basin (Central Graben, well 22/21-2; Moray Firth Basin, well 12/28-1) and middle Kimmeridgian (*mutabilis* zone), Eathie Haven, Cromarty.

Remarks. Differs from *A.*(?) sp. 1 by having significantly larger test. Also differs from *Cenosphaera euganea* illustrated by Gorican (1983, pl. 2, fig. 1) by having less pore frames (12 to 13 in comparison to 20) in equatorial view. The morphotype is very similar to *Stylosphaera* (?) *asperalla* illustrated by Kozlova (1971) and *Stylosphaera asperalla* illustrated and described by Kozlova (1973) from the Lower Kimmeridgian of the Timano-Ural region (Russia) but the preservation of the North Sea specimens does not allow observation of the presence of an inner latticed layer and the 3 to 4 small pores which are embraced in the large pores of the outer shell (Kozlova, 1973, p. 58).

7. *Archaeocenosphaera*(?) sp. 6
(Pl. 2, Fig. 2, 3; Pl. 19, Fig. 5-6, 9)

Description. Test spherical to subspherical, lacking spines and having small polygonal to subcircular pore frames. Test surface slightly nodose (although this may be due to preservational factors).

Dimensions (in µm). Test diameter (TD), 205-283 (mean, 249); maximum diameter of pore frames (MDP), 7-12 (mean, 10).

specimen	Pl. Fig.	TD	MDP
CK 38	19, 6	226	7
CK 36	19, 9	205	11
CK 37	2, 2-3	283	12
CK 550	19, 5	249	9

Occurrence (present work). Biozone 3. Unitary Associations 8 to 11. Fairly common recovered from the Lower Volgian of Central Graben (wells 28/5-1, 22/21-2, 29/12-1, 23/27-4) and Moray Firth Basin (14/18-2).

Remarks. Differs from *Archaeocenosphaera*(?) sp. 5 by having significantly smaller polygonal to subcircular pore frames and less nodose test surface (although this can be due to preservation factors). Also differs from *A.*(?) sp. 1 by having smaller pore frames and relative larger test. *Archaeocenosphaera*(?) sp. 6 is questionably assigned to the genus for the same reason as in all morphotypes above.

Archaeocenosphaera(?) spp. indet.
(Pl. 2, Fig. 4)

Remarks. Included here are all spherical to subspherical (usually squashed) specimens which exhibit pore frames but which, owing to poor preservation, cannot be assigned to any of the above morphotypes.

Genus CENODISCUS Haeckel

Remarks. *Cenodiscus* was originally described by Haeckel from samples collected by the Challenger Expedition which at the time were interpreted Recent in age. Pessagno (1977b, p. 35) suggested that all Mesozoic spumellarians referred to this genus in his work from the early Cretaceous and that of Aliev (1965) should be placed under a new genus. There is no phylogenetic relationship between Mesozoic and Cenozoic forms (Pessagno *et al.*, 1993).

8. "*Cenodiscus*" sp. A

(Pl. 2, Fig. 5-6, 9)

(?) 1969 *Cenodiscus* sp. Lozynyak, pl. 1, fig. 11a & 11b.

1989 *Cenodiscus* sp. 2 Dyer & Copestake, p. 226.

Description. Test large, biconvex, thick with a sharp periphery, usually having a rim. Test surface smooth with very small pore frames arranged irregularly (when preserved).

Dimensions (in µm). (based on six specimens) Average test diameter, 291; thickness of test, 144.

Range. Neocomian (Lozynyak, 1969); not given by Dyer & Copestake (1989).

Occurrence (literature). Ukranian Carpathians?, North Sea Basin.

Occurrence (present work). Biozone 3. Middle Volgian of the Central Graben (well 23/27-4).

Remarks. Lozynyak (1969) illustrated a similar specimen having a thicker test.

Differs from "*Cenodiscus*" sp. B by having a sharp, angled periphery. Differs also from Spongodiscidae sp. B specimens by having larger, thicker test with much smaller pore frames. Spongodiscidae sp. C which possess shallow concentric grooves on both sides of the test and a shallow circumferential notch, differ from "*Cenodiscus*" sp. A

9. "*Cenodiscus*" sp. B

(Pl. 2, Fig. 8)

1989 *Cenodiscus* sp. 1 Dyer & Copestake, p. 226, pl. 1, fig. 13.

Description. Test thick, discoidal, biconvex with a smooth surface and small circular? pores (owing to poor preservation few specimens exhibit pores). The morphotype having a rounded margin in edge view and ellipsoidal outline.

Dimensions (in µm). (based on 4 specimens) Average test diameter, 280; thickness of test, 149.

Range. Not given by Dyer & Copestake (1989) for reasons of confidentiality.

Occurrence (literature). North Sea.

Occurrence (present work). Biozone 3. Fairly common in the Middle Volgian of Central Graben (well 23/27-4), co-occurs with" *Cenodiscus*" sp. A.

Remarks. Differs from Spongodiscidae sp. B specimens by having larger, thicker test with much smaller pores. Also differs from Spongodiscidae sp. C by lacking concetric grooves on test surface.

10. "*Cenodiscus*" sp. C

(Pl. 2, Fig. 7, 10)

Description. Test very small, discoidal, thick with a shallow depresssion on one side of the test. Small circular pore frames arranged regularly on test surface.

Dimensions (in µm). Diameter of test, 131; thickness of test, 88.

Occurrence (present work). Biozone 3. Middle Volgian of the Central Graben (well 29/12-1).

Remarks. A single specimen has been recovered. Differs from "*Cenodiscus*" sp. B by having a small depression on test surface and significantly smaller test.

11. "*Cenodiscus*"(?) cf. "*C.*" *alievi* Pessagno

(Pl. 2, Fig. 11)

cf. 1977b "*Cenodiscus*" *alievi* Pessagno, n.sp; p. 35, pl. 3, fig. 16.

Original Description. "Test disc-shaped with irregular pore frames having variably shaped pores; pore frames often obscured by accreted shell material; when exposed tending to be triangular, tetragonal, and pentagonal; periphery lobate in lateral view with 8 to 12 imperforate lobes; some specimens with V-shaped notch on periphery. Test in peripheral view elliphical in outline; larger specimens with imperforate keel" (Pessagno, 1977b, p. 35).

Dimensions (in µm). Diameter of test, 191; thickness of test, 92.

Range (literature). Berriasian to middle Valanginian (Pessagno, 1977b).

Occurrence (literature). California Coast Ranges.

Occurrence (present work). Biozone 5. Upper Jurassic/Lower Cretaceous of the South Viking Graben (well 9/18A-4).

Remarks. Only one specimen has been recovered. Questionably included under the genus owing to limitations in observing pore frames on test surface. However, it follows the description of Pessagno's species but differs in having a wider imperforate keel as well as a larger test (diameter of holotype, 43µm).

Genus HEXASTYLUS Haeckel

Hexastylus Haeckel, 1887, p. 171.

Type species. *Hexastylus phaenaxonius* Haeckel 1887, p. 171, pl. 21, fig. 3 (subsequent designation by Campbell, 1954; p. D58).

Original Diagnosis. "Cubosphaerida with one simple lattice-sphere and six simple spines of equal size" (Haeckel 1887, p. 171).

Cubosphaerida according to Haeckel (1887, p. 169) are "Sphaeroidae with six radial spines on the test surface of the spherical shell, opposite in pairs in the three dimensive axes, perpendicular one to another".

Range. Mesozoic to Cenozoic.

Occurrence. Worldwide.

Remarks. The type species is Cenozoic. The genus is classified in the Family Actinommidae Haeckel, emend. Riedel.

12. *Hexastylus*(?) sp. 1

(Pl. 2, Fig. 12, 15)

Description. Test spherical, latticed with 6 spines which are placed in 3 perpendicular planes. Large, circular to subcircular, irregularly arranged pore frames on test surface with well-developed nodes at junctions. Spines slender with 4 longitudinal ridges alternating with 4 longitudinal grooves but not completely preserved. Axial section of spines cross-like. Full length of spines not preserved.

Dimensions (in µm). Diameter of test, 152; length of preserved spine, 41; width of spines near their base, 19; diameter of pores, 7-12.

Occurrence (present work). Biozone 5. A single specimen recovered from the Ryazanian of the Norwegian Sea (well 7B).

Remarks. It is not clear whether the morphotype possesses a medullary shell and is questionably assigned to the genus.

Genus ORBICULIFORMA Pessagno, emend. Pessagno

Orbiculiforma Pessagno, 1973b, p. 71.

Type species. *Orbiculiforma quadrata* Pessagno, 1973b, p. 73, pl. 16, figs. 1-4; pl. 18, fig. 3.

Emended Diagnosis. "Test disc-shaped, circular, elliptical, triangular or square in outline with short peripheral spines. Center of test markedly depressed; central cavity flanked by prominent rim. Central cavity occasionally obscured by fragile secondary meshwork" (Pessagno, 1976, p. 34).

Range. Upper Triassic (Norian) to Upper Cretaceous (Maastrichtian).

Occurrence. Worldwide in Tethyan and Boreal Provinces.

Remarks. Pessagno (1977b, p. 27) included in the genus forms which possess cylindrical, perforate peripheral tubes similar to the bracchiopyle of *Patulibracchium* Pessagno. The genus assigned to the Family Orbiculiformidae Pessagno.

13. *Orbiculiforma mclaughlini* Pessagno
(Pl. 2, Fig. 13-14; Pl. 3, Fig. 1-2; Pl. 19, Fig. 8)

1977a *Orbiculiforma mclaughlini* Pessagno, n. sp.; p. 74, pl. 4, figs. 4-7.

(?) 1983 *Orbiculiforma* cf. *mclaughlini* Pessagno; Gorican, p. 125, pl. 2, fig. 2.

1989 *Orbiculiforma mclaughlini* Pessagno; Dyer & Copestake, p. 224, pl. 1, figs. 3 & 4.

1992 *Orbiculiforma mclaughlini* Pessagno; Steiger, p. 37, pl. 6, fig. 8.

1993 *Orbiculiforma mclaughlini* Pessagno; Ellis, p. 965, pl. 1, fig. 20.

Original Description. "Test thick with large, deep central cavity; central cavity commonly three-quarters the width of the test. Meshwork consisting of coarse hexagonal and pentagonal pore frames. Short spines on periphery of some specimens. Margin of test nearly vertical" (Pessagno, 1977a, p. 74).

Dimensions (in µm). Total diameter (TD), 188-200 (mean, 191.5); diameter of central cavity (DCC), 97-130 (mean, 111.5); thickness of test (TT), 75-90 (mean, 81); ratio DCC/TD, 0.51-0.65 (mean, 0.58).

specimen	Pl. Fig.	TD	DCC	TT	DCC/TD
CK 73	2, 14; 3, 1	200	130	94	0.65
CK 74		188	105	75	0.56
CK 75	2, 13; 3, 2	189	114	75	0.6
CK 76	19, 8	189	97	80	0.51

Range. Oxfordian?, upper Kimmeridgian - Berriasian; upper Aptian - lower Albian.

Occurrence (literature). Californian Coast Ranges, Yugoslavia, North Sea Basin, Austrian Alps, western Australia. Also recorded from North Eastern Russia (abstract of Krimsalova, 1993, but no figure is included).

Occurrence (present work). Biozone 5. Unitary Associations 16 to 18. Rare species recorded from the i) Upper Volgian/Lower Ryazanian of the South Viking Graben, well 16/17-5 and 9/18A-4, and ii) Ryazanian of the Norwegian Sea, well 7B.

Remarks. Pessagno (1977a) in his description did not mention that the species possesses a constriction on the test periphery. This can be seen on his illustration of the holotype (Pl. 4, Fig. 5). The North Sea specimens are characterised by a wide central cavity and well-developed constriction on the nearly vertical edge margin. Differs slightly from the original description of Pessagno (1977a) by having shorter central cavity (DCC/TD = 0.58 compared to Pessagno's average of 0.75) and smaller test.

14. *Orbiculiforma lowreyensis* Pessagno
(Pl. 3, Fig. 3, 6)

1977a *Orbiculiforma lowreyensis* Pessagno, n. sp.; p. 74, pl. 3, figs. 14 & 15, pl. 4, figs. 1-3.

1984 *Orbiculiforma lowreyensis* Pessagno; Pessagno *et al.*, p. 22, pl. 1, figs. 9-11.

1986 *Orbiculiforma lowreyensis* Pessagno; Li, pl. 1, fig. 4.

1989 *Orbiculiforma lowreyensis* Pessagno; Dyer & Copestake, p. 224, pl. 1, figs. 1 & 2.

1992 *Orbiculiforma lowreyensis* Pessagno; Steiger, p. 37, pl. 6, fig. 9.

Original Description. "Test with small central cavity, width of central cavity about one-third that of test diameter. Sides of test sloping from central cavity to periphery resulting in angled periphery. Meshwork with tetragonal to pentagonal pore frames" (Pessagno, 1977a, p. 74).

Dimensions (in µm). Total diameter (TD), 175-178 (mean, 176.5); diameter of central cavity (DCC), 59-70 (mean, 64.5); thickness of test (TT), 86-89 (mean, 87.5); ratio DCC/TD, 0.34-0.39 (mean, 0.365).

specimen	Pl. Fig.	TD	DCC	TT	DCC/TD
CK 77	3, 6	175	59	76	0.34
CK 78	3, 5	178	70	89	0.39

Range. Tithonian.

Occurrence (literature). Californian Coast Ranges, China, North Sea Basin, Austrian Alps.

Occurrence (present work). Biozone 5. Unitary Associations 16 to 17. Rare species recovered from the i) Upper Jurassic/Lower Cretaceous of the South Viking Graben, well 9/18A-4, and ii) Ryazanian of the Norwegian Sea, well 7B.

Remarks. North Sea and Norwegian Sea individuals are much smaller that those of Pessagno (1977a), Pessagno *et al.* (1984) (test diameter of ten Pessagno's specimens: 276 to 336µm), and Steiger (1992). No circumferential notch is preserved.

15. *Orbiculiforma* sp. 1
(Pl. 3, Fig. 5)

(?) 1992 *Orbiculiforma* sp. cf. *O. lowreyensis* Pessagno; Steiger, p. 37, pl. 6, fig. 10.

Description. Test circular with a large, deep central cavity. Width of central cavity about half the test diameter. The sides of the test slope from the central cavity to circumference, resulting in angled periphery. No meshwork is preserved.

Dimensions (in µm). Total diameter (TD), 355-285 (mean, 320); diameter of central cavity (DCC), 187-140 (mean, 163.5); thickness of test (TT), 110-101 (mean, 105.5); ratio DCC/TD, 0.49-0.52 (mean, 0.505).

specimen	Pl. Fig.	TD	DCC	TT	DCC/TD
CK 80	3, 5	285	140	101	0.49
CK 79		355	187	110	0.52

Occurrence (present work). Biozone 5. Unitary Associations 16 to 17. The morphotype recovered from the South Viking Graben: i) uppermost Ryazanian/Lower Valanginian, well 16/17-5, and ii) Upper Jurassic/Lower Cretaceous, well 9/18A-4.

Remarks. *Orbiculiforma* sp. 1 differs from *O. lowreyensis* Pessagno by possessing much a larger central cavity (DCC/TD is 0.52 comparing to 0.365). Steiger (1992, p. 37) described and illustrated a similar form from the Berriasian of the Austrian Alps. Owing to poor preservation this specimen only slightly resembles that of Steiger.

16. ***Orbiculiforma*** **sp. 2**

(Pl. 3, Fig. 4, 7-10, 12; Pl. 19, Fig. 7)

Description. Test circular to subcircular in outline, thick with a deep, small diameter central cavity. Meshwork consists of polygonal pore frames when preserved. Sides of test relatively rounded with a shallow V-shaped notch occasionally preserved as well as small, stout spines.

Dimensions (in µm). Total diameter (TD), 165-205 (mean, 180); diameter of central cavity (DCC), 62-86 (mean, 71); thickness of test (TT), 75-98 (mean, 83); ratio DCC/TD, 0.35-0.42 (mean, 0.39).

specimen	Pl. Fig.	TD	DCC	TT	DCC/TD
CK 86	3, 4	177	62	98	0.35
CK 85	3, 7 & 10	165	71	75	0.42
CK 82		205	86	88	0.42
CK 83	3, 8	178	64	80	0.36
CK 84	3, 9	176	73	78	0.41
CK 81	19, 7	181	72	77	0.40

Occurrence (present work). Biozone 1. Unitary Associations 1 to 2. Recovered from the middle Kimmeridgian (*mutabilis* zone) of Eathie Haven, Cromarty and from the South Viking Graben, well 9/18A-4 upper Callovian/Lower Oxfordian.

Remarks. The morphotype differs from *O. lowreyensis* Pessagno by possessing a deeper central cavity and less angled periphery. The morphotype resembles *O. iniqua* Blome but differs by having larger polygonal pore frames on test surface, shallower V-shaped notch and thicker test.

17. *Orbiculiforma* sp. 3

(Pl. 3, Fig. 11, 13-15; Pl. 19, Fig. 10-11)

Description. Included here are all specimens with tests circular in outline, deep central cavity with width less than half the test diameter, and meshwork of polygonal pore frames becoming slightly smaller on the central cavity area. A V-shape circumferential notch is present. Sides of test rounded, possessing spines when test well-preserved.

Dimensions (in μm). Test diameter (TD), 172-298 (mean, 228); diameter of central cavity (DCC), 75-145 (mean, 99); thickness of test (TT), 51-95 (mean, 73.5); ratio DCC/TD, 0.40-0.48 (mean, 0.43).

specimen	Pl. Fig.	TD	DCC	TT	DCC/TD
CK 87		252	103	90	0.4
CK 100	3, 13	298	145	95	0.48
CK 97		220	93	67	0.42
CK 96		227	93	78	0.41
CK 95	19, 11	226	95	79	0.42
CK 94		216	98	65	0.45
CK 93		276	114	69	0.41
CK 92	3, 11 & 14	189	86	51	0.45
CK 89		172	75	67	0.44
CK 88		205	90	74	0.44

Occurrence (present work). Biozones 1 to 3. Unitary Associations 2 to 10. This morphotype is present throughout the North Sea Basin. In detail it has been recovered from:

i) Eathie Haven, Cromarty (middle Kimmeridgian, *mutabilis* zone);

ii) Central Graben, well 23/27-4 in the Middle Volgian and well 22/21-2 in the middle Kimmeridgian; and

iii) South Viking Graben, well 9/18A-4 in the Middle Oxfordian and well 16/17-5 Lower/Middle Oxfordian.

Remarks. The morphotype differs from *O. mclaughlini* Pessagno by having rounded test sides, and in lacking a constriction; the central cavity is smaller.

18. *Orbiculiforma* sp. 4

(Pl. 4, Fig. 1-3)

Description. Test circular, relatively thin with a large central cavity. Sides of test rounded with small spines when preserved. A circumferential notch may be present.

Dimensions (in μm). Total diameter (TD), 202-249 (mean, 227); diameter of central cavity (DCC), 135-154 (mean, 149); thickness of test (TT), 39-62 (mean, 52); ratio DCC/TD, 0.61-0.72 (mean, 0.66).

specimen	Pl. Fig.	TD	DCC	TT	DCC/TD
CK 107	4, 3	202	145	39	0.72
CK 106		222	135	54	0.61
CK 108	4, 1	249	154	52	0.62
CK 109		234	161	62	0.69

Occurrence (present work). Biozone 1 to 2. Unitary Associations 1 to 3. *Orbiculiforma* sp. 4 recovered from Eathie Haven, Cromarty (middle Kimmeridgian, *mutabilis* zone), Moray Firth Basin (well 12/28-1, Upper Oxfordian/lower Kimmeridgian), and from the South Viking Graben (well 16/17-5, Lower Oxfordian and well 9/18A-4, upper Callovian/Lower Oxfordian).

Remarks. The morphotype differs from *O. mclaughlini* Pessagno by having a thinner test with a larger central cavity, and periphery lacking constriction. Differs from *Orbiculiforma* sp. 3 in virtue of its larger central cavity and thinner test.

19. *Orbiculiforma* sp. 5

(Pl. 4, Fig. 4)

Description. Test circular, extremely thick. Central cavity narrow and deep. Sides of test straight. Periphery of test with well-developed constriction. Due to poor preservation of studied specimens pore frames cannot be defined.

Dimensions (in µm). Test diameter (TD), 261-278 (mean, 270); diameter of central cavity (DCC), 84-91 (mean, 89); thickness of test (TT), 119-128 (mean, 124); ratio DCC/TD, 0.3-0.35 (mean, 0.325).

specimen	Pl. Fig.	TD	DCC	TT	DCC/TD
CK 110	4, 4	278	84	119	0.3
22/21-2 12190		261	93	128	0.35

Occurrence (present work). Biozone 3. Central Graben, Lower Volgian (well 22/21-2).

Remarks. The morphotype differs from *Orbiculiforma* sp. 2 by having extremely thick test, with straight side of periphery developing a prominent constriction. Differs from *O. mclaughlini* Pessagno in virtue of the smaller central cavity, thick test and wider constriction.

20. *Orbiculiforma* sp. 6

(Pl. 4, Fig. 5-6, 8-9; Pl. 19, Fig. 12-13)

Description. Test thick, elliptical in outline with a deep ellipsoidal central cavity. Meshwork consists of polygonal pore frames. Sides of test straight possessing a well-developed constriction.

Dimensions (in µm). Length of test (LT), 253-295 (mean, 279); width of test (WT), 138-187 (mean, 169); length of central cavity (LCC), 110-189 (mean, 162); width of central cavity (WCC), 71-118 (mean, 93); thickness of test (TT), 69-81 (mean, 72).

specimen	Pl. Fig.	LT	WT	LCC	WCC	TT
CK 115	4, 6	276	178	171	118	69
CK 114		295	172	189	87	81
CK 116	4, 8 & 9	253	138	157	71	67
CK 112	19, 12	269	140	161	91	70
CK 117	4, 5	290	187	110	90	73
CK 111	19, 13	287	187	158	99	72
CK 118		281	180	188	93	72

Occurrence (present work). Biozones 1 to 3. Unitary Associations 2 to 7. A common species recovered from Eathie Haven, Cromarty (middle Kimmeridgian, *mutabilis* zone) and the Central Graben (well 23/27-4, Kimmeridgian/Lower Volgian).

Remarks. Differs from all other *Orbiculiforma* North Sea morphotypes by having an elliptical test in outline. Also differs from *Orbiculiforma* (?) *sempiterna* Pessagno described from the Campanian of North America by having significantly larger pore frames. Yang & Wang (1990) illustrated (pl. 2, fig. 17) a very similar form from the Upper Kimmeridgian/Lower Tithonian of Tibet, China but they did not describe it. It is not clear from their illustration whether a peripheral constriction is present or not (*Orbiculiforma* sp. 7).

21. *Orbiculiforma* sp. 7

(Pl. 4, Fig. 7, 10-11)

Description. Test elliptical in outline with a deep ellipsoidal central cavity. Sides of test rounded. Meshwork of polygonal pore frames on test surface.

Dimensions (in μm). Length of test (LT), 281-331; width of test (WT), 170-177; length of central cavity (LCC), 155-185; width of central cavity (WCC), 75-110; thickness of test (TT), 71-104.

specimen	Pl. Fig.	LT	WT	LCC	WCC	TT
CK 119		289	170	155	75	71
CK 120	4, 7 & 10-11	331	177	185	110	104

Occurrence (present work). Biozone 4. Unitary Associations 13 to 15. A rare morphotype recovered from the Upper Volgian of Central Graben (well 22/21-2) and Volgian of the Barents Sea (well 7430/10-U-01).

Remarks. Differs from *Orbiculiforma* sp. 6 by having rounded test sides lacking a well-developed constriction. Differs also from *Orbiculiforma* (?) *sempiterna* Pessagno in having larger pore frames.

Orbiculiforma spp. indet.

(Pl. 4, Fig. 12; Pl. 19, Fig. 16)

Remarks. Included here are all specimens possessing disc-shaped tests with central cavities on both sides of test. Owing to poor preservation specific identification is not possible.

Genus PORODISCUS Haeckel, emend. Kozlova

Porodiscus Haeckel 1887, p. 491.

Type species. *Porodiscus concentrica* (Ehrenberg) 1838, p. 132.

Emended Diagnosis. "The skeleton is flat or slightly concave in its centre, has a rounded outline and is composed of annular equatorial rings (the rest is not developed); first system is of the *Archidiscus* type (central chamber and one ring), d=30μ, very rarely submerged in the skeleton; distance between the annular rings is less that or equal to the initial chamber. Main spines are indistinct and as a rule cannot be distinguished from the secondary spines, the number of which in the latter systems exceeds fifty. The rim of the skeleton is either smooth or covered by numerous spines. Rings in the genus sometimes merge into a spiral" (Kozlova in Petrushevskaya & Kozlova, 1972, p. 525).

Range. Lower Cretaceous to Recent (Petrushevskaya & Kozlova, 1972).

Occurrence. Worldwide.

Remarks. According to Petrushevskaya & Kozlova (1972, p. 525) the genus differs from *Stylodictya* Ehrenberg, emend. Kozlova "by the absence of cupola-shaped chambers in the first system and by the more or less constant width of the rings". The genus is classified in the Family Porodiscidae Haeckel, emend. Kozlova.

22. *Porodiscus*(?) sp. 1

(Pl. 4, Fig. 13; Pl. 19, Fig. 14-15)

Description. Test disc-shaped, slightly convex, having a spongy meshwork of small polygonal pore frames arranged in rings which merge into spirals. When viewed with a transmitted light microscope, specimens exhibit a number of spines extented from the centre to the periphery. Traces of small spines on periphery of the test exist.

Dimensions (in μm). (based on 5 specimens). Average test diameter, 149.

Occurrence (present work). Biozone 5. Fairly common in the Ryazanian of the Norwegian Sea (well 7B).

Remarks. The morphotype is questionably assigned to the genus owing limitations on observation of the central part of test and the secondary spines. Owing to the lack of a triangular pore frames, the morphotype cannot be assigned to any of the genera of the subsuperfamily Pseudoaulophacidae Riedel. The morphotype resembles to *P. cretaceus* Campbell & Clark and *P. delicatulus* Lipman which both illustrated by Petrushevskaya & Kozlova (1972).

Genus PRAECONOCARYOMMA Pessagno

Praeconocaryomma Pessagno, 1976, p. 40

Type species. *Praeconocaryomma universa* Pessagno, 1976, p. 42, pl. 6, figs. 14-16.

Original Diagnosis. "Cortical shell invariably with radial spines protruding from mammae. Pore frames differing in size, shape and distribution between cortical shell and each medullary shell, tending to be proportionately and progressively larger on each medullary shell. Radial beams connecting medullary shell about one third as thick as those connecting cortical shell to first medullary shell" (Pessagno 1976, p. 41).

Range. Lower Jurassic (Upper Pliensbachian) to Upper Cretaceous (Middle Campanian).

Occurrence. Worldwide in Tethyan and Boreal faunal provinces.

Remarks. Pessagno (1976, p. 41) noted that the genus is distinguished from *Conocaryomma* Lipman (known from the Eocene) on the basis of the number of medullary shells (3 in comparison to 4 or 5 of *Conocaryomma*). Empson-Morin (1981, p. 260) considered the genus as a junior synonym of *Conocaryomma* Lipman. *Phaenicosphaera* Haeckel having one medullary shell also differs from *Praeconocaryomma* Pessagno. The genus is assigned to Family Praeconocaryommidae Pessagno.

23. *Praeconocaryomma hexagona* (Rüst)

(Pl. 4, Fig. 14-16; Pl. 20, Fig. 1-2)

1898 *Acanthosphaera hexagona* Rüst, n. sp.; p. 12, pl. 3, fig. 10.

1977a *Praeconocaryomma hexagona* (Rüst); Pessagno, p. 77, pl. 5, fig. 13.

1984 *Praeconocaryomma hexagona* (Rüst); Gorican & Kolar-Jurkovsek, p. 153, pl. 7, fig. 1.

1989 *Praeconocaryomma hexagona* (Rüst); Dyer & Copestake, p. 225, pl. 1, figs. 5 & 6.

1990 *Praeconocaryomma hexagona* (Rüst); Ozvoldova, pl. 4, fig. 4.

Original Description. "Die ober Fläche der Gitterkugel dieser Art ist mit 26 halbkugligen Erhabenheiten besetzt, die so angeordnet sind dass die Kugel wie ein Sechseck mit abgerundeten Ecken erscheint. Jede Erhabenheiten trägt einen mittelgrossen Spitzen Stachel. Die kleinen nicht engstehenden Löcher sind in regelmässigen Reihen angeordnet" (Rüst, 1898).

Translation. The surface of the lattice shell of this species shows 26 half-spherical mammae which are arranged in a way that the sphere seems to be a hexagon with smooth corners. Each mamma has a medium sized pointed spine. The small not closely spaced holes are arranged in regular rows.

Dimensions (in µm). (based on 20 specimens) Average test diameter, 185.

Range. Upper Tithonian - Berriasian (Pessagno, 1977a). Ozvoldova (1990) recovered the species from late Oxfordian sediments.

Occurrence (literature). Italy, North America, Slovenia (Yugoslavia), North Sea Basin, West Carpathians.

Occurrence (present work). Biozones 2 to 3. Unitary Associations 4 to 12. Common in Middle Volgian to Kimmerigdian of the Central Graben and Moray Firth Basin (wells 22/21-2, 23/27-4, 28/5-1, 14/18-2 and 12/28-1) as well as in Eathie Haven, Cromarty (middle Kimmeridgian, *mutabilis* zone).

24. *Praeconocaryomma* sp. A

(Pl. 5, Fig. 1; Pl. 20, Fig. 3)

1989 *Praeconocaryomma* sp. 1 Dyer & Copestake, p. 225; pl. 1, fig. 7.

Description. Test spherical with irregularly arranged, numerous, short, sharp mammae. Large circular to oval pore frames persist on the area between the mammae when specimens well preserved. Test lacking spines.

Dimensions (in µm). Average test diameter (of 20 measured specimens), 157.

Range. Not given by Dyer & Copestake (1989).

Occurrence (literature). North Sea Basin.

Occurrence (present work). Biozone 5. Unitary Associations 16 to 17. Fairly common morphotype recovered from the uppermost Middle Volgian to Upper Volgian of the Central and South Viking Grabens (wells 29/12-1, 28/5-1 & 16/17-5 respectively).

Remarks. Differs from all other described *Praeconocaryomma* morphotypes by virtue of its numerous, very sharp mammae and large pore frames in the area between the mammae.

25. *Praeconocaryomma* sp. B

(Pl. 5, Fig. 2)

Description. Test spherical with cortical shell possessing numerous mammae, surrounded by moderately small pore frames. No primary spines are preserved (this may be owing to preservational factors).

Dimensions (in µm). Test diameter, 223.

Occurrence (present work). Biozone 5. Unitary Associations 16 to 17. Rare in the Ryazanian of the Norwegian Sea (well 7B) and uppermost Volgian of Central Graben (well

22/21-2).

Remarks. Differs from *P. hexagona* (Rüst) by having spherical test (not giving the impression of a hexagon) and also having more numerous, high relief mammae. Also differs from *Praeconocaryomma* sp. A by having smooth, regularly arranged mammae.

26. *Praeconocaryomma* sp. C
(Pl. 5, Fig. 3, 5-6)

Description. Test spherical. Cortical shell possessing slightly raised, smooth mammae. Large triangular to oval pores, 5 to 6 in number, surrounding each mamma.

Dimensions (in μm). Average test diameter (of 4 measured specimens), 179.

Occurrence (present work). Biozone 1. Unitary Associations 1 to 2. Fairly common morphotype recovered from the South Viking Graben (well 16/17-5, Lower Oxfordian and well 9/18A-4, upper Callovian/Lower Oxfordian).

Remarks. Differs from *P. hexagona* (Rüst) by having fewer, significantly larger pore frames in the area between mammae. Also differs from *Praeconocaryomma* sp. B by virtue of its mammae and larger pore frames.

27. *Praeconocaryomma* sp. D
(Pl. 5, Fig. 4)

Description. Test with cortical shell possessing mammae which are extremely high in relief. Irregularly spaced stout beams forming pore frames connect the mammae.

Dimensions (in μm). Diameter of test, 186+.

Occurrence (present work). Biozone 5. Ryazanian of the Norwegian Sea (well 7B).

Remarks. Only one specimen has been picked. Differs from all the other *Praeconocaryomma* morphotypes have been described in this study by having mammae which are extremely high in relief. Also differs from *P. magnimamma* (Rüst) by lacking triangular meshwork in the area between the mammae.

28. *Praeconocaryomma*(?) sp. E
(Pl. 5, Fig. 7-8)

Description. Test moderate in size, spherical, ornamented with small, smooth mammae. Pore frames have not been observed on test surface.

Dimensions (in μm). (based on two specimens) Average test diameter, 189; average diameter of mammae, 15.

Occurrence (present work). Biozone 3. Unitary Association 12. Middle Volgian of

Central and South Viking Grabens (wells 23/27-4 & 9/18A-4 respectively).

Remarks. Pore frames are not visible and no medullary shells can be observed, thus the morphotype is questionably assigned to the genus. Differs from the sponge spicule Sterraster sp. 1 by having larger smooth mammae and significantly larger test.

Praeconocaryomma spp. indet.

(Pl. 5, Fig. 9, 11-12)

Remarks. Included here are all poorly preserved specimens which exhibit a test surface ornamented with various sizes mammae and lack pore frames in the area between the mammae. Medullary shells cannot be observed.

Genus STAUROSPHAERA Haeckel, sensu Foreman

Staurosphaera Haeckel, 1881, p. 450.

Type species. *Staurosphaera crassa* Dunikowski, 1882, p. 187, pl. 5, fig. 52 (by subsequent monotypy).

Diagnosis. "Grouped here are all the Mesozoic forms, excluding the Pseudoaulophacidae Riedel, with four main spines disposed in a cross, regardless of the nature of the shell (porous or spongy), the shape of the shell (spherical, ellipsoidal, or rectangular), or the length of the spines" (Foreman 1973, p. 259).

Range. Mesozoic.

Occurrence. Northwest Pacific, European Alps, Greece, West Atlantic Ocean, California.

Remarks. Foreman (1973) did not give any details of the internal structure of the genus.

Emiluvia Foreman, emend. Pessagno also possesses four spines forming a cross but it differs from *Staurosphaera* by having "surfaces of cortical shell planiform and sides concave to vertical" (Pessagno 1977a, p. 76). *Staurolonche* Pessagno possesses a convex test externally and having two medullary shells. Pessagno (1977a, p. 75) suggested that the use of the name *Staurosphaera* has no validity, as the type species of the genus is poorly illustrated and the nature of its test is not clear; he argued that the name be treated as a *nomen dubium*. The genus is placed in the Family Actinommidae Haeckel, emend. Riedel.

29. "*Staurosphaera*" sp. 1

(Pl. 5, Fig. 10, 13-14)

Description. Morphotype with latticed spherical shell having four spines disposed in a cross. Spines slender at their bases, three-bladed and partly preserved. Test with circular to subcircular pores of various size irregularly arranged.

Dimensions (in μm). Test diameter (TD), 170-199 (mean, 186); width of spines near their base (WSB), 20-33 (mean, 25); maximum diameter of pore frames (MDP), 14-19 (mean, 16).

specimen	Pl. Fig.	TD	WSB	MDP
CK 203	5, 10 & 13	199	21	16
CK 204		196	27	14
CK 205		191	33	19
CK 206	5, 14	170	25	
CK 208		175	20	15

Occurrence (present work). Biozones 4 & 5. Unitary Associations 13 to 16. Fairly rare morphotype recovered from the Ryazanian of the Norwegian Sea (well 7B) and the Volgian of the Barents Sea (well 7340/10-U-01).

Remarks. Differs from *S. amplissima* Foreman by having a spherical test; from *S. reticulata* Parona by lacking large, regularly arranged, hexagonal pore frames; from *S. aspera* Parona by lacking very small, irregularly arranged, polygonal pore frames; finally, from *S. micropora* Parona which possesses minute pore frames. All species of Parona described from the Jurassic of Italy (Parona, 1890).

ACTINOMMIDAE Haeckel, emend. Riedel

Actinommidae gen. et. sp. indet.

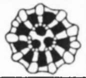
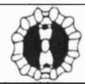
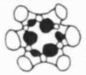
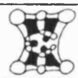
(Pl. 20, Fig. 4)

Remarks. Included here are all poorly preserved specimens with broken spines on the test surface. Number of spines cannot be clearly defined, thus the specimens cannot be assigned to any of the above morphotypes described herein, and therefore are placed informally in this general category of Actinommidae.

HAGIASTRIIDAE Riedel, sensu Baumgartner & PATULIBRACCHIIDAE Pessagno, emend. Baumgartner

Remarks. The following morphotypes, owing to limitations due to preservational factors, cannot be assigned to genera of the Family i) Hagiastridae Riedel, sensu Baumgartner (possessing cortical and medullary shells and having continuous canals in the rays) or ii) Patulibracchiidae Pessagno, emend. Baumgartner (having spongy central area and rays). Although specimens with broken rays have been found the nature of the ray cross-section is not clear. A classification summary of the Hagiastridae and Patulibracchiidae is given on Table 8.1. Baumgartner (1980), De Wever (1981b), Kito & De Wever (1990, 1992) offer

Family HAGIASTRIDAE Riedel, sensu Baumgartner (cortical and medullary shells, canals)

Subfamilies: Nature of ray-cross section		Genera: Number of rays: 2	3	4
HAGIASTRINAE Riedel, emend. Baumgartner		*Didactylum* Baumgartner	*Homoeoparonaella* Baumgartner / *Cavabracchia* Kito & De Wever (cross-section changes distally)	*Hagiastrum* Haeckel, emend. Baumgartner
ARCHAEOTRIASTRINAE Kito & De Wever		not observed	*Archaeotriastrum Kito & De Wever*	*Archaeohagiastrum* Baumgartner
HIGUMASTRINAE Baumgartner		not observed	*indeterminatun*	*Higumastra* Baumgartner
		not observed	not observed	*Pseudocrucella* Baumgartner
TRITRABINAE Baumgartner		*Ditrabs* Baumgartner	*Tritrabs* Baumgartner	*Tetratrabs* Baumgartner
TETRADITRYMINAE Baumgartner		not observed	not observed	*Tetraditryma* Baumgartner

Family PATULIBRACCHIIDAE Pessagno, emend. Baumgartner (central area and rays spongy)

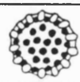
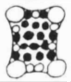
Subfamilies: Nature of ray-cross section		Genera: Number of rays: 2	3	4
PATULIBRACCHIINAE Pessagno, emend. Baumgartner		*Amphibrachium* Muller, emend. Baumgartner	*Paronaella* Pessagno, emend. Baumgartner	*Crucella* Pessagno, emend. Baumgartner
ANGULABRACCHIINAE Baumgartner		not observed	*Halesium* Pessagno, emend. Baumgartner	*indeterminatun*

Table 8.1 Classification summary of Hagiastrudae and Patulibracchiidae (adopted from Baumgartner 1980, Text-Figure 8; Kito & De Wever, 1990, Fig. 13. *Cavabracchia* Kito & De Wever, is also included).

discussions on the classification and phylogeny of Hagiastridae.

30. Hagiastridae(?) group 1
(Pl. 5, Fig. 15; Pl. 6, Fig. 1-2)

Description. Included here are all specimens with four rays possessing a depression on the central area of test. Rays decreasing in width towards the end. Traces of a patagium in some specimens.

Dimensions (in µm). Maximum length of preserved rays, 160+.

Occurrence (present work). Biozone 2. Unitary Associations 3 to 6. Rare in the middle Kimmeridgian of the Eathie Haven, Cromarty onshore exposure (*mutabilis* zone). Specimens also picked from Lower Volgian (Central Graben, well 22/21-2) and middle Callovian (South Viking Graben, well 9/18A-4).

Remarks. The morphotype could be assigned to one of the Hagiastridae or Patulibracchiidae genera with four rays (Table 8.1). The morphotype is more likely to belong to the genus *Pseudocrucella* Baumgartner which possesses tapering tips and usually a depression on the central area. *Crucella* Pessagno, emend. Baumgartner also possesses tapering tips.

31. Hagiastridae(?) group 2
(Pl. 6, Fig. 3-4, 7; Pl. 20, Fig. 5-6)

Description. A morphotype with four rays at right angles. Rays long, with polygonal pore frames when well-preserved. Full length of rays never preserved but the width is constant. Some specimens bear traces of a patagium.

Dimensions (in µm). Maximum length of preserved ray, 168; maximum width of rays, 101.

Occurrence (present work). Biozone 2. Rare in the middle Kimmeridgian of Eathie Haven, Cromarty (*mutabilis* zone).

Remarks. The specimens differ from Hagiastridae(?) group 1 in lacking a well-developed cavity on the centre of the test and in having longer rays of uniform width. The morphotype could be assigned to genera of Hagiastridae or Patulibracchiidae which have four rays (Table 8.1). *Archaeohagiastrum* Baumgartner which is ranging from Sinamurian (or older) to Callovian (Baumgartner 1984a, p. 759) is exluded from this concept. More likely, Hagiastridae(?) group 2 belong to *Hagiastrum* Haeckel, emend. Baumgartner, or *Higumastra* Baumgartner, or *Tetratrabs* Baumgartner, or *Tetraditryma* Baumgartner which all possess long rays.

32. Hagiastridae(?) group 3

(Pl. 6, Fig. 6)

Description. A four ray morphotype. The rays are very short, wide, approximately of equal length and forming right angles. One of them terminates with a central spine. Polygonal pore frames preserved on the test surface.

Dimensions (in µm). Maximum length of rays (including spine), 85; maximum width, 80.

Occurrence (present work). Biozones 1 to 2. Unitary Associations 1 to 5. Eathie Haven, Cromarty, middle Kimmeridgian (*mutabilis* zone) in all studied sections.

Remarks. Differs from the two previously described morphotypes by having shorter rays. The morphotype could be assigned to a genus of Hagiastridae or Patulibracchiidae which possesses four arms (Table 8.1).

33. Hagiastridae(?) group 4

(Pl. 6, Fig. 5)

Description. Test large with four rays which are short, wide and of equal length forming right angles. Ray tips large, club-shaped and may terminate on a central spine. Test surface nodose.

Dimensions (in µm). Maximum length of rays (including spine), 151; maximum width of ray tip, 122.

Occurrence (present work). Biozone 2. Eathie Haven, Cromarty, middle Kimmeridgian (*mutabilis* zone).

Remarks. Only one specimen has been recovered. Differs from the described above four ray morphotypes in having club-shaped ray tips. The morphotype probably belongs to one of the genera of Hagiastridae with four rays. *Pseudocrucella* Baumgartner and *Crucella* Pessagno, emend. Baumgartner are less likely to be included in this concept because both possess tapering tips.

34. Hagiastridae(?) group 5

(Pl. 6, Fig. 8-10)

Description. A morphotype with three arms. Test surface with polygonal pore frames and nodes at the pore frame junctions. Rays very short, slender, having a large club-shaped termination on a central spine.

Dimensions (in µm). Length of rays, 180 to 195; width of ray, 53 to 58; width of ray tip, 108 to 144.

Occurrence (present work). Biozone 2 to 3. Unitary Associations 3 to 8. Rare morphotype in Eathie Haven, middle Kimmeridgian (*mutabilis* zone). Rare in the Middle Volgian of the Moray Firth Basin (well 14/18-2).

Remarks. The morphotype could be assigned to a genus of Hagiastridae or Patulibracchiidae which possesses three rays. *Homoeoparonaella* Baumgartner and *Paronaella* Pessagno, emend. Baumgartner also possess bulbous (club-shaped) tips.

35. Hagiastridae(?) group 6

(Pl. 20, Fig. 7)

Description. Test small with two opposite, short, stout rays. Ray tips club-shaped with a central spine.

Dimensions (in μm). Length of test, 174; width of rays, 48; width of club-shaped ray tips, 76.

Occurrence (present work). Biozone 2. Unitary Association 5. Rare in Eathie Haven, middle Kimmeridgian (*mutabilis* zone).

Remarks. The morphotype could be assigned to the genus *Didactylum* Baumgartner (range: Tithonian and younger) or *Amphibrachium* Hertwig, emend. Baumgartner (range: Jurassic or older to early Cretaceous). Although preservation of the specimens found is bad, it is clear that the morphotype lacks three external beams on each ray and thus cannot be assigned to the genus *Ditrabs* Baumgartner (range: Berriasian and younger).

Hagiastridae(?) spp. indet.

(Pl. 6, Fig. 11-12)

Remarks. Included here all poorly preserved three or four ray spumellarians that cannot be placed with any of the above morphotypes.

SPONGODISCIDAE Haeckel, emend. Riedel

Remarks. The following morphotypes are included in the Spongodiscidae Haeckel, emend. Riedel. They possess doscoidal spongy tests (with or without marginal spines). However, these morphotypes have not here been assigned to a generic classification pending examination of better preserved material.

36. Spongodiscidae sp. A

(Pl. 6, Fig. 13-14, 17-18; Pl. 20, Fig. 9-10)

1989 *Spongodiscus* sp. 2 Dyer & Copestake, p. 225.

1989 *Spongodiscus* sp. 3 Dyer & Copestake, p. 225, pl. 1, figs. 14 & 15.

Description. A morphotype with a discoidal, circular, flattened test having a straight or rounded margin in edge view. Meshwork of irregularly arranged polygonal pore frames when specimens well-preserved. Size of pores variable. No peripheral spines are preserved.

Dimensions (in μm). Test diameter (TD), 168-276 (mean, 213); thickness of test (TT), 72-104 (mean, 86).

specimen	Pl. Fig.	TD	TT
CK 170		224	72
CK 167		183	85
CK 169	6, 14	181	75
CK 174	6, 17	255	104
CK 168	20, 9	168	
CK 172	20, 10	276	
CK 173	6, 18	240	90
CK 171	6, 13	188	78
CK 175		219	95
CK 177		198	90

Range. Not given by Dyer & Copestake (1989).

Occurrence (literature). North Sea Basin.

Occurrence (present work). Biozone 3. Unitary Associations 8 to 11. Common in abundance from the Lower to Middle Volgian of the Central Graben and Moray Firth Basin (wells 22/21-2, 23/27-4 & 12/28-1, 14/18-2 respectively).

Remarks. Dyer & Copestake (1989) distinguish two different morphotypes on the basis of the test margin in edge view. However, owing to preservational factors it is difficult to define whether a margin is rounded or nearly straight and both morphotypes are therefore included in Spongodiscidae sp. A in this study. Usually co-occurs with Spongodiscidae sp. B.

37. Spongodiscidae sp. B

(Pl. 6, Fig. 15-16; Pl. 7, Fig. 1-3; Pl. 20, Fig. 8)

(?) 1989 *Spongodiscus* sp. 1 Dyer & Copestake, p. 225.

Description. A morphotype with discoidal, circular, biconvex test in outline and subacute margin in edge view. Meshwork of small polygonal pore frames, arranged asymmetrically on test surface when specimens well-preserved. No peripheral spines are preserved.

Dimensions (in µm). Test diameter (TD), 153-206 (mean, 182); thickness of test (TT), 71-94 (mean, 80).

specimen	Pl. Fig.	TD	TT
CK 187		153	71
CK 180	6, 16	201	78
CK 186		158	75
CK 184	7, 3	188	94
CK 190	7, 1-2	162	74
CK 179	6, 15	199	82
CK 181		206	88
CK 182		192	75

Range. No data given by Dyer & Copestake (1989).

Occurrence (literature). North Sea Basin.

Occurrence (present work). Biozones 3 to 4. Unitary Associations 8 to 13. Common in abundance in the Lower to Middle Volgian of Central Graben and Moray Firth Basin (wells 22/21-2, 23/27-4 & 12/28-1, 14/18-2 respectively), rare in the Volgian of the Barents Sea (well 7430/10-U-01).

Remarks. Differs from Spongodiscidae sp. A by virtue of its biconvex test and subacute test margin in edge view. The description of *S.* sp. 1 Dyer & Copestake (1989) matches the description of S. sp. B from this study, however, *S.* sp. 1 was not illustrated and therefore is questionably synonymised with the form described and illustrated herein.

38. Spongodiscidae sp. C

(Pl. 7, Fig. 5-6, 8-9; Pl. 20, Fig. 12-13)

1989 *Spongodiscus* sp. 4 Dyer & Copestake, p. 225, pl. 1, fig. 16.

Description. Morphotype with a circular, discoidal test with rhomboidal shape (biconvex) in cross-section view. A circumferential shallow notch is often preserved on test periphery. Both sides of test possess shallow, concentric grooves giving the impression of a central cavity when specimens are viewed with transmitted light. Meshwork of polygonal pore frames arranged irregularly on well-preserved specimens.

Dimensions (in µm). Test diameter (TD), 225-351 (mean, 275); thickness of test (TT), 90-148 (mean, 117).

specimen	Pl. Fig.	TD	TT
CK 199	20, 13	281	125
CK 195		225	90
CK 198	7, 8	280	131
CK 193		308	148
CK 194	7, 9	351	131
CK 192	7, 5-6	255	98
CK 197	20, 12	228	99

Range. Dyer & Copestake (1989) did not give any data for reasons of confidentiality.

Occurrence (literature). North Sea Basin.

Occurrence (present work). Biozone 3. Unitary Associations 8 to 11. Fairly common in abundance in the Lower to Middle Volgian of the North Sea Basin (all three studied grabens, wells 22/21-2, 23/27-4, 12/28-1), though reworked in the Lower Oxfordian in the South Viking Graben, well 16/17-5) and very rare in Barents Sea (Volgian and ?older strata, well 7430/10-U-01).

Remarks. Differs from Spongodiscidae sp. B by having a larger test, developing concentric grooves on surface and possessing a shallow notch on the periphery.

39. Spongodiscidae sp. D

(Pl. 7, Fig. 4; Pl. 20, Fig. 11)

Description. Morphotype with flattened, discoidal, polygonal (heptagonal or octagonal) test in outline. Traces of spines on each angle of the periphery are preserved, as well as a meshwork of small polygonal pore frames. Central area of test slightly shallow.

Dimensions (in µm). Test diameter (TD), 202-239 (mean, 222); thickness of test (TT), 71-75 (mean, 73).

specimen	Pl. Fig.	TD	TT
CK 201	7, 4	224	71
CK 202	20, 11	202	72
12/28-1 5840		239	75

Occurrence (present work). Biozone 3. Rare morphotype recorded from the lowermost Middle Volgian of the Moray Firth Basin (well 12/28-1).

Remarks. The heptagonal/octagonal periphery differentiates this morphotype from the others which have been described above.

Spongodiscidae spp. indet.

(Pl. 7, Fig. 7)

Remarks. Included here are all poorly preserved discoidal forms, devoid of pore frames. Their margins in edge view are difficult to determine and cannot be placed with any of the above morphotypes.

SPUMELLARIA

Remarks. The following morphotypes are left in open nomenclature owing to bad preservation limiting observation of internal test structure or general poor preservation. All other incomplete/broken spherical specimens are placed under Spumellaria gen. et sp. indet. (e.g. Pl. 7, Fig. 11).

40. Spumellaria gen. et sp. indet. A
(Pl. 7, Fig. 10)

Description. Test triangular in outline, relatively thick, flattened. The three angles of test are rounded, lacking spines (not observed). Test surface smooth, with traces of polygonal pore frames.

Dimensions (in µm). (based on four specimens) Average width of test, 175; average thickness of test, 77.

Occurrence (present work). Biozones 2 to 3. Unitary Associations 5 to 11. Rare in the Middle Volgian and Lower Volgian of Central Graben (well 23/27-4 and 22/21-2 respectively), fairly common in the Middle Volgian of Moray Firth Basin (wells 14/18-2 & 12/28-1).

Remarks. Grouped here are all specimens that exhibit a test as in the above description. They differ from *Perispyridium* Dumitrica in general geometry of the test.

41. Spumellaria gen. et sp. indet. B
(Pl. 7, Fig. 12, 16)

Description. Test very small, having a circular outline. One side of test with a deep central cavity while the other side possesses a low projection. Traces of pore frames on surface. Periphery rounded in edge view.

Dimensions (in µm). Diameter of test, 109; thickness of test, 41.

Occurrence (present work). Biozone 5. Ryazanian of Central Graben (well 22/21-2).

Remarks. Only one specimen has been recovered. The morphotype cannot be assigned to *Orbiculiforma* Pessagno owing to lack of a central cavity on both sides of test.

42. Spumellaria gen. et. sp. indet. C
(Pl. 20, Fig. 14)

Description. Test relatively flat, biconvex, rectangular in outline with the two opposite sides slightly rounded. Test surface with polygonal pore frames, arranged irregularly.

Dimensions (in µm). Length on the greatest axis, 131; length on the smallest axis, 94; thickness, 61.

Occurrence (present work). Biozone 2. Middle Kimmeridgian (*mutabilis* zone), Eathie Haven, Cromarty.

Remarks. A single specimen has been recovered.

43. Spumellaria gen. et sp. indet. D
(Pl. 7, Fig. 13-15; Pl. 20, fig. 15-16)

(?) 1927 *Stypolarcus laboriosus* Tan Sin Hok, p. 38, pl. 7, figs. 17a, 17b.

(?) 1992 *Tripocalpis laboriosus* Tan Sin Hok; Baumgartner, p. 326, pl. 13, fig. 10.

Description. Test oval, egg-shaped in outline. Test surface usually irregular with traces of polygonal pore frames. Test lacking an aperture. Internal structure difficult to define (owing poor preservation), but it is likely the morphotype has only one chamber.

Dimensions (in µm). (based on six specimens) Average length of test, 180-300; maximum width, 100-188.

Occurrence (present work). Biozone 2 to 3. Common in the Middle Volgian of the Moray Firth Basin (well 14/18-2).

Remarks. The morphotype resembles to the test outline of *Stypolarcus laboriosus* described and illustrated by Tan Sin Hok (1927) from the Jurassic of the Indian Ocean. Tan Sin Hok assigned the genus *Stypolarcus* to the Spumellaria. Baumgartner (1992) illustrated the same species from the Upper Tithonian to Barremian of the Indian Ocean as *Tripocalpis laboriosus* Tan Sin Hok and placed it in the Nassellaria. Owing to poor preservation (pore frames on test surface not observed) the morphotype cannot be reliably assigned to the species.

Suborder NASSELLARIINA Ehrenberg 1875

Genus ARCHAEODICTYOMITRA Pessagno, emend. Pessagno
Achaeodictyomitra Pessagno, 1976, p. 49.

Type species. *Archaeodictyomitra squinaboli* Pessagno, 1976, p. 50, pl. 5, fig. 2-8.

Original Diagnosis. "Test conical, spindle-shaped; cephalis, thorax, abdomen and postabdominal segments covered by linearly arranged continuous costae converging in cephalis and thorax area; single pores between costae" (Pessagno 1976, p. 49).

Emended Diagnosis. "The genus also includes forms with constrictions which are not occurring at joints" (Pessagno 1977b, p. 41).

Range. Middle Jurassic (Bajocian) to Upper Cretaceous (Campanian).

Occurrence. Worldwide.

Remarks. The genus differs from: i) *Dictyomitra* Zittel, emend. Pessagno and *Zifondium* Pessagno in having a test without strictures. This feature and the lack of an apical horn distinguish the genus from *Diplostrobus* Squinabol; ii) *Mita* Pessagno, *Zifondium* Pessagno and *Thanarla* Pessagno by having relict pores and lacking primary pores. Also differs from *Thanarla* by having costal projections on the final postabdominal chamber. Pessagno (1976, 1977b) assigned the genus to the Family Archaeodictyomitridae Pessagno. Pessagno (1977b) and Pessagno & Whalen (1982) have discussed the phylogenetic relationships of the family and the genus with other nassellarian families and genera.Takemura (1986) classified it in the Family Theoperidae Haeckel, emend. Takemura.

44. *Archaeodictyomitra rigida* Pessagno

(Pl. 8, Fig. 1; Pl. 21, Fig. 1)

1977a *Archaeodictyomitra rigida* Pessagno; Pessagno, p. 81, pl. 7, figs. 10-11.

1977 *Archaeodictyomitra rigida* Pessagno; Nakagawa & Nakaseko, pl. 1, fig. 8, pl. 4, fig. 4.

(?) 1981 *Arcaeodictyomitra* sp. aff. *A. rigida* Pessagno; Isozaki *et al.*, pl. 4, fig. 6.

1981 *Archaeodictyomitra rigida* Pessagno; Kocher, p. 57, pl. 12, fig. 18.

1982 *Archaeodictyomitra rigida* Pessagno; Aoki, p. 17, pl. 1, fig. 10; pl. 4, fig. 1; pl. 5, figs. 7a & 7b.

(?) 1982 *Archaeodictyomitra rigida* Pessagno group; Kido *et al.*, pl. 1, fig. 7-9.

(?) 1982b *Archaeodictyomitra* aff. *rigida* Pessagno; Matsuoka, pl. 1, fig. 8.

(?) 1985 *Archaeodictyomitra* cf. *A. rigida* Pessagno; Conti *et al.*, pl. 2, fig. 1.

1986 *Archaeodictyomitra rigida* Pessagno; Li, pl. 3, fig. 5.

(?) 1992 *Archaeodictyomitra rigida* Pessagno; Ozvoldova, pl. 4, fig. 5.

1993 *Archaeodictyomitra rigida* Pessagno; Wu, p. 123, pl. 2, fig. 18.

Original Description. "Test conical, rather wide with approximately 30 closely spaced costae; costae parallel on postabdominal chambers; converging on earlier chambers" (Pessagno, 1977a, p. 81).

Dimensions (in µm). Length of test (LT), 150-152; maximum width of test (MW), 88-90.

specimen	Pl. Fig.	LT	MW
CK 217	8, 1	150	88
CK 218	21, 1	152	90

Range. Upper Kimmeridgian/lower Tithonian to Berriasian or younger (Pessagno, 1977a).

Occurrence (literature). California Coast Ranges, Puerto Rico, Japan, Southern European Alps, China, Greece, Corsica, southern Tibet. Also recorded from the Far East Russia (abstract of Smirnova, 1993, but no figure is included).

Occurrence (present work). Biozone 5. Rare species recovered from the Norwegian Sea (well 7B, Ryazanian).

45. *Archaeodictyomitra* sp. A

(Pl. 8, Fig. 2)

Description. Test slender, with very pointed apical end and a few slight constrictions; thorax, abdomen and first postabdominal chambers increasing in width; final postabdominal chambers decreasing in width, giving a rounded end; 12 continuous costae visible in lateral view on postabdominal segments; no relict pores preserved; total number of chambers cannot be defined.

Dimensions (in µm). Length of test, 212; maximum width of test, 98.

Occurrence (present work). Biozone 1. Rare in the ?Upper Bathonian/lower Callovian of the South Viking Graben (well 9/18A-4).

Remarks. Differs from *Archaeodictyomitra prisca* Kozur & Mostler (in Grill & Kozur, 1986) (Aalenian to lower Bajocian of Hungary) by having the last postabdominal chambers significantly decreasing in width. The pore arrangement described by Kozur & Mostler cannot be observed in the studied specimen owing to poor preservation.

46. *Archaeodictyomitra* sp. 1

(Pl. 8, Fig. 3-4)

Description. Test long, cylindrical, slender with an apical part slightly broken (on studied material), but narrow, dome-shaped, smooth(?). Distal part of the test with fourteen to fifteen parallel, continuous (most of them), longitudinal costae, with one row of circular pores in between. Sometimes adjoining costae anastomosing. Total number of chambers cannot be defined. Last postabdominal chamber slightly decreases in width. Large circular aperture present at the base of test.

Dimensions (in µm). Maximum preserved length of test, 231; maximum width, 104.

Occurrence (present work). Biozone 5. Rare in the Ryazanian of the Norwegian Sea (well 7B).

Remarks. Differs from *A. apiarium* (Rüst) by having a longer test (?more postabdominal chambers), with a few anastomosing costae and the last postabdominal chamber very slightly decreasing in width.

47. *Archaeodictyomitra* sp. 2

(Pl. 8, Fig. 7-8)

Description. Test long, conical, with 13 continuous costae visible in lateral view on the postabdominal chambers, converging on apical part of test and having one row of circular pores. Some costae anastomosing. Last postabdominal constricted chambers increasing rapidly in width. A circular aperture is present at the base of the test.

Dimensions (in µm). Length of test, 219; maximum width of test, 101.

Occurrence (present work). Biozone 5. Rare morphotype in the Ryazanian of the Norwegian Sea (well 7B).

Remarks. The morphotype resembles *Archaeodictyomitra* sp., illustrated by Wakita (1988b, pl. 4, fig. 2) from the Lower Cretaceous of Japan but differs by having anastomosing costae.

48. *Archaeodictyomitra* sp. 3
(Pl. 8, Fig. 5-6)

Description. Test with a notable constriction in the apical part and 15 continuous, parallel costae in lateral view, with a few relict pores preserved between the costae. Some costae anastomosing on the last postabdominal chambers. Another well-defined constriction is present on the last postabdominal segments which later increase in width. A circular aperture is present at the base of test.

Dimensions (in µm). Length of test, 210; maximum width of test, 113.

Occurrence (present work). Biozone 5. Rare morphotype present in the Ryazanian of the Norwegian Sea (well 7B).

Remarks. Differs from *Archaeodictyomitra* sp. 2 in having a constriction on the apical part of the test.

49. *Archaeodictyomitra* sp. 4
(Pl. 8, Fig. 11-12)

Description. Test with a tapering apical part. First chambers increasing rapidly in width. Last postabdominal chamber(s?) increasing in width giving a barrel-shaped proximal end. Thirteen costae are visible in lateral view with circular pores inbetween. Internal structure not known.

Dimensions (in µm). Length of test, 157; maximum width of test, 88.

Occurrence (present work). Biozone 5. Rare species in the Ryazanian of the Norwegian Sea (well 7B).

Remarks. The morphotype resembles *Archaeodictyomitra brouweri alpha* (Tan Sin Hok) from the Early Cretaceous of the Indian Ocean (Tan Sin Hok, 1927; Renz, 1974; Baumgartner, 1992) but possesses more numerous costae and lacks a cephalic horn (although it may be broken).

50. *Archaeodictyomitra* sp. 5

(Pl. 8, Fig. 10)

Description. Test relatively long with 15 continuous, parallel costae in lateral view, some of which anastomosing. Apical part of test conical, smooth. One row of small circular pores is present between the costae. Last postabdominal chambers increasing in width.

Dimensions (in µm). Length of test, 185; maximum width of test, 85.

Occurrence (present work). Biozone 5. Rare in the Ryazanian of the Norwegian Sea (well 7B).

Remarks. The morphotype differs from *Archaeodictyomitra* sp. 1 in having the last postabdominal chambers increasing more rapidly in width. Also differs from *A*. sp. 2 on the distal part of the test.

Archaeodictyomitra spp. indet.

(Pl. 8, Fig. 9)

Remarks. Included here are all broken and poorly preserved archaeodictyomitrids that cannot be assigned any of the above morphotypes.

Genus BROCTUS Pessagno & Whalen

Broctus Pessagno & Whalen, 1982, p. 120.

Type species. *Broctus selwynensis* Pessagno & Whalen 1982, p. 121, pl. 1, fig. 6; pl. 2, figs. 18, 20; pl. 12, fig. 10.

Original Diagnosis. "Test as with family: spindle-shaped. Final post-abdominal chamber terminating in narrow, tubular structure extending from aperture; cephalis lacking horn. Pore frames regular to irregular, tending to be more regular distally than proximally" (Pessagno & Whalen 1982, p. 120).

Range. Lower Jurassic.

Occurrence. North and Central America.

Remarks. Pessagno & Whalen (1982) discussed how the genus differs from *Bagotum*, *Droltus*, and *Noritus* and assigned it to their new Family Bagotidae. The same authors considered (p. 113-115) the phylogenetic relationship of the Bagotidae with other families.

51. *Broctus*(?) sp. 1

(Pl. 8, Fig. 15)

Description. Test conical on apical part and cylindrical on distal part. Total number of chambers cannot be defined. Cephalis small, porous, and lacking apical horn. Thorax, abdomen and first few(?) postabdominal chambers increasing in width, with irregularly arranged pore frames. Remaining chambers with smaller polygonal pore frames more regularly arranged. Final postabdominal chamber increasing in width. Studied material partly broken on distal part of the test. Test lacking constrictions.

Dimensions (in μm). Length of test, 211; maximum width of test, 109.

Occurrence (present work). Biozone 1. Lower Oxfordian of South Viking Graben (well 16/17-5).

Remarks. Only one specimen recovered. Differs from species of the genus *Milax* Blome by lacking a final inflated postabdominal chamber and spines at the pore frames vertices. Questionably assigned to the genus *Broctus* Pessagno & Whalen owing to preservational limitations on observation of a narrow, tubular structure extending from the aperture. Pessagno & Whalen (1982) gave the range of this genus as Lower Jurassic.

Genus CANUTUS Pessagno & Whalen

Canutus Pessagno & Whalen, 1982, p. 127.

Type species. *Canutus tipperi* Pessagno & Whalen 1982, p. 129, pl. 4, figs. 7-9, 11, 12, 14-17; pl. 12, fig. 21.

Original Diagnosis. "Test spindle-shaped to subconical; when spindle-shaped, often quite inflated. Cephalis without horn. Abdomen and post-abdominal chambers with two or three layers of fragile polygonal pore frames" (Pessagno & Whalen 1982, p. 127).

Range. Lower Jurassic (Sinemurian to Toarcian) (Pessagno & Whalen, 1982).

Occurrence. North and Central America (Oregon, California, Baja California Sur).

Remarks. The genus differs from *Archaeodictyomitra* Pessagno according to Pessagno & Whalen (1982, p. 127) "by having a test with several latticed layers of pore frames, by developing pillar-like nodes, and by lacking costae". The same authors classified the genus in the Family Canutidae Pessagno & Whalen and discussed (p. 113-115) the phylogenetic relationships of the family with the Bagotidae, Hsuidae, Archaeodictyomitridae and Parvicingulidae.

52. *Canutus*(?) sp. 1

(Pl. 8, Fig. 13-14)

Description. Test conical, with chambers increasing in width, broken on distal part and lacking circumferential ridges. Cephalis hemispherical, knob-like, smooth, bearing a few pores?. Remaining chambers trapezoidal, with well-developed polygonal pore frames, varying in size. An inner latticed layer of pore frames is probably present under the test surface.

Dimensions (in μm). Length of preserved test, 141; maximum width, 79; width of cephalis, 18.

Occurrence (present work). Biozone 1. Middle Callovian of South Viking Graben (well 9/18A-4).

Remarks. Only one specimen recovered. Questionably assigned to the genus owing preservational limitations on observation of internal structure and distal part of the test. Pessagno & Whalen (1982) gave the range of the genus as Lower Jurassic. However, Kito (1989) described and illustrated two morphotypes from Middle Jurassic sediments

Genus CRYPTAMPHORELLA Dumitrica

Cryptamphorella Dumitrica, 1970, p. 80.

Type species. *Hemicryptocapsa conara* Foreman, 1968, p. 35, pl. 4, figs. 11a & 11b.

Original Diagnosis. "Cryptothoracic tricyrtids with large inflated adbomen, without aperture, with or without well-individualized sutural pore; cephalo-thorax small, poreless, partly to almost completely depressed into the abdominal wall and cavity, without descending thoracic spines, usually with a short, conical apical horn" (Dumitrica, 1970, p. 80).

Range. Upper Jurassic (Tithonian) to Upper Cretaceous (Maastrichtian).

Occurrence. Europe, Puerto Rico, California, Indian Ocean.

Remarks. Differs from *Williriedellum* Dumitrica and *Hemicryptocapsa* Dumitrica in lacking abdominal aperture. Also differs from *Zhamoidellum* Dumitrica in virtue of its poreless thorax. Dumitrica (1970) assigned the genus to his new Family Williriedellidae. Takemura (1986, p. 53) stated "all cryptocephalic and cryptothoracic nassellarians described by Dumitrica (1970), except *Squinabollum* Dumitrica, probably possess the same cephalic structure" as his new Family Arcanicapsidae.

53. *Cryptamphorella*(?) sp. 1

(Pl. 8, Fig. 16, 19)

Description. Test with three segments. Cephalis small, conical, partly broken. Thorax small, with rough surface, partly depressed into the abdominal cavity. Abdomen large, subspherical with the upper part slightly flattened, without aperture, having strong, well-developed hexagonal pore frames. Large sutural pore questionably present.

Dimensions (in µm). Height of test, 131+; diameter of abdomen, 118; width of thorax, 48; average diameter of abdominal pore frames, 15.

Occurrence (present work). Biozone 4. Volgian of the Barents Sea (well 7430/10-U-01).

Remarks. Only one specimen has been recovered. The specimen is questionably assigned to the genus. It is not clear if pores are present on the cephalo-thorax. Resembles *C. macropora* Dumitrica but the very large sutural pore cannot be defined owing preservational limitations.

54. *Cryptamphorella*(?) sp. 2

(Pl. 8, Fig. 17-18)

Description. Test relatively large. Cephalis conical, smooth(?). Thorax hidden in the abdominal cavity. Abdomen large, inflated, subspherical with small, irregularly arranged polygonal pore frames. Abdomen lacking an aperture. Sutural pore cannot be defined (owing to poor preservation).

Dimensions (in µm). (based on two specimens) Height of test, 159-182; width of abdomen, 165-185.

Occurrence (present work). Biozone 5. Rare in the uppermost Middle Volgian of the Central Graben (well 29/12-1).

Remarks. The morphotype is questionably assigned to the genus owing to limitations in observing the internal structure and presence of a sutural pore. Differs from *Cryptamphorella*(?) sp. 1 in having a larger test and significantly smaller polygonal pore frames.

Genus HSUUM Pessagno

Hsuum Pessagno, 1977a, p. 81.

Type species. *Hsuum cuestaense* Pessagno 1977a (=nomen correctum), p. 81, pl. 7, fig. 12, 13.

Original Diagnosis. "Test multicyrtoid, conical lacking strictures. Cephalis conical, with small horn and sparse irregularly displaced pores. Thorax trapezoidal with sparse irregularly displaced pores. Abdomen and post-abdominal chambers with massive, continuous to discontinuous, diverging costae; three to six rows of small square pore frames with circular pores between costae. Costae of some species with irregular branches that link adjoining costae and obscure linearly arranged pore frames beneath. Pores of all post-thoracic chambers tending to remain open during ontogeny and to be primary pores" (Pessagno 1977a, p. 81).

Range. Lower Jurassic (lower Pliensbachian) to Lower Cretaceous (lower Hauterivian).

Occurrence. Worldwide.

Remarks. Takemura (1986) emended the genus and included species with continuous longitudinal costae and 1 to 4 longitudinal lines of pores in between. He assigned the emended genus to the Family Theoperidae Haeckel, emend. Takemura. His genus *Transhsuum* treated by Pessagno *et al.* (1993, p. 135) as a junior synonym of *Hsuum* Pessagno.

Hsuum Pessagno differs from *Archaeodictyomitra* Pessagno by having more rows of pores between the costae and having primary pores rather that relict pores (Pessagno 1977a, p. 81). Differs from *Semihsuum* Pessagno, Blome & Hull by having a horn. Also differs from *Linaresia* El Kadiri, emend. Pessagno, Blome & Hull by having conical test which does not rapidly expands in width and is not inflated distally (Pessagno *et al.* 1993, p. 137).

Pessagno & Whalen (1982) classified the genus under their new Family Hsuidae and discussed the formation of the test for the family and genus as well as the supergeneric phylogenetic relationship of the Hsuidae with other families.

55. *Hsuum*(?) sp. A
(Pl. 9, Fig. 1-3, 5-6; Pl. 21, Fig. 2)

1989 *Hsuum* sp. 1 Dyer & Copestake, p. 227, Pl. 2, Fig. 1, 2.

Description. Test conical with a smooth cephalis having a horn(?) and subsequent chambers trapezoidal, increasing slightly in width. Test surface with longitudinal costae. Costae irregularly arranged over apical part (abdomen and first postabdominal chambers) of test giving a rough surface. Three rows of polygonal pore frames between circumferential ridges. Pores between costae cannot be defined. Internal structure not known.

Dimensions (in µm). Length of test (LT), 184-254 (mean, 244+); maximum width of test (MW), 97-130 (mean, 127+).

specimen	Pl. Fig.	LT	MW
CK 234	9, 2	254	130
CK 237	9, 1 & 5-6	252	127
CK 238	9, 3	184+	97+
CK 236	21, 2	225	124

Range. Kimmeridgian, *cymodoce* zone (Gregory, 1986); not given by Dyer & Copestake (1989).

Occurrence (literature). North Sea Basin (Sutherland, onshore eastern Scotland).

Occurrence (present work). Biozone 1 to 2. Unitary Associations 1 to 3. Fairly common in the middle Kimmeridgian (*mutabilis* zone, Eathie Haven) and rare in the upper Callovian/Lower Oxfordian of the South Viking Graben (well 9/18A-4).

Remarks. Questionably assigned to the genus owing limitations in recognising i) whether the cephalis possesses a horn, and ii) pores occur between costae. Differs from *Hsuum*(?) sp. B by having apical part with more irregular test surface (more pronounced costae).

56. *Hsuum*(?) sp. B
(Pl. 9, Fig. 4, 7)

Description. Test conical with smooth cephalis and a possible horn (it may be broken). Thorax trapezoidal, with few small circular pores. Remaining segments increasing in width. Test surface with longitudinal costae, usually strongly developed over chamber joints. Three rows of polygonal pore frames are present between circumferential ridges. Distal part of test broken so total number of chambers cannot be defined.

Dimensions (in µm). Length of preserved test, 222; maximum width 108.

Occurrence (present work). Biozone 1. Rare in the middle Kimmeridgian at Eathie Haven, Cromarty (*mutabilis* zone).

Remarks. Questionably assigned to the genus owing to poor preservation.

Hsuum(?) spp. indet.
(Pl. 9, Fig. 8)

Remarks. Included here are all poorly-preserved specimens that cannot be assigned to any of the above two *Hsuum* species but which bear costae on the test surface and usually co-occur with the two previously described morphotypes.

Genus MILAX Blome
Milax Blome, 1984, p. 372.

Type species. *Milax alienus* Blome 1984, p. 374, pl. 13, figs. 2-4, 10, 11, 16, 18, 20, 22.

Abridged Original Diagnosis. Multicyrtid nassellarian with conical test having 5 to 7 chambers poorly constricted. Cephalis imperforate, with or without apical horn. Thorax sparsely perforate. Abdomen and postabdominal chambers increasing in width and (slightly) in height with variable sized polygonal pore frames with nodes at junctions. Last postabdominal chamber inflated with large polygonal pore frames and spines at the pore frame vertices (from Blome, 1984, p. 372).

Range. Middle Jurassic.

Occurrence. Oregon, Alaska.

Remarks. Differs from *Canesium* Blome in possessing: i) 2 to 4 postabdominal chambers (instead of one), ii) postabdominal chambers which increase less abruptly in width, iii) porous thorax and abdomen, and iv) spines at the last postabdominal chamber. It also differs from *Sethocapsa* Haeckel in the number of postabdominal chambers. Blome (1984, p. 372) pointed out that the genus cannot be included in any existing taxonomic classification at family level.

57. *Milax*(?) sp. 1
(Pl. 9, Fig. 9)

Description. Test small, conical, consisting of six chambers. Cephalis very small, poreless. Thorax trapezoidal in outline having few pores. Abdomen and postabdominal chambers increasing slightly in height and in width as added. Final postabdominal chamber slightly inflated (but broken on its base). Polygonal pore frames on test surface becoming significantly smaller on the base of last segment.

Dimensions (in µm). Length of preserved test, 151; maximum width of test, 75.

Occurrence (present work). Biozone 1. Middle Callovian of South Viking Graben (well 9/18A-4).

Remarks. Only one specimen recovered. The morphotype is questionably assigned to the genus having a less inflated, broken final postabdominal chamber which lacks spines at the pore frame vertices.

58. *Milax*(?) sp. 2

(Pl. 9, Fig. 10-11)

Description. Test subconical with 5 to 6 preserved chambers. Cephalis dome-shaped lacking horn. Thorax and abdomen subtrapezoidal, increasing in width and slightly in height. Final postabdominal chamber slightly inflated. Test surface nodose but owing to bad preservation pore frames not preserved.

Dimensions (in µm). Length of test (LT), 210-215 (mean, 213); maximum width of test (MW), 108-129 (mean, 121).

specimen	Pl. Fig.	LT	MW
CK 241	9, 10	213	117
CK 242		215	129
CK 243		214	108
CK 244	9, 11	210	128

Occurrence (present work). Biozone 1. Middle Callovian and upper Callovian/Lower Oxfordian of the South Viking Graben (well 9/18A-4).

Remarks. Questionably assigned to the genus owing to bad preservation which makes it difficult to observe pore frames and spines at the pore frame vertices. Differs from *Milax*(?) sp. 1 in having chambers increasing more rapidly in width, while last postabdominal chamber is more inflated.

Milax(?) spp. indet.

(Pl. 9, Fig. 12)

Remarks. Included here are all poorly-preserved specimens that cannot be assigned to any of the above two morphotypes. They have an outline similar to the genus and are thus questionably placed under *Milax* Blome.

Genus PARVICINGULA Pessagno, emend. Pessagno, Blome & Hull.

Parvicingula Pessagno, 1977a, p. 84.

Type species. *Parvicingula santabarbarensis* Pessagno 1977a, p. 86, pl. 9, figs. 11-13.

Emended Diagnosis. "Test with variably sized horn, spindle-shaped to subcylindrical; final postabdominal chamber always terminating in narrow tube which may be open or end with a spinose projection. Length of tube on final postabdominal chamber may be often equal length of horn. Final postabdominal chamber(s) always decreasing rapidly in width" (Pessagno *et al.* 1993, p. 144).

Range. Upper Jurassic (uppermost Kimmeridgian/lowermost Tithonian) to Lower Cretaceous (upper Valanginian/lower Hauterivian) (Pessagno *et al.*, 1993).

Occurrence. Worldwide.

Remarks. Differs from *Dictyomitra* Zittel by lacking costae and having circumferential ridges. Baumgartner (1984a, p. 778; 1992, p. 322) included in the genus forms with or without apical horn. The same author distinguished *Parvicingula* Pessagno, sensu Baumgartner from *Ristola* Pessagno & Whalen, emend. Baumgartner by the lack of an outer layer on the apical part of the test, which obscures the regular hexagonal pore frames. The genus is assigned to Family Parvicingulidae Pessagno, emend. Pessagno & Whalen. Discussion for the phylogenetic relationship of Parvicingulidae with other families can be found on Pessagno & Whalen (1982). Takemura (1986, p. 52) tentatively assigned the genus to the Family Theoperidae Haeckel, emend. Takemura.

59. *Parvicingula*(?) cf. *P. jonesi* Pessagno

(Pl. 9, Fig. 13; Pl. 21, Fig. 3)

cf. 1977b *Parvicingula jonesi* Pessagno, n.sp.; p. 48, pl. 8, fig. 14.

cf. 1984 *Parvicingula jonesi* Pessagno; Pessagno *et al.*, p. 28, pl. 3, figs. 5-7, 14, 19, 24 & 25.

1989 *Parvicingula jonesi* Pessagno; Dyer & Copestake, p. 228, pl. 2, figs. 7 & 8.

(?) 1989 *Parvicingula* sp. cf. *P. jonesi* Pessagno; Pujana, p. 1050, pl. 1, fig. 6 & 7.

cf. 1992 *Parvicingula jonesi* Pessagno; Holdsworth & Nell, fig. 6 (o).

Original Description. "Test as with genus; conical in shape. Cephalis dome-shaped with short, massive horn. All subsequent chambers trapezoidal in outline. Cephalis and thorax with small polygonal pore frames. Abdomen and postabdominal chambers separated by well-developed circumferential ridges and having three rows of large pentagonal pore frames. Postabdominal chambers 8 to 12 in number; final postabdominal chamber with tubular extension, conical in proximal portion" (Pessagno 1977b, p. 48).

Dimensions (in μm). (based on 2 specimens). Average length of preserved test, 301;

average maximum width, 150.

Range. Upper Tithonian to Ryazanian (Pessagno *et al.*, 1984).

Occurrence (literature). North America (California Coast Ranges, Baja California Sur), Mexico, North Sea, Argentina, Antarctic Peninsula. Blome (1992) identified *P.* (?) *jonesi* in sediments from the Indian Ocean (no figure is included).

Occurrence (present work). Biozone 5. Unitary Associations 16 to 17. Rare in the uppermost Volgian and Ryazanian of the Central Graben (wells 23/27-4 & 22/21-2).

Remarks. North Sea specimens lacking the tubular extension on the final postabdominal chamber (owing to poor preservation), but otherwise match the description of Pessagno (1977a). Last postabdominal chamber(s) decreasing in width.

60. *Parvicingula* sp. 1
(Pl. 9, Fig. 14, 17; Pl. 21, Fig. 4)

Description. Test conical on apical part then cylindrical. Cephalis conical internally, with a strongly developed horn. Thorax and abdomen trapezoidal and, together with the first postabdominal chambers, increasing in width. Remaining chambers maintain the same width except the last one which decreases rapidly in width (when preserved), probably ending with a tubular neck. Test lacking circumferential ridges and having polygonal pore frames arranged in rows (observed only with transmitted light microscope). Number of postabdominal chambers 8 to 9.

Dimensions (in μm). Length of preserved test (including horn) (LT), 242-260 (mean, 247+); maximum width (MW), 104-110 (mean, 107).

specimen	Pl. Fig.	LT	MW
CK 248	9, 14	242	105
CK 249	21, 4	243	104
CK 251		260	110
CK 250	9, 17	244	106
10423 EATHIE A		252	108
10419 EATHIE B1		245	110
10512 EATHIE B2		242	107

Occurrence (present work). Biozones 1 to 2. Unitary Associations 2 to 5. Common in the middle Kimmeridgian (*mutabilis* zone, Eathie Haven). Rare in the lowermost Volgian of the Central Graben (well 22/21-2).

61. *Parvicingula* sp. 2
(Pl. 9, Fig. 15-16; Pl. 21, Fig. 5)

Description. Test conical, sharp on apical part. Cephalis conical internally, with small polygonal pore frames arranged irregularly. Thorax and abdomen trapezoidal in outline with small polygonal pore frames. Postabdominal chambers usually six in number, externally separated by weakly-developed circumferential ridges (owing to poor preservation they may be absent). First postabdominal chambers with two rows of polygonal pore frames with circular to subcircular pores. Last postabdominal chambers with three rows of pore frames. All postabdominal chambers increase in width except for the last (preserved) one which decreases in width.

Dimensions (in μm). Length of test (LT), 221-298 (mean, 259+); maximum width of test (MW), 121-156 (mean, 142).

specimen	Pl. Fig.	LT	MW
CK 254	21, 5	234	147
CK 252	9, 15-16	273+	156
13990 16/17-5		298	150
CK 253		221	121
13970 16/17-5		267	138

Occurrence (present work). Biozone 1. Fairly common in the Lower Oxfordian of the South Viking Graben (well 16/17-5).

62. *Parvicingula*(?) sp. 3
(Pl. 10, Fig. 1)

(?) 1989 *Parvicingula blowi* Pessagno; Dyer & Copestake, p. 227, pl. 2, figs. 3 & 4.

Description. Test cylindrical, rounded apically. Cephalis, thorax, abdomen and first postabdominal chamber with irregularly arranged, well-developed, large hexagonal pore frames with nodes at junctions. Remaining chambers maintain same width. A stout apical horn is present on cephalis. Circumferential ridges persist after the first postabdominal chamber(?). Three rows of hexagonal pore frames between the ridges. Central row of pore frames significantly smaller. Distal part of test not preserved.

Dimensions (in μm). (based on 4 specimens). Average length of preserved test (including horn), 235; average maximum width, 100.

Range. Not given by Dyer & Copestake (1989). However, the same authors (p. 227) mentioned that Gregory (1986) "recovered the species from the Kimmeridgian (*cymodoce* to *mutabilis* Zones) of Sutherland, eastern Scotland".

Occurrence (literature). North Sea Basin.

Occurrence (present work). Biozone 1. Fairly common in the middle Kimmeridgian (*mutabilis* zone), Eathie Haven, Cromarty.

Remarks. Questionably assigned to the genus owing preservational limitations in observation of the distal part of the test (whether final postabdominal chamber(s) decreases in width or not). Differs from *Praeparvicingula* sp. 1 in having postabdominal chambers which, except the first, maintain the same width (cylindrical distal portion of test) as well as in having larger, less numerous, polygonal pore frames on apical part of the test. Differs also from *Parvicingula*(?) sp. 4 by having more numerous, smaller and more regularly arranged pores frames on the apical part of test and in lacking a strong, thick cephalic horn.

63. *Parvicingula*(?) sp. 4
(Pl. 10, Fig. 2-4)

Description. Apical part of test dome-shaped. Cephalis with a very long, extremely strong and thick horn, sometimes slightly bent, circular in cross-section. First chambers (cephalis, thorax, which is trapezoidal in outline, and abdomen) with large, irregularly arranged, massive polygonal pore frames and high relief nodes. First postabdominal chambers increasing slightly in width, with well-developed circumferential ridges and three(?) rows of polygonal pore frames in between. Distal part of test not preserved. Internal structure not known.

Dimensions (in µm). Maximum width of preserved test, 114; width of horn at its base, 26; maximum length of preserved horn, 101.

Occurrence (present work). Biozones 1 to 3. Fairly common in the Volgian (?and older strata) of the Barents Sea (well 7430/10-U-01).

Remarks. Questionably assigned to the genus for the same reason as the previously described morphotype. The massive horn and few, strongly developed polygonal pore frames on apical part of test serve to differentiate this morphotype from other *Parvicingula* forms.

64. *Parvicingula*(?) sp. 5
(Pl. 10, Fig. 5-6)

Description. Test slender, conical on apical part; distal portion of test not preserved. Cephalis smooth, poreless with a stout horn (only its base is preserved). Thorax and abdomen trapezoidal in outline with irregular, large pore frames. Postabdominal chambers increasing in width and slightly in height as added, separated by well-developed circumferential ridges with two(?) rows of large polygonal pore frames. Internal structure not known.

Dimensions (in µm). Length of preserved test, 251; maximum width, 133.

Occurrence (present work). Biozone 5. Volgian in the Barents Sea (well 7430/10-U-01).

Remarks. Questionably assigned to the genus (as discussed for previous morphotypes). One specimen has been recovered and it differs from *Praeparvicingula*(?) sp. A and *Parvicingula*(?) sp. 6 by having larger pore frames on thorax and abdomen and two rows of polygonal pore frames between circumferential ridges. The latter and the poreless, smooth cephalis distinguish the morphotype from *Parvicingula*(?) cf. *P. jonesi* Pessagno. The slender test also differentiates this morphotype from *Parvicingula*(?) sp. 6.

65. *Parvicingula*(?) sp. 6

(Pl. 10, Fig. 7-8)

Description. Test conical in outline (broken on distal part in studied material). Cephalis small, smooth, with a horn (preserved only the base). Thorax trapezoidal, having few pore frames. Abdomen and preserved postabdominal chambers with well-developed circumferential ridges and three rows of small polygonal pores in between. Postabdominal chambers increasing rapidly in width and slightly in height as added.

Dimensions (in µm). Maximum preserved length of test, 235; maximum width, 153.

Occurrence (present work). Biozones 4 to 5. Unitary Associations 15 to 17. Rare in the Ryazanian and Upper Volgian of Central Graben (wells 23/27-4 and 22/21-2 respectively).

Remarks. Questionably assigned to the genus *Parvicingula* Pessagno, emend Pessagno *et al.* owing preservational limitations on observation of distal part of the test.

Genus PERISPYRIDIUM Dumitrica

Perispyridium Dumitrica, 1978, p. 35.

Type species. *Trilonche* (?) *ordinaria* Pessagno 1977a, p. 79, pl. 6, fig. 14.

Original Diagnosis. "Flat eptingiids with cephalis small, surrounded in frontal plane by a triangular or subcircular peripheral latticed shell; sagital ring inserted in the cephalic wall; arches more or less distinct (Dumitrica, 1978, p. 35).

Range. Lower Jurassic (upper Pliensbachian/lower Toarcian) to Upper Jurassic (Tithonian).

Occurrence. Jurassic of Romania, Italy, Austria, Greece, southern Switzerland, Atlantic Basin, Baja California Sur, east-central Oregon, western Washington, Alaska, Mexico, Japan, North Sea Basin.

Remarks. Dumitrica (1978) placed the genus within his Family Eptingiidae. Pessagno & Blome (1982), Blome (1984) and other workers tentatively included the genus in the Eptingiidae. Takemura (1986) observed the cephalic skeletal structure of a *Perispyridium* species and modified the interpretation of Dumitrica. He concluded (p. 42) that the genus does not belong to the Family Eptingiidae but to his new Subfamily Perispyridiinae of the Family Acanthodesmiidae Haeckel. MacLeod (1988) discussed the status of the genus and assigned it to nassellarian *incertae sedis*, pointing out that more information on the phylogenetic relationships is needed. The above publications offer discussion on the genus.

66. *Perispyridium*(?) spp. indet.•

(Pl. 10, Fig. 9-15)

Description. Included here are all specimens that bear the characteristic test shape of the genus, having three radially arranged horns. Test surface smooth or coarse; pore frames not preserved.

Dimensions (in μm). (based on 15 specimens). Diameter measured across the greatest width of the test, 105-212; diameter measured across the smallest width of the test, 70-201.

Occurrence (present work). Biozone 1. Unitary Associations 1 to 2. Rare to common in abundance in the ?Upper Bathonian/lower Callovian to Lower Oxfordian of the South Viking Graben (wells 9/18A-4 & 16/17-5).

Remarks. Owing to poor preservation the pore frames are not present and the full length of horns was not observed. For these reasons is questionably assigned to the genus. All specimens recovered are preserved as pyrite.

Genus PRAEPARVICINGULA Pessagno, Blome & Hull

Praeparvicingula Pessagno, Blome & Hull, 1993, p. 144.

Type species. *Parvicingula profunda* Pessagno & Whalen 1982, p. 140, pl. 10, figs. 3-6, 14, 15, 18, 19; pl. 13, fig. 7.

Original Description. "Test conical to subcylindrical (never spindle shaped) with horn. Final postabdominal chamber(s) either increasing in width or maintaining same width. Final chamber lacking narrow terminal tube as with *Parvicingula* s.s." (Pessagno *et al.* 1993, p. 144).

Range. Lower Jurassic (Toarcian) to Lower Cretaceous (upper Valanginian/lower Hauterivian) (Pessagno *et al.*, 1993).

Occurrence. Worldwide.

Remarks. The genus differs from *Parvicingula* s.s. according to Pessagno *et al.* (1993, p. 144) by "lacking a narrow tube on the final postabdominal chamber" and possessing final postabdominal chamber(s) which "continue to increase in width, either rapidly or slowly, as added".

67. *Praeparvicingula* sp.1

(Pl. 10, Fig. 16-18; Pl. 11, Fig. 1-3)

(?) 1989 *Parvicingula* sp. 1 Dyer & Copestake, p. 228, pl. 2, fig. 12.

Description. Test cylindrical. Cephalis dome shaped having a strong horn; thorax trapezoidal externally. Cephalis, thorax, abdomen and first postabdominal chambers with

• After discussion with the external examiner it was decided that this form should not be placed within *Perispyridium* Dumitrica. Radiolaria gen. et sp. indet. A should be used instead.

well-developed, irregularly arranged, polygonal pore frames having nodes at pore frames junctions. Remaining postabdominal chambers increasing in width. Three rows of polygonal (hexagonal) pore frames between circumferential ridges on postabdominal chambers, which are maximum eight in number.

Dimensions (in µm). (based on 8 specimens) Average length of test, 282; average maximum width, 149.

Range. Not given by Dyer & Copestake (1989).

Occurrence (literature). North Sea Basin.

Occurrence (present work). Biozones 4 to 5. Unitary Associations 14 to 17. Rare to common in the uppermost Middle Volgian to Ryazanian of the Central Graben (wells 23/27-4 & 22/21-2).

Remarks. Differs from *Parvicingula*(?) sp. 3 as stated under the latter morphotype.

68. *Praeparvicingula* sp. 2
(Pl. 11, Fig. 4-6)

Description. Test short, conical on apical part then cylindrical. Cephalis bearing a very short, usually bent horn (which is reminiscent of a cat's claw). Irregularly arranged pore frames with well-developed nodes persist on cephalis, thorax (which is trapezoidal in outline) and abdomen. First few postabdominal chambers increasing slightly in width. Remaining chambers maintain same width, and have weakly developed circumferential ridges with three rows of polygonal pore frames. Distal end of test flat. Internal structure is not known. Overall test surface rough.

Dimensions (in µm). Length of test (including horn) (LT) 178-229, (mean, 213+); maximum width of test (MW) 122-130, (mean, 125).

specimen	Pl. Fig.	LT	MW
CK 291	11, 4	208	122
CK 292		204	124
CK 293		227	127
CK 294	11, 5	178	123
CK 295		218	123
CK 296	11, 6	226	130
CK 298		229	128

Occurrence (present work). Biozone 3. Unitary Associations 10 to 12. Rare to common in the Lower to Middle Volgian of the Central Graben (wells 23/27-4 & 22/21-2) and Moray Firth Basin (well 14/18-2), and also reworked in the Middle Oxfordian (well 16/17-5).

Remarks. The short, strong cylindrical test and the bent, short, characteristic horn distinguish this morphotype from other forms/taxa of the genus.

69. *Praeparvicingula* sp. 3

(Pl. 11, Fig. 7-10; Pl. 21, 6-7)

(?) 1971 *Eucyrtidium haeckeli* (Pantanelli); Kozlova, pl. 1, fig. 17.

Description. Included here are all praeparvicingulids with a long, cylindrical test. Cephalis conical having few pores and stout, long apical horn (when preserved). Thorax trapezoidal with small polygonal pore frames. Abdomen and postabdominal chambers subtrapezoidal in outline, increasing slightly in width. Well-developed circumferential ridges present after the second (or first) postabdominal chamber and having three rows of equal sized hexagonal pore frames. Total number of preserved postabdominal chambers 8 to 12. Final postabdominal chambers maintain the same width.

Dimensions (in μm). Length of test (including horn) (LT), 322-490 (mean, 360+); maximum width of test (MW), 123-155 (mean, 141+).

specimen	Pl. Fig.	LT	MW
CK 300		340	137
CK 301		490	155
CK 302		363	153
CK 309	11, 7	322+	123+
CK 304		336	135
CK 307	21, 6-7	341	140
CK 305		327	147

Occurrence (present work). Biozones 1 to 2. Unitary Associations 2 to 6. Common in the middle Kimmeridgian (*mutabilis* zone), Eathie Haven, Cromarty.

Remarks. Kozlova (1971, pl. 1, fig. 17) illustrated a similar form from the Lower Kimmeridgian of the Timano-Uraljsk area but she did not describe it. She stated that the form is quantitatively predominant on her assemblage which was also composed of predominant "spherical forms". *Praeparvicingula* sp. 3 is also adundant on the *mutabilis* zone at Eathie.

Differs from *Parvicingula*(?) sp. 3 and *Praeparvicingula* sp. 1 by having apical part of test (cephalis, thorax abdomen and first postabdominal chambers) with much smaller polygonal pore frames. Also differs from *Parvicingula*(?) sp. 3 by possessing postabdominal chambers which increase in width rather than maintain uniform.

Praeparvicingula sp. 3 also differs from *Praeparvicingula*(?) sp. A by possessing a porous cephalis and well-developed circumferential ridges.

70. *Praeparvicingula* sp. 4

(Pl. 11, Fig. 11-13)

Description. Test conical. Cephalis with few, sparse pores, and bearing a strong apical horn, tetragonal in cross section. Thorax and abdomen trapezoidal in outline with few pores. Chambers increasing in width and having weakly developed circumferential ridges with traces of three rows of polygonal pore frames in between. Distal part of test flat with large circular aperture.

Dimensions (in µm). (based on three specimens). Average length of test, 203; average maximum width, 136.

Occurrence (present work). Biozone 3. Unitary Association 11. Rare in the ?Lower to Middle Volgian of the Central Graben (wells 22/21-2 & 23/27-4) and Moray Firth Basin (wells 12/28-1 & 14/18-2).

Remarks. Differs from *Praeparvicingula* sp. 5 by having a different horn and a test with weakly developed circumferential ridges with 3 rows of pores. Specimens usually found preserved without the horn but the circumferential ridges differentiate them from *Praeparvicingula* sp. 5.

71. *Praeparvicingula* sp. 5
(Pl. 11, Fig. 14; Pl. 12, Fig. 1; Pl. 21, Fig. 8)

Description. Test conical, wide, short. Cephalis with a strong, thick, apical horn which is wide at its base. Thorax trapezoidal externally, increasing rapidly in width with all subsequent chambers. Test lacking circumferential ridges and having small polygonal pore frames arranged irregularly on test surface. Internal structure not known. Total number of chambers cannot be defined.

Dimensions (in µm). Length of test (LT), 162-210 (mean, 184); maximum width of test (MW), 110-130 (mean, 119).

specimen	Pl. Fig.	LT	MW
CK 319	21, 8	185	126
CK 318	12, 1	162	110
10512 EATHIE B2		180	117
10514 EATHIE B2		173	112
CK 320	11, 14	184	112
CK 322		191	126
CK 321		210	130

Occurrence (present work). Biozone 2. Unitary Associations 3 to 6. Fairly common in the middle Kimmeridgian (*mutabilis* zone) at Eathie Haven, Cromarty and rare in the Kimmeridgian/Lower Volgian of Central Graben (well 23/27-4).

Remarks. Differs from *Praeparvicingula* sp. 4 as stated under the latter morphotype.

72. *Praeparvicingula* sp. 6
(Pl. 12, Fig. 2-5)

Description. Test conical on apical part, cylindrical, with a flat distal end. Cephalis bearing a short, strong horn. Thorax and abdomen trapezoidal with polygonal pore frames of large and medium size arranged irregularly. Two lateral short projections develop on thoracic(?) surface. Postabdominal chambers increase slightly in width, lacking circumferential ridges and having regularly arranged well-developed hexagonal pore frames with nodes at junctions. Base of test with large circular aperture.

Dimensions (in µm). Length of test (LT) (including horn), 180-242 (mean, 216); maximum width (MW), 109-140 (mean, 126).

specimen	Pl. Fig.	LT	MW
CK 324	12, 2, 4-5	242	140
CK 323	12, 3	180	109
168.96 7430/10-U-01		231	138
168.96 7430/10-U-01		209	115

Occurrence (present work). Biozone 4. Common in the Volgian of the Barents Sea (well 7430/10-U-01).

Remarks. Differs from *Praeparvicingula* sp. 2 by lacking circumferential ridges and having different horn.

73. *Praeparvicingula* sp. 7
(Pl. 12, Fig. 6-7; Pl. 21, Fig. 9)

(?) 1971 *Stichopilium* sp. Kozlova, pl. 1, fig. 14.

Description. Test conical with a flat distal end. Cephalis bearing three symmetrically arranged, strong apical horns. Thorax, abdomen and postabdominal chambers trapezoidal increasing rapidly in width. Test lacking circumferential ridges. Shape of pore frames cannot be defined (owing to poor preservation).

Dimensions (in µm). Length of test (including horns) (LT), 195-252 (mean, 221); maximum width of test (MW), 101-142 (mean, 122).

specimen	Pl. Fig.	LT	MW
CK 325	12, 6	252	121
CK 327	12, 7	227	142
CK 326	21, 9	195	101
10423 EATHIE A		235	128
10404 EATHIE B1		215	130
10512 EATHIE B2		199	107

Occurrence (present work). Biozone 2. Unitary Associations 3 to 6. Fairly common in the middle Kimmeridgian (*mutabilis* zone), Eathie Haven, Cromarty, in all studied sections.

Remarks. The morphotype resembles *Stichopilium* sp. illustrated by Kozlova (1971, pl. 1, fig. 14) from lower Kimmeridgian deposits of the Timano-Ural region (Russia) but she did not give a description. However, her illustration shows the same arrangement of three apical horns and wide, conical test. Owing to poor preservation the existence of small circular pores cannot be clearly recognised on North Sea specimens.

Differs from Nassellaria sp. 11 in lacking spines at the sides of test and from Nassellaria sp. 12 in having postabdominal chambers increasing rapidly in width; apical horns are also different in comparison with both of these morphotypes.

74. *Praeparvicingula*(?) sp. A
(Pl. 12, Fig. 8-9)

Description. Test elongate, apically pointed cylindrically on remaining part. Cephalis small, conical externally, smooth, poreless with an apical horn (partly preserved). Thorax trapezoidal, perforate with small pores. Abdomen trapezoidal in outline with larger, hexagonal pore frames arranged irregularly. First postabdominal chambers increasing slightly in width and having circumferential ridges with three rows of hexagonal pore frames between. Remaining postabdominal chambers poorly preserved.

Dimensions (in μm). Length of preserved test, 298; maximum width, 111.

Occurrence (present work). Biozone 1. Middle Kimmeridgian (*mutabilis* zone) of Eathie Haven, Cromarty.

Remarks. Only one specimen has been recovered. Questionably assigned to the genus owing to preservational limitations on observation of the distal part of the test (broken). Differs from *Praeparvicingula*(?) sp. B by having a thinner and more apically pointed test and in lacking prominent circumferential ridges. Also differs from *Praeparvicingula* sp. 1 and *Parvicingula*(?) sp. 3 by virtue of its poreless cephalis and pointed apical portion.

75. *Praeparvicingula*(?) sp. B
(Pl. 12, Fig. 10-13; Pl. 21, Fig. 10)

Description. Test conical (not completely preserved). Cephalis smooth, poreless, with an apical horn sometimes bent. Thorax trapezoidal with few pores. Abdomen porous with hexagonal pore frames arranged regularly. Postabdominal chambers increasing slightly in width and height as added and having prominent circumferential ridges with three rows of hexagonal pore frames in between.

Dimensions (in μm). Maximum length of preserved test, 247; maximum width of test, 143.

Occurrence (present work). Biozone 5. Common in the Ryazanian of the Norwegian Sea (well 7B).

Remarks. Questionably assigned to the genus owing to limitations in observing the distal part of the test. The morphotype is characterised by its prominent, well-developed circumferential ridges and apical part of test. •

76. *Praeparvicingula*(?) sp. C
(Pl. 12, Fig. 14-15; Pl. 21, Fig. 11)

Description. Test short, rounded on apical part then cylidrical with a flat distal end. Cephalis with few large polygonal pore frames and a small, short horn. Thorax, abdomen and first postabdominal chambers increasing in width; remaining postabdominal chambers maintain the same width. Test surface lacking circumferential ridges and having large, irregularly arranged, polygonal pore frames with well-developed nodes at pore frame junctions. Base of test with a circular aperture. Internal structure not known.

Dimensions (in µm). Length of test (LT), 166-186 (mean, 174); maximum width of test (MW), 104-134 (mean, 116).

specimen	Pl. Fig.	LT	MW
CK 336	12, 14	166	104
CK 337	12, 15	170	110
CK 335	21, 11	186	134

Occurrence (present work). Biozone 4. Rare in the uppermost Middle Volgian of Central Graben (well 23/27-4).

Remarks. Questionably assigned to the genus. Differs from *Stichocapsa decorata* Rüst by having cylindrical distal portion of the test (postabdominal chambers maintain the same width) and a small apical horn. Also differs from *Praeparvicingula* sp. 2 in lacking weakly-developed circumferential ridges and having a different cephalic horn.

Praeparvicingula(?) spp. indet.
(Pl. 12, Fig. 16)

Remarks. Included here are all specimens for which identification is not possible. They possess a horn (broken) and poorly-preserved test surface, occasionally with circumferential ridges and broken distal portion. Owing to very poor preservation they cannot be assigned to any of the above morphotypes.

Genus SPONGOCAPSULA Pessagno, emend. Pessagno, Blome & Hull
Spongocapsula Pessagno, 1977a, p. 88.

Type species. *Spongocapsula palmerae* Pessagno 1977a, p. 88, pl. 11, figs. 12-14, 16.

Original Diagnosis. "Test elongate, slightly lobulate with six or more postabdominal chambers which increase slowly in height and moderately rapidly in width proximally,

• The morphotype is probably conspecific with *Parvicingula* sp. A of Baumgartner (1992, Pl. 9, Figs. 1-4) and is also of the same age.

gradually decreasing in width distally" (Pessagno 1977a, p. 88).

Emended Diagnosis. As the original but "restricted to forms having strictures developed at the joints between postabdominal chambers" (Pessagno *et al.* 1993, p. 157).

Range. Middle Jurassic (upper Bathonian) to Upper Jurassic (upper Tithonian) or younger (Pessagno *et al.*, 1993).

Occurrence. Worldwide.

Remarks. Differs from *Obesacapsula* Pessagno in having more chambers which increase more slowly in height and width. The genus is assigned to Family Spongocapsulidae Pessagno.

77. *Spongocapsula*(?) sp. 1

(Pl. 12, Fig. 17-20; Pl. 21, Fig. 12)

Description. Test conical with a flat distal end, lacking circumferential ridges. Cephalis dome-shaped, poreless, smooth. Thorax trapezoidal in outline, with sparsely distributed pores. Abdomen and first postabdominal chambers increasing in width, having small pore frames of weak relief and circular to subcircular pores. Last postabdominal chambers increasing in width, and having irregularly arranged pore frames with well-developed nodes at junctions giving a rough surface to the distal part of test. Circular aperture is present at the base of test. Total number of chambers cannot be defined.

Dimensions (in μm). Length of test (LT), 157-209 (mean, 184); maximum width of test (MW), 97-126 (mean, 112); diameter of aperture (DA), 41-51 (mean, 44.5).

specimen	Pl. Fig.	LT	MW	DA
CK 338		157	97	41
CK 339	12, 19	202	112	
CK 340	12, 20	192	121	44
CK 341		161	105	42
CK 342	12, 17-18	209	126	51

Occurrence (present work). Biozone 5. Ryazanian of the Norwegian Sea (well 7B).

Remarks. Questionably assigned to the genus owing to difficulty in observing the increase in height on the postabdominal chambers. Differs from *Spongocapsula*(?) sp. 3 on the ornamentation of the test surface.

78. *Spongocapsula*(?) sp. 2

(Pl. 21, Fig. 13, 16)

(?) 1971 *Dictyomitra* sp. Kozlova, pl. 1, fig. 16.

Description. Test conical with six to eight? chambers. Cephalis conical with few pores. Thorax and abdomen trapezoidal in outline having small pore frames. Postabdominal chambers increasing in width and height as added and having small circular pores arranged irregularly on test surface. A circular aperture is present at the base of the test.

Dimensions (in µm). (based on two specimens) Average length of test, 167; maximum width, 110.

Range. Lower Kimmeridgian (Kozlova, 1971).

Occurrence (literature). ?Russia (Timano-Ural region).

Occurrence (present work). Biozone 1 to 2. Unitary Associations 2 to 4. Rare in the upper Kimmeridgian/Lower Volgian of the Central Graben (well 22/21-2) and Eathie Haven, middle Kimmeridgian (*mutabilis* zone).

Remarks. The morphotype cannot be assigned to the genus *Dictyomitra* Zittel owing to lack of costae. Questionably assigned to *Spongocapsula* Pessagno, emend. Pessagno, Blome & Hull owing to bad preservation. Similar form illustrated by Kozlova (1971, pl. 1, fig. 16) from the Timano-Ural region (Russia). Kozlova, however, did not give a description of the morphotype and therefore it is only tentatively synonymised with *Dictyomitra* sp. Kozlova (1971).

79. *Spongocapsula*(?) sp. 3
(Pl. 13, Fig. 1-4)

Description. Test conical in proximal portion with a flat distal end. Cephalis smooth, without pores, lacking a horn. Thorax and abdomen trapezoidal in outline. Massive, irregular ridges persist on post-cephalic test surface. Polygonal pore frames and nodes of various sizes, with circular pores are distributed irregularly on surface. Circumferential ridges developed on some postabdominal chambers. Circular aperture present at the base of shell. Internal structure not known.

Dimensions (in µm). Length of test (LT), 200-214 (mean, 206); width of test (MW), 114-121 (mean, 118).

specimen	Pl. Fig.	LT	MW
CK 349	13, 1 & 3	203	116
CK 348	13, 2	178+	114
CK 347	13, 4	214	120
86.94 7B		200	121

Occurrence (present work). Biozone 5. Fairly common morphotype in the Ryazanian of the Norwegian Sea (well 7B).

Remarks. Differs from *Spongocapsula*(?) sp. 1 by having a very nodose test surface and more cylindrical test. Differs from genera of the genus *Xitus* Pessagno in lacking: i) two layers of meshwork on postabdominal chambers, ii) test surface with tubercles interconnected by bars, and iii) cephalic horn (Pessagno 1977b).

Genus STICHOCAPSA Haeckel

Stichocapsa Haeckel, 1881, p. 439.

Type species. *Stichocapsa jaspidea* Rüst 1885, p. 317, pl. 6, fig. 6 (subsequent designation by Campbell, 1954; p. D143).

Original Diagnosis. "Stichocapsida (vel Stichocyrtida eradiata clausa) without apical horn, and without basal spine" (Haeckel 1887, p. 1515).

Stichocapsida according to Haeckel (1887, p. 1511) are "Lithocampida with the terminal mouth of the shell fenestrated (vel Stichocyrtida eradiata clausa)".

Lithocampida are "Cyrtoidea with an annulated shell, divided by three or more transverse constrictions into four or more annular joints, without radial apophyses" (Haeckel 1887, p. 1467).

Range. Mesozoic and Cenozoic (Pessagno *et al.*, 1993).

Occurrence. Worldwide.

Remarks. Differs from *Diacanthocapsa* Squinabol, emend. Dumitrica and *Tricolocapsa* Haeckel by having more than 3 segments. *Sethocapsa* Haeckel differs from this genus in having a globose last chamber lacking an aperture. The absence of a cephalic horn differentiate the genus from *Cyrtocapsa* Haeckel. According to Haeckelian classification, the genus was assigned to Family Stichocapsidae Haeckel. Takemura (1986) placed the genus in his new Family Arcanicapsidae. Ellis (1993, p. 973) postulated that *Stichomitra sensu* Foreman (1968) is a junior synonym for the genus.

80. *Stichocapsa decorata* Rüst

(Pl. 13, Fig. 5-12; Pl. 21, Fig. 14-15, 17-19)

1885 *Stichocapsa decorata* Rüst, n.sp.; p. 318, pl. 41, figs. 7 & 8.

1898 *Stichocapsa decorata* Rüst; Rüst, p. 65.

1931 *Stichocapsa decorata* Rüst; Khudayev, p. 45, pl. 1, fig. 46.

1982 *Stichocapsa decorata* Rüst; Wang & Sheng, p. 91, pl. 3, fig. 14 & 15.

1989 *Stichocapsa devorata* Rüst; Dyer & Copestake, p. 228, pl. 2, figs. 9-11.

Original Description. "Der Umriss dem der Vorigen ähnlich. Mit 6 Gliedern, jedes mit Reihen etwas grösserer und weitläufig stehender Löcher" (Rüst, 1885, p. 318).

Translation. Similar to *S. japonica* (shape elongated to egg-like) with 6 segments each with 3 rows of holes but the holes are now larger in diameter and the distance between the holes is greater.

Dimensions (in µm). Length of test (LT), 176-220 (mean, 200); maximum width of test (MW), 105-140 (mean, 128).

specimen	Pl. Fig.	LT	MW
CK 354	13, 5	176	140
CK 356	13, 9	192	105
CK 363		217	125
CK 369	13, 7	200	131
CK 370	13, 8	198	132
CK 368	13, 10	209	136
CK 372	21, 17	207	132
CK 359		195	130
CK 376	13, 12	220	140
CK 375		190	110
CK 357	21, 15	190	127
CK 350		208	133

Range. Rüst (1885, 1898) described the species from the Lower Cretaceous of Germany and Switzerland; Upper Jurassic to Lower Cretaceous (Khudayev, 1931); Upper Jurassic (Wang & Sheng, 1982); Dyer & Copestake (1989, p. 228) found the species "consistently present throughout the Kimmeridge Clay".

Occurrence (literature). Germany, Switzerland, Russia, China, North Sea.

Occurrence (present work). Biozones 4 to 5. Unitary Associations 13 to 18. Common to abundant species in the uppermost Middle Volgian to Ryazanian of the North Sea Basin (recovered from all three grabens), Norwegian Sea and Barents Sea.

Remarks. Also included here are well-preserved specimens from the North Sea and Norwegian Sea which possess one to three minute projections on the apical part of the test and match the description of the species. Apical part of test is less sharp in comparison with the original illustration of Rüst (1885) and distal part has a large circular aperture.

81. *Stichocapsa* sp. A

(Pl. 13, Fig. 13)

Description. Morphotype with small, conical test. Internal structure not known. All segments increasing in width apart from the last postabdominal one which decreases. Test surface lacking circumferential ridges and having large, well-developed hexagonal pore frames with nodes at junctions arranged irregularly on apical portion and becoming larger, arranged in rows, on distal part of test.

Dimensions (in μm). Length of preserved test, 156; maximum width, 111.

Occurrence (present work). Biozone 3. Lower Volgian of Moray Firth Basin (well 12/28-1).

Remarks. Only one specimen has been recovered. Differs from *Stichocapsa decorata* Rüst by having smaller test with larger hexagonal pore frames.

82. *Stichocapsa* sp. B

(Pl. 13, Fig. 14-15; Pl. 22, Fig. 1)

Description. Test conical with a sharp proximal part and a flat distal end. Test surface lacking circumferential ridges and having small polygonal pore frames, arranged irregularly, with circular to subcircular pores. Apical part smooth. Total number of chambers cannot be defined. Last postabdominal chamber(s) decreasing in width.

Dimensions (in μm). Length of test (LT), 142-190+ (mean, 179.5+); maximum width of test (MW), 109-125 (mean, 118).

specimen	Pl. Fig.	LT	MW
CK 384	13, 15	190+	125
CK 380	13, 14	175	118
CK 381	22, 1	186	109
10740 23/27-4		167	119

Occurrence (present work). Biozone 3. Unitary Associations 7 to 11. Common to abundant in the Lower to Middle Volgian of the North Sea Basin (Central Graben and Moray Firth Basin, wells 23/27-4, 22/21-2 and 14/18-2, 12/28-1 respectively).

Remarks. Differs from *Stichocapsa decorata* Rüst by having test with a sharper, poreless apical part and narrower distal part of test. Pore frames are smaller.

83. *Stichocapsa*(?) sp. C

(Pl. 13, Fig. 16)

Description. Test with a sharp, pointed apical part and round, inflated distal part. Cephalis conical externally. All subsequent chambers increasing rapidly in width with the last one being inflated, probably lacking an aperture. Pore frames on test surface cannot be defined.

Dimensions (in μm). Length of test, 259; width of last postabdominal chamber, 152.

Occurrence (present work). Biozone 3. Kimmeridgian/Lower Volgian of the Central Graben (well 23/27-4).

Remarks. Only one specimen has been recovered. Owing to bad preservation the morphotype is questionably assigned to the genus. Differs from *Stichocapsa* sp. B by having an inflated distal part.

84. *Stichosapsa*(?) sp. D

(Pl. 22, Fig. 2)

Description. Test fusiform, with a tapering apical part. First chambers increase rapidly in width, while the last ones decrease. Distal part of test broken. There is an impression of thick costae on apical part of test. Pore frames on test surface cannot be defined.

Dimensions (in µm). Length of preserved test, 170; maximum width, 86.

Occurrence (present work). Biozone 3. Lowermost Middle Volgian of the Moray Firth Basin (well 12/28-1).

Remarks. A single specimen has been recovered. Owing preservational limitations on observation of the internal structure of test and pore frames on surface this morphotype is questionably assigned to the genus.

85. *Stichocapsa*(?) sp. E

(Pl. 13, Fig. 17-19)

Description. Test relatively small, drop-like in outline, having 6 to 7 longitudinal plicae running along the test surface on lateral view. Pores cannot be recognised between the plicae. Small circular aperture is present at the base of test. Number of chambers cannot be defined. Test lacking constrictions. Internal structure not known.

Dimensions (in µm). (based on three specimens). Total height of test, 178; maximum width of test, 123.

Occurrence (present work). Biozone 3. Unitary Association 8. Rare in Lower Volgian of Central Graben (wells 29/12-1 & 22/21-2) and Middle Volgian of Moray Firth Basin (well 14/18-2).

Remarks. Owing preservational limitations on observation of the internal test structure the morphotype is questionably assigned to the genus *Stichocapsa* Haeckel. •

86. *Stichocapsa*(?) sp. F

(Pl. 14, Fig. 1-2)

Description. Test big, with a rounded protruding apical part and egg-shaped, wider, distal part. Number of segments cannot be defined. Test surface rough with traces of pore frames. Test lacking an aperture (it may be obscured owing to poor preservation).

Dimensions (in µm). Length of test, 280; maximum width of test, 176.

Occurrence (present work). Biozone 1. Middle Kimmeridgian of Central Graben (well 22/21-2).

Remarks. A single specimen has been recovered. Questionably assigned to the genus for the same reason as the previously described morphotypes.

• The morphotype could be assigned to the genus *Protunuma* Ichikawa & Yao.

87. *Stichocapsa*(?) sp. G

(Pl. 14, Fig. 3; Pl. 22, Fig. 3)

Description. Test small with a smooth, poreless cephalis. Thorax trapezoidal increasing rapidly in width. Remaining chambers cannot be defined but increasing slightly in width except the last one(?). Large polygonal pore frames persist on test surface.

Dimensions (in µm). (based on three specimens). Average length of test, 148; average maximum width, 85.

Occurrence (present work). Biozone 3. Rare in Lower Volgian of the Gentral Graben (well 22/21-2).

Remarks. Questionably assigned to the genus.

88. *Stichocapsa*(?) sp. H

(Pl. 14, Fig. 4-5)

Description. Grouped here are specimens regardless of test size with a drop-like test in outline, lacking constrictions. Total number of segments cannot be defined. Cephalis small, hemispherical, smooth. Distal part of test inflated, spherical to subspherical in outline. Test surface with traces of pore frames. Aperture at the base of test not observed.

Dimensions (in µm). Length of test, 117- 195; maximum width of test, 84-160.

Occurrence (present work). Biozone 1. Upper Callovian/Lower Oxfordian of the South Viking Graben (well 9/18A-4, small size test) and Lower Volgian of Central Graben (well 29/12-1).

Remarks. Questionably assigned to the genus owing to preservational limitations on observation of the internal structure. Differs from *Stichocapsa*(?) sp. F by having a shorter test and spherical to subspherical distal part of the test, rather than oval.

89. *Stichocapsa*(?) sp. I

(Pl. 14, Fig. 6-7; Pl. 22, Fig. 4)

Description. Test spindle-shaped with a conical, sharp apical part and rounded distal end. Test surface lacking circumferential ridges and having polygonal pore frames irregularly arranged. All chambers increase slightly in width except the last one which decreases. Total number of chambers cannot be defined (inner structure cannot be observed).

Dimensions (in µm). (based on 3 specimens). Length of test, 255; maximum width of test, 120.

Occurrence (present work). Biozone 5. Rare in the Ryazanian of the Central Graben (well 23/27-4).

Remarks. Questionably assigned to the genus. Differs from Nassellaria group D in lacking weakly-developed constrictions between chambers and a possible terminal tubular extension on the last postabdominal chamber. Also differs from Nassellaria sp. 10 and *Stichocapsa decorata* Rüst in the general outline of the test.

Stichocapsa(?) spp. indet.

(Pl. 14, Fig. 8-9)

Remarks. Included here are all poorly-preserved specimens which exhibit the general test outline as *Stichocapsa decorata* Rüst and *Stichocapsa* sp. B but cannot be assigned to the above morphotypes owing to poor preservation.

Genus TRICOLOCAPSA Haeckel

Tricolocapsa Haeckel, 1881, p. 436.

Type species. *Tricolocapsa theophrasti* Haeckel, 1887 (subsequent designation by Campbell, 1954; p. D136).

Original Diagnosis. "Theocapsida (vel Tricyrtida eradiata clausa) without apical horn, with a terminal lattice-plate on the mouth" (Haeckel 1887, p. 1431).

Theocapsida according to Haeckel (1887, p. 1426) are "Theocyrtida with the basal mouth of the shell fenestrated (vel Tricyrtida eradiata clausa)".

Tricyrtida eradiata are "Cyrtoidea with a three-jointed shell, divided by two transverse constrictions into cephalis, thorax, and abdomen, without radial apophyses" (Haeckel 1887, p. 1395).

Range. Mesozoic (Lower Jurassic, Toarcian) to Cenozoic.

Occurrence. Worldwide.

Remarks. Haeckel's type species is Cenozoic. According to Haeckelian classification this genus was included under the Family Theocorythidae Haeckel. Until recently, it was believed that the classification at family level was not yet sufficiently settled. Takemura (1986) classified the genus, according to its cephalic skeletal structure, under his new Family Arcanicapsidae. Pessagno *et al.* (1993, p. 160) questioned the classification of "most Mesozoic forms figured by various workers as *Tricolocapsa*" to the genus.

90. *Tricolocapsa* sp. A

(Pl. 14, Fig. 10-14; Pl. 22, Fig. 5-7)

1989 *Tricolocapsa* sp. 1 Dyer & Copestake, p. 228, pl. 2, fig. 13-15.

Description. Test small, consisting of three segments. Cephalis smooth, poreless. Thorax low, trapezoidal, with small polygonal pores. Abdomen large, spherical to subspherical, with irregularly arranged polygonal pore frames having circular to subcircular pores and well-developed nodes at the junctions, when specimens well-preserved. Small circular aperture is present at the base of abdomen having slightly raised rim. Distal end of test slightly truncated.

Dimensions (in µm). Total height (TH), 108-140 (mean, 127); maximum width of test (WT), 99-127 (mean, 112); width of cephalis (WC), 14-24 (mean, 18); height of thorax (HT), 20-25 (mean, 22); height of abdomen (HA), 81-113 (mean, 100); width of thorax (WTH), 41-46 (mean, 43); diameter of aperture (DA), 12-17 (mean, 15); average diameter of abdominal pore frames (DPa), 8; average thickness of wall test, 15.

specimen	Pl. Fig.	TH	MW	WC	HT	HA	WTH	DA	DPa
CK 407		140	127	24	21	113	46	17	
CK 403	14, 14	119	105			100	41		9
CK 399	22, 6	108	99	16	20	81	46	12	
CK 406	22, 5	140	116	14	25	106	40		8

Range. Not given by Dyer & Copestake for reasons of confidentiality.

Occurrence (literature). North Sea Basin.

Occurrence (present work). Biozone 5. Unitary Associations 16 to 18. Uppermost Volgian to Ryazanian of the North Sea Basin (all three studied grabens, wells 23/27-4, 22/21-2, 29/12-1, 14/18-2, 9/18A-4), Ryazanian of the Norwegian Sea (well 7B), and Berriasian of the Barents Sea (well 7430/10-U-01).

Remarks. Differs from *Tricolocapsa* sp. B by having a shorter thorax and spherical to subspherical abdomen. Also included here are specimens with a narrow thorax. Differs from *Tricolocapsa* sp. A, described and illustrated by Baumgartner (1992, p. 326, pl. 13, figs. 6, 7) from the Late Tithonian(?) - Berriasian of the Indian Ocean, in lacking pore frames arranged in vertical rows on abdomen.

91. *Tricolocapsa* sp. B

(Pl. 14, Fig. 15-19; Pl. 22, Fig. 8)

Description. Test small with three segments. Cephalis rounded, poreless. Thorax trapezoidal in outline, porous. Abdomen inflated, trapezoidal having a truncate distal end with a circular aperture. When well-preserved, abdomen exhibits irregular distributed pentagonal to hexagonal pore frames around small circular pores.

Dimensions (in µm). Total height (TH), 131-164 (mean, 147); maximum width of test (MW), 74-138 (mean, 112); width of cephalis (WC), 16-25 (mean, 20); height of thorax (HT), 24-29 (mean, 27); height of abdomen (HA), 70-121 (mean, 99); width of thorax (WTH), 39-55 (mean, 46); diameter of aperture (DA), 17-20 (mean, 18); diameter of abdominal pore frames (DPa), 11.

specimen	Pl. Fig.	TH	MW	WC	HT	HA	WTH	DA
CK 412	14, 16	148	109	25	29	103	44	18
CK 413			74	20	25	70	39	
CK 414	14, 17-18	143	121	18	24	110	40	17
CK 417	14, 15	164	138	16	29	121	54	20
CK 415	22, 8	131	117	22	26	92	55	

Occurrence (present work). Biozone 5. Unitary Associations 16 to 18. Uppermost Volgian to Ryazanian of the North Sea Basin (Central and South Viking Grabens, wells 23/27-4, 29/12-1 & 9/18A-4 respectively) and Ryazanian of the Norwegian Sea (well 7B).

Remarks. The morphotype is characterised by its inflated trapezoidal outline abdomen. Differs from *Tricolocapsa triangulosa* Tan Sin Hok by lacking "cortinar septum" on cephalis. Co-occurs with *Tricolocapsa* sp. A.

92. *Tricolocapsa* sp. C
(Pl. 15, Fig. 1-2; Pl. 22, Fig. 9-10)

Description. Cephalis hemispherical with few very small pores. Thorax long, trapezoidal. Two first segments of test (cephalis and thorax) one third of total test height. Abdomen inflated spherical to subtrapezoidal. Hexagonal pore frames around small circular pores persist on thorax and abdomen, being smaller on thoracic surface.

Dimensions (in µm). Total height (TH), 114-163 (mean, 138); maximum width of test (MW), 89-126 (mean, 108); width of cephalis (WC), 16-32 (mean, 22); height of thorax (HT), 25-39 (mean, 30); width of thorax (WTH), 42-62 (mean, 50); heigth of abdomen (HA), 79-107 (mean, 97).

specimen	Pl. Fig.	TH	MW	WC	HT	WTH	HA
CK 423	15, 2	114	89	18	25	42	79
CK 419	15, 1	163	126	32	39	62	107
CK 422	22, 9	136	109	16	25	47	106

Occurrence (present work). Biozone 5. Unitary Associations 17 to 18. Lower/Upper Ryazanian of the Central Graben (well 29/12-1), Upper Volgian/Upper Ryazanian of the South Viking Graben (well 16/15-5), Ryazanian of the Norwegian Sea (well 7B), and Berriasian of the Barents Sea (well 7430/10-U-01).

Remarks. Differs from *Tricolocapsa* sp. A in having a more prominent/extended cephalis and thorax and larger pore frames on thoracic surface. Co-occurs with *T.* sp. A and *T.* sp. B.

93. *Tricolocapsa* sp. D
(Pl. 15, Fig. 3-6)

1989 *Tricolocapsa* sp. 2 Dyer & Copestake, p. 229, pl. 2, fig. 16 & 17.

Description. A morphotype with relatively large test, consisting of a small, hemispherical (porous?) cephalis, a large trapezoidal thorax and an inflated spherical abdomen, and lacking an aperture (it may be closed). Hexagonal pore frames with well-developed nodes at junctions persist on thorax and abdomen, becoming significantly larger on abdominal surface.

Dimensions (in µm). Total height of test (TH), 212-223 (mean, 217); maximum width of test (MW), 164-165 (mean, 164); diameter of cephalis (DC), 22-32 (mean, 27); height of thorax (HT), 55-78 (mean, 66); width of thorax (WTH), 89-111 (mean, 102); height of abdomen (HA), 110-147 (mean, 132); average diameter of thoracic pore frames (DPt), 11; average diameter of abdominal pore frames (DPa), 17.

specimen	Pl. Fig.	TH	MW	DC	HT	HA	WTH	DPt	DPa
CK 426	15, 4-6	212	164	32	78	110	111	11	18
CK 425		223	164	28	55	147	89		
CK 424	15, 3	217	165	22	65	138	106	11	16

Range. Not given by Dyer & Copestake for reasons of confidentiality.

Occurrence (literature). North Sea Basin.

Occurrence (present work). Biozone 5. Unitary Association 18. Uppermost Volgian/Ryazanian of the Central Graben (wells 22/21-2 & 29/12-1).

Remarks. The morphotype differs from *Tricolocapsa cuvierii* Rüst, which is described from the Upper Jurassic-Cretaceous of Italy (Rüst, 1898; Degl' Innocenti, 1927; Cita & Pasquare, 1959) by having a larger thorax and spherical rather than oval abdomen. Differs also from *T. obesa* Rüst: i) form a of Heitzer (1930b) by having larger, more prominent thorax, and ii) form b of Heitzer (1930b) by possessing significantly bigger pore frames on thorax and abdomen. *Tricolocapsa* sp. D also differs from *T. dispar* Tan Sin Hok described from the Upper Jurassic of Indian Ocean in virtue of its less prominent, hemispherical cephalis and well-developed pore frames on thorax and abdomen.

94. *Tricolocapsa*(?) sp. 1
(Pl. 15, Fig. 7)

Description. Test with a small and smooth hemispherical cephalis. Thorax low, small, trapezoidal in outline. Abdomen inflated, spherical with a flat top at the contact with thorax. Hexagonal pore frames, with well-developed nodes at junctions, present on thoracic and abdominal surface.

Dimensions (in µm). Total height of test, 159; maximum width of test, 122; diameter of cephalis, 21; height of thorax, 25; height of abdomen, 118; maximum width of thorax, 36.

Occurrence (present work). Biozone 5. Ryazanian of the Norwegian Sea (well 7B).

Remarks. Only one specimen has been recovered. Differs from *Tricolocapsa* sp. A and *Tricolocapsa* sp. C by having an abdomen with a flat top. Also differs from *Tricolocapsa* sp. B described and illustrated by Baumgartner (1992, p. 326, pl. 13, fig. 9) from the Late Tithonian - Berriasian to Barremian of the Indian Ocean in lacking a terminal apendage at the base of the abdomen. It is not clear whether the thorax is partly hidden in the abdominal cavity, thus the morphotype is questionably assigned to *Tricolocapsa* Haeckel.

95. *Tricolocapsa*(?) sp. 2
(Pl. 15, Fig. 8)

Description. Test very small, present material broken on apical part. Thorax trapezoidal in outline, lacking pores (this may be due to poor preservation). Abdomen inflated, spherical with twelve longitudinal plicae in lateral view with traces of small circular pores between. Base of abdomen with large aperture (it may well be broken).

Dimensions (in µm). Total height of test, 98+; maximum width of test, 84; height of abdomen, 73; maximum width of thorax, 34.

Occurrence (present work). Biozone 3. Lower Volgian of Central Graben (well 22/21-2).

Remarks. Only one specimen has been recovered. Owing to poor preservation (broken apical part of test) the specimen is questionably assigned to the genus *Tricolocapsa* Haeckel.

96. *Tricolocapsa*(?) sp. 3
(Pl. 15, Fig. 9-12)

Description. Test with three segments visible externally. Cephalis small, hemispherical, poreless, smooth. Thorax trapezoidal in outline, porous. Abdomen large, subtrapezoidal in outline with large pores arranged irregularly on test surface. The pores are circular, raised above the test surface. Large circular aperture with a smooth rim is present at base of abdomen giving a truncated outline to the distal end of test.

Dimensions (in µm). Total height (TH), 119-135 (mean, 127); maximum width of test (MW), 95-128 (mean, 112); diameter of cephalis (DC), 13-20 (mean, 16.5); height of thorax (HT), 34-35 (mean, 34.5); height of abdomen (HA), 75-85 (mean, 78); maximum width of thorax (WTH), 52-63 (mean, 57.5); diameter of aperture (DA), 43-56 (mean, 49.5); diameter of abdominal pore frames (DPa), 4.6.

specimen	Pl. Fig.	TH	MW	DC	HT	HA	WTH	DA	DPa
CK 429	15, 9-10	135	128	20	34	85	63	56	4.6
CK 431	15, 11-12	119	113	14	35	75	52		4.6
CK 430			95			75		43	

Occurrence (present work). Biozone 1. Rare morphotype recovered from the middle Callovian of the South Viking Graben (well 9/18A-4).

Remarks. Questionably assigned to the genus owing to the presence of a large aperture. The morphotype cannot be assigned to *Eucyrtidiellum* Baumgartner, emend. Takemura; the latter is 4-segmented nassellarian with relict pores on thorax.

97. *Tricolocapsa*(?) sp. 4
(Pl. 15, Fig. 14)

Description. Morphotype with three visible segments externally. Cephalis hemispherical. Thorax large and long, trapezoidal in outline. Abdomen inflated, oval in outline, possibly with large aperture at the base (distal part of test broken?). Thorax and abdomen having moderately spaced longitudinal plicae (8 to 9 visible on lateral view of abdomen). Pores between the plicae cannot be defined (owing to poor preservation).

Dimensions (in µm). Total height of test (TH), 193; maximum width of thorax (MT), 65; height of abdomen (HA), 138; width of abdomen (WA), 144.

Occurrence (present work). Biozone 3. Lower Volgian of Central Graben (well 22/21-2).

Remarks. A single specimen has been recovered. Questionably assigned to the genus *Tricolocapsa* Haeckel owing to poor preservation.

Tricolocapsa(?) spp. indet.
(Pl. 15, Fig. 13, 15)

Remarks. Included here are all broken nassellarians which exhibit a general test outline similar to *Tricolocapsa* Haeckel but owing to preservational limitations on observation of morphological features and internal structure cannot be assigned to any of the above described morphotypes.

Genus TURANTA Pessagno & Blome, emend. Takemura
Turanta Pessagno & Blome 1982, p. 296.

Type species. *Turanta capsensis* Pessagno & Blome 1982, p. 297, pl. 4, figs. 3, 11, 12, 14, 17; pl. 7, fig. 5.

Abridged Emended Diagnosis. "Test consists of one segment; cephalis large, subspherical, latticed with large, circular pores, regularly or irregularly arranged. Test having three triradiate spines located in the same plane, perpendicular to the collar plate. Dorsal spine is usually curved towards the apical spine. Cephalic pores are large and circular, regularly or irregularly distributed" (from Takemura 1986, p. 64).

Range. Lower Jurassic (lower Toarcian) to Upper Jurassic (lower Tithonian).

Occurrence. North American Jurassic basins (east-central Oregon, Baja California Sur), Japan.

Remarks. The genus cannot be at present assigned to any formal taxonomic classification at family level (Pessagno & Blome 1982, p. 289; Takemura, 1986). Pessagno & Blome (1982) described the genus as having two segments (partially formed cephalis and thorax). However, Takemura (1986, p. 64-65) emended the definition based on the cephalic skeletal structures. The genus differs from *Tripocyclia* Rüst by virtue of its asymmetrically placed spines.

98. *Turanta*(?) spp. indet.

(Pl. 15, Fig. 16)

Description. Test subspherical, possessing traces of three spines. Test surface slightly coarse. Pore frames are not preserved and a small flattened area is present between the dorsal spine and one of the other two spines (apical or vertical).

Dimensions (in µm). Length of thorax (distance from base of horn to opposite end of test), 174; width of thorax (distance between feet), 169.

Occurrence (present work). Biozone 1. Only one specimen have been recovered from the middle Callovian of the South Viking Graben (well 9/18A-4).

Remarks. Differs from *Perispyridium* forms by virtue of its test shape, differently arranged spines and flattened area between dorsal and apical or vertical spine. However, owing preservational limitations the morphotype is questionably assigned to *Turanta* Pessagno & Blome, emend. Takemura.

Genus WILLIRIEDELLUM Dumitrica

Williriedellum Dumitrica, 1970, p. 69.

Type species. *Williriedellum crystallinum* Dumitrica 1970, p. 69, pl. 10, figs. 60a-c, 62, 63.

Original Diagnosis. "Cryptothoracic tricyrtids with large inflated abdomen having a constricted aperture and a complex sutural pore; cephalis free, poreless, with four collar pores, with or without a short apical horn; thorax porous, campanulate, small, without descending spines and partly depressed into abdomen" (Dumitrica 1970, p. 69).

Range. Middle Jurassic to Lower Cretaceous.

Occurrence. Romania, Japan.

Remarks. Differs from *Zhamoidellum* Dumitrica and *Cryptamphorella* Dumitrica by having an aperture at the base of the abdomen. In addition, differs from *Zhamoidellum* by having a sutural pore. Dumitrica (1970) assigned the genus to his new Family Williriedellidae.

99. *Williriedellum*(?) sp. 1

(Pl. 15, Fig. 17; Pl. 16, Fig. 1-2)

Description. Test with three chambers. Cephalis small, hemispherical, smooth externally, without pores. Thorax trapezoidal externally, partly depressed into the abdomen. Abdomen large, inflated, spherical to slightly oval, with an aperture at its base and a possible sutural pore near the thoracic area. Polygonal pore frames on the abdominal surface.

Dimensions (in µm). Total height of test (TH), 110-139 (mean, 127); maximum width of test (MW), 108-114 (mean, 112); width of cephalis (WC), 18-25 (mean, 21); width of thorax (WTH), 39-48 (mean, 43).

specimen	Pl. Fig.	TH	MW	WC	WTH
CK 439	16, 1-2	139	113	25	48
CK 442	15, 17	133	114	18	39
CK 440		110	108	21	41

Occurrence (present work). Biozone 4. Unitary Association 14. Rare in the Upper Volgian of the Central Graben (well 23/27-4) and ?Lower Volgian (well 22/21-2).

Remarks. Questionably assigned to the genus owing preservational limitations on definite observation of a sutural pore. Differs from *Zhamoidellum*(?) sp. 1 by having an aperture and a possible sutural pore. These features are usually difficult to define with the reflected light microscope and SEM work is needed. Differs also from *Tricolocapsa* sp. A in lacking well-defined cephalis and thorax in outline view and having a possible sutural pore.

Genus XITUS Pessagno

Xitus Pessagno, 1977b, p. 55.

Type species. *Xitus plenus* Pessagno 1977b, p. 55, pl. 9, figs. 15, 21, 22, 26; pl. 12, fig. 15.

Original Diagnosis. " Test as with family. Cephalis with horn. Final postabdominal chamber terminating in tubular extension with a large aperture. Tubular extension lacking double layer structure and planiform partition with smaller circular aperture. Test cone-shaped; circular in axial section; with or without strictures at joints" (Pessagno 1977b, p. 55).

Range. Upper Jurassic - Cretaceous.

Occurrence. North America (California), Russia, European Alps, Atlantic Ocean, North Pacific, Japan, Greece, Romania, Oman, Sicily.

Remarks. Pessagno (1977b, p. 55) gave the differences of *Xitus* Pessagno from *Crolanium* Pessagno. The genus is assigned to the Family Xitidae Pessagno.

100. *Xitus*(?) sp. 1
(Pl. 16, Fig. 5)

Description. Test conical on apical part then cylindrical (although distal portion broken). Cephalis without pores and apical horn. Thorax and abdomen trapezoidal in outline having relatively small, polygonal pore frames of various size. Postabdominal chambers possibly with two layers of meshwork and tubercle-like, small projections, connected with strong bars. Test surface with irregularly arranged pore frames varying in size and shape. Total number of segments cannot be defined. Internal structure not known.

Dimensions (in μm). Length of preserved test, 201; maximum width of test, 114.

Occurrence (present work). Biozone 5. Ryazanian of the Norwegian Sea (well 7B).

Remarks. A single specimen has been recovered. Questionably assigned to the genus owing to poor preservation (broken distal part of the test) and lack of a cephalic horn.

Genus ZHAMOIDELLUM Dumitrica
Zhamoidellum Dumitrica, 1970, p. 79.

Type species. *Zhamoidellum ventricosum* Dumitrica 1970, p. 79, pl. 9, figs. 55a & 55b.

Original Diagnosis. "Cryptothoracic tricyrtids with large inflated abdomen without aperture or sutural pore. Cephalis poreless, with four collar pores, with or without a short apical horn; thorax campanulate, porous, partly depressed into the abdominal cavity, its opening without descending spines" (Dumitrica, 1970, p. 79).

Range. Middle Jurassic to Lower Cretaceous.

Occurrence. Europe (Romania, Alps), Japan, New Zealand.

Remarks. Differs from *Cryptamphorella* Dumitrica by having porous thorax and lacking sutural pore (although *Cryptamphorella* Dumitrica does not always possess one). Dumitrica (1970) assigned the genus to his Family Williriedellidae.

101. *Zhamoidellum*(?) sp. 1
(Pl. 15, Fig. 18; Pl. 16, Fig. 3; Pl. 22, Fig. 11-12)

Description. Test with three segments. Cephalis small, hemispherical. Thorax oval, porous and partly hidden in abdominal cavity. Abdomen large, spherical to subspherical with meshwork of polygonal pore frames.

Dimensions (in μm). Total height of test (TH), 108-116 (mean, 113); maximum width of test (MW), 96-106 (mean, 101); width of cephalis (WC), 16-20 (mean, 18); height of thorax (HT), 30; height of abdomen (HA), 75-88 (mean, 81.5); width of thorax (WTH), 39-46 (mean, 42).

specimen	Pl. Fig.	TH	MW	WC	HT	HA	WTH
CK 438	16, 3	115	96	16		88	39
CK 441	15, 18	108	101	20			40
CK 436	22, 11	116	106	19	30	75	46

Occurrence (present work). Biozone 5. Unitary Associations 16 to 18. Fairly common in abundance, recovered from the uppermost Volgian to Upper Ryazanian of the Central Graben (wells 29/12-1, 23/27-4 & 22/21-2).

Remarks. Questionably assigned to the genus owing preservational limitations on observation of the presence/absence of an abdominal aperture. The morphotype co-occurs with *Tricolocapsa* sp. A from which it differs in having the thorax partly depressed into the abdominal cavity. When this feature cannot be observed (owing to pyritisation of specimens) the morphotype can be distinguished from *Tricolocapsa* sp. A by lacking a distinctive thorax between the cephalis and abdomen.

102. *Zhamoidellum*(?) sp. 2

(Pl. 16, Fig. 4)

Description. A very small form with hemispherical cephalis, short thorax partly depressed into the abdominal cavity which is large, inflated, elliptical in shape and lacks an aperture. Meshwork of polygonal pore frames and well-preserved nodes at each junction is preserved on abdominal surface of specimens studied.

Dimensions (in μm). Total height of test (TH), 91; maximum width of test (MW), 100; diameter of cephalis (DC), 18; height of thorax (HT), 15+; height of abdomen (HA), 61; width of thorax (WTH), 34+.

specimen	Pl. Fig.	TH	MW	DC	HT	HA	WTH
CK 443	16, 4	86	98	18	15+	62	34+
CK 444		95	101			59	

Occurrence (present work). Biozone 4. Rare morphotype recovered from the ?Lower Volgian of the Central Graben (well 22/21-2).

Remarks. Differs from *Zhamoidellum*(?) sp. 1 by possessing an abdomen elliptical in outline. The morphotype is questionably assigned to the genus. The presence of pores on the thoracic surface is not clear.

CRYPTOCEPHALIC & CRYPTOTHORACIC NASSELLARIA

Remarks. The classification of the Cryptothoracic nassellarians requires well-preserved specimens in order to define the nature of cephalis, thorax and abdomen, presence/absence of an aperture and sutural pore as well as other features. Most of the North Sea specimens have been found pyritised and observation of the internal structure is not possible. Owing to these preservational limitations, the following morphotypes are left in open nomenclature. A classification summary of the Cryptocephalic and Cryptothoracic Nassellaria, according to Dumitrica (1970) and the recent addition of *Complexapora* Kiessling is given on Table 8.2.

103. Cryptothoracic Nassellaria sp. A
(Pl. 16, Fig. 6)

Description. Cephalis small, smooth, hemispherical. Thorax completely hidden in abdomen which is large, oval with rough surface lacking an aperture. Sutural pore cannot be defined (it may be obscured), owing to poor preservation.

Dimensions (in μm). Total height of test, 211; maximum width of test, 168; diameter of cephalis, 39.

Occurrence (present work). Biozone 5. Ryazanian of the Central Graben (well 23/27-4).

Remarks. Only one specimen has been recovered.

104. Cryptothoracic Nassellaria sp. B
(Pl. 16, Fig. 7-9)

Description. Cephalis small, hemispherical, with a rough surface (owing to poor preservation it is not clear if the cephalis has pores or not). Thorax hidden into the abdomen which is large, oval with polygonal pore framework. Large aperture possibly present at the base of abdomen.

Dimensions (in μm). Total height of test (TH), 165; maximum width of test (MW), 120; diameter of cephalis (DC), 35.

Occurrence (present work). Biozone 4. Uppermost Middle Volgian of the Central Graben (well 23/27-4).

Remarks. Only one specimen has been recovered. Differs from Cryptothoracic Nassellaria sp. A by having a more protruding cephalothorax and higher abdomen with a possible aperture.

GENUS	NUMBER OF CHAMBERS	CEPHALIS	THORAX	ABDOMEN	APERTURE	SUTURAL PORE	OTHER FEATURES	RANGE	
Gongylothorax Foreman, emend. Dumitrica	2	small, poreless	large, inflated		YES (constricted)	YES (near the junction cephalis/thorax)		Upper Jurassic-Cretaceous	CRYPTOCEPHALIC
Heliocryptocapsa Dumitrica	2	small, poreless	large, inflated, discoidal to subspherical		NO	YES (faintly individualized)	equatorial spines on thorax	Upper Cretaceous	CRYPTOCEPHALIC
Diacanthocapsa Squinabol, emend. Dumitrica	3	small, poreless with/without horn	campanulate, porous	thinner-walled than the thorax	YES (constricted)	YES, sometimes NO (lumbar position)	oval or spindle-shaped test	Upper Jurassic-Upper Cretaceous	CRYPTOCEPHALIC
Lithocampe Ehrenberg	4	small	with rounded apex	the largest chamber	YES (constricted, on 4th chamber)		spindle-shaped, small pores on last 3 chambers	Upper Cretaceous-Recent (possibly earlier)	CRYPTOCEPHALIC
Willriedellum Dumitrica	3	poreless, with 4 collar pores, with/without horn	porous, small, campanulate, without descending spines	large, inflated	YES (constricted)	YES (complex, on abdomen)		Middle Jurassic-Lower Cretaceous	CRYPTOTHORACIC
Hemicryptocapsa Tan Sin Hok, emend. Dumitrica	3	poreless, with 4 collar pores, usually without horn	porous, campanulate	large, inflated	YES (strongly constricted)	YES (simple, on abdomen)	3 descending spines on thorax	Lower to Upper Cretaceous	CRYPTOTHORACIC
Holocryptocapsa Tan Sin Hok, emend. Dumitrica	3	poreless, without apical spine	porous, campanulate, with 4 to 6 basal spines	generally spherical	YES (strongly constricted)	YES (simple, on abdomen)	spherical test	Upper Cretaceous	CRYPTOTHORACIC
Holocryptocanium Dumitrica	3	simple, poreless	porous, with 3 descending spines	large, usually spherical	YES (strongly constricted)	YES (closed innerside by porous plate)	spherical test, cephalis & thorax fully depressed into adbomen	Lower to Upper Cretaceous	CRYPTOTHORACIC
Excentropylomma Dumitrica	3	poreless	porous, campanulate, without descending spines		YES (lateral)	NO	oval-shaped test	Upper Cretaceous	CRYPTOTHORACIC
Immersothorax Dumitrica	4	poreless, open in 4 collar pores	campanulate, without descending spines		YES (axial constricted, on 4th chamber)	YES (in lumbar position)		Upper Cretaceous	CRYPTOTHORACIC
Zhamoidellum Dumitrica	3	poreless, with 4 collar pores, with/without horn	campanulate, without descending spines	large, inflated	NO	NO		Middle Jurassic-Lower Cretaceous	CRYPTOTHORACIC
Cryptamphorella Dumitrica	3	poreless, usually with short horn	small, poreless, without descending spines	large, inflated	NO	YES or NO	cephalo-thorax partly to almost fully depressed into abdomen	Upper Jurassic to Upper Cretaceous	CRYPTOTHORACIC
Solenotryma Foreman	4	small, smooth, poreless, without horn	tronconical, short	subspherical, large, half or more encased in the 4th segment	YES (on both abdomen and 4th chamber, constricted)		oval, 3-chambered part half encased into 4th chamber, small pores	Upper Jurassic(?) to Upper Cretaceous	CRYPTOTHORACIC
Squinabollum Dumitrica	3	poreless, divided into 2 chambers, horn on upper one	porous	large, inflated	NO	NO		Upper Cretaceous	CRYPTOTHORACIC
Complexapora Kiessling	3	poreless, small, free, without horn	porous, small, campanulate, without descending spines	large, inflated	NO	YES (complex, on abdomen)		Upper Jurassic	CRYPTOTHORACIC

Table 8.2 Taxonomic summary of the classification of the Cryptocephalic and Cryptothoracic Nassellaria (after Dumitrica, 1970; Kiessling, 1992). Ranges are composite.

105. Cryptocephalic & Cryptothoracic Nassellaria sp. C
(Pl. 16, Fig. 10)

Description. Test subspherical (partly broken), with small hexagonal pore frames on test surface and a depression which probably marks the cephalic zone. A small smooth area without pores is present next to the depression and shows traces of a sutural pore. Cephalis and thorax completely hidden in the abdomen.

Dimensions (in μm). Width of abdomen, 162.

Occurrence (present work). Biozone 5. Uppermost Middle Volgian of the Central Graben (well 28/5-1).

Remarks. Only one specimen has been recovered. Owing to preservational limitations on observation of a completely depressed cephalo-thorax into the abdominal cavity, the specimen cannot be assigned to genus *Holocryptocanium* Dumitrica.

NASSELLARIA

Remarks. The following morphotypes are left in open nomenclature owing to bad preservation often limiting observation of internal test structure or owing to difficulties in assigning to generic level at present.

106. Nassellaria sp. 1
(Pl. 16, Fig. 11)

Description. Test conical on apical portion and cylindrical on remaining part, lacking circumferential ridges and having a flat distal end. Cephalis and thorax smooth with a few pores. All subsequent chambers with large polygonal pore frames, irregularly arranged. Well-developed nodes at pore frame junctions. Total number of segments cannot be defined. Circular aperture present at the base of the test.

Dimensions (in μm). (based on 3 specimens). Length of test, 146; maximum width of test , 94.

Occurrence (present work). Biozone 5. Rare in the Ryazanian of the Norwegian Sea (well 7B).

Remarks. Differs from *Stichocapsa decorata* Rüst by having a cylindrical distal part and larger, irregularly arranged pore frames. The morphotype resembles *Cyrtocapsa*(?) sp. aff. *C. pseudacerra* Tan Sin Hok described and illustrated by Baumgartner (1992, pl. 5, figs. 3, 4, 7, 8) from the Tithonian? or Berriasian to Valanginian of the Indian Ocean except that the Norwegian Sea specimen has a more cylindrical test.

107. Nassellaria sp. 2
(Pl. 16, Fig. 12)

Description. Test robust, large, composed of six externally visible segments or generally two parts on basis of symmetry. Apical part of test broken but chambers increasing rapidly in width, and having a nodose test surface. Second part of test (postabdominal chambers) cylindrical with a rounded distal end. Final two segments with hexagonal pore frames irregularly arranged on test surface. A circular aperture is present at the base of the test.

Dimensions (in μm). Length of preserved test, 371; maximum width of test, 145.

Occurrence (present work). Biozone 1. ?Upper Bathonian/lower Callovian of the South Viking Graben (well 9/18A-4).

Remarks. Only one specimen recovered.

108. Nassellaria sp. 3
(Pl. 16, Fig. 13-14)

Description. Test small with six preserved parts (segments?). Cephalis rounded, smooth, dome-shaped. Next few chambers increasing in width with the final two postabdominal chambers decreasing rapidly in width giving a unique shape to the test. Few pores are preserved at the junction of the fourth and fifth chambers.

Dimensions (in μm). Length of test, 125; maximum width of test, 95.

Occurrence (present work). Biozone 1. Middle Callovian of South Viking Graben (well 9/18A-4).

Remarks. A single specimen was recovered.

109. Nassellaria sp. 4
(Pl. 16, Fig. 15)

Description. Test composed of three preserved parts (segments?). Cephalis (first segment) dome-shaped, broken(?). Thorax larger, rectangular. Abdomen inflated, oval in outline. Distal part of test broken. No pore frames preserved.

Dimensions (in μm). Length of preserved test, 191; height of thorax, 35; width of thorax , 50; height of abdomen, 130; width of abdomen, 115.

Occurrence (present work). Biozone 1. Middle Callovian of South Viking Graben (well 9/18A-4).

Remarks. Only one specimen recovered. The specimen bears some resemblance to the general test outline of *Eucyrtidiellum* Baumgartner, emend. Takemura.

110. Nassellaria sp. 5

(Pl. 16, Fig. 16)

Description. Test with externally eight(?) or more segments. Cephalis small, porous, dome-shaped. Thorax and abdomen cannot be clearly defined but together with the first postabdominal chambers increasing in width, and last postabdominal chambers decreasing rapidly. Traces of three rows of pores preserved on first postabdominal segments.

Dimensions (in µm). Length of test, 185; maximum width of test, 95.

Occurrence (present work). Biozone 1. Middle Callovian of South Viking Graben (well 9/18A-4).

Remarks. A single specimen recovered. The morphotype cannot be assigned to *Milax* Blome. The latter genus possesses 5 to 7 (maximum) chambers.

111. Nassellaria sp. 6

(Pl. 16, Fig. 17)

Description. Test conical, externally with six(?) preserved chambers. Apical part of test broken but first few chambers increasing in width. Last two chambers decreasing in width and final postabdominal one possessing a large circular aperture giving a truncated outline to the distal end. Test having traces of pore frames but owing to poor preservation the shape of these cannot be defined.

Dimensions (in µm). Length of preserved test, 201; maximum width of test, 143.

Occurrence (present work). Biozone 5. Uppermost Middle Volgian of South Viking Graben (well 9/18A-4).

Remarks. A single specimen has been recovered.

112. Nassellaria sp. 7

(Pl. 16, Fig. 18)

Description. Test short, conical. Total number of chambers cannot be defined. Cephalis hemispherical externally, smooth, poreless(?). All remaining chambers except last two increasing in width. Last two chambers with well-developed circumferential ridges and polygonal pore frames in between. There is an impression of longitudinal costae on test surface. Distal part with a large circular aperture.

Dimensions (in µm). Length of test, 151; maximum width of test, 95.

Occurrence (present work). Biozone 3. Lower Volgian of Central Graben (well 22/21-2).

Remarks. A single specimen has been recovered.

113. Nassellaria sp. 8

(Pl. 17, Fig. 1)

Description. Test small, bell-shaped. Apical part rounded with massive horn(?). Number of chambers cannot be defined. Distal part of test having a rim and a large circular aperture. Test surface rough, pore frames cannot be defined. Internal structure not known.

Dimensions (in µm). Length of test, 142; maximum width of test, 80.

Occurrence (present work). Biozone 3. Lower Volgian of Central Graben (well 22/21-2).

Remarks. A single specimen has been recovered. It resembles some morphotypes of the genus *Deflandrecyrtium* Kozur & Mostler which have been described from Triassic and Lower Jurassic strata.

114. Nassellaria sp. 9

(Pl. 17, Fig. 2)

Description. Test conical on apical part, cylindrical on distal part. Cephalis hemispherical, with small pores(?) and lacking an apical horn. Thorax porous, trapezoidal in outline. Next few chambers increasing in width, having well-developed circumferential ridges with polygonal pore frames. Remaining test cylindrical, poorly-preserved although circumferential ridges are present.

Dimensions (in µm). Length of test, 221; maximum width of test, 120.

Occurrence (present work). Biozone 3. Middle Volgian of Central Graben (well 23/27-4).

Remarks. One specimen was recovered.

115. Nassellaria sp. 10

(Pl. 17, Fig. 3; Pl. 22, Fig. 13-15)

Description. Test elongate. Cephalis relatively large, internally conical in shape, dome-shaped externally. Thorax subtrapezoidal, slightly wider. Abdomen subtrapezoidal. Remaining postabdominal chambers slightly increase in width or maintain the same width. Specimens lacking circumferential ridges. Polygonal pore frames on test surface. Number of postabdominal chambers cannot be defined.

Dimensions (in µm). (based on four specimens). Average length of test, 157; average maximum width, 82.

Occurrence (present work). Biozones 2 to 3. Unitary Associations 4 to 8. Rare in the Lower Oxfordian of the South Viking Graben (well 16/17-5), fairly common in the middle

Kimmeridgian of Eathie Haven (*mutabilis* zone), upper Kimmeridgian/Lower Volgian of Central Graben (wells 22/21-2 & 23/27-4) and Lower Volgian of the Moray Firth Basin (well 14/18-2).

Remarks. Differs from *Stichocapsa*(?) sp. I as stated under the latter morphotype.

116. Nassellaria sp. 11
(Pl. 17, Fig. 4-5; Pl. 22, Fig. 16)

Description. Test conical, relatively short. Cephalis with three asymmetrically positioned, robust, short apical horns. Remaining chambers increasing in width except for the last postabdominal one which decreases in width. Large circular aperture is present at the base of test. Two or possible 3 spines (foot-like) project at the sides of the test. Total number of chambers six to seven. Three rows of large hexagonal pore frames are arranged irregularly on each postabdominal chamber.

Dimensions (in µm). (based on two specimens). Average test length, 204; average maximum test width, 138; length of horns, 23.

Occurrence (present work). Biozone 5. Rare morphotype recovered from the Ryazanian of the Norwegian Sea (well 7B).

Remarks. Differs from Nassellaria sp. 12 as stated under the later morphotype.

117. Nassellaria sp. 12
(Pl. 17, Fig. 6-9)

Description. Test cylindrical, lacking circumferential ridges. Proximal portion of test with three stout, irregularly positioned, short, apical horns. Test surface between the horns smooth. Postabdominal chambers maintain the same width and have irregularly arranged polygonal pore frames with nodes at junctions. Internal structure not known.

Dimensions (in µm). Length of test (LT), 180-185 (mean, 183); maximum width of test (MW), 101-105 (mean, 103).

specimen	Pl. Fig.	LT	MW
CK 446	17, 6 & 9	185	105
CK 445	17, 7-8	184	103
10507 EATHIE B2		180	101

Occurrence (present work). Biozone 1. Fairly common morphotype in the middle Kimmeridgian of Eathie Haven, Cromarty (*mutabilis* zone).

Remarks. Differs from Nassellaria sp. 11 by having cylindrical in outline test lacking spines at the sides.

118. Nassellaria sp. 13

(Pl. 17, Fig. 10)

Description. Test externally with four visible parts (segments?). Apical part of the test conical and slightly broken with the first three chambers increasing rapidly in width. Last preserved chamber give a cylindrical outline to the distal portion of test which is probably broken. Test surface with traces of pore frames.

Dimensions (in µm). Length of preserved test, 195; width of last segment, 95.

Occurrence (present work). Biozone 2. Middle Kimmeridgian (*mutabilis* zone), Eathie Haven, Cromarty.

Remarks. A single specimen has been recovered.

119. Nassellaria sp. 14

(Pl. 17, Fig. 11-12)

Description. Test very long, lacking circumferential ridges and having conical apical part while remaining test is cylindrical. Cephalis bearing a thick, strong horn when not broken. Thorax trapezoidal in outline as well as the abdomen. Large polygonal pore frames, irregularly arranged, persist on test surface, having high relief nodes at pore frame junctions. Total number of segments cannot be defined. Internal structure not known.

Dimensions (in µm). (based on two specimens). Average length of test, 332; average maximum width, 122.

Occurrence (present work). Biozone 4. Rare in the Volgian of the Barents Sea (well 7430/10-U-01).

Remarks. Differs from Nassellaria group C in lacking circumferential ridges on the chamber joints.

120. Nassellaria sp. 15

(Pl. 17, Fig. 13-14)

Description. Test with two visible parts on basis of symmetry. Apical portion of test rounded, subtrapezoidal in outline. Remaining test inflated, subspherical. Test surface having small circular pores when not closed. Base of test lacking an aperture (it may be obscured).

Dimensions. Length of test, 290; maximum width, 162.

Occurrence (present work). Biozone 3. Lower Volgian of the Central Graben (well 23/27-4).

Remarks. Differs from *Stichocapsa*(?) sp. F on the basis of test symmetry (shape).

121. Nassellaria sp. 16

(Pl. 17, Fig. 15)

Description. Test conical in apical portion. Externally three parts are visible. First part conical, small; second part large, subtrapezoidal; last portion of test large, with a truncated outline at the distal end. Test surface poorly preserved (pore frames not observed). Internal structure not known.

Dimensions (in μm). Length of preserved test, 234; maximum width of third portion, 132.

Occurrence (present work). Biozone 5. Upper Volgian of Moray Firth Basin (well 14/18-2).

Remarks. Only one specimen has been recovered.

122. Nassellaria sp. 17

(Pl. 17, Fig. 16-17)

Description. Morphotype with small test. Apical part broken, conical, probably includes cephalis and thorax (but difficult to define externally), lacking pore frames but having weakly developed ridges that may end on an apical horn. Remaining portion of test (abdomen?) inflated, subspherical, with a large circular aperture which gives a truncated outline on distal end of test. Rim of aperture with small, short projections. Abdomen(?) with large (in relation to test size), hexagonal, irregularly arranged, well-developed pore frames with nodes at pore frame junctions and circular to subcircular pores often filled with secondary deposits.

Dimensions (in μm). Height of preserved test, 110; maximum width, 98; diameter of aperture, 35; diameter of pores, 7.

Occurrence (present work). Biozone 5. Ryazanian of Central Graben (well 22/21-2).

Remarks. Only one specimen has been recovered. Its excellent state of preservation suggests that it may be reworked down into the Ryazanian.

123. Nassellaria sp. 18

(Pl. 22, Fig. 17)

Description. Test conical, pointed on apical part then cylindrical. First few chambers increasing in width; remaining ones maintain the same width. Internal structure not known. Test surface smooth, with traces of pore frames.

Dimensions (in μm). Length of test, 206; maximum width of test, 113.

Occurrence (present work). Biozone 5. Uppermost Ryazanian/Lower Valanginian of the South Viking Graben (well 16/17-5).

Remarks. A single specimen has been recovered. The morphotype bears the general test outline of *Archaeodictyomitra* Pessagno, emend. Pessagno but owing to poor preservation (limitations in observing internal structure and costae) is left in open nomenclature.

124. Nassellaria sp. 19
(Pl. 22, Fig. 18)

Description. Test flat, triangular in outline. Apical part with a strong, broken horn. Internal structure not clearly defined. Three to four well-developed, relatively thick circumferential ridges present on test surface with very small polygonal pore frames in between.

Dimensions (in µm). (based on two specimens) Height of test (including broken part of horn), 114-149; maximum width of test, 92-95.

Occurrence (present work). Biozone 3. Rare in the Lower Volgian of the Central Graben (well 22/21-2).

125. Nassellaria group A
(Pl. 17, Fig. 18-20; Pl. 18, Fig. 1)

Description. Test long but always broken on apical part. Preserved chambers increase slightly in width and have trapezoidal to rectangular shape in outline. Best preserved specimens show small polygonal pore frames arranged irregularly on test surface. Maximum number of preserved chambers nine.

Dimensions (in µm). Maximum length of preserved test, 246; maximum width, 115.

Occurrence (present work). Biozone 1. Unitary Association 1. Middle Kimmeridgian (*cymodoce* zone, at Eathie Haven, Cromarty) and middle Callovian to upper Callovian/Lower Oxfordian (South Viking Graben, well 9/18A-4).

Remarks. Grouped here are all specimens that fall within the general description. Kimmeridgian specimens (from Eathie) exhibit wider and shorter chambers.

126. Nassellaria group B
(Pl. 18, Fig. 2-5)

Description. Morphotype with a very long test and externally two visible parts on basis of symmetry. First part elongate and including the cephalis, thorax abdomen and first postabdominal chambers. Second part inflated including the remaining postabdominal chambers. Total number of chambers cannot be defined. Traces of polygonal pore frames on a few specimens and weakly developed circumferential ridges (probably owing to poor preservation).

Dimension (in µm). Length of preserved test, 390 to 453; width of inflated second part, 145 to 172.

Occurrence (present work). Biozone 3. Unitary Association 9. Kimmeridgian/Lower Volgian to Middle Volgian of Central Graben (well 23/27-4) and Volgian (?and older strata) of Barents Sea (well 7430/10-U-01).

Remarks. The specimens are probably representatives of the genus *Mirifusus* Pessagno, emend. Baumgartner. They possess an inflated second part of the test but lack a distal cylindrical portion. Owing to poor preservation they are here left in open nomenclature.

127. Nassellaria group C

(Pl. 18, Fig. 6-8; Pl. 22, Fig. 19)

Description. Grouped here are all nassellarians with badly preserved long tests, having weakly developed circumferential ridges (owing to poor preservation), traces of polygonal pore frames in between and lacking an apical horn. First chambers increasing in width while remaining postabdominal chambers maintain the same width.

Dimensions (in µm). Average length of test, 310; average maximum width of test, 118.

Occurrence (present work). Biozone 2. Unitary Association 6. Common in the lowermost Volgian and Kimmeridgian of the Central Graben and Moray Firth Basin (wells 22/21-2 and 12/28-1 respectively).

Remarks. Specimens of this group could belong to the genus *Parvicingula* Pessagno, emend. Pessagno, Blome & Hull or to the genus *Praeparvicingula* Pessagno, Blome & Hull.

128. Nassellaria group D

(Pl. 18, Fig. 9-11)

Description. Included here are all Nassellaria having conical tests with a pointed apical part and rounded distal part. Specimens lacking circumferential ridges or having weakly developed. Polygonal pore frames on test surface. Number of segments cannot be defined. All chambers except the last few increase slightly in width. Final postabdominal chamber slightly tapering, possibly with a terminal tube.

Dimensions (in µm). Average length of test, 208; average maximum width of test, 95.

Occurrence (present work). Biozone 3. Unitary Associations 9 to 11. Common in the Kimmeridgian/Lower Volgian to Middle Volgian of the Central Graben (wells 22/21-2 & 23/27-4).

Remarks. The morphotype differs from Nassellaria group C in having a different test outline. Resembles some *Eusyringium* Haeckel morphotypes which have been described and illustrated by Baumgartner (1992) from the Upper Jurassic - Lower Cretaceous of the Indian Ocean but North Sea specimens lack a thin, terminal tube (although traces exist).

Nassellaria gen. et sp. indet.

Remarks. Included here are all poorly-preserved nassellarians that cannot be assigned to any of the above described morphotypes. The only distinctive characteristic is the bullet-shaped test.

SPONGE SPICULES (MICROSCLERES)

Remarks. The occurrence of sponge spicules in conjuction with radiolaria and other siliceous microfossils is well-documented. Sponge spicules have been found to be present and in high abundance in many samples from the wells/onshore exposure studied here. Forms include: *Rhaxella* group sponge spicules, Sterraster sp. 1 which is an important morphotype for biostratigraphy, and various Calthrops and derivative forms (see Pokorny, 1965, p. 10, Fig. 556). The latter include: oxycalthrops, microtetrode, and microcalthrops (Pl. 18, Fig. 18 in this study).

Rhaxella group
(Pl. 18, Fig. 12; Pl. 22, Fig. 20)

1890b *Rhaxella perforata* Hinde n.sp.; p. 59, pl. 6.

1911 *Rhaxella perforata* Hinde; Hinde, p. 210, pl. 11, figs. 7, 7a-f.

1965 Sterraster (rhax); Pokorny, fig. 563i.

1967 Rhax; Reif, pl. 15, fig. 19.

1992 Rhax; Kiessling, pl. 2, fig. 12.

Description. A small, bean-shaped or kidney-shaped form, often with a pitted surface. A hilum is usually present on the concave surface (when specimens well-preserved).

Dimensions (in μm). Length of kidney-shaped spicule, 120-170.

Occurrence (literature). Lower Calcareous Grit of Scarborough, Coral Rag (Yorkshire), Dorset, Austria, and elsewhere.

Occurrence (present work). Present throughout the North Sea Basin (including the onshore sections) and Norwegian Sea; absent in the Barents Sea, well 7430/10-U-01.

Remarks. The taxonomic affinity of such spicules is debated among palaeontologists

(Rützler & Macintire, 1978). Various workers have reported the presence of such sponge spicules from Britain: Hinde (1890) initially introduced a genus *Rhaxella* for such spicules; Wilson (1968) from Osmington Oolite Series, Southern England; Talbot (1973), Collavian Beds (Oxfordian) of Southern England; Andrews & Brown (1987) offshore Oxfordian strata of Moray Firth Basin; Haslett (*in press*) from the Portlandian of Dorset; Partington *et al.* (1993) record bioevents of *Rhaxella perforata*. Rützler & Macintire (1978) published a work on siliceous sponge spicules from coral reef sediments, and offer a detailed discussion on such spicules. Briefly, sponge spicules (microscleres) are produced by sponges as part of their skeleton and are released to form sediments grains (Rützler & Macintire, 1978). Rhaxes, according to the same authors are the sturdiest of all biogenic opal in the sea. Reif (1967) gave a detailed list of recorded occurrences for the rhaxes.

129. Sterraster sp. 1

(Pl. 18, Fig. 13-17; Pl. 22, Fig. 21-22)

1989 *Praeconocaryomma* (?) sp. 2 Dyer & Copestake, p. 225, pl. 1, figs. 8, 12.

Description. A sponge spicule (microsclere) with a spherical (or approximately spherical when preservational factors are taken into account) "test" having surface covered by small, short projections often giving the impression that are star-like ornamented, usually perforate centrally. Specimens with a small depression (called hilum in sponge spicules), which gives the impression of an aperture.

Dimensions (in µm). Test diameter (TD), 91-130 (mean, 110); number of projections on lateral view of diameter (NP), 13-17 (mean, 15); diameter of "mammae" (DM), 4.3-5.7 (mean, 5).

specimen	Pl. Fig.	TD	NP	DM
CK 519	18, 17	101	14	5
CK 520		106	13	5.7
CK 522	18, 14	97	15	
CK 523		103	15	4.6
CK 524		110		
CK 528	18, 15-16	120		
CK 534		129	14	
CK 540	22, 22	130	17	5
CK 539		115		
CK 542	18, 13	91		4.3

Range. Not given by Dyer & Copestake (1989).

Occurrence (literature). North Sea Basin.

Occurrence (present work). Biozone 5. Unitary Associations 16 to 17. Common sponge spicule, significant in biostratigraphy, at the uppermost Middle Volgian to Lower Ryazanian of the North Sea Basin (all three studied grabens, wells 22/21-2, 29/12-1, 28/5-1, 14/18-2, 16/17-5 and 9/18A-4) and the Ryazanian of the Norwegian Sea (well 7B).

Remarks. Dyer & Copestake (1989) tentatively assigned this to the radiolarian genus *Praeconocaryomma* Pessagno. They stated (p. 226) "an inner medullary shell is often revealed when specimens are viewed in transmitted light". However, on the examination of many well-preserved specimens under transmitted light microscope no medullary shell has been observed. This morphotype cannot be assigned to the radiolarian genus *Holocryptocanium* Dumitrica owing to the lack of a cephalis and a thorax depressed into an abdomen.

Rützler & Macintire (1978) have detailed discussed sterrasters. Almost identical forms have been illustrated by the same authors (Fig. 1:1, Fig. 3:3 & Fig. 3:5). Such sterrasters are originally covered by spines (Figs. 1:3 & Fig. 1:6 of Rützler & Macintire, 1978), which subject to erosion lose their surface ornamentation and exposing axial cannals; these can become enlarged as the erosion progresses (compare Fig. 16 with Fig. 17 of Pl. 18). A similar form has been illustrated by Riha (1983) (Pl. 11, Fig. 61).

CHAPTER 9

BIOSTRATIGRAPHY

9.1 Introduction

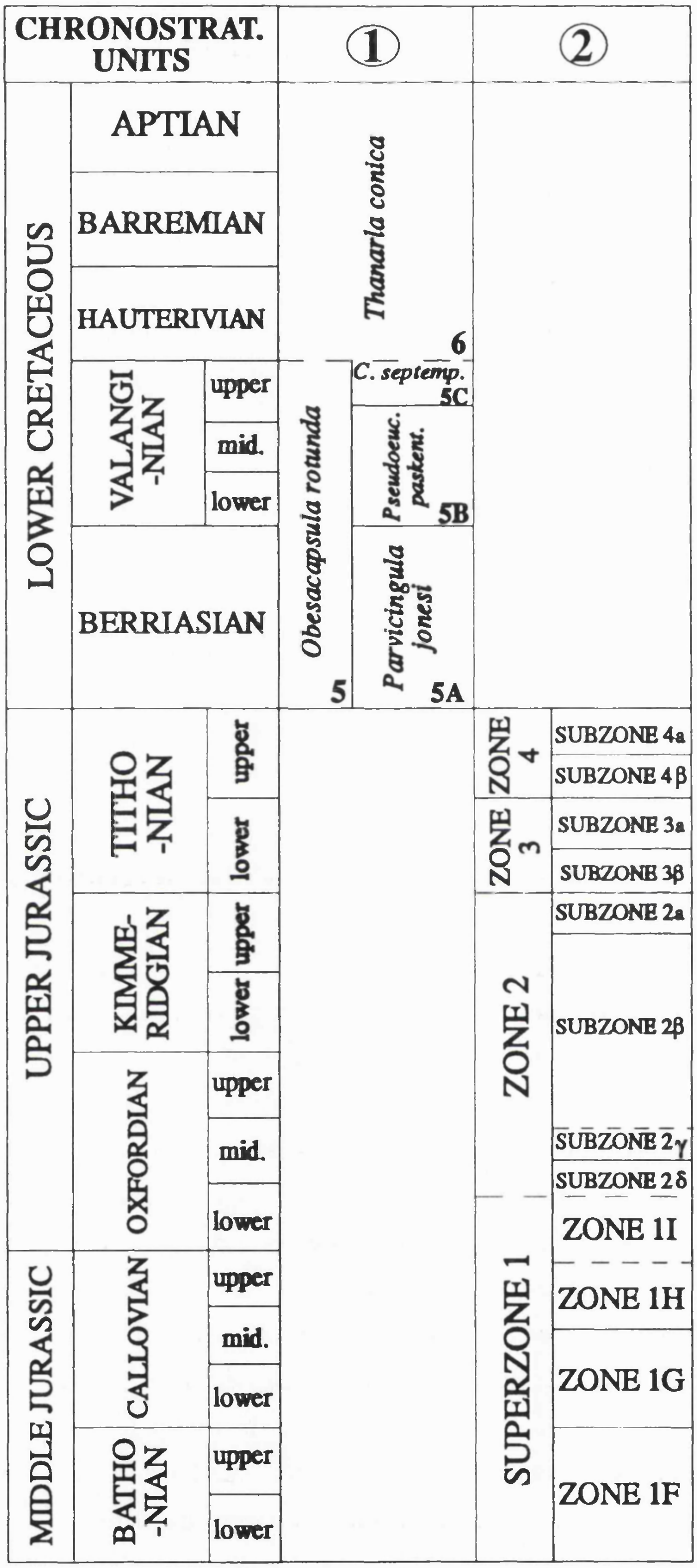
The potential of radiolarians for biostratigraphical purposes and for age dating purposes had been largely overlooked by stratigraphers and palaeontologists until the beginning of the 1970's. This was mainly due to the erroneous notion that these organisms were long-ranging and difficult to study.

The development and use of the Scanning Electron Microscope in Micropalaeontology, the discovery of new and successful processing techniques (e.g. Dumitrica, 1970; Pessagno & Newport, 1972), the DSDP and ODP studies, and a better understanding of the nature of radiolarians led to the first attempts to erect radiolarian zonal schemes for the Upper Jurassic and especially for the Cretaceous and Cenozoic (Moore, 1973; Foreman, 1973, 1975, 1977; Riedel & Sanfilippo, 1974). All these zonations were based on data from oceanic strata (DSDP and ODP material).

9.2 Biostratigraphy in North America

Pessagno (1976, 1977a, 1977b) made the first attempt to define a radiolarian zonation in North America. His studies were focused on land-based sections, and he presented a detailed zonation for the Upper Jurassic to Upper Cretaceous of N.W. America using interval and Oppel zones. After additional work had been done on sections containing ammonites and other significant macrofossils, Pessagno *et al.* (1984) revised the existing scheme. This zonation has been modified and emended in parts since then by Pessagno *et al.* (1987b), Pessagno *et al.* (1989), Pessagno & Blome (1990), Pessagno & Mizutani (1992), and recently by Pessagno *et al.* (1993) with the inclusion of several new biozones in the upper part of their Superzone 1 (Fig. 9.1). This zonal scheme is based on taxa having sturdy tests and which may be found preserved in a variety of rock types (limestones, cherts, shales, tuffs) (Pessagno *et al.*, 1986; Pessagno *et al.*, 1987b). Three categories of marker taxa are recognised in the scheme: "primary marker taxa", "supplementary marker taxa" and 'corporeal taxa" (definition of the terms can be found in Pessagno *et al.* (1993), p. 94-95).

Other major zonations produced by American radiolarian workers include those of Riedel & Sanfilippo (1974) for the Upper Jurassic to Upper Cretaceous (DSDP material) and Sanfilippo & Riedel (1985) for the Cretaceous.



① = Pessagno (1977b)

② = Pessagno *et al.* (1993)

Fig. 9.1 North American zonation scheme for the Middle Jurassic to Lower Cretaceous.

9.3 Biostratigraphy in Europe

Mesozoic radiolarian biostratigraphy was initiated in Europe in the beginning of the 1980's. Baumgartner *et al.* (1980) first established a detailed zonal scheme, by means of the Unitary Associations method (UA) (discussed later in this chapter). This work was based on studies from Tethyan areas. The initial scheme has been modified and improved by Baumgartner (1984a, 1987a) and O'Dogherty *et al.* (1989) (with age calibration of zones). Sections offering other than radiolarians as age diagnostic fossils have also been examined by Baumgartner. Fourteen UA resulting in 9 major biochronozones are recognised for the Bajocian to Hauterivian interval (fig. 9.2).

Recently, Baumgartner *et al.* (1991) presented a new tentative UA zonation scheme and Jud (1991) produced a new Tethyan zonation for the Early Cretaceous, where 35 UA can be grouped in 11 biozones (Jud & Baumgartner, 1991). Complete results have not been published yet but an "abstract" of the zonation scheme can be found in Baumgartner (1993, fig 3: A).

Other European workers include: Kocher (1981) who studied Tethyan sections and created 9 UA resulting in 6 preliminary biochronozones for the Callovian to Valanginian interval, Schaaf (1985) who produced a composite zonation scheme (21 zones) for the Cretaceous based on 42 DSDP sites and onshore sampling, and Steiger (1992) who recognised 4 zones and 6 subzones for the Oxfordian to Valanginian of the Alps.

Currently, the Jurassic-Cretaceous Working Group (1991, 1992) is attempting a worldwide zonation using the UA method. The study is based on low-latitude radiolarians (various Tethyan localities) of Mid Jurassic to Early Cretaceous age.

9.4 Biostratigraphy in Russia

Although significant studies on Mesozoic radiolarians from this part of the world started as early as in the 1950's and 1960's (e.g. Lipman, 1953; Aliev, 1965, 1969b), the first detailed biostratigraphic scheme was produced by Tikhomirova (1984). This work was based on thin-sections and according to Vishnevskaya (1993, p. 175) "is out-of-date, insufficient and often simply subjective".

Vishnevskaya (1988) produced a detailed radiolarian zonation for the Lower Jurassic to Cretaceous of the Caucasus area (Fig. 9.2) based on sections containing ammonites and other fossils. The same author (1991, 1992b, 1993) presented a zonation for the Jurassic to Cretaceous of the Far East and for the Russian Pacific Rim (Fig. 9.2). A drawback in the latter zonation is that the ages of the zones have not been calibrated with age diagnostic ammonites and other fossils.

Finally, Amon (1988, 1993) zoned the Cretaceous of the Ural area, including a biozone for the Berriasian.

9.5 Biostratigraphy in Japan

Nakaseko *et al.* (1979) and Nakaseko & Nishimura (1981) were the first to distinguish radiolarian assemblage zones for the Upper Jurassic to Cretaceous in Japan. At the same time Yao *et al.* (1980) zoned the Triassic to Middle Jurassic interval. Other zonal schemes (most of them using successive assemblage zones and having limited applicability to certain geographic provinces only) were proposed by Yao *et al.* (1982), Matsuoka (1982b, 1983b), with modifications to these made by Yao (1983, 1984) and Matsuoka (1984b). Aita (1987) produced a zonal scheme for the Shikoku area, as well as for sections studied from Europe.

Matsuoka & Yao (1986) published a biostratigraphic scheme for the entire Jurassic of Japan (Fig. 9.2). This was partly adopted from Matsuoka (1983b) and since then has become the standard zonation for the western Pacific area (Matsuoka, 1993). The scheme has been used recently for zonal purposes with radiolaria from ODP Leg 129 (Matsuoka 1991, 1993).

A major problem with the Japanese radiolarian-bearing sections is the total lack of other age-diagnostic fossils, which would help towards an independent age calibration of the zonal schemes.

9.6 Biostratigraphy in N.W. Europe (North Sea)

Dyer & Copestake (1989) first published a biostratigraphic study for the area, with 13 radiolarian events recognised for the Kimmeridgian to Ryazanian interval. The events included first and final occurrences of species and upper and lower limits of species abundances (Dyer & Copestake 1989, p. 220). Reasons of confidentiality did not allow the authors to name these events. Recently, Partington *et al.* (1993) presented a biozonation for the Jurassic to Earliest Cretaceous of the North Sea based on microfossils (foraminifera, radiolaria), including 7 radiolarian zones (Fig. 9.7). This scheme is also based on the "datum concept".

9.7 Unitary Associations Method

The quantitative stratigraphic method called Unitary Associations has been applied with increasing frequency to interpretation of radiolarian assemblages for biostratigraphic purposes. The Unitary Associations technique is a "deterministic" biostratigraphic method (Baumgartner, 1984a, b; Guex, 1991) which was first proposed by Guex (1977) and then

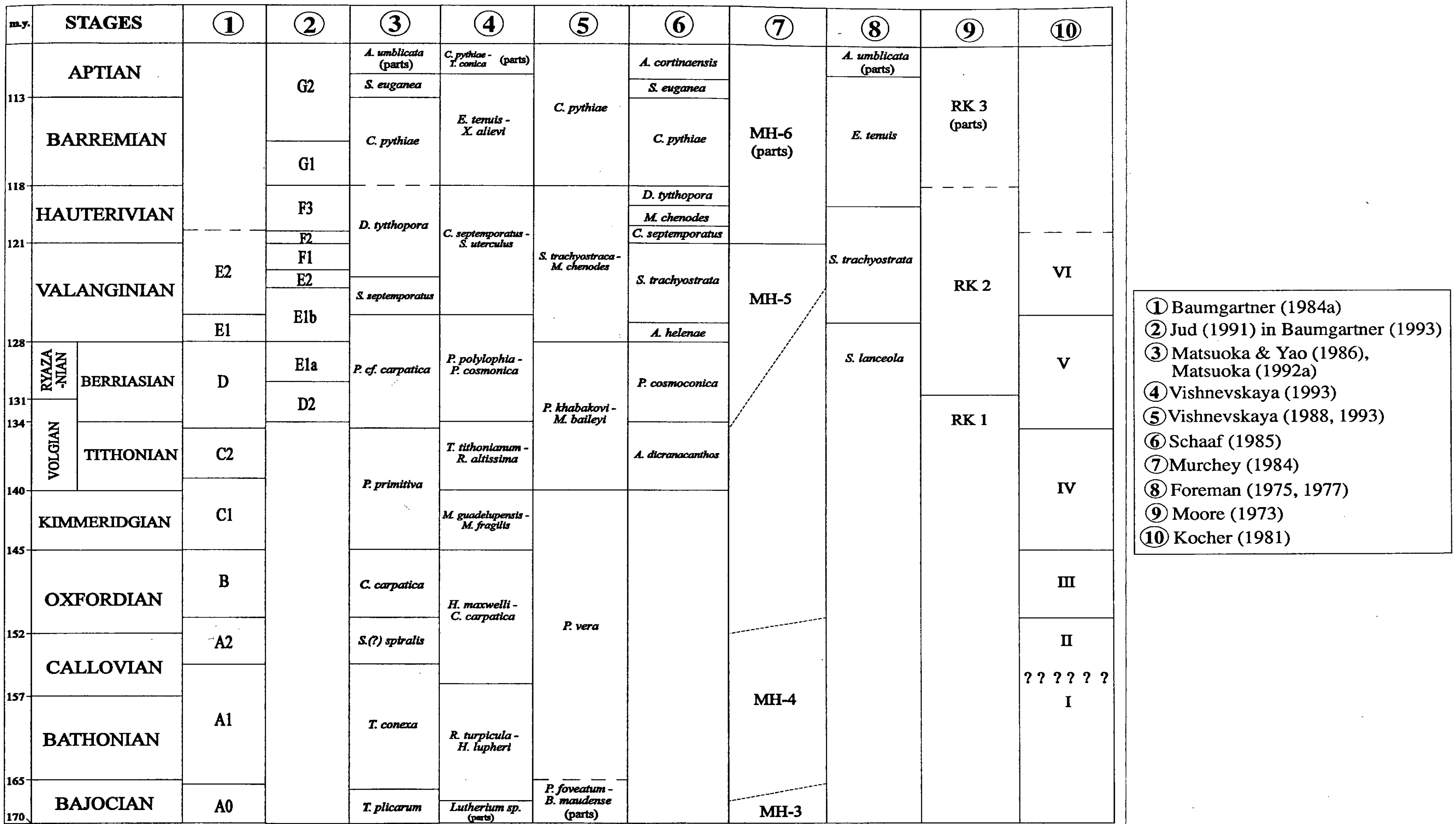


Fig. 9.2 Selected important zonation schemes from around the world (correlation based on Baumgartner & Murchey (1984), Vishnevskaya (1988), Aita (1987), Matsuoka (1992a), Schaaf (1985)).

developed by the same author (Guex, 1978, 1979). The method is based on the concurrent range zones or Oppel - assemblage zones concept and emphasizes not the end-points of taxa occurrences but the actual ranges, and establishes stratigraphically successive maximal sets of co-occurring or potentially co-occurring species. These sets are called Unitary Associations (U.A.). Each U.A. is characterised by species and/or pairs of species which are exclusively present only in this interval, and thus enable the worker "to identify a U.A. in a stratigraphic section or assign fossil-bearing beds to a particular U.A." (Guex 1991, p. 15).

The method analyses the first and final appearances of morphotypes in various sections and produces a range chart with "maximal ranges for every morphotype in respect to all the others, no matter whether this range has a patchy or continuous stratigraphic distribution" (Baumgartner 1984b, p. 167).

The detailed procedures of the method are discussed by Baumgartner (1984a,b) and Guex (1991) and are not given here.

The Unitary Associations method for biostratigraphic studies of Mesozoic radiolarians has successfully been used by Baumgartner *et al.* (1980), Baumgartner (1984a,b; 1987a; 1993), Kocher (1981), Jud & Baumgartner (1991), Jud (1991) and Carter (1993). The method has great correlation potential, especially as it minimises the effect of "preservational ranges".

Guex (1991, p. 2) notes the problems which may be encountered when working towards establishing a zonation scheme. These are summarized here as:

1) nature of sedimentation,
2) dissolution-controlled fossils (especially Mesozoic radiolarians) and diagenesis,
3) ecologic and biostratigraphic control on the taxa distribution,
4) reworking, contamination and condensation of studied sections, and
5) taxonomic problems.

When using Ranking and Scaling the problems 1, 2 and 3 can obviously affect the results. The sequence of morphotype events can differ in stratigraphic sections (as in the present study). These ranges may be "preservational ranges" and not true "life ranges". By using the U.A. method workers are able to overcome these problems by making best use of the available occurrence data (Baumgartner, 1984b).

9.8 North Sea Biostratigraphy for this study

The zonation schemes already published, mentioned earlier and with selected ones shown on Fig. 9.1 & Fig. 9.2, cannot be applied to the North Sea Basin. This is mainly due to the following factors:

1) preservation, which hinders confident identification of the diagnostic zonal marker species used in schemes erected elsewhere;

2) possible provincialism and ecological factors - most of the zonations have been constructed for a different palaeobiogeographic province (Tethys).

The Unitary Association method has therefore been used for the biostratigraphic part of this study. Its advantages have been given above. In addition, Baumgartner (1984a, p. 736) stated that "a zonal unit defined by species pairs has more chance to be recognised in a poorly preserved sample than a zone based on the presence of one or two "marker" species". The poorly preserved state of North Sea Jurassic radiolarians is discussed in Chapter 7 and therefore Baumgartner's observation is particularly appropriate to the assemblages studied here.

The ranges of species/morphotypes which are found present in more than one well/section have been compared with the known age assignment of samples (based on work by SPT using palynology) and some ammonite zones when available. Preservational "tops" to ranges are inconsistent (as to be expected with radiolaria, especially forms where SiO_2 has been replaced). These can be interpreted as facies or dissolution/diagenesis controlled, or possible ecologically controlled (different sedimentary basins in the North Sea Basin and provincialism). For the above reason, and because of all its advantages, the use of the Unitary Associations method was considered necessary.

9.8.1 Drawback of the Unitary Associations method for this study

The drawback with the use of the Unitary Associations method for this study was the state of samples. The majority of samples were ditch cuttings and it is known when working with such samples that only the FDO (First Downhole Occurrence, which is usually the range "top" or species extinction) is safe to use. However, after discussion with Dr. R. Titterton (Technical Supervisor, SPT) the LDO (Last Downhole Occurrence, which is the range "base" or possible species inception) has also been used, after careful assessment to minimise the effect of downhole "caving". •

9.8.2 The Method

Two input files were prepared for computer treatment using the BioGraph program. This has been written by Savary (in Savary & Guex, 1991) and more details about it can be found in Guex (1991, p. 80-81). The files consist of the lowest and highest occurrences of each species/morphotype in each locality.

In the first input file (BioGraph 1) all the identified species/morphotypes (129 in total) in the 13 wells/sections are included, while in the second one (BioGraph 2) (Table 9.1) only those appearing in more than one well/section are included. Some of those morphotypes are rare ones but they have been included because they occur at the same stratigraphic

• Criteria used to make these judgements were: i) decrease in abundance, and ii) unexpected occurrences. For example, the range of Spongodiscidae sp. B in well 12/28-1 (Table 9.9) was taken between samples 5800 to 5880.

* Data of C. N. Kavouras.
* Mid Jurassic to Earliest Cretaceous.
* North Sea Basin, Norwegian Sea & Barents Sea.
* Input file for BioGraph (included morphotypes appearing in more than one section).

```
TAXA 129
NSEC 13

SECION EATHIE A
LEVEL 6
20 5 6
6 6 6
69 5 6
115 6 6
60 6 6
73 6 6
35 6 6
32 5 6
17 5 6
22 6 6
2 6 6
18 5 5
34 5 5
71 5 5
55 5 5
} EATHIE A

SECTION EATHIE B1
LEVEL 8
69 7 8
60 7 8
73 7 8
20 7 8
18 7 8
71 7 8
30 7 8
55 7 7
} EATHIE B1

SECTION EATHIE B2
LEVEL 15
20 10 15
6 15 15
69 10 15
115 13 15
73 15 15
35 15 15
32 4 15
17 10 15
22 13 15
2 15 15
71 12 15
40 15 15
78 10 10
60 8 10
18 10 10
55 10 10
16 10 10
56 8 8
125 4 4
} EATHIE B2

SECTION 16/17-5
LEVEL 54
15 54 54
92 52 52
13 52 52
129 51 51
80 51 51
23 51 51
23 51 51
66 8 14
18 9 9
25 8 9
17 5 5
} 16/17-5

SECTION 22/21-2
LEVEL 57
80 52 53
93 53 53
90 52 52
101 52 52
129 52 52
24 52 52
67 52 52
59 52 52
21 50 50
65 50 50
99 44 44
2 15 42
128 37 42
36 38 42
37 40 42
40 41 41
7 37 41
70 38 41
82 39 41
38 39 40
68 38 40
22 19 38
30 33 33
127 23 23
6 16 23
60 22 22
78 20 22
115 19 19
17 13 13
} 22/21-2

SECTION 23/27-4
LEVEL 61
90 57 59
101 58 59
67 54 59
65 59 59
80 57 59
59 58 58
23 58 58
91 57 58
99 56 56
68 33 45
22 21 44
27 41 41
36 24 38
70 38 38
38 34 38
37 27 38
40 37 37
17 34 34
128 22 34
2 16 34
126 27 32
82 20 31
7 27 28
115 18 21
20 14 20
71 14 14
} 23/27-4

SECTION 14/18-2
LEVEL 40
129 36 37
90 37 37
80 34 37
40 26 27
2 15 26
36 15 25
37 16 25
22 18 25
70 25 25
34 22 22
82 15 21
85 16 17
115 14 16
7 10 10
} 14/18-2

SECTION 12/28-1
LEVEL 28
2 8 28
37 24 28
36 24 28
82 25 27
38 24 26
39 26 26
40 26 26
70 26 26
7 25 26
22 18 18
6 5 5
127 5 5
18 2 2
} 12/28-1

SECTION 9/18A-4
LEVEL 21
13 21 21
91 21 21
90 21 21
2 21 21
15 21 21
14 21 21
129 20 20
27 18 18
17 14 14
16 12 12
25 12 12
66 4 12
125 8 12
55 12 12
18 12 12
} 9/18A-4

SECTION 29/12-1
LEVEL 58
92 58 58
90 58 58
91 58 58
101 58 58
129 54 56
80 54 57
93 57 57
23 54 56
2 55 55
7 46 46
85 45 45
} 29/12-1

SECTION 7B
LEVEL 16
80 1 9
90 9 9
91 9 9
92 9 9
14 4 4
24 4 4
129 2 3
29 2 3
13 1 1

SECTION 7430/10-U-01
LEVEL 16
90 13 13
92 13 13
80 10 10
21 10 10
29 10 10
37 10 10
126 1 1
38 1 1
} 7430/10-U-01

SECTION 28/5-1
LEVEL 12
80 9 12
23 9 12
129 11 11
2 10 10
105 10 10
22 7 7
36 4 4
70 4 4
7 3 3
} 28/5-1
```

Table 9.1 Input files for BioGraph 2.

Abbreviation: NSEC = Total number of studied sections.

Explanation: LEVEL = Total number of samples studied in each section.
1st column = Code number of species/morphotype (can be found in Chapter 8).
2nd column = lowest occurrence (sequentially numbered sample from base of section) of species/morphotype.
3rd column = highest occurrence (sequentially numbered sample from base of section) of species/morphotype.

interval. All morphotypes have been identified with care. A code number has been given for each species/morphotype (these can be found in Chapter 8).

In summary, BioGraph 2 includes: 392 samples from 13 localities, 6 to 61 sequential samples in each locality and 52 species/morphotypes included. The input dataset is shown on Table 9.1. The dataset was kindly computed by Professor J. Guex.

9.8.3 Biostratigraphic Results

Results with the BioGraph 1 dataset were not good. Most of the maximal cliques were in a huge strongly connected component (Guex, *pers. comm.*). However, results with the BioGraph 2 dataset were quite good, even with the ditch cuttings (Guex, *pers. comm.*). Eighteen Unitary Associations have been produced. Interpretation of the ditch cuttings allowed 5 acceptable zones to be constructed (Guex, *pers. comm.*). The Unitary Associations are grouped to define biochronozones in order to assure optimum lateral reproducibility. The resulting radiolarian protoreferential range chart is given in Fig. 9.3. The chart shows the maximum ranges of each species/morphotype (used in the method) with respect to the maximum ranges of all the others. The term "protoreferential" is used by Guex (1991, p. 2) and implies a chart which "represents superpositions and coexistences of taxa without regard to the chronologic significance of their stratigraphic relationships" (see Fig. 9.3)

The reproducibility of the 5 zones and the 18 Unitary Associations is given in Fig. 9.4 and Fig. 9.5. The low rate of reproducibility could well be due to the limited number of wells/sections which cover a certain interval. From Table 5.5 it is obvious that: i) there is a break in sedimentation in the Middle Volgian for some wells (28/5-1, 22/21-2 and 9/18A-4), and ii) there is a barren interval for radiolarians for the Middle Volgian in wells 16/17-5 and 7430/10-U-01. Therefore, the reproducibility of zone 4 and the Unitary Associations 13 to 15 can be expected to be low.

A zonal range chart with all the recovered morphotypes has also been produced (Fig. 9.6).

Range charts of species/morphotypes recovered from each well/section studied are provided (Table 9.2 to Table 9.14), showing the biozones and Unitary Associations identified for each sample. These can be found at the end of the chapter.

9.8.4 Age assignments for biozones and calibration with the ammonite zones of Cope *et al.* (1980)

In order to assess the ages of the 5 biozones recognised, other biochronostratigraphic evidence from the studied wells has been taken into account. This has been done by Simon Petroleum Technology using their scheme of palynology zones. These palynology zones have

1		2				3						4			5			ZONES
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	UNITARY ASSOCIATIONS
1																		(125) Nassellaria group A
1	2																	(16) Orbiculiforma sp. 2
1	2																	(25) Praeconocaryomma sp. C
1	2																	(66) Perispyridium spp. indet.
1	2	3																(18) Orbiculiforma sp. 4
1	2	3																(55) Hsuum(?) sp. A
1	2	3	4	5														(32) Hagiastridae(?) group 3
	2	3	4															(78) Spongocapsula(?) sp. 2
	2	3	4	5														(60) Parvicingula sp. 1
	2	3	4	5	6													(69) Praeparvicingula sp. 3
	2	3	4	5	6	7												(20) Orbiculiforma sp. 6
	2	3	4	5	6	7	8	9	10									(17) Orbiculiforma sp. 3
		3	4	5	6													(30) Hagiastridae(?) group 1
		3	4	5	6													(71) Praeparvicingula sp. 5
		3	4	5	6													(73) Praeparvicingula sp. 7
		3	4	5	6	7	8											(34) Hagiastridae(?) group 5
			4	5	6													(6) Archaeocenosphaera(?) sp. 5
			4	5	6	7	8											(115) Nassellaria sp. 10
			4	5	6	7	8	9	10	11	12							(22) Praeconocaryomma hexagona
			4	5	6	7	8	9	10	11	12	13	14	15	16	17		(2) Archaeocenosphaera(?) sp. 1
				5														(35) Hagiastridae(?) group 6
				5	6	7	8	9	10	11								(40) Spumellaria gen. et sp. indet. A
					6													(127) Nassellaria group C
						7	8	9	10	11								(82) Stichocapsa sp. B
							8											(85) Stichocapsa(?) sp. E
							8	9	10	11								(36) Spongodiscidae sp. A
							8	9	10	11								(7) Archaeocenosphaera(?) sp. 6
							8	9	10	11	12	13						(37) Spongodiscidae sp. B
								9										(126) Nassellaria group B
								9	10	11								(128) Nassellaria group D
								9	10	11								(38) Spongodiscidae sp. C
									10	11	12							(68) Praeparvicingula sp. 2
										11								(70) Praeparvicingula sp. 4
											12							(27) Praeconocaryomma(?) sp. E
												13	14	15				(21) Orbiculiforma sp. 7
												13	14	15	16			(29) Staurosphaera(?) sp. 1
												13	14	15	16	17	18	(80) Stichocapsa decorata
													14					(99) Williriedelum(?) sp. 1
													14	15	16	17		(67) Praeparvicingula sp. 1
														15	16	17		(65) Parvicingula(?) sp. 6
															16	17		(129) Sterraster sp. 1
															16	17		(14) Orbiculiforma lowreyensis
															16	17		(15) Orbiculiforma sp. 1
															16	17		(23) Praeconocaryomma sp. A
															16	17		(24) Praeconocaryomma sp. B
															16	17		(59) Parvicingula(?) cf. P. jonesi
															16	17	18	(101) Zhamoidellum(?) sp. 1
															16	17	18	(13) Orbiculiforma mclaughlini
															16	17	18	(90) Tricolocapsa sp. A
															16	17	18	(91) Tricolocapsa sp. B
																17	18	(92) Tricolocapsa sp. C
																	18	(93) Tricolocapsa sp. D

Fig. 9.3 Protoreferential chart of Unitary Associations method (results of BioGraph 2).

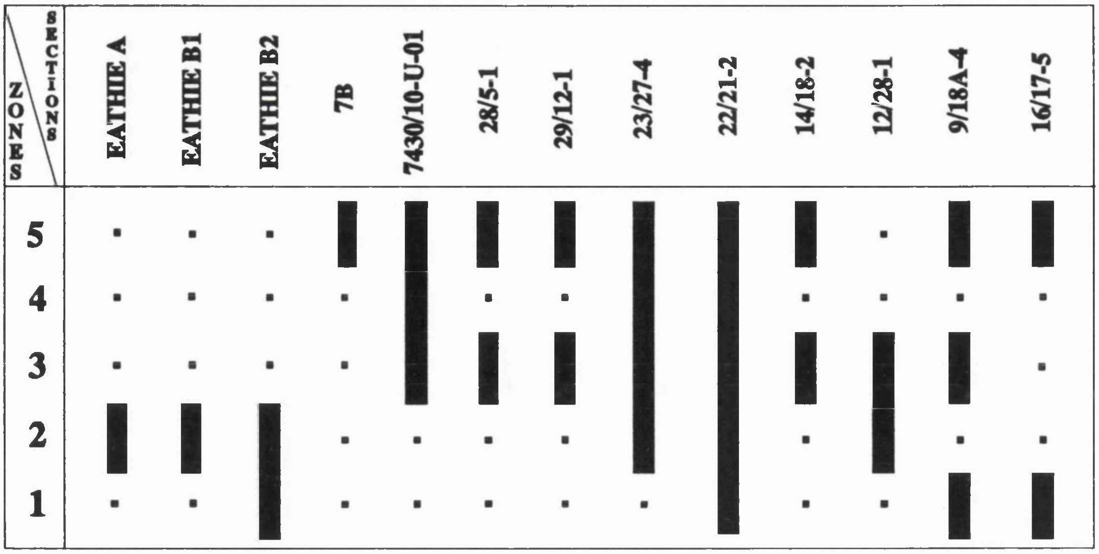


Fig. 9.4 Reproducibility of Biozones 1 to 5 for the studied sections.

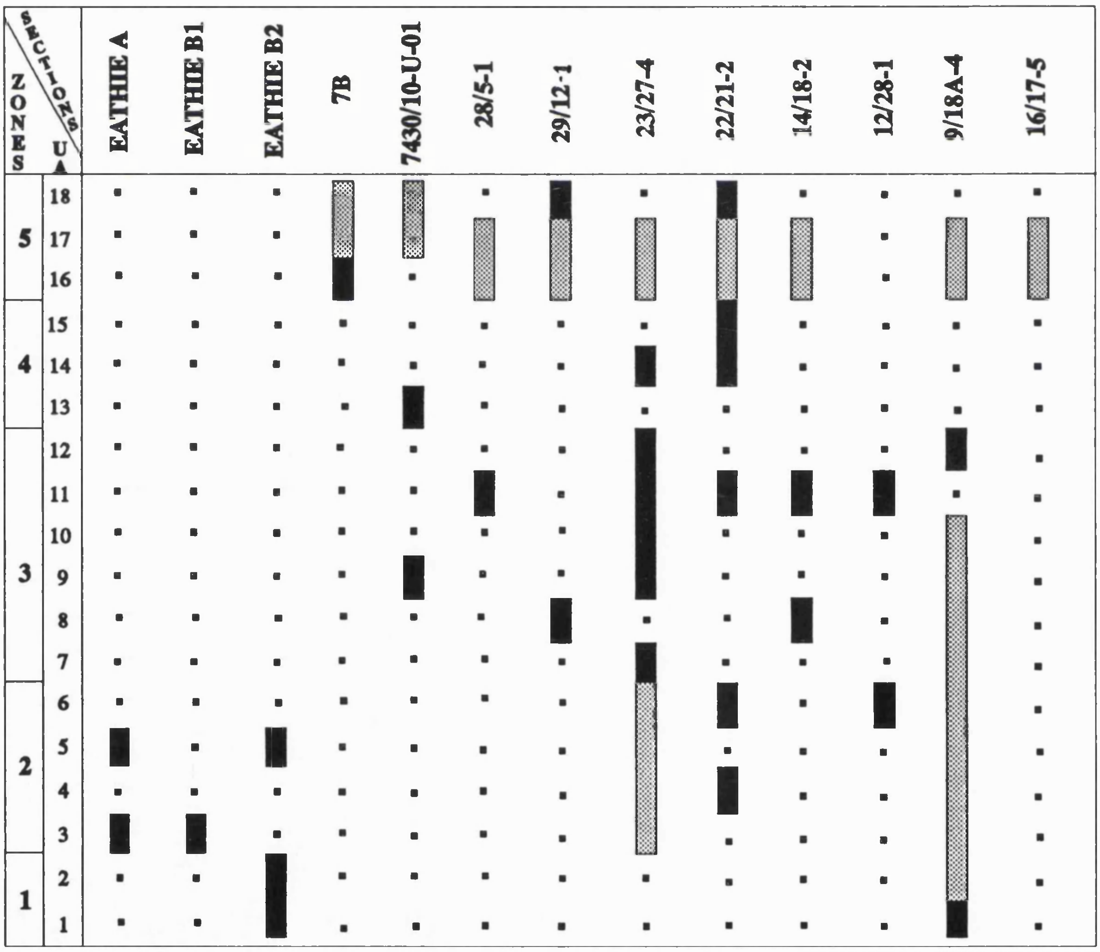


Fig. 9.5 Reproducibility of 18 Unitary Associations for the studied sections.

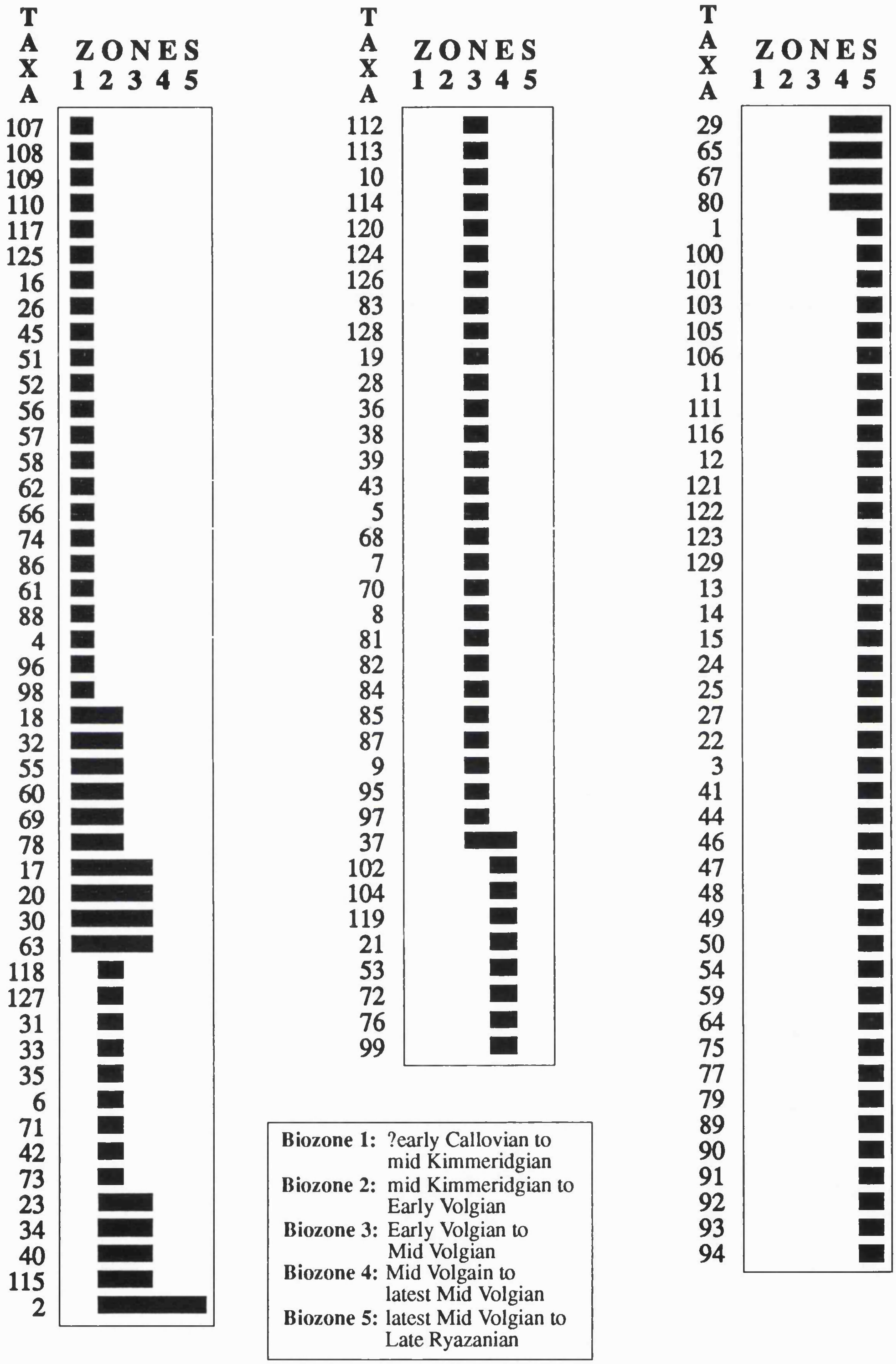


Fig. 9.6 Occurrence of all recovered radiolaria species/morphotypes in Biozones 1 to 5 (species/morphotypes code numbers in Chapter 8).

been used to tie the 5 biozones to the standard ammonite zonation scheme of the North Sea Basin of Cope *et al.* (1980). However, problems exist with the precise correlation of some zonal boundaries, and therefore these have been tentatively defined at present.

9.8.4.1 Biozone 1 (UA 1 - UA 2)

The base of the biozone cannot be clearly defined (this is usual with any zonation). In well 9/18A-4 the sample 11230 which is assigned to Biozone 1 is the oldest sample in this study to yield radiolarians used for the UA method. This has been dated by SPT to occur in the interval of *calloviense* to *progracilis* ammonite zones, which is early Callovian to Mid Bathonian in age (Cope *et al.*, 1980). However, fully marine conditions for this part of the basin (South Viking Graben) had not been established earlier than early Callovian times (maps J7a and J7b of Bradshaw *et al.*, 1992 and Chapter 4). Partington *et al.* (1993) recognise an early influx of pyritised radiolarians for the Viking Graben in the lower Callovian.

Well 9/18A-4. UA 1 (and Biozone 1) is well-defined here and spans an interval up to the Early to Mid Oxfordian, then follows an interval barren of radiolarians.

Well 16/17-5. UA 1 and UA 2 are not clearly defined here but samples 14050 to 14170 (Biozone 1) have been dated as Early Oxfordian in age. Higher up a barren interval for radiolarians follows.

Well 22/21-2. A single sample (13080) yielded a radiolarian fauna which allowed it to be assigned to Biozone 1. It has been dated as mid Kimmeridgian (*eudoxus* to *cymodoce* zones) in age.

Sections at Eathie. The upper boundary of Biozone 1 can be recognised from the onshore sections. In section Eathie B2 sample 10510 is assigned to UA 2 while any sample higher than this is placed in Biozone 2. From the other sections it is obvious that the lower limit of Biozone 2 falls within the *mutabilis* zone (mid Kimmeridgian).

Therefore, Biozone 1 is assigned to the ?early Callovian - mid Kimmeridgian (mid *mutabilis*) interval.

9.8.4.2 Biozone 2 (UA 3 - UA 6)

Eathie A, B1 & B2. In these onshore exposures the biozone spans the remaining part of the *mutabilis* zone, from where the lower limit (UA 3, samples 10404 & 10419 in Eathie B1 and sample 10430 in Eathie A) can be recognised.

Well 22/21-2. The lower limit here certainly falls in the middle Kimmeridgian. Sample 12850 is assigned in the interval *eudoxus* to *cymodoce* zones. UA 6 has been individually reproducible in sample 12630 (which marks the extinction of *Archaeocenosphaera*(?) sp. 5) which has been dated (by SPT) as Lower Volgian (*scitulus* zone). Higher in the section samples 12340, 12290 and 12240 are assigned to either Biozone 2 or 3. These have also been dated to occur in the Lower Volgian, in the interval *hudlestoni* to *scitulus* zones. In summary, in this well Biozone 2 does not occur higher than the *scitulus* zone.

Well 23/27-4. Here, UA 3 to UA 6 are not well defined. Sample 10970 is assigned to Biozone 2 and placed in the ?Kimmeridgian (*?autissiodorensis* to *?cymodoce* zone interval). The Lower Volgian is not clearly defined in this well. However, Biozone 2 does not occur higher than sample 10880 (UA 7) which is Early Volgian in age (earlier than *hudlestoni* zone).

Well 12/28-1. A single sample (6280) is assigned to UA 6 and dated as mid Kimmeridgian, *eudoxus* to *cymodoce* zones. However, the Biozone may occur higher in the section (samples 6000, 5980 & 5940-5900). These are all Early Volgian in age and occur in the middle part of the *hudlestoni* - *elegans* zone interval. Biozone 3 almost certainly occurs in samples 5960 (UA 4-17) and 5880 (UA 9-11) and higher in the section. These samples are older than the mid *hudlestoni* zone.

From the above it can be concluded that Biozone 2 can be assigned to mid Kimmeridgian (mid *mutabilis* zone) to Early Volgian (*scitulus* zone) interval.

9.8.4.3 Biozone 3 (UA 7 - UA 12)

The Biozone is documented in 8 wells.

Well 23/27-4. The biozone spans the interval Lower to Middle Volgian. The following Unitary Associations are individually reproducible are: UA 7 (sample 10880, Lower Volgian, lower than *hudlestoni* zone), UA 9 (samples 10760-10680, assigned to *pallasioides* - *pectinatus* interval), UA 11 (sample 10650, assigned to the same interval as 10760-10680) and UA 12 (sample 10550, *albani* zone). The upper limit of the biozone for this well can be picked in sample 10480 (UA 10-12) which is Mid Volgian in age (*glaucolithus* zone).

Well 28/5-1. UA 11 is crearly identified here (sample 6630, Lower Volgian, *pectinatus* zone). Biozone 3 does not occur lower than sample 6680 (UA 8-11), which marks the *hudlestoni* zone. Sample 6520 is assigned to Biozone 2 or 3 and is Mid Volgian in age (*?kerberus* zone).

Well 22/21-2. The biozone spans the Lower Volgian interval. The lower limit can be traced somewhere in the *hudlestoni* - *scitulus* zone interval, as discussed in the previous part (Biozone 2). UA 11 is individually reproducible is samples 12190-12100 (Lower Volgian, *?pectinatus* zone). Above this interval the section becomes barren of radiolarians. There is a major unconformity and the boundary of Lower/Middle Volgian is questionably placed for this well (by SPT).

Well 14/18-3. Sample 8270 (UA 8-11) is assigned to Biozone 3 and is dated as Early Volgian (*hudlestoni* zone). The biozone spans the Middle Volgian interval in this well. UA 8 is individually reproducible in samples 8180-8140 (*pallasioides* - mid *hudlestoni* zone interval) and sample 8040 (*albani* - *rotunda* zone interval). UA 11 is well defined in sample 7980 (top *albani* zone). Biozone 3 is extended higher in the section to the uppermost Middle Volgian (?*oppressus* zone) but no UA have been individually reproduced. In summary, Biozone 3's lower limit is lower than the *hudlestoni* zone.

Well 9/18A-4. UA 12 is individually reproducible in sample 10800 (Middle Volgian, placed in the *anguiformis* - ?*pallasioides* zone interval).

Well 12/28-1. The lower boundary of Biozone 3 in this well is discussed under Biozone 2.

Well 29/12-1. The biozone has been identified in two samples (8260, 8240) and occurs in the Lower/Middle Volgian interval, higher than the *hudlestoni* zone (sample 8280).

Well 7430/10-U-01. A single sample (221.78) has been assigned to UA 9. Århus (1991) did not study this interval but its age is Volgian.

Concluding, Biozone 3 is assigned to the Early Volgian (*scitulus* zone) to Mid Volgian (*glaucolithus* zone, tentatively) time interval.

9.8.4.4 Biozone 4 (UA 13 - UA 15)

The biozone is documented in 3 wells. Its limited lateral reproducibility has been discussed earlier in this chapter.

Well 23/27-4. The lower limit of the biozone can be drawn from sample 10320, which is dated as Mid Volgian in age (?*kerberus* zone). UA 14 is individually reproducible in sample 10260 and this falls within the Late Volgian/latest Mid Volgian (*lamplughi* - *oppressus* zones) time interval. UA 15 has not been identified in this well.

Well 22/21-2. Sample 12030 yields a radiolarian assemblage which falls within UA 14. This sample has been questionably dated as Early Volgian in age. As mentioned earlier, the Lower/Middle Volgian boundary for this well is uncertain. There is a gap barren of radiolarians above sample 12030. Sample 11840 is assigned to UA 15. The age of this sample is earliest Late Volgian (*primitivus* - *oppressus* zones).

Well 7430/10-U-01. Here, sample 168.96 is assigned to UA 13. Århus (1991) did not study this interval but it is older than Berriasian.

Therefore, Biozone 4 can be assigned to Mid Volgian (tentatively *glaucolithus* zone) to latest Mid Volgian (*oppressus* zone, tentatively) age.

9.8.4.5 Biozone 5 (UA 16 - UA 18)

The biozone is present in 9 wells. Most of the sections are condensed and therefore treated with caution.

Well 7B. Biozone 5 spans the Ryazanian. The section has been dated as Ryazanian (Mørk *et al.*, 1982). UA 16 is individually reproducible.

Well 29/12-1. The lower limit of Biozone 5 (sample 8040) is within the uppermost Middle Volgian. The sample corresponds to the *anguiformis* zone. The upper limit is in sample 7920, which occurs in the Upper Ryazanian, higher than the *kochi* ammonite zone.

Well 22/21-2. Sample 11770 is assigned to Biozone 5 (UA 16-17) and this falls within the Upper Volgian, in the mid *lamplughi* - ?*oppressus* interval. The upper limit of the biozone has been identified in sample 11740 which marks the mid *stenomphalus* zone (Upper Ryazanian), and corresponds with the top of the Kimmeridge Clay Formation in the well.

Well 9/18A-4. Two samples are assigned to the biozone. Base of Biozone 5 (sample 10780, UA 16-17) is in the uppermost Middle Volgian (top *anguiformis* zone), while sample 10760 marks the top of the Kimmeridge Clay and is dated as Early Cretaceous in age (mid *stenomphalus* zone).

Well 7430/10-U-01. Two samples (153.54 & 155.84) occur in the biozone and are dated as Berriasian (Århus, 1991).

Well 14/18-2. The biozone spans the uppermost Middle Volgian to Ryazanian interval. Sample 7800 is assigned to the biozone and corresponds to the top *oppressus* zone. The upper limit is in sample 7740 (UA 16-17) which falls within the *kochi* - *primitivus* interval.

Well 28/5-1. The lower limit is seen in sample 6490 (UA 16-17), dated as latest Mid Volgian, (*oppressus* zone). Sample 6440 is the highest to be examined (Kimmeridge Clay Formation is overlain by the Late Cretaceous Tor Formation) and falls in the mid *lamplughi* zone.

Well 23/27-4. The lower limit can be drawn from sample 10240 (UA 16-17), which marks the Lower Ryazanian (*ructoni* zone). Sample 10200 corresponds to the upper limit of the biozone in this well and is dated as Ryazanian in age (?mid *stenomphalus*).

Well 16/17-5. The biozone spans the Upper Volgian to Upper Ryazanian interval. Sample 12040 (UA 16-17) falls within the *primitivus* - *oppressus* interval, while sample 12000 covers the mid *stenomphalus* zone and probably extends slightly higher.

In summary, the Biozone 5 is assigned an age range of latest Mid Volgian (tentatively *oppressus* zone) - Late Ryazanian (mid *stenomphalus* and possible younger) interval.

Fig. 9.7 shows the 5 zones correlated to chronostratigraphic stages and ammonite zones of Cope *et al.* (1980) as well as other zonation schemes for the North Sea Basin.

9.8.5 Correlation with Partington *et al.* (1993)

Partington *et al.* (1993) give a zonal scheme which is based on tops, bases and acme zones of certain radiolarian morphotypes as well as foraminifera (Fig. 9.7). In order to compare the two schemes, the taxonomic names which have been used in this study for the marker species of Partington *et al.* (1993) are given below.

Partington *et al.* (1993)		**This study**
Tricolocapsa sp. 1 D & C	=	(90) *Tricolocapsa* sp. A

Praeconocaryomma ? sp. 2 D & C	=	(129) Sterraster sp. 1
Praeconocaryomma sp. 1 D & C	=	(23) *Praeconocaryomma* sp. A
Parvicingula sp. 1 D & C	?=	(67) *Praeparvicingula* sp. 1
Cenosphaera sp. 1 D & C	?=	(2) *Archaeocenosphaera*(?) sp. 1
Orbiculiforma lowreyensis Pessagno	=	(14) *O. lowreyensis* Pessagno
Parvicingula blowi Pessagno	?=	(62) *Parvicingula*(?) sp. 3

The correlation is given on Fig. 9.7 and is based on the ammonite zones. The correlation is discussed in descending stratigraphic order for ease of comparison with Partington *et al.* (1993).

1) Biozone 5 which spans the *oppressus* (tentatively) - mid *stenomphalus* interval (this study) is correlated to the MJ24 - MK 2 zones, which includes most of the *P.* sp. 1 D & C acme zone (MJ24), the *P.* ? sp. 2 D & C acme zone (MJ25), the unassigned interval (MK1), and the *T.* sp. 1 D & C/*H. infracalloviensis* zone (MK2). The upper limit of their MK 2 zone is considered to fall at the top of *stenomphalus* zone. In this study, as discussed earlier, from the majority of the wells the upper limit of Biozone 5 is in the mid *stenomphalus* zone. However, in well 16/17-5 this level can be taken slightly higher, which agrees with Partington *et al.* (1993), but sample 12000 (well 16/17-5) cannot be assigned to any ammonite zone (SPT). Therefore, the upper limit of Biozone 5 is the mid *stenomphalus* zone for this study.

The ranges of Sterraster sp. 1 and *Praeconocaryomma* sp. A, which occur within the Biozone 5, also agree with Partington *et al.* (1993). *Stichocapsa decorata* Rüst and Sterraster sp. 1 top in the *stenomphalus* zone according to the same authors, and *O. mclaughlini* Pessagno is included in the same interval.

2) Biozone 4 is correlated with most of the *P.* sp. 1 D & C acme zone (MJ23). *Praeparvicingula* sp. 1 makes its first appearance in UA 14, and in Partington *et al.* (1993) the base of its acme is in the top *fittoni* zone. However, as stated earlier the lower limit of Biozone 4 is tentatively placed in the *glaucolithus* zone owing to dificulties in precisely correlating the well samples with the standard ammonite zones.

3) Biozone 3 is correlated with the remaining part of MJ23 zone, all the *Cenosphaera* sp. 1 D & C acme zone (MJ22), and part of the *O. lowreyensis* Pessagno zone (MJ21). *Archaeocenosphaera*(?) sp. 1 occurs within this interval in this study as well as Spongodiscidae sp. A and S. sp. C (their reappearance is reported in this part by Partington *et al.* (1993)). *O. lowreyensis* Pessagno has not been recorded from this interval; its range is given as UA 16 to UA 17 (core material from 7B and well 9/18A-4, cuttings).

4) Biozone 2 is correlated with the remaining part of MJ21 and most of the *P. blowi* zone (MJ20). *Hsuum*(?) sp. A and *P. hexagona* (Rüst) occur in this interval according to these authors.

5) Biozone 1 is correlated with the remaining part of MJ20 and spans the interval to the ?lower Callovian. Partington *et al.* (1993) have reported the appearances of

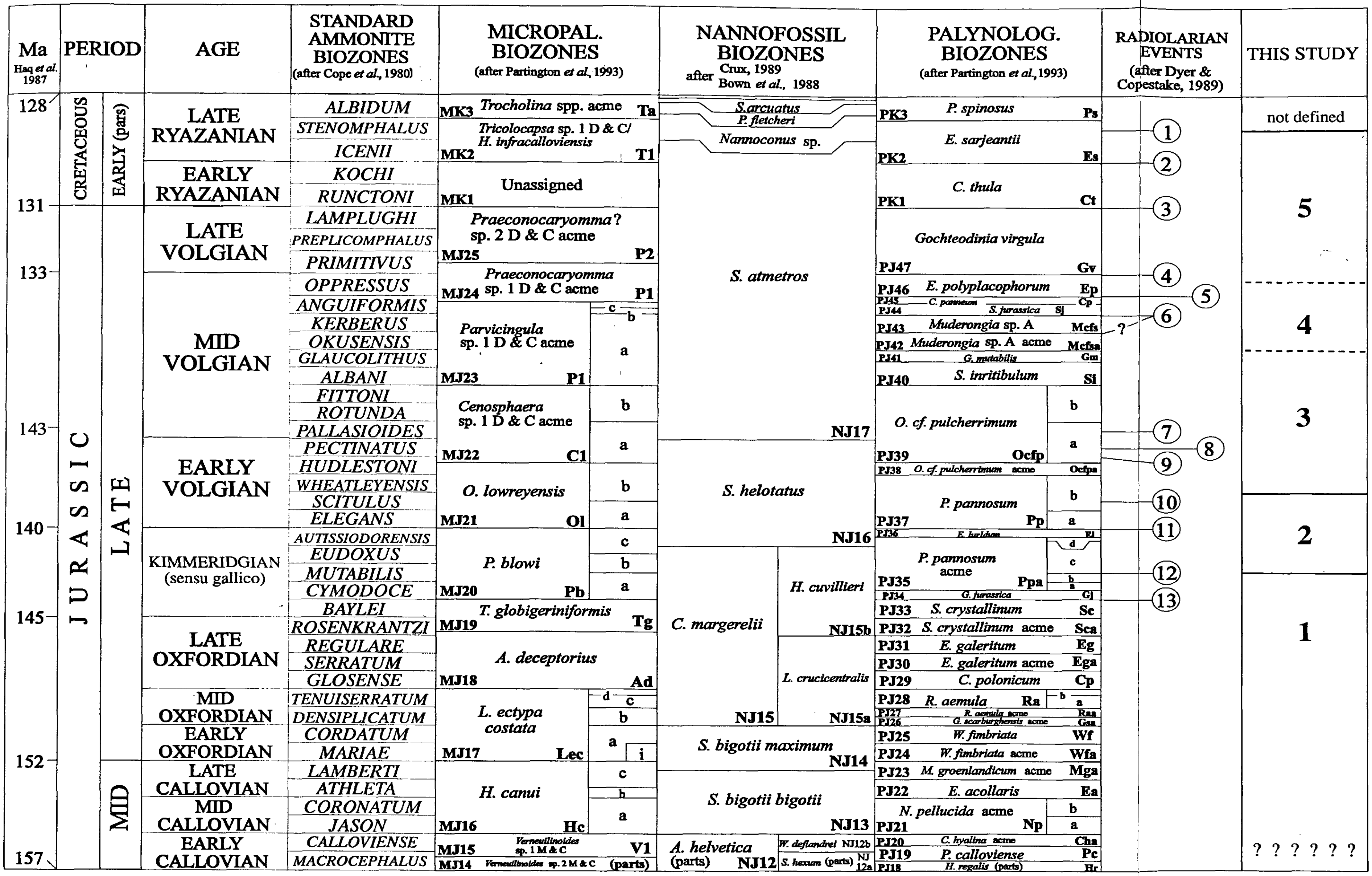


Fig. 9.7 Correlation of the proposed Biozones of this study with other zonations for the North Sea Basin.

Orbiculiforma iniqua Blome and *O.* aff. *O. iniqua* in the Callovian. These species almost certainly correspond to *Orbiculiforma* sp. 2 in this study.

Most of the radiolarian events of Dyer & Copestake (1989) and Partington *et al.* (1993) can be recognised in the studied wells. However, some of the events identified by the above authors gave inconsistent results when applied to the material studied here (e.g. different stratigraphic ranges for different studied wells). As discussed previously (p. 239), the nature of sedimentation, dissolution, diagenesis, and ecological control on the distribution of taxa may account for these results.

9.8.6 Correlation of wells and studied sites

Biostratigraphic correlation of the 13 studied wells/sections, expressed in terms of zones is shown in Fig. 9.8. Explanation for the figure is provided with the caption.

9.8.7 Rates of faunal turnover

The rate of faunal turnover for the radiolarians found in this study has been estimated using the method of Guex (1991, p. 166-168). However, it should be pointed out that the data from the present study are poor in comparison with those of Baumgartner (1984a) for which the rates of faunal turnover have been calculated by Guex (1991).

Fig. 9.9 shows the number (cumulative) of morphotypes that appear and disappear in each different Unitary Association. In order to test the significance (and validity) of this diagram, the distance (D) or similarity between each adjacent UA has been calculated (Fig. 9.10) according to Guex (1991), using the formula:

$$D=\frac{|k_i-k_j|}{|k_i|}+\frac{|k_j-k_i|}{|k_j|}$$

with k_i and k_j each pair of Unitary Associations. •

The first two dots of Fig. 9.9 are established as follows:

$D_{UA1-2} = 1/7 + 5/11 = 0.59$

$D_{UA2-3} = 3/11 + 4/12 = 0.6$

There is a low similarity for most of the Unitary Associations. This can be interpreted as insufficient data or gaps in the fossil record (Guex, 1991). However, high similarity seems to occur in two intervals. These are: a) age interval UA 4 to UA 6 (late Kimmeridgian to Early Volgian), and b) age interval UA 9 to UA 11 (Early to Mid Volgian). In both intervals high extinction rates of radiolaria could have occurred.

• $|k_i - k_j|$ equals to the number of species/morphotypes which are present in UA_i but not in the UA_j.

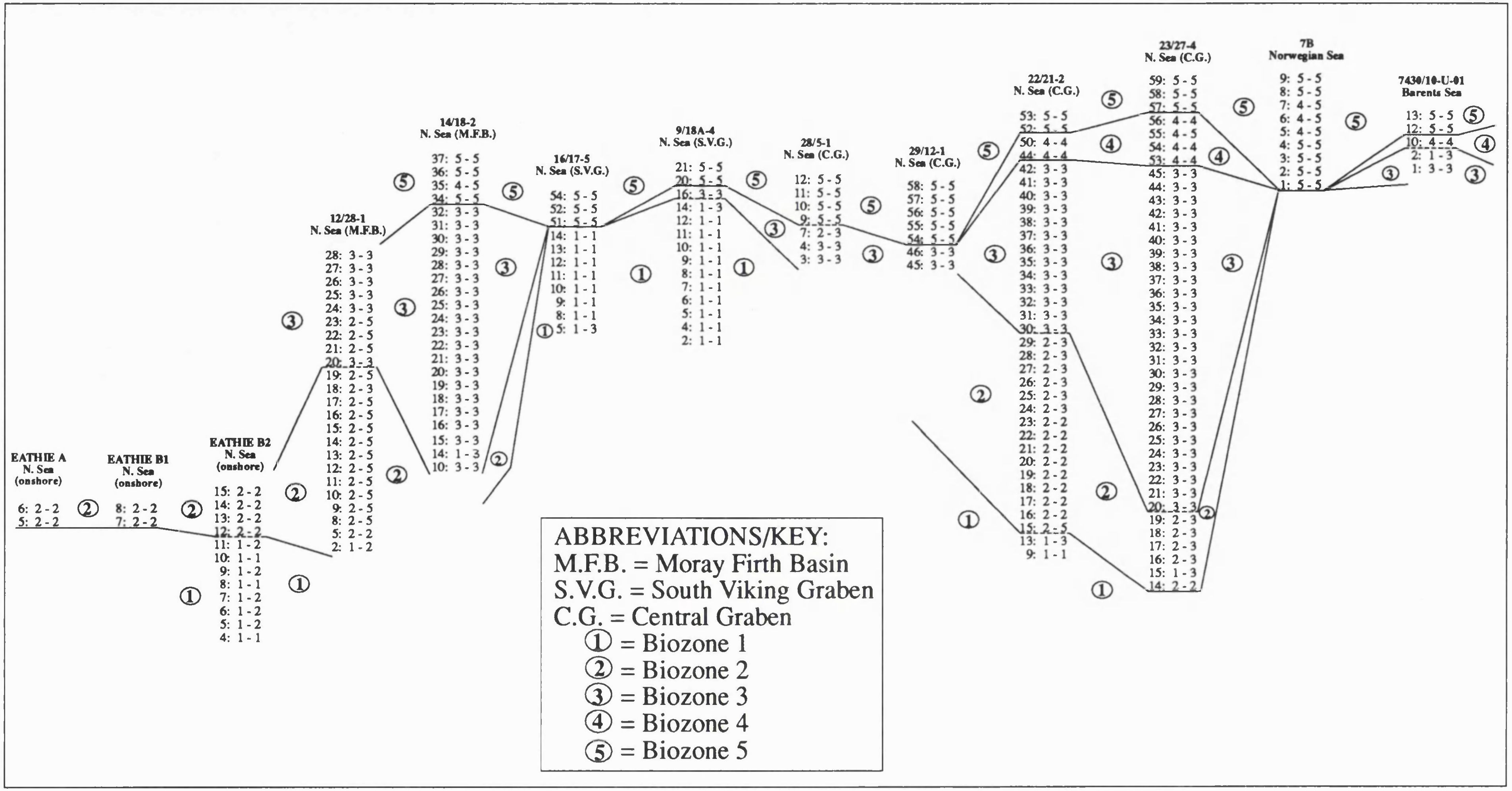


Fig. 9.8 Biostratigraphic correlation of sections/wells studied expressed in terms of zones (dashed lines indicate uncertain correlations).
Explanation for well columns: first column = number of sample (sequentially numbered from bottom).
second & third columns = Biozone identified.

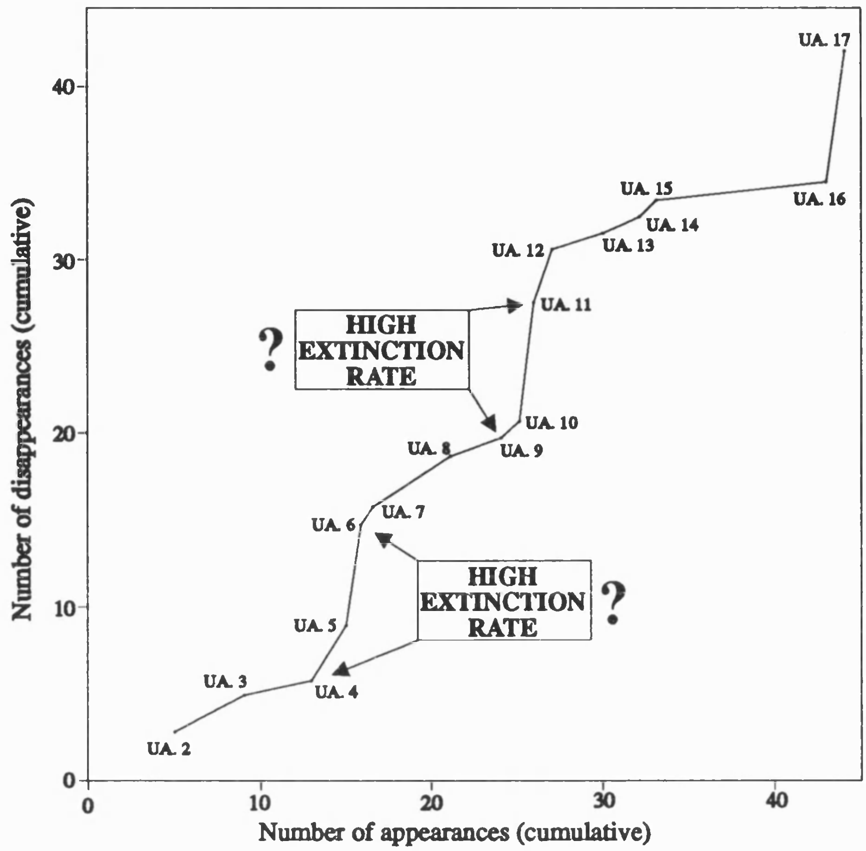


Fig. 9.9 Rate of faunal turnover for the interval U.A.2 - U.A.17.

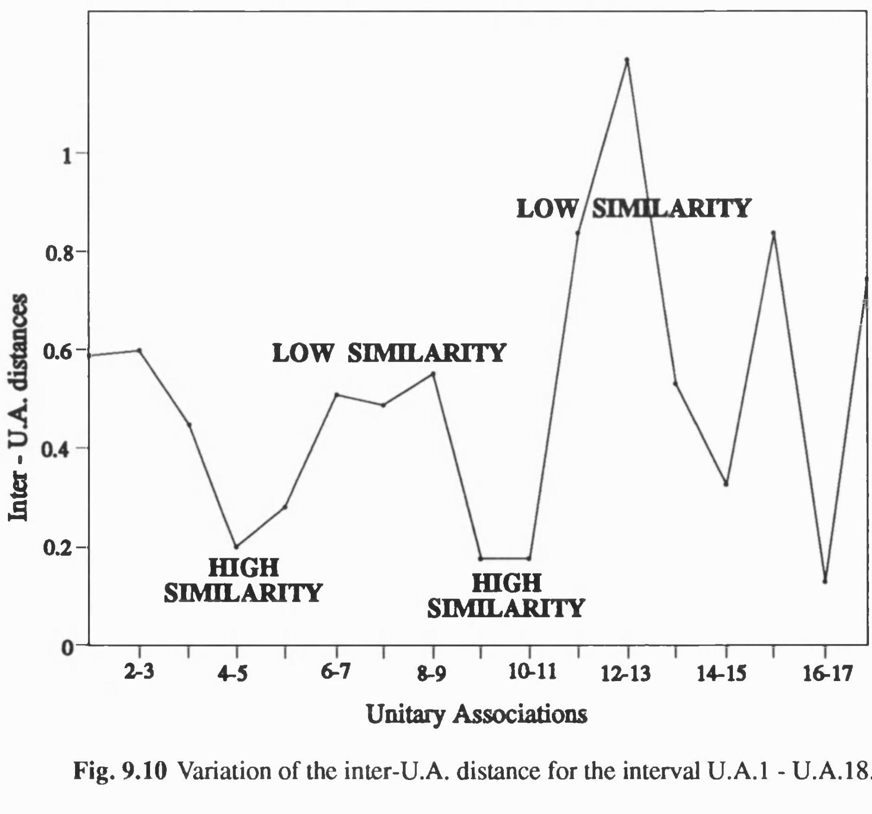


Fig. 9.10 Variation of the inter-U.A. distance for the interval U.A.1 - U.A.18.

SECTION EATHIE A

	10426	10422	10429	10421	10430	10423
STAGE	KIMMERIDGIAN					
AMMONITE ZONE	*MUTABILIS*					
BIOZONES	Not defined	Not defined	Not defined	Not defined	2	
UNITARY ASSOCIATIONS	Not defined	Not defined	Not defined	Not defined	3-3	5-5
SAMPLE	10426	10422	10429	10421	10430	10423
Rhaxella group (not pyritised)						P
Rhax group (pyritised)					P	P
Nassellaria gen. et. sp. indet.					120	20
Spumellaria gen. et. sp. indet.					28	18
(20) Orbiculiforma sp. 6					2	6
(6) Archaeocenosphaera(?) sp. 5						90
Praeparvicingula(?) spp. indet.					2	157
(69) Praeparvicingula sp. 3					4	31
(115) Nassellaria sp. 10						7
60) Parvicingula sp. 1						5
(73) Praeparvicingula sp. 7						5
(35) Hagiastridae(?) group 6						1
(33) Hagiastridae(?) group 4						1
(31) Hagiastridae(?) group 2					4	1
(32) Hagiastridae(?) group 3					6	7
Orbiculiforma spp. indet.					1	6
(17) Orbiculiforma sp. 3					2	6
(23) Praeconocaryomma hexagona (Rust)						5
Praeconocaryomma spp. indet.					86	10
(2) Archaeocenosphaera(?) sp. 1						68
Archaeocenosphaera(?) spp. indet.					20	80
(18) Orbiculiforma sp. 4					2	
(34) Hagiastridae(?) group 5					2	
(71) Praeparvicingula sp. 5					25	
(55) Hsuum(?) sp. A					8	
Hsuum(?) spp. indet.					5	
STATE OF PRESERVATION					P	G
NUMBER OF SPUMELLARIA					153	299
NUMBER OF NASSELLARIA					162	227
TOTAL NUMBER OF RADIOLARIA					315	526
NUMBER OF PYR. RADIOLARIA					10	
NUMBER OF NON-PYR. RADIOLARIA					305	526
% PYRITISED RADIOLARIA					3	
% NON-PYRITISED RADIOLARIA					97	100

NOT DEFINED

KEY
for Tables 9.2 to 9.14

G = good
M = moderate
P = poor
VP = very poor

for full explanation see p. 106

Table 9.2 Range chart of radiolarian species/morphotypes recovered in section Eathie A (P = present).

SECTION EATHIE B1

	10425	10416	10405	10403	10402	10418	10404	10419
STAGE	KIMMERIDGIAN							
AMMONITE ZONE	*MUTABILIS*							
BIOZONES	NOT DEFINED						2	
UNITARY ASSOCIATIONS	NOT DEFINED						3-3	3-3
SAMPLE	10425	10416	10405	10403	10402	10418	10404	10419
Rhaxella group (pyritised)								P
Nassellaria gen. et. sp. indet.					9	2	177	186
Spumellaria gen. et. sp. indet.					8	2	20	25
Praeparvicingula(?) spp. indet.							40	58
(69) Praeparvicingula sp. 3							21	17
(60) Parvicingula sp. 1							7	15
(73) Praeparvicingula sp. 7							14	6
Orbiculiforma spp. indet.							17	3
(20) Orbiculiforma sp. 6							1	1
Praeconocaryomma spp. indet.							2	4
(18) Orbiculiforma sp. 4							4	2
(71) Praeparvicingula sp. 5							2	7
(30) Hagiastridae(?) group 1							2	1
(18) Nassellaria sp. 13								1
(55) Hsuum(?) sp. A							1	
Archaeocenosphaera(?) spp. indet.							2	
STATE OF PRESERVATION					VP	VP	P	P
NUMBER OF SPUMELLARIA					8	2	48	36
NUMBER OF NASSELLARIA					9	2	261	290
TOTAL NUMBER OF RADIOLARIA					17	4	309	326
NUMBER OF PYR. RADIOLARIA							8	3
NUMBER OF NON-PYR. RADIOLARIA					17	4	301	323
% PYR. RADIOLARIA							3	1
% NON-PYR. RADIOLARIA					100		97	99

Table 9.3 Range chart of radiolarian species/morphotypes recovered in section Eathie B1 (P = present).

SECTION EATHIE B2

	10515	10506	10505	10504	10503	10502	10501	10507	10508	10509	10510	10514	10513	10511	10512
STAGE	KIMMERIDGIAN														
AMMONITE ZONES	*CYMODOSE*				*MUTABILIS*										
BIOZONES	(not defined)			1	1-2			1	1-2	1	1-2	2			
UNITARY ASSOCIATIONS	(not defined)			1-1	1-5			2-5		2-2	2-5	3-5	4-5		5-5
SAMPLE	10515	10506	10505	10504	10503	10502	10501	10507	10508	10509	10510	10514	10513	10511	10512
Rhaxella group (not pyritised)														P	P
Rhaxella group (pyritised)				P				P	P			P			P
Nassellaria gen. et. sp. indet.				9				98	57	88	5	39	48	1	154
Spumellaria gen. et. sp. indet.				7				6	15	20	7	6	4	9	43
(20) Orbiculiforma sp. 6										7		1	4		13
(6) Archaeocenosphaera(?) sp. 5															107
Praeparvicingula(?) spp. indet.								9	5	16		3			84
(69) Praeparvicingula sp. 3										2			2		39
(15) Nassellaria sp. 10													5		21
(73) Praeparvivingula sp. 7															10
(35) Hagiastridae(?) group 6															2
(32) Hagiastridae(?) group 3				1									1		2
Orbiculiforma spp. indet.										21			6		15
(17) Orbiculiforma sp. 3										7		1	1		15
(23) Praeconocaryomma hexagona (Rust)													10		21
Praeconocaryomma spp. indet.													52		32
(2) Archaeocenosphaera(?) sp. 1															67
Archaeocenosphaera(?) spp. indet.										4			6		20
(71) Praeparvicingula sp. 5												3	5		5
(40) Spumellaria gen. et sp. indet. A															1
(78) Spongocapsula(?) sp. 2										1					
(60) Parvicingula sp. 1								1		6					
(18) Orbiculiforma sp. 4										2					
(55) Hsuum(?) sp. A										4					
Hsuum(?) spp. indet.								2		3					
Hagiastridae(?) spp. indet.									1	1					
(16) Orbiculiforma sp. 2										4					
(17) Nassellaria sp. 12								4							
Praeconocaryomma spp. indet.								17							
(62) Parvicingula(?) sp. 3								5							
(74) Praeparvicingula(?) sp. A								1							
(56) Hsuum(?) sp. B								2							
(25) Nassellaria group A				6											
STATE OF PRESERVATION				VP				P	VP	P	VP	VP	P	VP	G
NUMBER OF SPUMELLARIA				8				23	16	66	7	8	84	9	337
NUMBER OF NASSELLARIA				15				123	62	120	5	45	60	1	309
TOTAL NUMBER OF RADIOLARIA				23				146	78	186	12	53	144	10	646
NUMBER OF PYR. RADIOLARIA				23				30	5	10		3	1		
NUMBER OF NON-PYR. RADIOLARIA								116	73.	176	12	50	143	10	646
% PYRITISED RADIOLARIA				100				21	6	5		6			
% NON-PYRITISED RADIOLARIA								79	94	95	100	94	100	100	100

(Shaded box) NOT DEFINED

Table 9.4 Range chart of radiolarian species/morphotypes recovered in section Eathie B2 (P = present).

WELL 23/27-4

STAGE	BIOZONES	UNITARY ASSOCIATIONS	DEPTH (in ft)	Rhaxella group (not pyritised)	Rhaxella group (pyritised)	Nassellaria gen. et. sp. indet.	Spumellaria gen. et. sp. indet.	(90) Tricolocapsa sp. A	Tricolocapsa(?) spp. indet.	(101) Zhamoidellum(?) sp. 1	(103) Cryptothoracic Nassellaria sp. A	Hagiastridae(?) spp. indet.	(89) Stichocapsa(?) sp. 1	Praeparvicingula spp. indet.	(67) Praeparvicingula sp. 1	(65) Parvicingula(?) sp. 6	(80) Stichocapsa decorata Rust	(59) Parvicingula(?) cf. P. jonesi Pessagno	(24) Praeconocaryomma sp. A	(91) Tricolocapsa sp. B	Praeconocaryomma spp. indet.	Stichocapsa(?) spp. indet.	(99) Williriedellum(?) sp. 1	Hsuum(?) spp. indet.	(104) Cryptothoracic Nassellaria sp. B	(76) Praeparvicingula(?) sp. C
RYAZANIAN			10160																							
			10180																							
	5	16-17	10200		P	30	2	5	3	2	1	1	3	19	24	2	5									
			10220		P	40	4	10	10	3					9		8	3	1	2						
			10240		P	10	2	4	3				1		9		1			1	1					
*1	4	14-14	10260			8	1								4							1	1			
	3-4	14-17	10280		P	6									2									1		
MID VOLGIAN	4		10300			8	2								3		1			1					1	
			10320			22	5								7											3
			10340			3	3								2											
			10360																							
			10380			2																				
			10400			2																				
			10420																							
			10440			2																				
			10460																							
	3	10-12	10480			19	3							1												
			10500			16								4			1									
			10520			15	1							3			1									
			10540			13	2																			
		12-12	10550			3	1							2			2									
		10-12	10560			4																				
			10580			3								1												
		11-11	10600			10																				
		10-11	10610			20	2																			
			10620			24	4																			
			10640			124	15							1												
		11-11	10650			100	11																			
		10-11	10663			99	9																			
		9-9	10680			104	16																			
			10700			179	10																			
KIMMERIDGIAN - EARLY VOLGIAN			10720			176	12														5					
			10740			223	4														3					
			10750			236	17														5					
			10760			192	23																			
		9-11	10780			149	22														2					
			10790			167	8														1					
			10800		P	220	15							1												
			10820		P	163	17							5												
			10840			88	20																			
		7-8	10860		P	162	18														4					
		7-7	10880			94	22							2							3					
	2-3	4-7	10900			23	6																			
			10920			91	17							1							2					
			10930			53	13							5												
			10940			56	46														2					
	1-3	2-7	10960			40	24														1					
	2	3-6	10970			24	22																			
			10980	P		15	7																			
			11000			5	3																			
			11020			4	2																			
			11040																							
			11050																							
			11060																							
			11080																							
			11150																							
			11160																							
			11200																							
			11220																							
			11240																							
			11300																							

DEPTH (in ft)	Praeconocaryomma spp. indet.	(68) Praeparvicingula sp. 2	(23) Praeconocaryomma hexagona (Rust)	Spongodiscidae spp. indet.	(8) "Cenodiscus" sp. A	(9) "Cenodiscus" sp. B	(28) Praeconocaryomma(?) sp. E	(36) Spongodiscidae sp. A	(70) Praeparvicingula sp. 4	(38) Spongodiscidae sp. C	(114) Nassellaria sp. 9	(37) Spongodiscidae sp. B	(40) Spumellaria gen. et sp. indet. A	Archaeocenosphaera(?) spp. indet.	(17) Orbiculiforma sp. 3	(128) Nassellaria group D	(2) Archaeocenosphaera(?) sp. 1	(126) Nassellaria group B	Orbiculiforma spp. indet.	(82) Stichocapsa sp. B	(71) Praeparvicingula sp. 5	(120) Nassellaria sp. 15	(7) Archaeocenosphaera(?) sp. 6	(83) Stichocapsa(?) sp. C	(115) Nassellaria sp. 10	(20) Orbiculiforma sp. 6
10160																										
10180																										
10200																										
10220																										
10240																										
10260																										
10280																										
10300																										
10320																										
10340																										
10360																										
10380																										
10400																										
10420																										
10440																										
10460																										
10480	1	3																								
10500	3	4	15	4	1																					
10520	1	8	10	3																						
10540	1		5	5	1																					
10550	2	2	5	3	4	4	1																			
10560			2	18	8	3																				
10580	1			2	8	5																				
10600	2	6	1	11	7	3		4	3	5	1	6														
10610		14	3	14		4		5		14		2	1													
10620	8	4	4	15	2	8		1		7		2														
10640	16	2		23	2	4		28						8												
10650	11	8	3	8	4	11		33		3		2		19	3	7	25									
10663		4		5		2		18						11		8	4									
10680	9	2		5		1		10		1		7		3		6	9	2								
10700	2			7				11				5		9		12	21	5	1	18						
10720	8			3				5				3		20		3	17	7		10						
10740	7			7				25				4		19		12	21	4		12						
10750	5			7				10						13		15	10	8		16		1	3			
10760	14		2	12				6				3		5		16	8	7		11		1	3	1		
10780	10			11				14				4		17	1	6	8			8						
10790	9		3	10				8				3		4		5			1	7						
10800	8	2		7				1						9		11	8			8		1				
10820	8		2	7				1						4		9	7									
10840	3			15				5						24		5	31									
10860	23		3	5										46		13	47			4					1	
10880	10			5										24		5	31		1	3						1
10900	3			2										3			8			2						
10920	5		2	1										4			9			2					1	
10930	7			3				1						8			6									1
10940	5							1						21			8									4
10960	6			3				2						21		1	6			1						4
10970	1																5				1					3
10980														2												
11000																										
11020																										
11040																										
11050																										
11060																										
11080																										
11150																										
11160																										
11200																										
11220																										
11240																										
11300																										

DEPTH (in ft)	STATE OF PRESERVATION	NUMBER OF SPUMELLARIA	NUMBER OF NASSELLARIA	TOTAL NUMBER OF RADIOLARIA	NUMBER OF PYR. RADIOLARIA	NUMBER OF NON-PYR. RADIOLARIA	% PYR. RADIOLARIA	% NON-PYRITISED RADIOLARIA
10160								
10180								
10200	M	4	94	98	96	2	99	1
10220	M	5	87	92	92		100	
10240	M	3	27	30	30		100	
10260	M	1	14	15	15		100	
10280	P		8	8	8		100	
10300	M	2	14	16	16		100	
10320	M	5	34	39	39		100	
10340	P	3	5	8	8		100	
10360								
10380								
10400								
10420								
10440								
10460								
10480	P	3	23	26	25	1	96	4
10500	M	23	25	48	46	2	96	4
10520	M	15	27	42	42		100	
10540	P	14	13	27	25	2	93	7
10550	P	19	7	26	26		100	
10560	VP	31	4	35	34	1	97	3
10580	P	16	9	25	24	1	96	4
10600	M	40	20	60	58	2	97	3
10610	M	46	28	74	73	1	99	1
10620	M	51	28	79	73	6	92	8
10640	P	95	128	223	22	201	10	90
10650	M	132	116	248	37	211	15	85
10663	P	49	111	160	4	156	3	97
10680	P	61	114	175	9	166	5	95
10700	P	66	214	280	3	277	1	99
10720	P	63	176	259		259		100
10740	M	90	251	341		341		100
10750	P	69	276	345	3	342	1	99
10760	P	76	230	306		306		100
10780	P	89	163	252	1	251		100
10790	VP	46	180	226		226		100
10800	P	69	242	311	2	309		100
10820	VP	47	172	219	1	218		100
10840	P	97	93	190	2	189	1	99
10860	M	146	180	326	2	324		100
10880	M	84	104	188	1	187		100
10900	VP	22	27	49		49		100
10920	P	40	95	135	3	132	2	98
10930	VP	39	58	97	2	95	2	98
10940	P	86	56	142		142		100
10960	P	75	42	117	2	115	2	98
10970	P	33	24	77		77		100
10980	VP	9	15	24		24		100
11000	VP	3	5	8		8		100
11020	VP	2	4	6		6		100
11040								
11050								
11060								
11080								
11150								
11160								
11200								
11220								
11240								
11300								

*1 = LATEST MID VOLGIAN - LATE VOLGIAN

NOT DEFINED (shaded)

Table 9.5 Range chart of radiolarian species/morphotypes recovered in well 23/27-4 (P = present).

WELL 28/5-1

STAGE	LATE VOLGIAN		LATEST MID VOLGIAN			MID VOLGIAN				EARLY VOLG. - KIMM. ?		
BIOZONES	5					2-3			3			
UNITARY ASSOCIATIONS	16-17					4-12			11-11	8-11		
DEPTH (in ft)	6440	6450	6470	6490	6510	6520	6570	6610	6630	6680	6780	6810
Rhaxella group (not pyritised)	P			P							P	P
Rhaxella group (pyritised)											P	
(80) Stichocapsa decorata Rust	5	3	4	1	1	1			1			
Nassellaria gen. et. sp. indet.	7	4	5	3	1	5		1	5	3		
(24) Praeconocaryomma sp. A	3	11	3	2						1		
(129) Sterraster sp. 1		3										
(2) Archaeocenosphaera(?) sp. 1			2									
(105) Cryptocephalic & Cryptothoracic Nassellaria sp. C			1									
Archaeocenosphaera(?) spp. indet.				3						2		
(23) Praeconocaryomma hexagona (Rust)						1						
(36) Spongodiscidae sp. A									2			
(70) Praeparvicingula sp. 4		NOT DEFINED							1			
Praeparvicingula(?) spp. indet.									2			
(7) Archaeocenosphaera(?) sp. 6										4		
STATE OF PRESERVATION	G	G	G	M		P			M	M		
TOTAL NUMBER OF RADIOLARIA	15	21	15	9	2	7			11	10		
NUMBER OF SPUMELLARIA	3	14	6	5		1			2	7		
NUMBER OF NASSELLARIA	12	7	9	4	2	6			9	3		
PYRITISED RADIOLARIA	2	3	5	1		6			8	9		
NON-PYR. RADIOLARIA	13	18	10	8		1			3	1		
% PYRITISED RADIOLARIA	13	14	33	11		86			73	90		
% NON-PYR. RADIOLARIA	87	86	67	89		14			27	10		

Table 9.6 Range chart of radiolarian species/morphotypes recovered in well 28/5-1 (P = present).

WELL 29/12-1

DEPTH (in ft)	9580	9560	9540	9500	9440	9420	9400	9380	9360	9300	9280	9260	9240	9220	9200	9180	9100	8900	8860	8840	8800	8780	8740	8720	8700	8680	8660	8640	8600	8580	8560	8540	8500	8480	8460	8440	8420
STAGE	MID JURASSIC									LATE OXFORDIAN						MID KIMM- LATE OXFORD.				MID - LATE KIMMERIDGIAN									EARLY VOLGIAN								
BIOZONES																																					
UNITARY ASSOCIATIONS																																					
Rhaxella group (not pyritised)			P																																		
Rhaxella group (pyritised)									P	P	P	P		P	P	P																					
Nassellaria gen. et. sp. indet.																																					
Spumellaria gen. et. sp. indet.																																					
(90) Tricolocapsa sp. A																																					
(91) Tricolocapsa sp. B																																					
(92) Tricolocapsa sp. C																																					
Tricolocapsa(?) spp. indet.																																					
(101) Zhamoidellum(?) sp. 1																																					
(129) Sterraster sp. 1																																					
(80) Stichocapsa decorata (Rust)																																					
(93) Tricolocapsa sp. D																																					
Praeconocaryomma spp. indet.																																					
(24) Praeconocaryomma sp. A																																					
(2) Archaeocenosphaera(?) sp. 1																																					
(54) Cryptamphorella(?) sp. 2																																					
Stichocapsa(?) spp. indet.																																					
Archaeocenosphaera(?) spp. indet.																																					
(10) "Cenodiscus" sp. C																																					
(7) Archaeocenosphaera(?) sp. 6																																					
(85) Stichocapsa(?) sp. E																																					
(88) Stichocapsa(?) sp. H																																					
STATE OF PRESERVATION																																					
NUMBER OF SPUMELLARIA																																					
NUMBER OF NASSELLARIA																																					
TOTAL NUMBER OF RADIOLARIA																																					
NUMBER OF PYR. RADIOLARIA																																					
NUMBER OF NON-PYR. RADIOLARIA																																					
% PYR. RADIOLARIA																																					
% NON-PYR. RADIOLARIA																																					

DEPTH (in ft)	8400	8380	8360	8340	8320	8300	8280	8260	8240	8220	8200	8190	8160	8130	8100	8070	8040	8010	7980	7950	7920
STAGE										MID VOLGIAN									*3	*2	*1
BIOZONES								3									5				
UNITARY ASSOCIATIONS								8-8	8-11								16-17			18-18	17-18
Rhaxella group (not pyritised)						P	P	P	P	P	P	P	P	P			P	P	P	P	
Rhaxella group (pyritised)																	P	P	P	P	
Nassellaria gen. et. sp. indet.		1							9	5	1		1			4	6	7	4	3	5
Spumellaria gen. et. sp. indet.				2			2		9	3	5	8				8	9	11	23	1	19
(90) Tricolocapsa sp. A																				2	13
(91) Tricolocapsa sp. B																					2
(92) Tricolocapsa sp. C																					1
Tricolocapsa(?) spp. indet.																					11
(101) Zhamoidellum(?) sp. 1																					2
(129) Sterraster sp. 1																	4	12	28		1
(80) Stichocapsa decorata (Rust)																	2	9	7	2	
(93) Tricolocapsa sp. D																				1	
Praeconocaryomma spp. indet.								4		4	4									2	
(24) Praeconocaryomma sp. A																	4		2		
(2) Archaeocenosphaera(?) sp. 1																		3			
(54) Cryptamphorella(?) sp. 2																		2			
Stichocapsa(?) spp. indet.																	10	18			
Archaeocenosphaera(?) spp. indet.							2	2	23	2	1	2									
(10) "Cenodiscus" sp. C												1									
(7) Archaeocenosphaera(?) sp. 6									6												
(85) Stichocapsa(?) sp. E								2													
(88) Stichocapsa(?) sp. H								1													
STATE OF PRESERVATION									VP	VP	VP	VP				VP	M	M	G	M	M
NUMBER OF SPUMELLARIA							4	6	38	9	10	11				8	17	25	53	3	20
NUMBER OF NASSELLARIA		1		2				3	9	5	1					4	18	36	11	8	34
TOTAL NUMBER OF RADIOLARIA		1		2			4	9	47	14	11	11				12	35	61	64	11	54
NUMBER OF PYR. RADIOLARIA																1	8				13
NUMBER OF NON-PYR. RADIOLARIA		1		2			4	9	47	14	10	11				11	27	61	64	11	41
% PYR. RADIOLARIA																8.3	22.8				24
% NON-PYR. RADIOLARIA								100	100	100	100	100				91.7	77.2	100	100	100	76

*1 = LATE - RYAZANIAN
*2 = EARLY RYAZANIAN
*3 = LATE-LTST MID VOLGIAN

NOT DEFINED

Table 9.7 Range chart of radiolarian species/morphotypes recovered in well 29/12-1 (P = present).

WELL 22/21-2

STAGE	BIOZONES	UNITARY ASSOCIATIONS	DEPTH (in ft)	Rhaxella group (not pyritised)	Rhaxella group (pyritised)	(80) Stichocapsa decorata Rust	(93) Tricolocapsa sp. D	Nassellaria gen et. sp. indet.	(122) Nassellaria sp.17	Spumellaria gen. et sp. indet.	(90) Tricolocapsa sp. A	(101) Zhamoidellum(?) sp. 1	(129) Sterraster sp. 1	(25) Praeconocaryomma sp. B	(67) Praeparvicingula sp. 1	Tricolocapsa(?) spp. indet	(59) Parvicingula(?) cf. P. jonesi	(41) Spumellaria gen et sp. indet. B	Spongodiscidae spp. indet.	Archaeocenosphaera(?) spp. indet.	(21) Orbiculiforma sp. 7	(65) Parvicingula(?) sp. 6	Praeconocaryomma spp. indet.	(102) Zhamoidellum(?) sp. 2	(99) Williriedellum(?) sp. 1
*1			11600																						
			11630																						
*2			11660																						
			11690																						
RYAZAN.	5	18-18	11740		P	16	1	4	1	1															
LATE VOLGIAN		16-17	11770		P	11	1	32		10	2	5	2	1	3	1	1	1							
			11800		P			1																	
	4	15-15	11840		P			9											2	1	1	1			
			11890		P	1		7		1						1									
MID VOLGIAN			11920	P	P			13		8															
			11940	P	P			7								1									
?			11970	P	P			2																	
EARLY VOLGIAN			12010	P	P			3		9									1				2		
	4	14-14	12030	P	P			6		9													7	2	2
			12040	P	P																				
	3	9-11	12060	P	P			24		3										10					
		11-11	12100	P	P			32		3							1			32					
			12120	P	P	1		34		8										33					
			12150	P	P			24		3									2	56			1		
			12190	P	P			52												48			15		
		9-11	12210	P	P			74											1	38			19		
	2-3	4-12	12240	P	P			9												18			11		
	3		12270	P	P			14											1	29			5		
	2-3		12290	P	P			15		8										52			18		
	3	4-6	12300	P	P			21												20			5		
	2-3	4-12	12340	P	P			9												31			18		
	3		12360		P			7												7			1		
			12390	P	P			22												22			12		
	2-3		12420	P	P			14												31			28		
			12470	P	P			14		5										67			17		
			12520	P	P			12											3	66			31		
			12550	P				6		5										55			47		
			12580					1												29			13		
			12610	P	P			19		10									2	84			13		
	2	6-6	12630	P	P			33											1	119			16		
		4-4	12650	P	P			26		6										52			29		
LATE KIMMERIDG.			12660	P	P			20		3									1	123			2		
			12700	P	P			52		6										23			242		
		4-6	12740	P	P			14		3										11			16		
			12790		P			4		3										8			31		
			12810		P			4		4													6		
			12850	P	P			17		4										61			24		
MID KIMMERIDGIAN	2-5	4-17	12880		P			16												20			3		
			12930	P	P			3												15			1		
	1-3	2-10	12950		P			3		14										14			4		
			12990	P	P			9		18										11			1		
			13020		P			7		3										12			5		
			13040					4												11			1		
	1		13080	P				5		5										20			2		
			13110	P	P			3		36										14			2		
			13150					3		45										7			12		
			13170		P			7		2										2			22		
			13190					4		7										1					
EARLY KIMMER. - OXFORDIAN			13210																						
			13240		P															3			2		
			13280					1		4										4					
			13320																	1					

DEPTH (in ft)	(2) Archaeocenosphaera(?) sp. 1	(128) Nassellaria group D	(36) Spongodiscidae sp. A	(37) Spongodiscidae sp. B	(113) Nassellaria sp. 8	(7) Archaeocenosphaera(?) sp. 6	(70) Praeparvicingula sp. 4	(82) Stichocapsa sp. B	(40) Spumellaria gen. et sp. indet A	(97) Tricolocapsa(?) sp. 4	(38) Spongodiscidae sp. C	(68) Praeparvicingula sp. 2	(23) Praeconocaryomma hexagona (Rust)	(19) Orbiculiforma sp. 5	(87) Stichocapsa(?) sp. G	(85) Stichocapsa(?) sp. E	(124) Nassellaria sp. 19	(30) Hagiastridae(?) group 1	(112) Nassellaria sp. 7	(5) Archaeocenosphaera(?) sp. 4	(95) Tricolocapsa(?) sp. 2	(127) Nassellaria group C	(6) Archaeocenosphaera(?) sp. 5	(60) Parvicingula sp. 1	(78) Spongocapsula(?) sp. 2	(115) Nassellaria sp. 10	(17) Orbiculiforma sp. 3	Orbiculiforma spp. indet.	(86) Stichocapsa(?) sp. F
11600																													
11630																													
11660																													
11690																													
11740																													
11770																													
11800																													
11840																													
11890																													
11920																													
11940																													
11970																													
12010																													
12030																													
12040																													
12060	9	2	5	2																									
12100	21	3	8	4	1	3	1	6	1																				
12120	86		14	4		5		1		1	14	1																	
12150	89		3					3			1	6																	
12190	51	2	2			8	3				1	1	81	2	3														
12210	29	2				10		2				1	33		2	1													
12240	8																												
12270	11												6				2												
12290	28		2										19																
12300	13	1	1			1							5					1	2										
12340	23												2																
12360	3																			1									
12390	13	2											9								1								
12420	10	1	1										12																
12470	35					1							10																
12520	52												5																
12550	45	1											22																
12580	9					1							4																
12610	44					3							7																
12630	85	1				1		2					11									6	4						
12650	49		4			2							9										7	1	1				
12660	71	1											3										151						
12700	23	1											97										6		2				
12740	15		1				1						3										2			1			
12790	2												4										8						
12810													1										1						
12850	5																						1						
12880	1																						2						
12930	2	1																					5						
12950	4																										1		
12990	5																												
13020													1															1	
13040	3												1																
13080																													1
13110	1																						1						
13150																							1						
13170																							1						
13190																													
13210																													
13240																													
13280																							1						
13320																													

DEPTH (in ft)	STATE OF PRESERVATION	NUMBER OF SPUMELLARIA	NUMBER OF NASSELLARIA	TOTAL NUMBER OF RADIOLARIA	NUMBER OF PYR. RADIOLARIA	NUMBER OF NON-PYR. RADIOLARIA	% PYR. RADIOLARIA	% NON-PYR. RADIOLARIA
11600								
11630								
11660								
11690								
11740	G	2	22	24	10	14	42	58
11770	G	13	56	69	55	14	80	20
11800								
11840	VP	4	10	14	9	5	60	40
11890	VP	1	9	10	5	5	50	50
11920	VP	8	13	21	11	10	52	48
11940	VP		8	8	2	6	25	75
11970			2					
12010	VP	12	3	15	1	14	7	93
12030	VP	16	10	26	5	21	19	81
12040								
12060	M	29	24	53	5	48	9	91
12100	G	72	40	112	2	110	2	98
12120	G	162	38	200	2	198	1	99
12150	G	155	33	188	4	184	2	98
12190	G	208	62	270				100
12210	G	141	77	218	2	216	2	98
12240	M	37	9	46		46		100
12270	G	52	16	68	3	65	4	96
12290	G	117	15	132		132		100
12300	M	48	26	74	9	65	12	88
12340	M	74	9	83	2	81	2	98
12360	M	12	7	19	1	18	6	94
12390	M	56	25	81	7	74	9	91
12420	M	82	15	97	1	96	1	99
12470	M	135	14	149		149		100
12520	M	157	12	169		169		100
12550	G	164	7	171		171		100
12580	G	55	1	56		56		100
12610	M	163	19	172		172		100
12630	G	237	42	279		279		100
12650	G	158	28	186		186		100
12660	G	354	21	375		375		100
12700	M	399	55	454		454		100
12740	M	51	16	67	4	64	6	94
12790	M	56	4	60		60		100
12810	P	12	4	16		16		100
12850	M	94	17	111		111		100
12880	M	26	16	42		42		100
12930	M	23	4	27		27		100
12950	M	38	3	41		41		100
12990	M	35	9	44		44		100
13020	P	22	7	29		29		100
13040	M	16	4	20		20		100
13080	M	27	6	33		33		100
13110	P	52	3	55		55		100
13150	VP	65	3	68		68		100
13170	VP	27	7	34		34		100
13190	VP	8	4	12	3	9	25	75
13210								
13240	VP	5		5		5		
13280	VP	9	1	10		10		100
13320								

*1 - EARLY HAUTERIVIAN - VALANGINIAN
*2 - EARLY VALANGINIAN
NOT DEFINED (shaded)

Table 9.8 Range chart of radiolarian species/morphotypes recovered in well 22/21-2 (P = present).

WELL 12/28-1

	6400	6360	6340	6320	6280	6240	6220	6200	6180	6160	6140	6120	6100	6080	6060	6040	6020	6000	5980	5960	5940	5920	5900	5880	5860	5840	5820	5800
STAGE	EAR. KIMM. - LT. OXF		MID KIMMERIDGIAN			LATE KIMMERIDGIAN											EARLY VOLGIAN								EARLIEST MID VOLGIAN			
BIOZONES		1-2			2			2-5										2-3	2-5	3	2-5			3				
UNITARY ASSOCIATIONS		1-3			6-6			4-17										4-12	4-17					9-11		11-11	8-11	
DEPTH (in ft)	6400	6360	6340	6320	6280	6240	6220	6200	6180	6160	6140	6120	6100	6080	6060	6040	6020	6000	5980	5960	5940	5920	5900	5880	5860	5840	5820	5800
Rhaxella group (not pyritised)																	P	P			P	P	P	P	P	P		P
Rhaxella group (pyritised)	P	P	P	P				P	P	P	P	P	P	P				P	P	P			P	P				
(2) Archaeocenosphaera(?) sp. 1				7	6			1				3	5	5	1	1		7		2	7	1		4	15	33	11	12
Archaeocenosphaera(?) spp. indet.		1		10	5			3	4	1	3	6	8	9	4	4		10	3	11	10	3	3	11	46	71	39	15
(37) Spongodiscidae sp. B								1				3	1											1	14	16		4
Nassellaria gen. et sp. indet.		3	2	17	19			1	4	9	21	2	1	5	6	1		3		1		1	1	2	11	29	8	15
(36) Spongodiscidae sp. A				2	1							1		1						2			1	1	4	7		1
Praeconocaryomma spp. indet.					1									1		3		1	1		1	1						1
(84) Stichocapsa(?) sp. D																												1
Spumellaria gen. et sp. indet.	3		1	1		1				2		6	2						4	2					2	2	3	1
(82) Stichocapsa sp. B																				2					1	7	1	
Spongodiscidae spp. indet.		2		2				4			1			3	2			2						1			2	
(38) Spongodiscidae sp. C				1														2		1			1	1	4	24		
(39) Spongodiscidae sp. D																										4		
(40) Spumellaria gen. et sp. indet. A																										1		
Orbiculiforma spp. indet.	1																									3		
(70) Praeparvicingula sp. 4																				1						1		
(7) Archaeocenosphaera(?) sp. 6																									2	6		
(81) Stichocapsa sp. A																				1								
(23) Praeconocaryomma hexagona (Rust)																		3										
(6) Archaeocenosphaera(?) sp. 5					8																							
(127) Nassellaria group C					6																							
(18) Orbiculiforma sp. 4		3																										
STATE OF PRESERVATION		M		M	M			M	P	VP	VP	G	G	G	M	M		G		G	G			G	G	G	G	G
NUMBER OF SPUMELLARIA	4	6	1	23	26			9	4	3	4	19	16	19	8	8		26	8	18	18	5	5	19	85	167	55	34
NUMBER OF NASSELLARIA		3	2	17	25			1	4	9	21	2	1	5	6	1		3		4		1		2	10	37	9	16
TOTAL NUMBER OF RADIOLARIA	4	9	3	40	51			10	8	12	25	21	17	24	14	9		29	8	22	18	6	5	21	95	204	64	50
NUMBER OF PYR. RADIOLARIA		8		23	28				2	5	13							1										
NUMBER OF NON-PYR. RADIOLARIA		1		17	23			10	6	7	12	21	17	24	14	9		28	8	22	18	6	5	21	95	204	64	50
% PYR. RADIOLARIA		89		58	54				25	42	52							3										
% NON-PYR. RADIOLARIA		11		42	46			100	75	58	48	100	100	100	100	100		97	100	100	100	100	100	100	100	100	100	100

NOT DEFINED

Table 9.9 Range chart of radiolarian species/morphotypes recovered in well 12/28-1 (P = present).

WELL 14/18-2

STAGE	BIOZONES	UNITARY ASSOCIATIONS	DEPTH (in ft)	Rhaxella group (not pyritised)	Rhaxella group (pyritised)	Nassellaria gen. et. sp. indet.	Spumellaria gen. et. sp. indet.	Stichocapsa(?) spp. indet.	Archaeocenosphaera(?) spp. indet.	(129) Sterraster sp. 1	(90) Tricolocapsa sp. A	Spongodiscidae spp. indet.	(80) Stichocapsa decorata Rust	(121) Nassellaria sp. 16	Praeconocaryomma spp. indet.	(43) Spumellaria gen. et sp. indet D	(40) Spumellaria gen. et sp. indet. A	(2) Archaeocenosphaera(?) sp. 1	(68) Praeparvicingula sp. 2	(36) Spongodiscidae sp. A	(37) Spongodiscidae sp. B	(23) Praeconocaryomma hexagona (Rust)	(70) Praeparvicingula sp. 4	(34) Hagiastridae(?) group 5	(82) Stichocapsa sp. B	Praeparvicingula spp. indet.	Orbiculiforma spp. indet.	(85) Stichocapsa(?) sp. E	(115) Nassellaria sp. 10	(7) Archaeocenosphaera(?) sp. 6	STATE OF PRESERVATION	NUMBER OF SPUMELLARIA	NUMBER OF NASSELLARIA	TOTAL NUMBER OF RADIOLARIA	NUMBER OF PYR. RADIOLARIA	NUMBER OF NON-PYR. RADIOLARIA	% PYR. RADIOLARIA	% NON-PYR. RADIOLARIA
*1			7620																																			
*2			7640			1																											1	1		1		
EARLY RYAZ. - LATE VOLG.			7720				2	1																								2	1	3		3		
	5	16-17	7740	P		46	64	4		3	2	3	3																		VP	70	52	122		122		100
			7760	P	P	11	47	2		2																					VP	49	13	62		62		100
	4-5	13-18	7780	P	P	74	55	15	4				12																		VP	59	86	145	2	143	1	99
	5		7800	P	P	29	26	4	2	1		2	2	1	1																VP	32	36	68		68		100
LTST MID VOLG.			7820	P	P	40	52	3	2	2		1	4																		VP	57	47	104		104		100
	3		7840	P	P	22	43		2			3				2															VP	48	24	72		72		100
			7860	P	P	32	48					1				3															VP	49	35	84		84		100
MID VOLGIAN			7880	P	P	15	13					2																			VP	15	15	30		30		100
			7900	P	P	35	74								2	5															VP	76	41	116	1	115		100
			7920	P		31	41		1						1	8															VP	43	39	82		82		100
		5-11	7940	P		36	52	1				4			3	2	2														VP	61	39	100		100		100
			7960	P		95	78	7	10			9			7	5	3	3	1												VP	112	98	210		210		100
		11-11	7980	P		73	55		7			4			33	1		2		3	4	9	5								P	117	79	196		196		100
		8-11	8000	P		79	78	2	4			10			31	3					1	7									VP	130	84	214		214		100
			8020	P		72	53	4	5			17			22	1						3									VP	100	77	177		177		100
		8-8	8040	P		73	90	2	4			11			40	4				2	5	3		1							VP	156	79	235		235		100
		8-11	8060	P		76	59		3			9			32	6		4		4	5	17			1						P	133	77	216		216		100
			8080	P		89	57		6			9			30	1				4	5	6			1						P	117	90	208		208		100
			8100	P	P	81	102		2			4			16					4	2	1				1					VP	131	82	213		213		100
			8120	P	P	88	77		30			13			9	5			1	5	10	2	1		3		1				P	147	93	245		245		100
		8-8	8140	P	P	84	80	2	8			2			11					2	5	1			1			2			VP	109	89	198		198		100
			8160	P	P	64	100	1	25			6			12	3		13		5	7				3			1	2		P	168	71	242		242		100
			8180	P	P	48	52		6			7			6			2		3		1			2				1		VP	77	51	128		128		100
	1-3	4-8	8220	P	P	47	62		6			3			4					1	4								1		VP	80	48	128		128		100
			8220	P	P	6	14		4			1													1				1		VP	19	8	27		27		100
			8230		P	6	30		2																						VP	32	8	40		40		100
			8250	P	P	11	29					2													1						VP	31	12	43		43		100
	3	8-11	8270		P	8	17					4									1									1	VP	22	8	30		30		100
EARLY VOLG. - LATE KIMMER.			8290		P	10	17																								VP	17	10	27		27		100
			8300	P	P	8	22								2			2													VP	26	8	34		34		100
			8320			13	13								1																VP	13	13	26		26		100
			8340	P	P	5	19		2									2													VP	22	5	27		27		100
			8360	P	P	20	13	2				2			1	1															VP	18	22	41		40		100
			8380		P	17	28		3						7	1									3						VP	39	20	60		60		100
			8400	P	P	23	24		2						1					1					2						VP	28	25	53		53		100
			8420	P	P	12	25								3																VP	28	12	40		40		100
*3			8440				2																									2		2		2		

*1 = EARLY VALANGINIAN
*2 = LATE RYAZANIAN
*3 = MID KIMMERIDGIAN
(shaded) NOT DEFINED

Table 9.10 Range chart of radiolarian species/morphotypes recovered in well 14/18-2 (P = present).

WELL 16/17-5

DEPTH (in ft)	14310	14290	14270	14250	14230	14210	14190	14170	14150	14130	14110	14090	14070	14050	14030	14010	13990	13970	13950	13940	13930	13920	13900	13860	13820	13780	13620	13502	13400	13240	13130	13000	12880	12760	12660	12560	12505	12469	12445	12400	12300	12240	12200	12144	12140	12120	12105	12100	12085	12080	12060	12040	12020	12000
STAGE	LATE CALLOVIAN		EARLY OXFORDIAN																					MID OXFORDIAN - EARLY VOLGIAN																								MID VOLGIAN			*2	LT. RYAZ.-LT. VOLG.		*1
BIOZONES					1-3			1													1-3																															5		
UNITARY ASSOCIATIONS					2-10			1-2																																												16-17	17-18	16-17
Rhaxella group (not pyritised)				P	P			P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P		P																										P			
Rhaxella group (pyritised)				P	P		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P																											P		P
Nassellaria gen. et sp. indet.				3			1	13	20	5	11	13	5	7	10	32	38	24	11	1	10	4	1	2	3																										6	3	1	2
(15) Orbiculiforma sp. 1																																																						1
Spongodiscidae spp. indet.																																																1						3
(123) Nassellaria sp. 18																																																						1
Spumellaria gen. et sp. indet.				1	4			19	12	6		6		2	2	4		2	3		2																															6		
(92) Tricolocapsa sp. C																																																				2		
(13) Orbiculiforma mclaughlini Pessagno																																																				1		
(129) Sterraster sp. 1																																																			11			
(80) Stichocapsa decorata Rust																			5	1	2																														2			
Archaeocenosphaera(?) spp. indet.									12	7				2		3	18	16	9	2	11																											1			3			
(24) Praeconocaryomma sp. A																																																			2			
Orbiculiforma spp. indet.																																											1					2						
(68) Praeparvicingula sp. 2																					1	2																																
(66) Perispyridium(?) spp. indet.								7		2	4	9		3					1		1																																	
(30) Hagiastridae(?) group 1																					1																																	
(37) Spongodiscidae sp. B																		1																																				
(61) Parvicingula sp. 2														2	2	4	10	11																																				
(4) Archaeocenosphaera(?) sp. 3										2	1	7		2	1		2	3																																				
(38) Spongodiscidae sp. C																	2	1																																				
(18) Orbiculiforma sp. 4									1																																													
(115) Nassellaria sp. 10									1																																													
(26) Praeconocaryomma sp. C					1			3	1																																													
(51) Broctus(?) sp. 1								1																																														
Hagiastridae(?) spp. indet.					1																																																	
(17) Orbiculiforma sp. 3					1																																																	
STATE OF PRESERVATION					P			M	M	M	M	M	VP	M	P	P	M	G	M		G	M																										P			G	M		VP
NUMBER OF SPUMELLARIA				1	3			23	26	15	1	22		6	3	7	22	23	12	2	14																											4			16	7		4
NUMBER OF NASSELLARIA				3	4			21	21	7	15	13	7	11	11	32	41	29	17	2	14	6	1	2	3																										8	5	1	3
TOTAL NUMBER OF RADIOLARIA				4	7			44	47	22	16	35	7	17	14	39	63	52	29	4	28	6	1	2	3																							4			24	12	1	7
NUMBER OF PYR. RADIOLARIA				4	7			36	15	5	4	13	3	6	1	1					5	6																										2				4		1
NUMBER OF NON-PYR. RADIOLARIA								8	32	17	12	22	3	11	13	38	63	52	29		23																											2			24	8	1	6
% PYR. RADIOLARIA					100			82	32	23	26	37	50	35	7	3					18	100																														33		14
% NON-PYRITISED RADIOLARIA								18	68	77	74	63	50	65	93	97	100	100	100		82																														100	67		86

*1 = EARL. VALANG.- LATEST. RYAZANIAN
*2 = LATE - MID VOLGIAN
[shaded] NOT DEFINED

Table 9.11 Range chart of radiolarian species/morphotypes recovered in well 16/17-5 (P = present).

WELL 9/18A-4

STAGE	BIOZONES	UNITARY ASSOCIATIONS	DEPTH (in ft)	Rhaxella group (not pyritised)	Rhaxella group (pyritised)	(13) Orbiculiforma mclaughlini Pessagno	(90) Tricolocapsa sp. A	(91) Tricolocapsa sp. B	Tricolocapsa(?) spp. indet.	Nassellaria gen. et sp. indet.	Spumellaria gen. et sp. indet.	Hagiastridae(?) spp. indet.	(11) "Cenodiscus"(?) cf. "C." alievi Pessagno	(2) Archaeocenosphaera(?) sp. 1	(15) Orbiculiforma sp. 1	Orbiculiforma spp. indet.	(14) Orbiculiforma lowreyensis Pessagno	(129) Sterraster sp. 1	(111) Nassellaria sp. 6	(28) Praeconocaryomma(?) sp. E	Archaeocenosphaera(?) spp. indet.	Praeconocaryomma spp. indet.	(17) Orbiculiforma sp. 3	Spongodiscidae spp. indet.
*1	5	16-17	10760			2	4	2	3	2	3	1	1	3	1	1	2							
MID VOLGIAN			10780	P					1	4								5	1					
			10790	P					1									1						
	3	12-12	10800							3	4	1								1	3			
MID - LATE OXFORD.			10830	P					1	1												1		
			10840																					
			10870																					
	1-3	2-10	10880	P						11	2	1				4							3	3
*2			10900																					
LATE CALLOVIAN	1	1-1	10930	P	P					17	1					4								6
			10980		P					1														
MID CALLOVIAN			11020	P	P					4														1
			11030		P					10	1					1								
			11050		P					5														
LATE BATHONIAN - EARLY CALLOVIAN		1-2	11080		P					20				1										4
			11130							1														
			11180		P				2	9														9
			11230							1														1
			11280							9						1								
	1		11340						1	3						1								
			11400																					

DEPTH (in ft)	(16) Orbiculiforma sp. 2	(26) Praeconocaryomma sp. C	(66) Perispyridium(?) spp. indet.	(58) Milax(?) sp. 2	(125) Nassellaria group A	(55) Hsuum(?) sp. A	(18) Orbiculiforma sp. 4	Praeparvicingula(?) spp. indet.	(88) Stichocapsa(?) sp. H	(98) Turanda(?) spp. indet.	(30) Hagiastridae(?) group 1	(57) Milax(?) sp. 1	(110) Nassellaria sp. 5	(109) Nassellaria sp. 4	(108) Nassellaria sp. 3	Milax(?) spp. indet.	(96) Tricolocapsa(?) sp. 3	(52) Canutus(?) sp. 1	(45) Archaeodictyomitra sp. A	(107) Nassellaria sp. 2	STATE OF PRESERVATION	NUMBER OF SPUMELLARIA	NUMBER OF NASSELLARIA	TOTAL NUMBER OF RADIOLARIA	NUMBER OF PYR. RADIOLARIA	NUMBER OF NON-PYR. RADIOLARIA	% PYR. RADIOLARIA	% NON-PYR. RADIOLARIA
10760																					M	14	11	25	8	17	32	68
10780																					M	5	6	11	6	5	56	44
10790																												
10800																					VP	9	3	12	8	4	67	33
10830																												
10840																												
10870																												
10880																					P	13	11	24	24		100	
10900																												
10930	3	6	4	4	1	1	1	1	1												P	21	29	50	50		100	
10980																												
11020			5	3	1					1											P	1	15	16	16		100	
11030	1		4		4						1	1	1	1	1						P	3	23	26	26		100	
11050			7		1											1	4	1			P		19	19	19		100	
11080			9														1				P	5	30	35	35	2	94	6
11130			1													1												
11180			8		1														1		P	9	21	30	30		100	
11230			1																1									
11280			7																		VP	2	16	18	18		100	
11340			2																	1	VP	1	7	8	8		100	
11400																												

*1 = EARLY CRET. - LATE JURAS.
*2 = EARL. - MID OXFORDIAN

[shaded] NOT DEFINED

Table 9.12 Range chart of radiolarian species/morphotypes recovered in well 9/18A-4 (P = present).

WELL 7B

STAGE	BIOZONES	UNITARY ASSOCIATIONS	DEPTH (in ft)	Rhaxella group (pyritised)	Spumellaria gen et sp. indet	Nassellaria gen et sp. indet	(80) Stichocapsa decorata Rust	(94) Tricolocapsa(?) sp. 1	(90) Tricolocapsa sp. A	(91) Tricolocapsa sp. B	Tricolocapsa(?) spp. indet.	(92) Tricolocapsa sp. C	(14) Orbiculiforma lowreyensis Prssagno	Archaeocenosphaera(?) spp. indet.	(25) Praeconocaryomma sp. B	(116) Nassellaria sp. 11	Archaeodictyomitra spp. indet.	(77) Spongocapsula(?) sp. 1	Hagiastridae(?) spp. indet.	(79) Spongocapsula(?) sp. 3	(129) Sterraster sp. 1	(106) Nassellaria sp. 1
RYAZANIAN			37.72																			
			41.50																			
			45.11																			
			50.20																			
			55.12			1																
			59.55			1																
			61.84			1																
	5	17-18	64.14	P		3	4	2	59	14	20	2										
			67.03	P		6					2	3										
			74.48																			
			80.51																			
			82.19																			
	5	16-17	85.14		19	7	4						2	2	3							
		16-16	86.94		23	119	59							3		1	5	10	1	6	3	3
			91.86		25	22	33							1		1					2	
		16-18	92.52		29	20	8															

DEPTH (in ft)	(3) Archaeocenosphaera(?) sp. 2	Praeconocaryomma spp. indet.	(27) Praeconocaryomma sp. D	(22) Porodiscus(?) sp. 1	(100) Xitus(?) sp. 1	Praeparvicingula(?) spp. indet.	(75) Praeparvicingula(?) sp. B	(29) "Staurosphaera" sp. 1	(12) Hexastylus(?) sp. 1	Orbiculiforma spp. indet.	(46) Archaeodictyomitra sp. 1	(47) Archaeodictyomitra sp. 2	(48) Archaeodictyomitra sp. 3	(49) Archaeodictyomitra sp. 4	(50) Archaeodictyomitra sp. 5	(44) Archaeodictyomitra rigida Pessagno	Actinommidae gen. et sp. indet.	(1) Acaeniotyle(?) sp. 1	(13) Orbiculiforma mclaughlini Pessagno
37.72																			
41.50																			
45.11																			
50.20																			
55.12																			
59.55																			
61.84																			
64.14																			
67.03																			
74.48																			
80.51																			
82.19																			
85.14																			
86.94	1	5	1	5	1	1	10	1	1	3	2	2	1	1	1	3			
91.86		1		1		1		2		1							2	1	
92.52		1								7							3	3	2

DEPTH (in ft)	STATE OF PRESERVATION	NUMBER OF SPUMELLARIA	NUMBER OF NASSELLARIA	TOTAL NUMBER OF RADIOLARIA	NUMBER OF NON-PYR. RADIOLARIA	NUMBER OF PYR. RADIOLARIA	% NON-PYR. RADIOLARIA	% PYR. RADIOLARIA
37.72								
41.50								
45.11								
50.20								
55.12								
59.55								
61.84								
64.14	G	102		102				100
67.03	M	11		11				100
74.48								
80.51								
82.19								
85.14	M	11	26	37	35	2	94	6
86.94	M	224	46	270	33	237	12	92
91.86	M	57	36	93	90	3	97	3
92.52	M	28	45	73	73		100	

NOT DEFINED

Table 9.13 Range chart of radiolarian species/morphotypes recovered in well 7B (P = present).

WELL 7430/10-U-01

DEPTH (in ft)	221.78	217.03	213.09	209.97	206.69	203.64	196.46	186.45	179.23	168.96	160.76	155.84	153.54	149.28	147.64	143.37
STAGE	VOLGIAN (?and older stata)											BERRIASIAN				
BIOZONES	3	1-3								4		5				
UNITARY ASSOCIATIONS	9-9									13-13			17-18			
Nassellaria gen. et sp. indet	37	17	14							143		9				2
Spumellaria gen. et sp. indet	3	4	2							147		5				2
(90) Tricolocapsa sp. A													1			
(92) Tricolocapsa sp. C													1			
Actinommidae gen. et sp. indet.													1			
(64) Parvicingula(?) sp. 5												1				
Praeconocaryomma spp. indet.										14		2				
Praeparvicingula(?) spp. indet.			2							3		1				
(80) Stichocapsa decorata Rust										2						
(53) Cryptamphorella(?) sp. 1										1						
(21) Orbiculiforma sp. 7										2						
(29) "Staurosphaera" sp. 1										1						
(72) Praeparvicingula sp. 6										12						
Orbiculiforma spp. indet.										5						
(37) Spongodiscidae sp. B										2						
Spongodiscidae spp. indet.										9						
(119) Nassellaria sp. 14										2						
Hagiastridae(?) spp. indet			1													
(63) Parvicingula(?) sp. 4		4														
(126) Nassellaria group B	8															
(38) Spongodiscidae sp. C	1															
STATE OF PRESERVATION	VP	VP	VP							P		P	P			
TOTAL NUMBER OF NASSELLARIA	45	21	16							163		10	2			
TOTAL NUMBER OF SPUMELLARIA	4	4	3							180		7	1			
NUMBER OF NON-PYR. RADIOLARIA										1			3			
NUMBER OF PYRITISED RADIOLARIA	49	25	19							342		17				
% NON-PYR. RADIOLARIA													100			
% PYRITISED RADIOLARIA	100	100	100							100		100				

NOT DEFINED

Table 9.14 Range chart of radiolarian species/morphotypes recovered in well 7430/10-U-01.

CHAPTER 10

DISCUSSION, CONCLUSIONS & FUTURE WORK

10.1 Palaeobiogeography

Studies have shown that Jurassic Radiolaria exhibit a faunal provincialism (Pessagno & Blome, 1986; Baumgartner, 1987a). In 1986, Pessagno & Blome postulated that it is possible to delimit two radiolarian faunal realms, the Tethyan and Boreal Realms, and gave criteria (based on the diversity and abundance of pantanelliids and parvicingulids) to differentiate these realms as well as to subdivide them into provinces. The latest modification of this palaeolatitudinal model is shown in Fig. 10.1 and the definition of realms using multiple criteria is also given (Fig. 10.2). Any application of the model should be treated with caution. Factors such as the influence of rock type and processing techniques using acid (especially HF) play an important role in biasing radiolarian palaeobiogeographic studies.

According to the model it is possible to distinguish in the Northern Hemisphere:

1) Central Tethyan and Northern Tethyan Provinces,

2) Southern Boreal and Northern Boreal Provinces, and

3) the boundary between the Tethyan and Boreal Realms.

Baumgartner (1987a) suggested that such differentiation is hypothetical. Palaeolatitude is not thought to have been a significant factor during the Jurassic. Rather, faunal provincialism was controlled by the degree of palaeoceanographic restriction of the basins (basin geometry and oceanic current pattern) (Baumgartner, 1987a, 1993). The same author stated that "Tethyan" radiolarian assemblages could well imply "high fertility-stirred ocean" and "Boreal" "low fertility-stratified ocean" (Baumgartner, 1987a, p. 870).

Three main reasons have been given by Baumgartner (1993, p. 331-332) to support his opinion about the validity of such a detailed palaeolatitudinal model. These were:

1) evidence for the model was from western North American and Mexican sections, which were displaced terranes in the Jurassic, with palaeolatitude and palaeogeography generally unknown; sections from known palaeolatitudes (e.g. European Tethys) have not been studied by Pessagno and his colleages;

2) oceanic boundary currents create oceanographic anomalies which radiolarian thanatocoenoses have been observed to closely resemble (based on studies on Recent material e.g. Casey *et al.* 1979); and

3) "thanatocoenoses of low latitude upwelling areas may contain assemblage components of middle or high latitude bioprovinces" (Baumgartner 1993, p. 332).

In addition, recent discoveries from the Indian Ocean (Baumgartner, 1992, 1993) contradict the model of Pessagno & Blome (1986) as far as the pantanelliids are concerned.

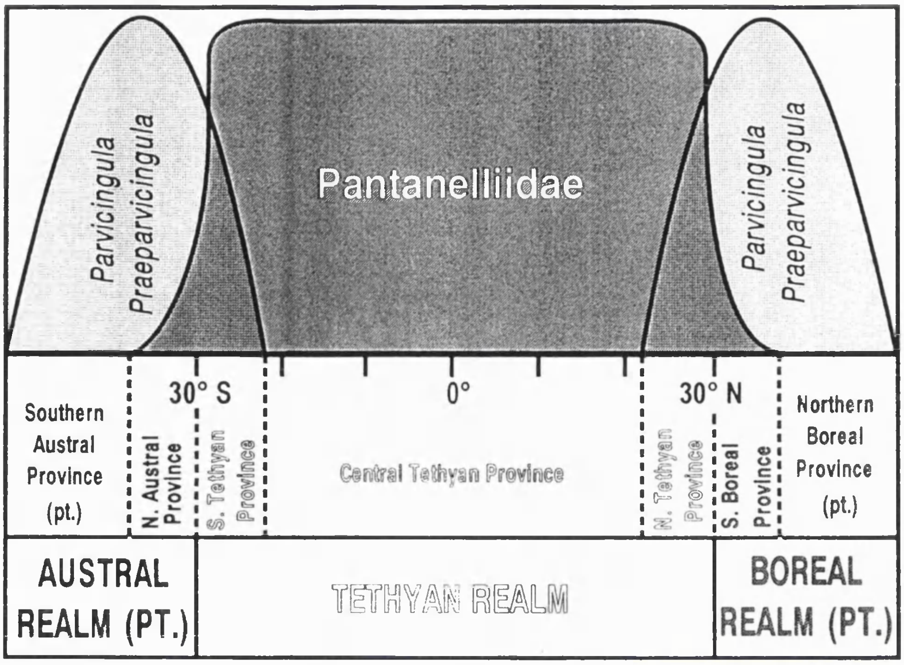


Fig. 10.1 The Jurassic palaeolatitudinal model of Pessagno & Blome (1986) as recently modified by Pessagno *et al.* (1993, Text-Figure 21).

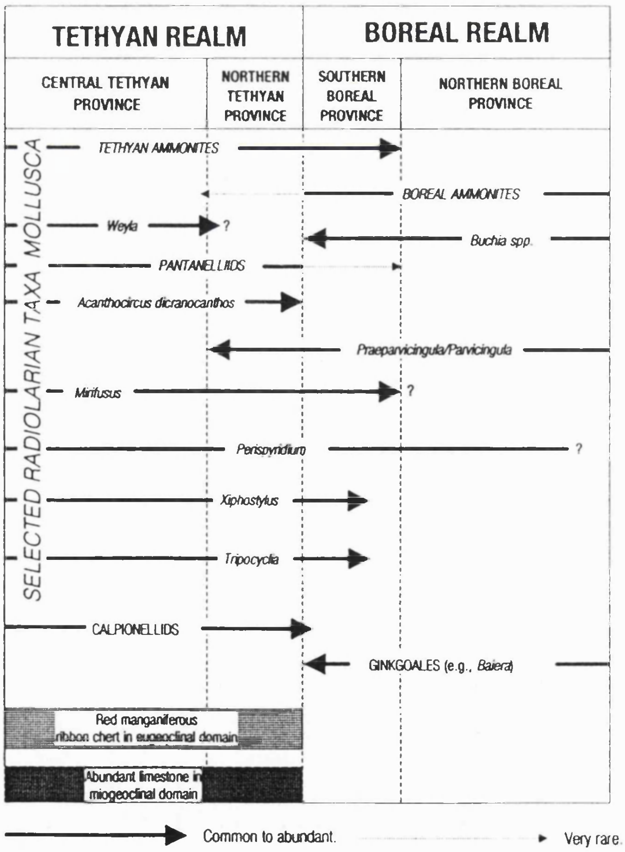


Fig. 10.2 Definition of Tethyan and Boreal Realms (and their Provinces), according to Pessagno *et al.* (1993, Text-Figure 22).

Their abundance and diversity is mainly controlled by surface-water fertility and not by palaeolatitude.

Studies from the Southern Hemisphere have shown that it is possible to define an Austral radiolarian Province but this is not yet clearly recognised (Baumgartner, 1993). The bipolar biogeography, whether symmetrical or not, has been discussed by Holdsworth & Nell (1993) after studying Late Jurassic and Early Cretaceous radiolarian assemblages from Antarctica.

10.2 Radiolaria assemblages recovered in this study

The North Sea radiolarian assemblages, as well as those recovered from the Norwegian and Barents Seas are Northern Boreal in character, *sensu* Pessagno *et al.* (1993) (Fig. 10.1 & 10.2). The assemblages are characterised by the lack of pantanelliids and the presence of parvicinguliids and praeparvicinguliids. *Perispyridium(?)* spp. is also present (in the Middle Jurassic of the North Sea Basin). Typical Tethyan morphotypes such as *Acanthocircus* or *Mirifusus* are absent, although such radiolarian tests might be expected to be absent from the preparations of the North Sea samples (poor preservation could account for this). The Boreal character of ammonites and other invertebrate fossils in the area has been stressed by various workers (e.g. Hallam, 1969, 1971b; Casey, 1971; Casey & Rawson, 1973).

The assemblages recovered include morphotypes of spumellaria such as: *Archaeocenosphaera*(?), *Orbiculiforma*, *Praeconocaryomma*, Spongodiscidae, and rare Actinommidae, Hagiastridae(?), "*Cenodiscus*". Nassellaria include: *Stichocapsa*, *Tricolocapsa*, *Parvicingula*, *Praeparvicingula*, cryptocephalic and cryptothoracic nassellaria morphotypes, and rare *Archaeodictyomitra*, *Spongocapsula*(?), *Hsuum*(?) and others.

As stated in earlier chapters, the main characteristic of the assemblages is their low diversity. Species/morphotypes show a pattern of rapid appearance and disappearance. Such assemblages have also been recovered from Early Cretaceous clays from the Indian Ocean (ODP Legs 123: Sites 765, 766 and DSDP Site 261, Baumgartner 1992, 1993). That author interpreted them as reflecting "an impoverished radiolarian fauna which became probably further decimated by some postmortem dissolution" (Baumgartner 1993, p. 335). The low diversity could well imply an isolated basin (Aarseth *et al.*, 1975 on Recent radiolarian faunas from fjords; Baumgartner, 1992, 1993 discussion). The North Sea Basin was an epicontinental sea during the Late Jurassic, a type of restricted deep-water arm of the sea, which was connected only to an oceanic area in the north (Fig. 10.3) and to Western Tethys in south (Spain, N. Africa).

10. 3 Comparison of the North Sea with the Norwegian Sea radiolarian assemblages

The North Sea Ryazanian radiolarian assemblages have been compared with the equivalent age ones recovered from the Norwegian Sea (well 7B) and reported by Goll (1991). The assemblages are very similar in both areas although, as stated in Chapter 7, the Norwegian Sea ones are far better preserved. The common species/morphotypes are given in Table 10.1. *Tricolocapsa* spp., *Orbiculiforma* spp., *Stichocapsa decorata* (Rüst) and the small sponge spicule form Sterraster sp. 1 were found present in both areas.

-*Stichocapsa decorata* (Rüst)
-*Tricolocapsa* sp. A
-*Tricolocapsa* sp. B
-*Tricolocapsa* sp. C
-*Orbiculiforma lowreyensis* Pessagno
-*Praeconocaryomma* sp. B
-Hagiastridae(?) spp. indet.
-Sterraster sp. 1
-*Orbiculiforma mclaughlini* Pessagno

Table 10.1 Species/morphotypes present in the North Sea Basin and Norwegian Sea.

Archaeodictyomitra spp., *Spongocapsula* spp. and Actinommidae morphotypes are totally absent in the North Sea assemblages for this interval, probably as a result of poor preservation.

10.4 Comparison of the North Sea with the Barents Sea radiolarian assemblages

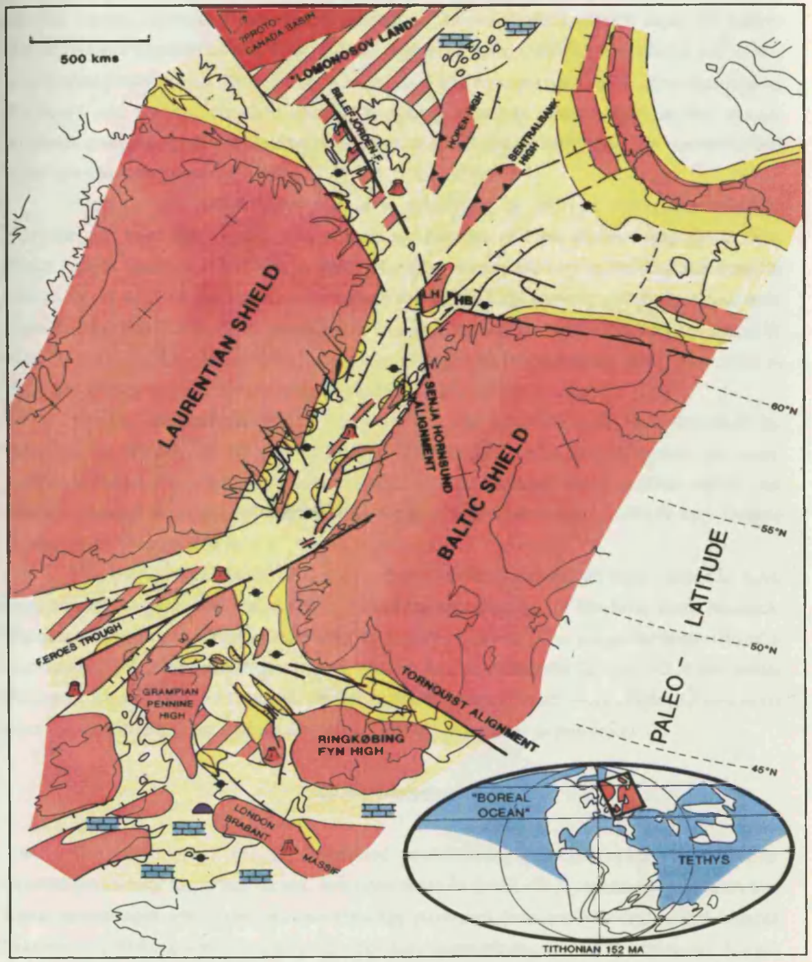
The Berriasian and older (Volgian) assemblages recovered from the Barents Sea are characterised by low diversity and poor preservation and are very similar to the North Sea ones. Table 10.2 gives the species/morphotypes present in both areas.

-*Tricolocapsa* sp. A
-*Tricolocapsa* sp. C
-*Stichocapsa decorata* (Rüst)
-*Orbiculiforma* sp. 7
-Spongodiscidae sp. B
-Hagiastridae group A
-Nassellaria group B
-Spongodiscidae sp. C

Table 10.2 Species/morphotypes present in the North Sea Basin and Barents Sea.

The connection of the North Sea Basin with the Norwegian and Barents Sea (as seen on Fig. 10.3) accounts for the presence of same species/morphotypes in the three main areas.

LATE JURASSIC
OXFORDIAN - VOLGIAN (TITHONIAN)



LEGEND

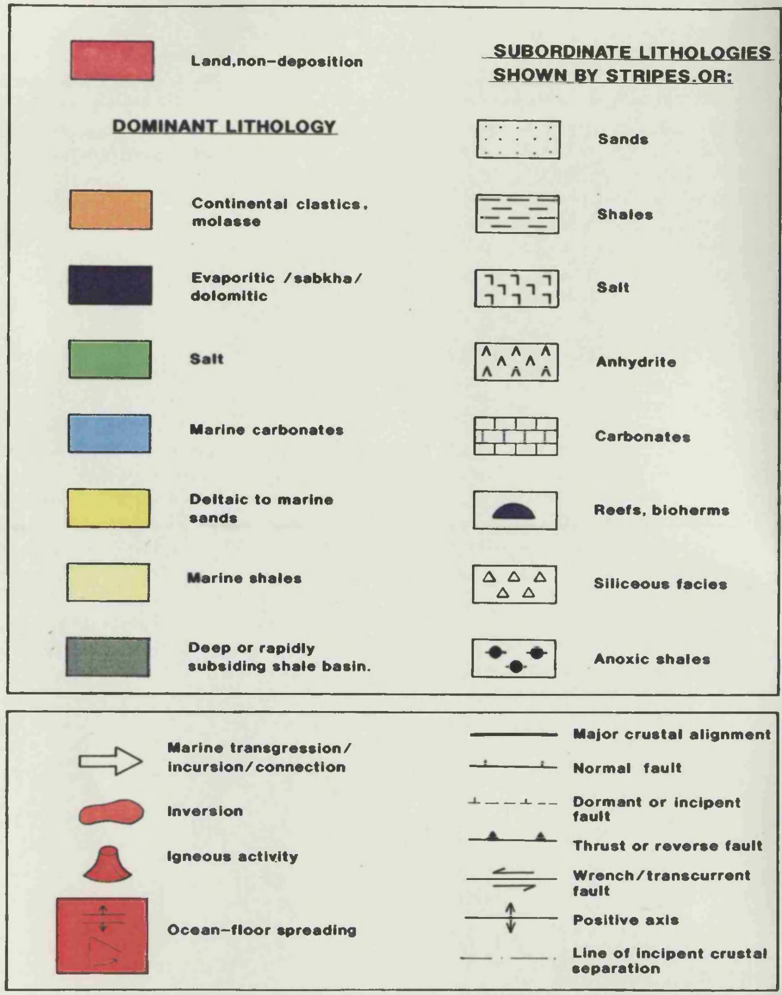


Fig. 10.3 Late Jurassic sedimentary (palaeogeographic) reconstruction for the N. W. Europe and the Arctic (after Dore, 1991; Pl. 15). Abbreviations: HB = Hammerfest Basin, LH = Loppa High.

10.5 Comparison of recovered assemblages with others around the world

A similar radiolarian assemblage to the one recovered from the onshore section (Eathie Haven, Cromarty) has been reported by Kozlova (1971, 1973) from the Lower Kimmeridgian deposits of the Timano-Ural region in Russia. Both assemblages are of the same age (*Amoeboceras (Amoebites) kitchini* Salf and *Rasenia* spp. ammonites reported by Kozlova) and possible common species/morphotypes include (names used in this study): *Archaeocenosphaera*(?) sp. 5, *Praeparvicingula* sp. 7, Hagiastridae(?) type spumellarians and *Parvicingula* type nassellarians.

Various thick-walled *Stichocapsa* morphotypes as well as *Spongocapsula* and *Parvicingula* have been reported from the Late Jurassic of New Zealand (Spörli & Aita, 1988; Aita & Spörli, 1992); these morphotypes show some similarity to the ones recovered in this study. In addition, depressions on the test surface of Late Jurassic and Early Cretaceous nassellarians (on *Stichocapsa, Spongocapsula,* and *Sethocapsa*) as illustrated by Spörli & Aita (1988), Aita & Spörli (1992), Spörli *et al.* (1989), and Baumgartner (1992) also occur in the present study (e.g. *Stichocapsa decorata* (Rüst), Pl. 13, Fig. 7).

Similar morphotypes of *Tricolocapsa* and *Parvicingula* have been described by Baumgartner (1992). As far as morphotypes of the latter genus are concerned, the same author pointed out the similarity with assemblages from offshore Norway (Goll, 1991; and detailed studied here), Boreal localities in Russia (e.g. Vishnevskaya, 1988) and Oregon (Pessagno & Whalen, 1982).

Finally, slightly similar morphotypes of *Parvicingula* and *Praeparvicingula* have been recently examined by Hull (*in press*) from the Late Jurassic of Western North America. The same author concluded that *Parvicingula* and *Praeparvicingula* are useful indicators of a high-latitude situation and possibly cooler water influence during the Jurassic. *O. lowreyensis* Pessagno, *O. mclaughlini* Pessagno and *A. rigida* Pessagno, which were originally described from the California Coast Ranges (Pessagno 1977a), also occur in this study.

10.6 Conclusions

- The description of all recovered radiolarian species/morphotypes, whether biostratigraphically important or not, has been made in detail. Comparison of the North Sea Basin assemblages with those of equivalent age recovered from the Norwegian and Barents Seas show a striking similarity, although the latter assemblages are better preserved. A total of 129 species/morphotypes from 392 samples from 13 wells/exposures has been recorded. These have been briefly compared with others around the world and are somewhat similar to radiolarians recovered from Siberia, New Zealand, Indian Ocean, and Western North America. The state of preservation of the North Sea assemblages did not allow a detailed comparison.

- Employing the best possible technique for extraction from the host lithology (boiling in a solution of Sodium carbonate (Na_2CO_3)) and taking into account the commonly poor preservation of radiolarians, the biostratigraphical value of radiolaria from the Middle Jurassic to Lower Cretaceous has been demonstrated by the recognition of 5 biozones, based on 18 reproducible Unitary Associations correlated to the standard ammonites zones. The biozones are as follows:

Biozone 1: ?early Callovian to mid Kimmeridgian (mid *mutabilis*).
Biozone 2: mid Kimmeridgian to Early Volgian (*scitulus*)
Biozone 3: Early Volgian to Mid Volgian (*glaucolithus*, tentatively).
Biozone 4: Mid Volgian to latest Mid Volgian (*oppressus*, tentatively).
Biozone 5: latest Mid Volgian to Late Ryazanian (mid *stenomphalus*).

- Discussion of the state of preservation of the assemblages is given, including the distribution of pyritised and non-pyritised forms as observed in reflected light. Electron Microprobe analyses performed on the radiolarian tests have revealed that the replacement of silica by minerals such as calcite, pyrite or sphalerite has not totally occurred and only a few radiolaria are found composed exclusively of silica. The elements aluminium, magnesium and potassium were also detected in small amounts by the Electron Microprobe analyses; these were derived from secondary minerals in the sediment.

- The geological setting and the sedimentation patterns of the North Sea Basin have been reviewed. Previous work on radiolaria for the studied interval was given and a database/list has been produced.

10.7 Suggestions for future work

"Boreal" and "non-Tethyan" (southern Hemisphere or "Austral") radiolarian assemblages have not been studied in detail. Only in the last few years has their value for biostratigraphy and palaeogeographical reconstruction been stressed (e.g. Baumgartner, 1992, 1993; Pessagno & his colleagues; Vishnevskaya, 1993). These assemblages offer a great challenge for study and also potential for better understanding and evaluation of Jurassic palaeobiogeography and palaeoceanography. In order to achieve this result more radiolarian-bearing wells/sections will need to be located and studied from the Northern (e.g. Arctic Ocean, Siberia, Alaska) and Southern (e.g. Indian Ocean, New Zealand, Antarctica) Hemispheres.

As far as this study is concerned, more well sites can be studied from the North Sea

Basin and areas such as the Norwegian and Barents Seas, and the radiolarian assemblages described. All these will be valuable for biostratigraphic purposes and the zonation proposed here can be greatly improved, particularly when the studied sections offer core samples and a more detailed ammonite/palynological zonation.

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PLATES

Plates 1-18: scanning electron micrographs.
Plates 19-22: transmitted light micrographs.
Each illustration includes the following:
i) catalogue number e.g. CK 1 = catalogue number of specimens deposited in the Postgraduate Unit of Micropalaeontology, University College London. Full locality/depth details for each figured specimen are given in Appendix 2;
ii) corresponding code number for Unitary Association(s) e.g. UA 16-18;
iii) age assignment of sample from which the specimen was recovered;
iv) location of well/section;
v) state of preservation; and
vi) length of scale bar on right = number of µm cited for each illustration (sc.).
Whenever possible well-preserved specimens (usually from the Norwegian Sea) are figured with less well-preserved material (usually from the North Sea).

PLATE 1

PLATE 1

1-2. *Acaeniotyle*(?) sp. 1
1: CK 1, UA 16-18; Ryazanian, Norwegian Sea, non-pyritised, sc. 89.
2: detail of test surface of CK 1, sc. 62.

3-7. *Archaecenosphaera*(?) sp. 1
3: CK 6, UA 16-17; uppermost Middle Volgian, North Sea, non-pyritised, sc. 48.
4: CK 4, UA 16-17; Upper Jurassic/Lower Cretaceous, North Sea, pyritised, sc. 56.
5, 6: CK 13, UA 8-11; lowermost Middle Volgian, North Sea, non-pyritised, stereopair, sc. 62.
7: CK 12, UA 4-17; Lower Volgian, North Sea, non-pyritised, sc. 80.

8. *Archaeocenosphaera*(?) sp. 2
8: CK 21, UA 16; Ryazanian, Norwegian Sea, non-pyritised, sc. 80.

9, 12. *Archaeocenosphaera*(?) sp. 3
9: CK 24, UA 1-2; Lower Oxfordian, North Sea, pyritised, sc. 74.
12: CK 23, UA 1-2; Lower Oxfordian, North Sea, pyritised, sc. 65.

10, 13-15. *Archaeocenosphaera*(?) sp. 5
10: CK 35, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 133.
13, 14: CK 26, UA 4; upper Kimmeridgian/Lower Volgian, North Sea, non-pyritised, stereopair, sc. 121.
15: detail of pore frames of CK 26, sc. 57.

11. *Archaeocenosphaera*(?) sp. 4
11: CK 25, UA 4-12; Lower Volgian, North Sea, non-pyritised, sc. 182.

PLATE 1

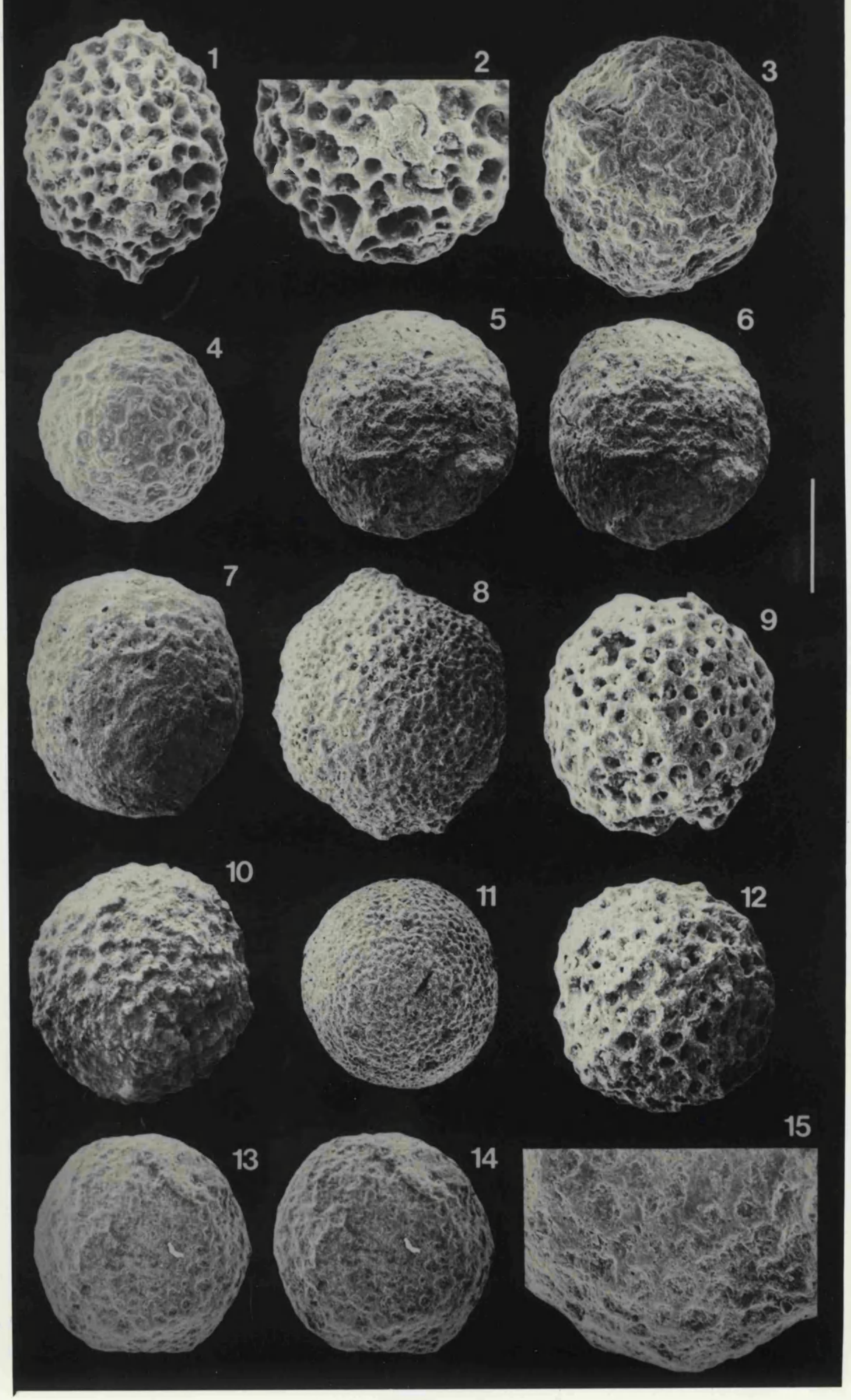

PLATE 2

PLATE 2

1. *Archaeocenosphaera*(?) sp. 5
   1: CK 33, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, view of cross section, sc. 116.

2, 3. *Archaeocenosphaera*(?) sp. 6
   2: CK 37, UA 11; Lower Volgian, North Sea, non-pyritised, sc. 133.
   3: detail of pore frames of CK 37, sc. 74.

4. *Archaeocenosphaera*(?) sp. indet.
   4: CK 551, UA not defined; Middle/Upper Volgian, North Sea, non-pyritised, sc. 81.

5-6, 9. "*Cenodiscus*" sp. A
   5, 6: CK 39, UA 12; Middle Volgian, North Sea, pyritised, stereopair, sc. 138.
   9: CK 40, UA 10-12; Middle Volgian, North Sea, pyritised, oblique view, sc. 167.

7, 10. "*Cenodiscus*" sp. C
   7: CK 42, UA not defined; Middle Volgian, North Sea, non-pyritised, sc. 63.
   10: detail of test surface of CK 42, sc. 25.

8. "*Cenodiscus*" sp. B
   8: CK 41, UA 11; Middle Volgian, North Sea, pyritised, lateral view, sc. 102.

11. "*Cenodiscus*"(?) cf. "*Cenodiscus*" *alievi* Pessagno
   11: CK 43, UA 16-17; Upper Jurassic/Lower Cretaceous, North Sea, non-pyritised, sc. 83.

12, 15. *Hexastylus*(?) sp. 1
   12: CK 72, UA 16; Ryazanian, Norwegian Sea, non-pyritised, sc. 74.
   15: detail of spine of CK 72, sc. 29.

13, 14. *Orbiculiforma mclaughlini* Pessagno
   13: CK 75, UA 16-18; Ryazanian, Norwegian Sea, non-pyritised, oblique view, sc.87.
   14: CK 73, UA 16-17; Upper Volgian/Upper Ryazanian, North Sea, pyritised, oblique view, sc. 87.

PLATE 2

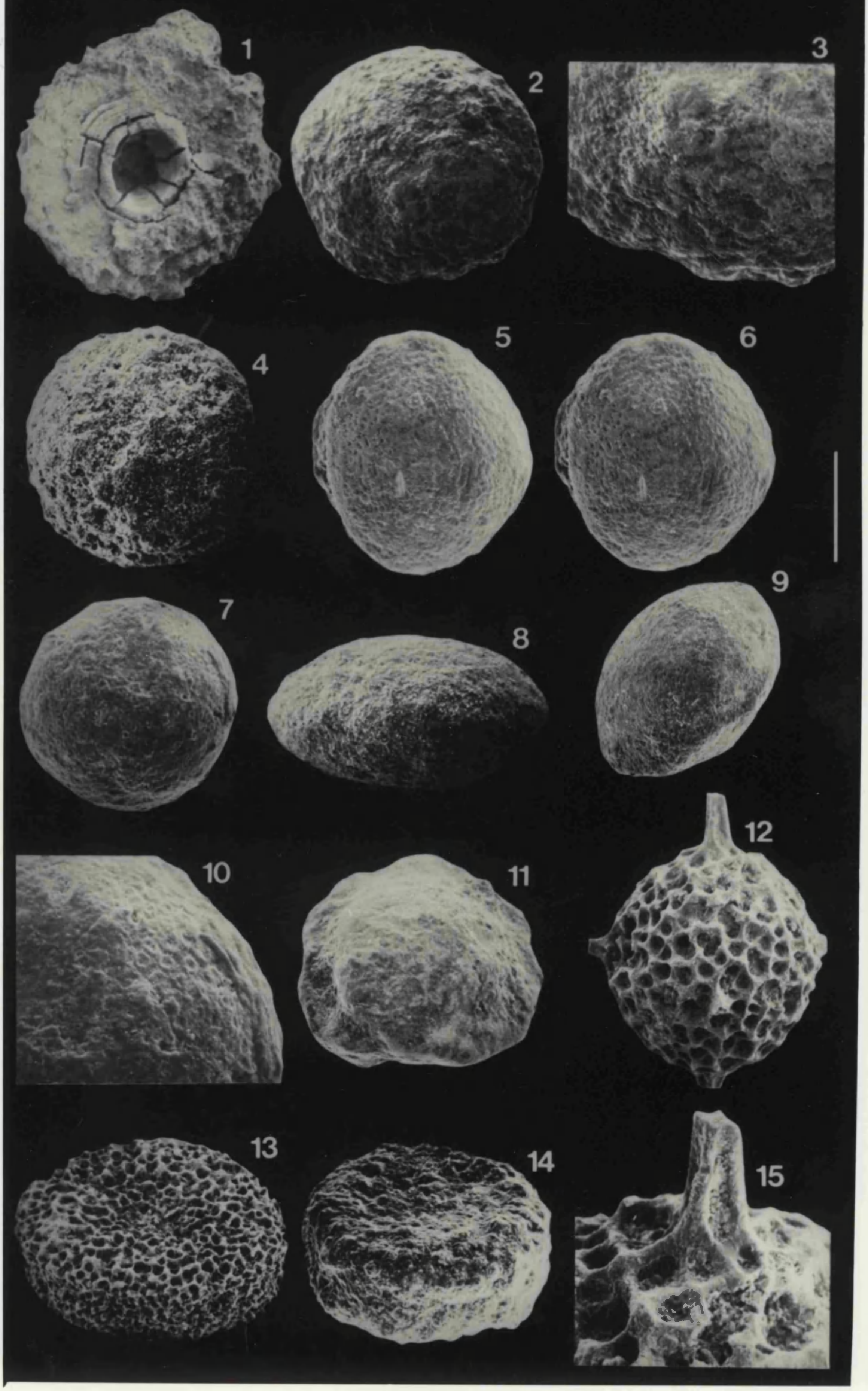

PLATE 3

PLATE 3

1, 2. *Orbiculiforma mclaughlini* Pessagno
1: lateral view of CK 73, sc. 74.
2: lateral view of CK 75, sc. 95.

3, 6. *Orbiculiforma lowreyensis* Pessagno
3: CK 78, UA 16-17; Ryazanian, Norwegian Sea, non-pyritised, sc. 83.
6: CK 77, UA 16-17; Upper Jurassic/Lower Cretaceous, North Sea, pyritised, sc. 85.

4, 7-10, 12. *Orbiculiforma* sp. 2
4: CK 86, UA 1: upper Callovian/Lower Oxfordian, North Sea, pyritised, oblique view, sc. 69.
7: CK 85, UA 1; middle Callovian, North Sea, pyritised, sc. 73.
8: CK 83, UA 2; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 89.
9: CK 84, UA 2; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 89.
10: detail of test surface of CK 85, sc. 40.
12: detail view of periphery and spine of CK 84, sc. 43.

5. *Orbiculiforma* sp. 1
5: CK 80, UA 16-17; Upper Ryazanian/Lower Valanginian, North Sea, non-pyritised, sc. 147.

11, 13-15. *Orbiculiforma* sp. 3.
11: CK 92, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 91.
13: CK 100, UA 11; Middle Volgian, North Sea, non-pyritised, sc. 143.
14: detail of pore frames of CK 92, sc. 40.
15: CK 87, UA 2-10; Lower Oxfordian, North Sea, non-pyritised, detail of periphery, sc. 50.

PLATE 3

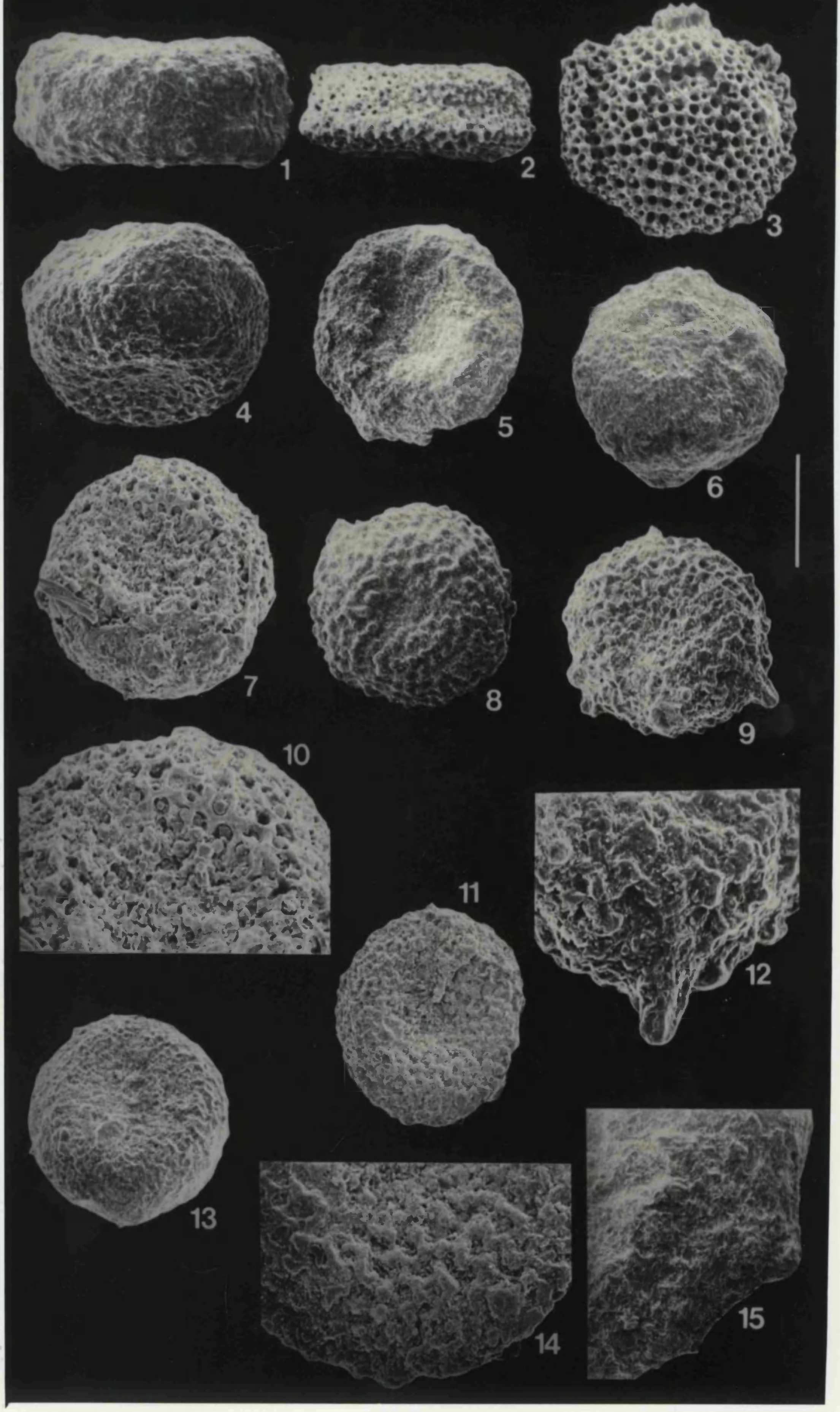

PLATE 4

PLATE 4

1-3. *Orbiculiforma* sp. 4

1: CK 108, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 110.
2: CK 552, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 90.
3: CK 107, UA 1-2; Lower Oxfordian, North Sea, non-pyritised, sc. 100.

4. *Orbiculiforma* sp. 5

4: CK 110, UA 11; Lower Volgian, North Sea, pyritised, sc. 95.

5-6, 8-9. *Orbiculiforma* sp. 6

5: CK 117, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 93.
6: CK 115, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 125.
8: CK 116, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 69.
9: detail of periphery of CK 116, sc. 35.

7, 10-11. *Orbiculiforma* sp. 7

7: CK 120, UA 15; Upper Volgian, North Sea, non-pyritised, sc. 154.
10: detail of periphery and central cavity of CK 120, sc. 59.
11: lateral view of CK 120, sc. 133.

12. *Orbiculiforma* sp. indet.

12: CK 553, UA 13; Volgian, Barents Sea, pyritised, sc. 108.

13. *Porodiscus*(?) sp. 1

13: CK 215, UA 16; Ryazanian, Norwegian Sea, non-pyritised, sc. 78.

14-16. *Praeconocaryomma hexagona* (Rüst)

14: CK 129, UA 10-12; Middle Volgian, North Sea, pyritised, sc. 85.
15: CK 127, UA 12; Middle Volgian, North Sea, pyritised, sc. 115.
16: detail of mammae of CK 129, sc. 40.

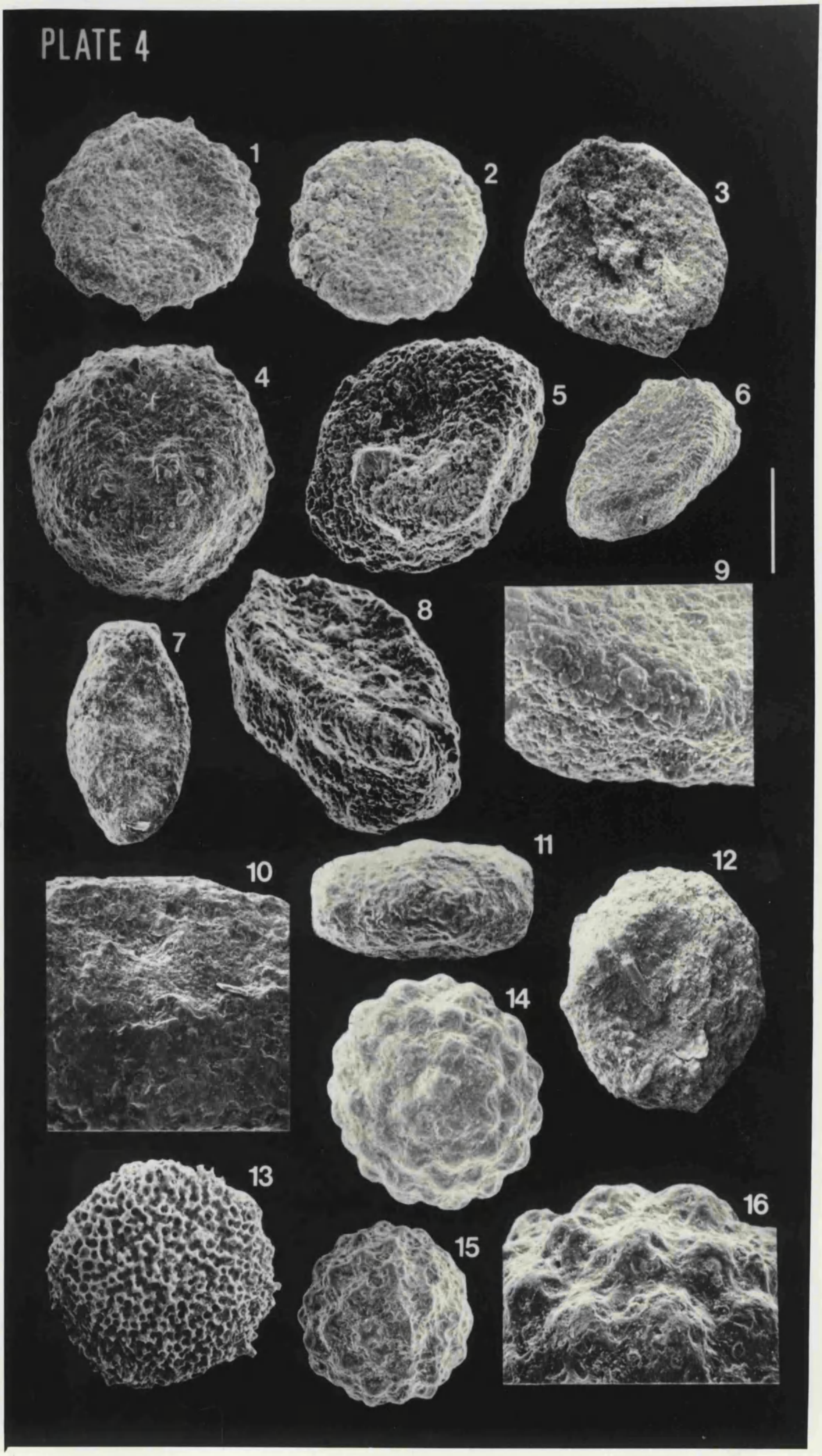
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PLATE 5

PLATE 5

1. *Praeconocaryomma* sp. A
   1: CK 152, UA 16-17; Middle/Upper Volgian, North Sea, pyritised, sc. 89.

2. *Praeconocaryomma* sp. B
   2: CK 160, UA 16-17; Ryazanian, Norwegian Sea, non-pyritised, sc. 91.

3, 5-6. *Praeconocaryomma* sp. C
   3: CK 161, UA 1-2; Lower Oxfordian, North Sea, pyritised, sc. 73.
   5: CK 162, UA 1-2; Lower Oxfordian, North Sea, pyritised, sc. 91.
   6: detail of mammae of CK 162, sc. 47.

4. *Praeconocaryomma* sp. D
   4: CK 163, UA 16; Ryazanian, Norwegian Sea, non-pyritised, sc. 79.

7-8. *Praeconocaryomma*(?) sp. E
   7: CK 164, UA 12; Middle Volgian, North Sea, pyritised, sc. 116.
   8: CK 165, UA 12; Middle Volgian, North Sea, pyritised, sc. 85.

9, 11-12. *Praeconocaryomma* sp. indet.
   9: CK 554, UA 16; Ryazanian, Norwegian Sea, non-pyritised, cross section with medullary shell, sc. 82.
   11: CK 556, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 85.
   12: CK 555, UA 13; Volgian, Barents Sea, pyritised, sc. 105.

10, 13-14. "*Staurosphaera*" sp. 1
   10: CK 203, UA 16; Ryazanian, Norwegian Sea, non-pyritised, sc. 106.
   13: detail of spine of CK 203, sc. 13.
   14: CK 206, UA 13; Volgian, Barents Sea, pyritised, sc. 79.

15. Hagiastridae(?) group 1
   15: CK 44, UA 4-6; Lower Volgian, North Sea, non-pyritised, sc. 174.

PLATE 5

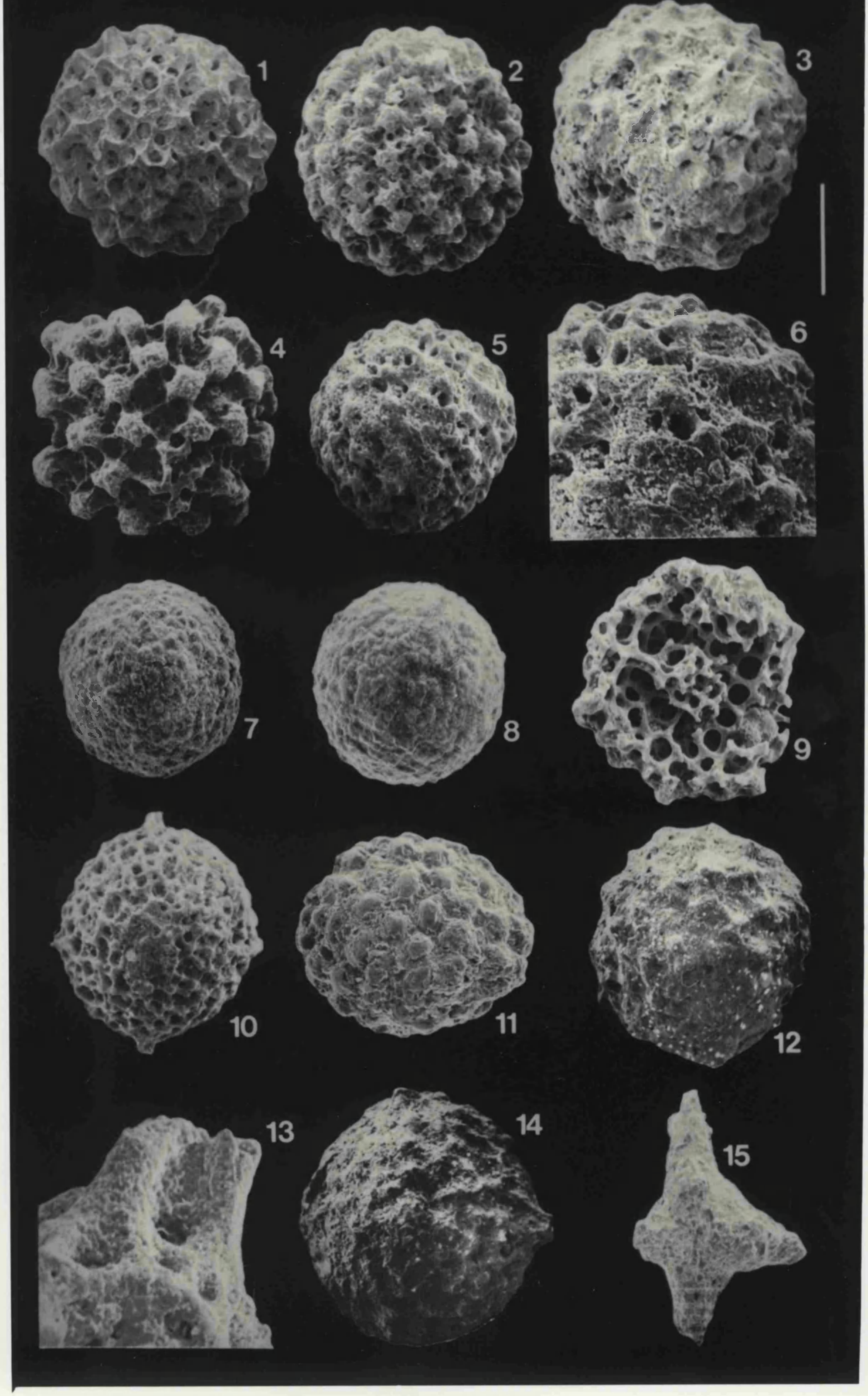

PLATE 6

PLATE 6

1-2. Hagiastridae(?) group 1
1: CK 47, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 100.
2: CK 45, UA 1; middle Callovian, North Sea, pyritised, sc. 73.

3-4, 7. Hagiastridae(?) group 2
3, 4: CK 53, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, stereopair, sc. 100.
7: CK 54, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, oblique view, sc. 182.

5. Hagiastridae(?) group 4
5: CK 59, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 211.

6. Hagiastridae(?) group 3
6: CK 58, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 93.

8-10. Hagiastridae(?) group 5
8: CK 60, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 100.
9: CK 61, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 100.
10: CK 62, UA 8; Middle Volgian, North Sea, non-pyritised, sc. 107.

11-12. Hagiastriadae(?) spp. indet.
11: CK 69, UA 16; Ryazanian, Norwegian Sea, non-pyritised, sc. 104.
12: CK 65, UA 16-17; Upper Jurassic/Lower Cretaceous, North Sea, non-pyritised, sc. 135.

13-14, 17-18. Spongodiscidae sp. A
13: CK 171, UA 11; Lower Volgian, North Sea, non-pyritised, sc. 70.
14: CK 169, UA 11; Lower Volgian, North Sea, non-pyritised, lateral view, sc. 71.
17: CK 174, UA 11; Lower Volgian, North Sea, non-pyritised, lateral view, sc. 88.
18: CK 173, UA 9; Middle Volgian, North Sea, non-pyritised, sc. 113.

15-16. Spongodiscidae sp. B
15: CK 179, UA 13; Volgian, Barents Sea, pyritised, lateral view, sc. 73.
16: CK 180, UA 11; lowermost Middle Volgian, North Sea, non-pyritised, lateral view, sc. 74.

PLATE 6

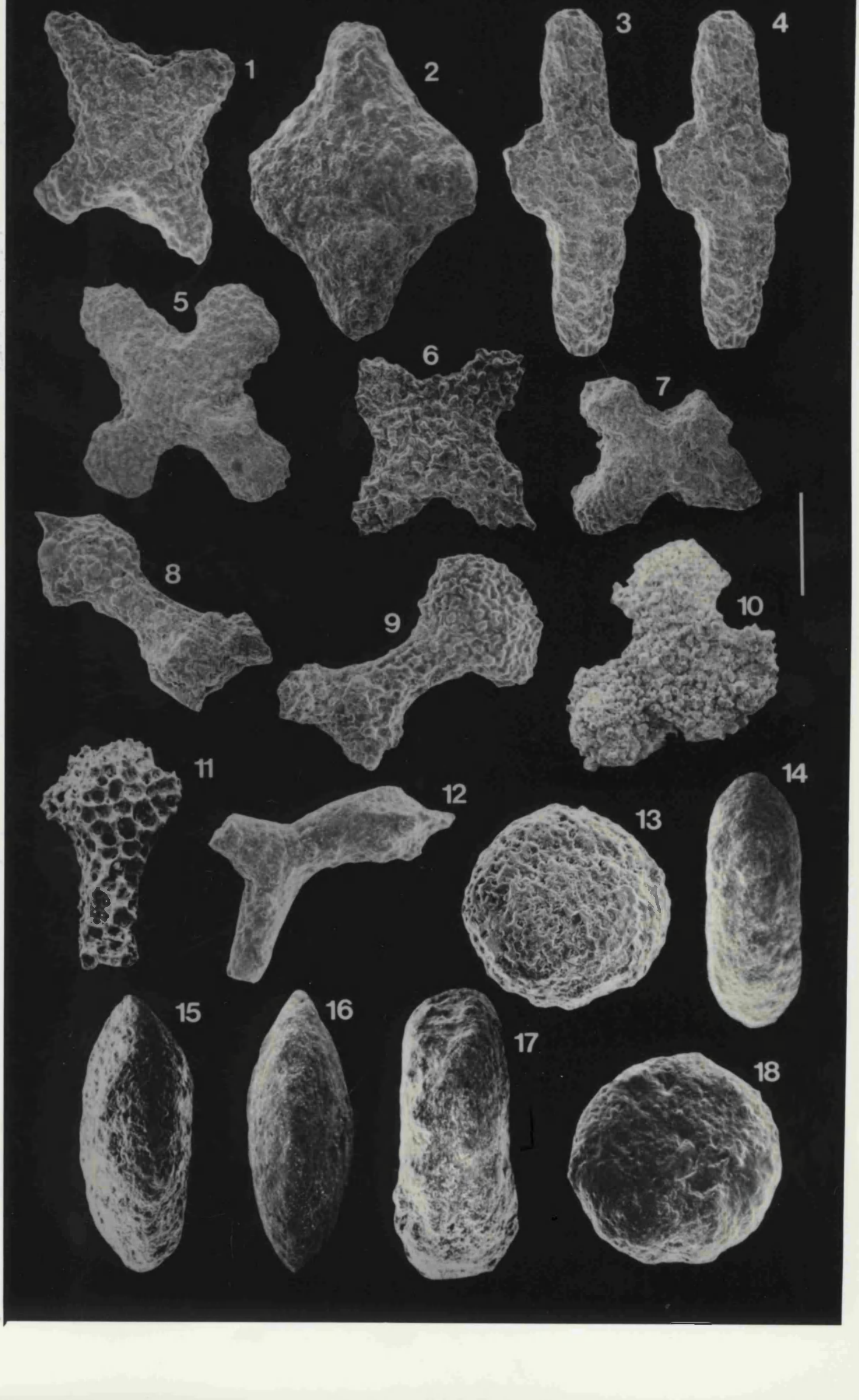

PLATE 7

PLATE 7

1-3. Spongodiscidae sp. B
1, 2: CK 190, UA 4-17; upper Kimmeridgian, North Sea, non-pyritised, stereopair, sc. 80.
3: CK 184, UA 11; Lower Volgian, North Sea, non-pyritised, lateral view, sc. 80.

4. Spongodiscidae sp. D
4: CK 201, UA 11; lowermost Middle Volgian, North Sea, non-pyritised, sc. 127.

5-6, 8-9. Spongodiscidae sp. C
5, 6: CK 192, reworked in Lower Oxfordian, North Sea, non-pyritised, stereopair, sc. 111.
8: CK 198, UA 11; lowermost Middle Volgian, North Sea, non-pyritised, lateral view, sc. 100.
9: CK 194, UA 11; Middle Volgian, North Sea, pyritised, sc. 160.

7. Spongodiscidae sp. indet.
7: CK 183, UA 4-12; Lower Volgian, North Sea, non-pyritised, oblique view, sc. 80.

10. Spumellaria gen. et sp. indet. A
10: CK 209, UA 11; lowermost Middle Volgian, North Sea, non-pyritised, sc. 83.

11. Spumellaria gen. et sp. indet.
11: CK 557, UA 16-17; Ryazanian, Norwegian Sea, non-pyritised, sc. 65.

12, 16. Spumellaria gen. et sp. indet. B
12: CK 210, UA 18; Ryazanian, North Sea, non-pyritised, oblique view, sc. 57.
16: view of other side of CK 210, sc. 65.

13-15. Spumellaria gen. et sp. indet. D
13, 14: CK 502, UA 4-7; Kimmeridgian/Lower Volgian, North Sea, non-pyritised, stereopair, sc. 125.
15: detail of test surface of CK 502, sc. 73.

PLATE 7

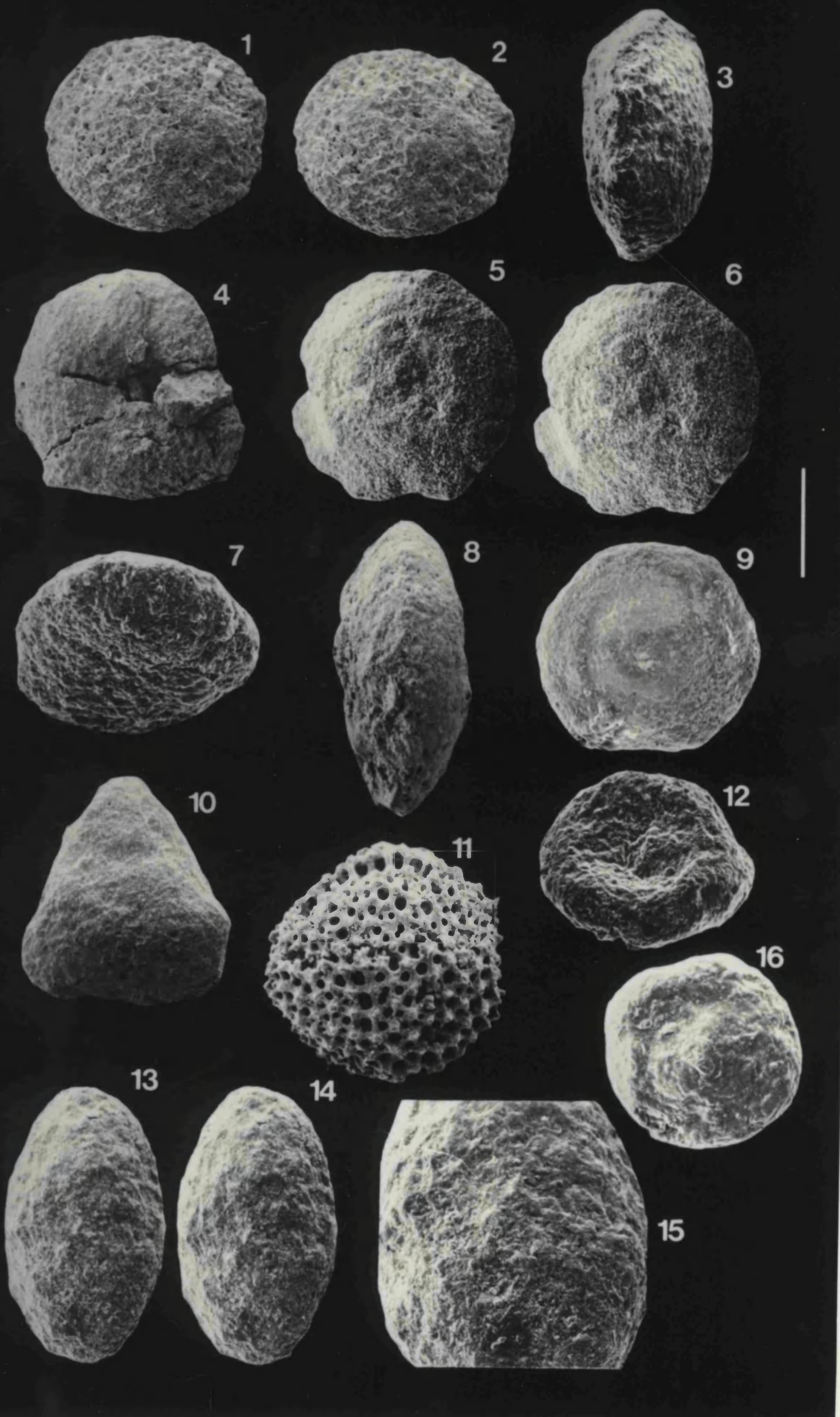

PLATE 8

PLATE 8

1. *Archaeodictyomitra rigida* Pessagno
   1: CK 217, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 67.

2. *Archaeodictyomitra* sp. A
   2: CK219, UA 1-2; lower Callovian, North Sea, pyritised, sc. 84.

3, 4. *Archaeodictyomitra* sp. 1
   3: CK 220, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 100.
   4: detail of distal part and aperture of CK 220, sc. 45.

5, 6. *Archaeodictyomitra* sp. 3
   5: detail of apical part of CK 224, sc. 36.
   6: CK 224, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 93.

7, 8. *Archaeodictyomitra* sp. 2
   7: CK 223, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 89.
   8: detail of distal part and aperture of CK 223, sc. 48.

9. *Archaeodictyomitra* sp. indet.
   9: CK 558, UA 1-2; lower Callovian, North Sea, pyritised, sc. 84.

10. *Archaeodictyomitra* sp. 5
   10: CK 222, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 77

11-12. *Archaeodictyomitra* sp. 4
   11: CK 225, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 65.
   12: detail of distal part and aperture of CK 225, sc. 44.

13-14. *Canutus*(?) sp. 1
   13: detail of apical part of CK 227, sc. 27.
   14: CK 227, UA 1; middle Callovian, North Sea, pyritised, sc. 50.

15. *Broctus*(?) sp. 1
   15: CK 226, UA 1-2; Lower Oxfordian, North Sea, pyritised, sc. 89.

16, 19. *Cryptamphorella*(?) sp. 1
   16: CK 231, UA 13; Volgian, Barents Sea, pyritised, sc. 62.
   19: different view of CK 231, sc. 59.

17, 18. *Cryptamphorella*(?) sp. 2
   17: CK 233, UA 16-17; uppermost Middle Volgian, North Sea, non-pyritised, sc. 93.
   18: CK 232, UA 16-17; uppermost Middle Volgian, North Sea, non-pyritised, sc. 87.

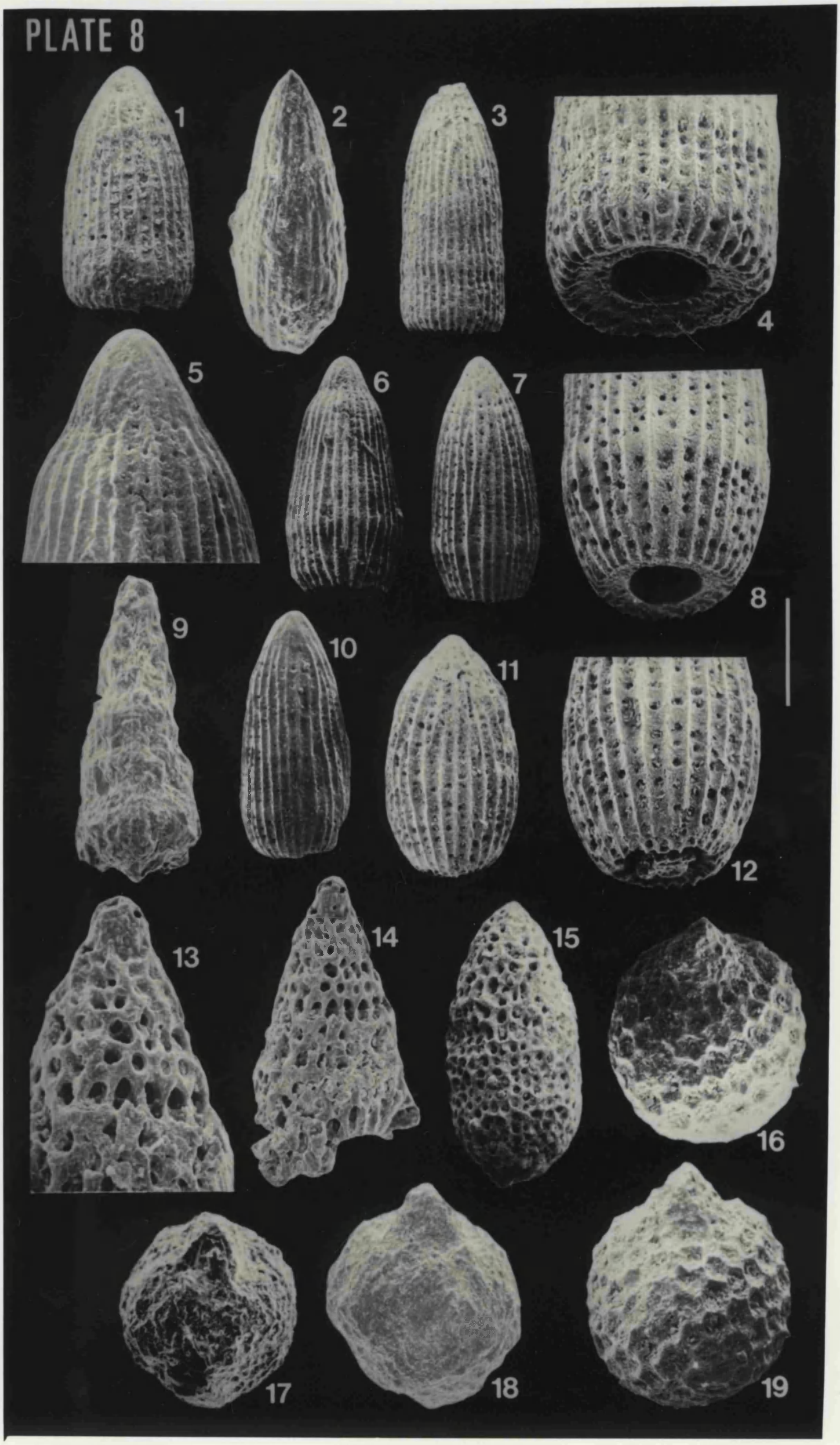
PLATE 8
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PLATE 9

PLATE 9

1-3, 5-6. *Hsuum*(?) sp. A
- 1: CK 237, UA 1; upper Callovian/Lower Oxfordian, North Sea, pyritised, sc. 105.
- 2: CK 234, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 105.
- 3: CK 238, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 74.
- 5: detail of test surface of CK 237, sc. 50.
- 6: detail of apical part of CK 237, sc. 40.

4, 7. *Hsuum*(?) sp. B
- 4: CK 239, UA 2-5; middle Kimmeridgian (*mutabilis* zone), North Sea, pyritised, sc. 93.
- 7: detail of apical part of CK 239, sc. 44.

8. *Hsuum*(?) sp. indet.
- 8: CK 559, UA 2-5; middle Kimmeridgian (*mutabilis* zone), North Sea, pyritised, sc. 100.

9. *Milax*(?) sp. 1
- 9: CK 240, UA 1; middle Callovian, North Sea, pyritised, sc. 56.

10-11. *Milax*(?) sp. 2
- 10: CK 241, UA 1; middle Callovian, North Sea, pyritised, sc. 83.
- 11: CK 244, UA 1; upper Callovian, North Sea, pyritised, sc. 87.

12. *Milax*(?) sp. indet.
- 12: CK 245, UA 1; middle Callovian, North Sea, pyritised, sc. 85.

13. *Parvicingula*(?) cf. *P. jonesi* Pessagno
- 13: CK 246, UA 16-17; Ryazanian, North Sea, pyritised, sc. 115.

14, 17. *Parvicingula* sp. 1
- 14: CK 248, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 77.
- 17: CK 250, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, detail of apical part, sc. 40.

15-16. *Parvicingula* sp. 2
- 15: detail of distal part of CK 252, sc. 53.
- 16: CK 252, UA not defined; Lower Oxfordian, North Sea, non-pyritised, sc. 117.

PLATE 9

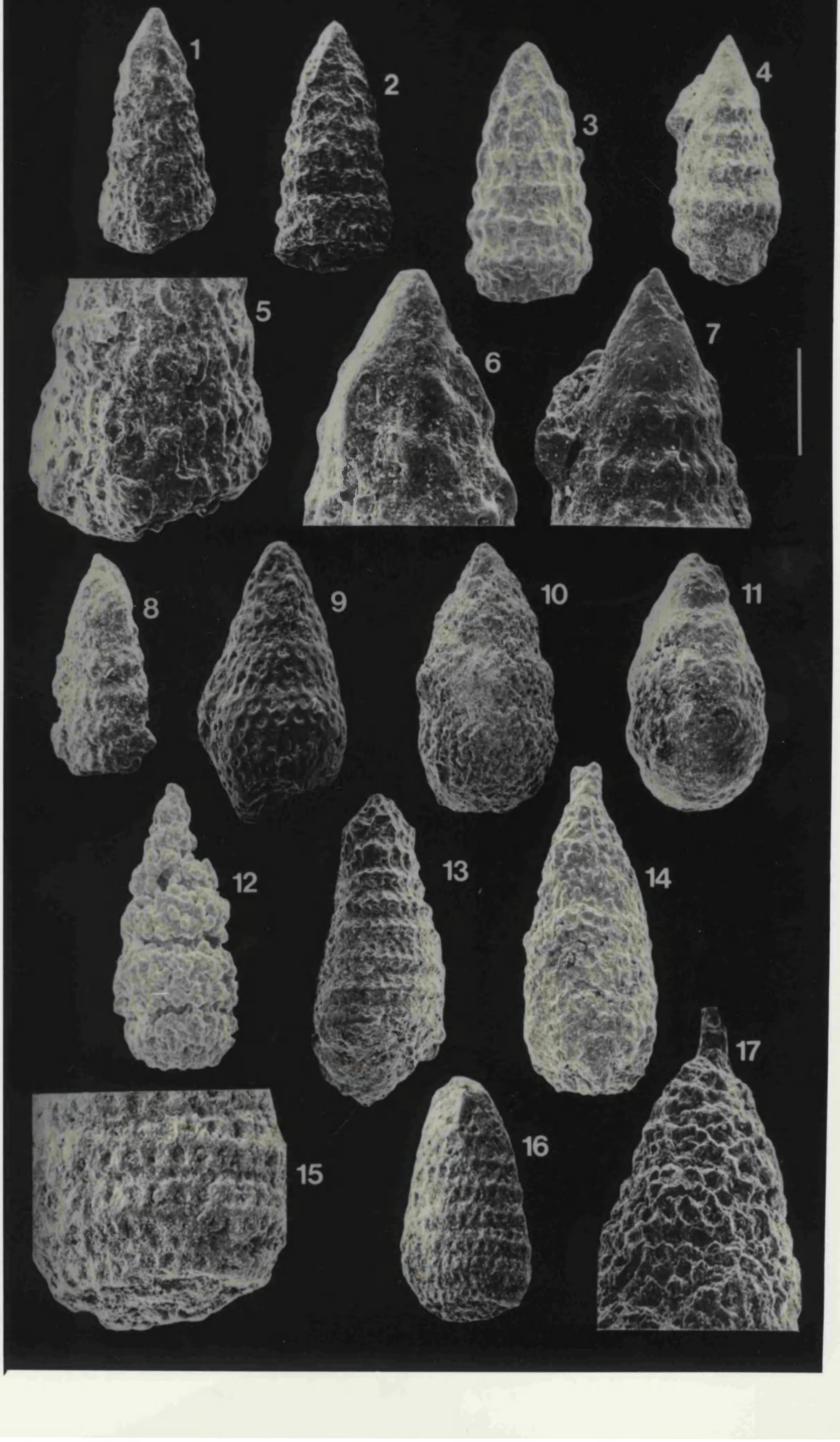

PLATE 10

PLATE 10

1. *Parvicingula*(?) sp. 3
1: CK 255, UA 2-5; middle Kimmeridgian (*mutabilis* zone), North Sea, pyritised, sc. 100.

2-4. *Parvicingula*(?) sp. 4
2: CK 256, UA not defined; Volgian, Barents Sea, pyritised, sc. 105.
3: detail of apical part of CK 256, sc. 51.
4: CK 560, UA not defined; Volgian, Barents Sea, pyritised, sc. 83.

5-6. *Parvicingula*(?) sp. 5
5: detail of apical part of CK 257, sc. 53.
6: CK 257, UA not defined; Volgian, Barents Sea, pyritised, sc. 106.

7-8. *Parvicingula*(?) sp. 6
7: CK 258, UA 16-17; Ryazanian, North Sea, pyritised, sc. 108.
8: CK 259, UA 15; Upper Volgian, North Sea, pyritised, sc. 91.

9-15. *Perispyridium*(?) sp. indet. •
9, 10: CK 275, UA 1; middle Callovian, North Sea, pyritised, stereopair, sc. 48.
11: CK 268, UA 1; middle Callovian, North Sea, pyritised, sc. 70.
12: CK 265, UA 1-2; lower Callovian, North Sea, pyritised, sc. 73.
13: CK 267, UA 1-2; middle Callovian, North Sea, pyritised, sc. 74.
14: CK 263, UA 1; middle Callovian, North Sea, pyritised, sc. 60.
15: CK 261, UA 1-2; Lower Oxfordian, North Sea, pyritised, sc. 97.

16-18. *Praeparvicingula* sp. 1
16: CK 284, UA 16-17; Ryazanian, North Sea, pyritised, sc. 147.
17: CK 280, UA 14; Upper Volgian, North Sea, pyritised, sc. 114.
18: CK 289, UA 16-17; Ryazanian, North Sea, pyritised, sc. 133.

• See footnote on p. 195 for correction of identification.

PLATE 10

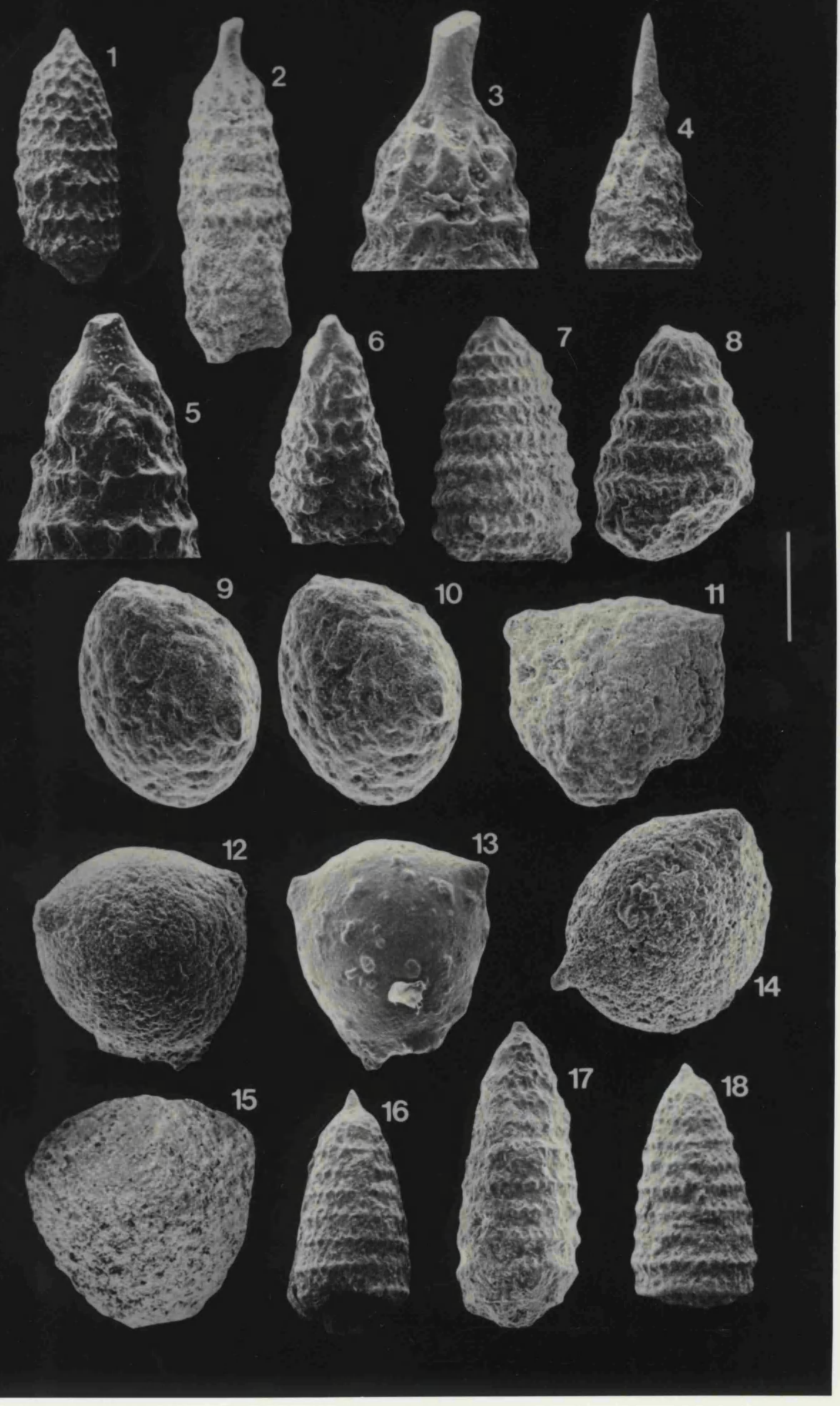

PLATE 11

PLATE 11

1-3. *Praeparvicingula* sp. 1

1: CK 288, UA 16-17; Ryazanian, North Sea, pyritised, sc. 135.
2: CK 286, UA 16-17; Ryazanian, North Sea, pyritised, detail of apical part, sc. 54.
3: detail of distal part of CK 289, sc. 59.

4-6. *Praeparvicingula* sp. 2

4: CK 291, UA 10-11; Middle Volgian, North Sea, pyritised, sc. 82.
5: CK 294, UA 11; Middle Volgian, North Sea, pyritised, sc. 82.
6: CK 296, UA 11; Middle Volgian, North Sea, pyritised, sc. 80.

7-10. *Praeparvicingula* sp. 3

7: CK 309, UA 5; middle Kimmeridgian (*mutabilis* zone), non-pyritised, sc. 100.
8: CK 310, UA 3; middle Kimmeridgian (*mutabilis* zone), non-pyritised, detail of pore frames, sc. 57.
9: CK 312, UA 3; middle Kimmeridgian (*mutabilis* zone), non-pyritised, sc. 89.
10: CK 561, UA 5; middle Kimmeridgian (*mutabilis* zone), non-pyritised, detail of distal part of test, sc. 57.

11-13. *Praeparvicingula* sp. 4

11: CK 316, UA 11; Middle Volgian, North Sea, pyritised, detail of distal part and aperture, sc. 40.
12: CK 317, UA 11; ?Lower Volgian, North Sea, non-pyritised, sc. 74.
13: CK 313, UA 11; Middle Volgian, North Sea, pyritised, oblique apical view, sc. 71.

14. *Praeparvicingula* sp. 5

14: CK 320, UA 5; middle Kimmeridgian (*mutabilis* zone), non-pyritised, sc. 73.

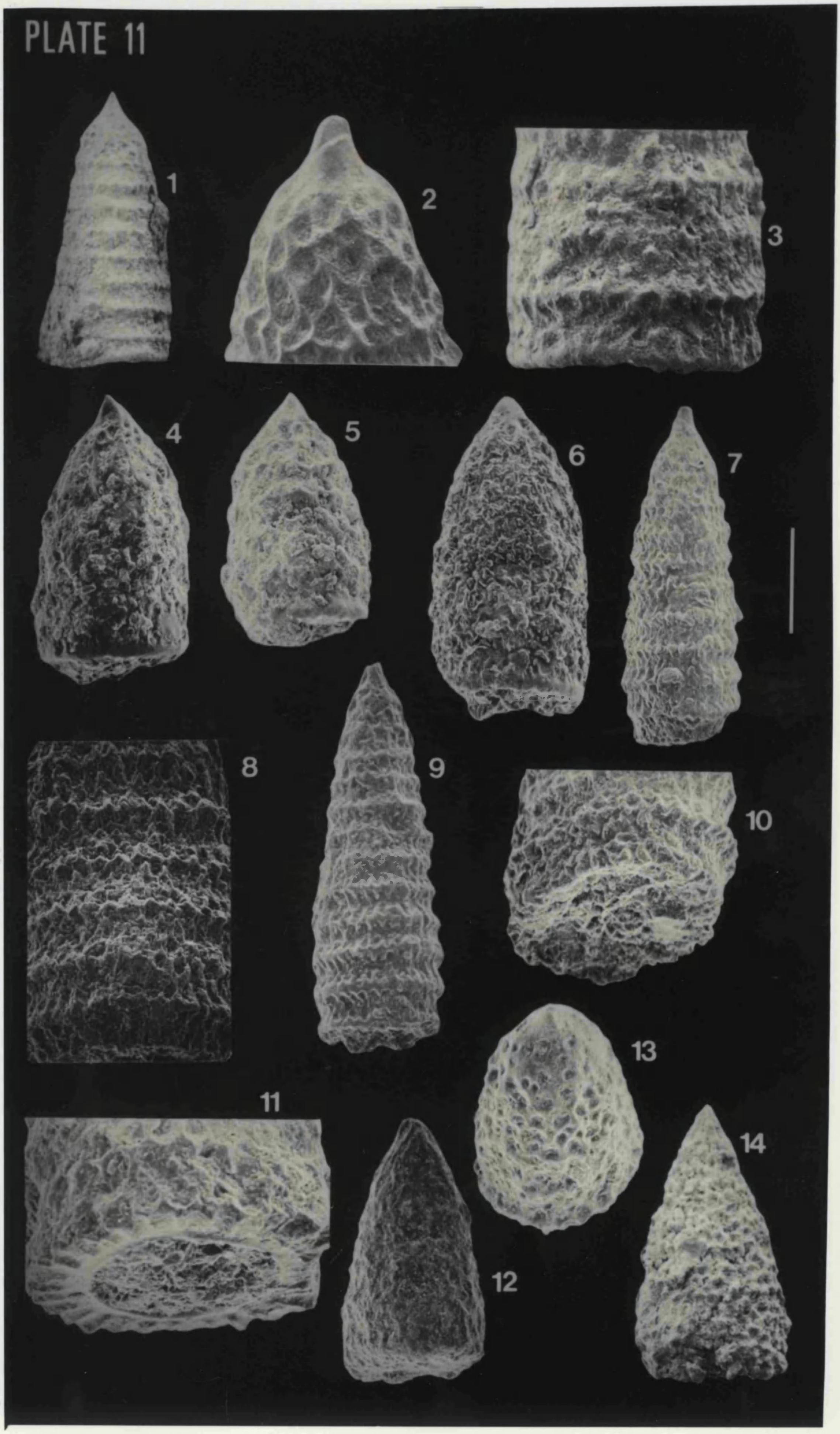
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PLATE 12

PLATE 12

1. *Praeparvicingula* sp. 5
   1: CK 318, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 56.

2-5. *Praeparvicingula* sp. 6
   2: CK 324, UA 13; Volgian, Barents Sea, pyritised, sc. 115.
   3: CK 323, UA 13; Volgian, Barents Sea, pyritised, sc. 82.
   4: detail of apical part of CK 324, sc. 53.
   5: detail of distal part of CK 324, sc. 65.

6-7. *Praeparvicingula* sp. 7
   6: CK 325, UA 3; middle Kimmeridgian (*mutabilis* zone), non-pyritised, sc. 90.
   7: CK 327, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 80.

8-9. *Praeparvicingula*(?) sp. A
   8: CK 328, UA 2-5; middle Kimmeridgian (*mutabilis* zone), North Sea, pyritised, sc. 100.
   9: detail of apical part of CK 328, sc. 65.

10-13. *Praeparvicingula*(?) sp. B
   10: CK 330, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 105.
   11: CK 331, UA 16; Ryazanian, Norwegian Sea, non-pyritised, sc. 57.
   12: CK 334, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 106.
   13: CK 333, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 78.

14-15. *Praeparvicingula*(?) sp. C
   14: CK 336, UA not defined; Middle Volgian, North Sea, pyritised, sc.73.
   15: CK 337, UA not defined; Middle Volgian, North Sea, detail of apical part of test, pyritised, sc. 45.

16. *Praeparvicingula*(?) spp. indet.
   16: CK 562, UA 11; Lower/Middle Volgian, North Sea, pyritised, sc. 83.

17-20. *Spongocapsula*(?) sp. 1
   17: CK 342, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 91.
   18: detail of distal part and aperture of CK 342, sc. 57.
   19: CK 339, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 73.
   20: CK 340, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 89.

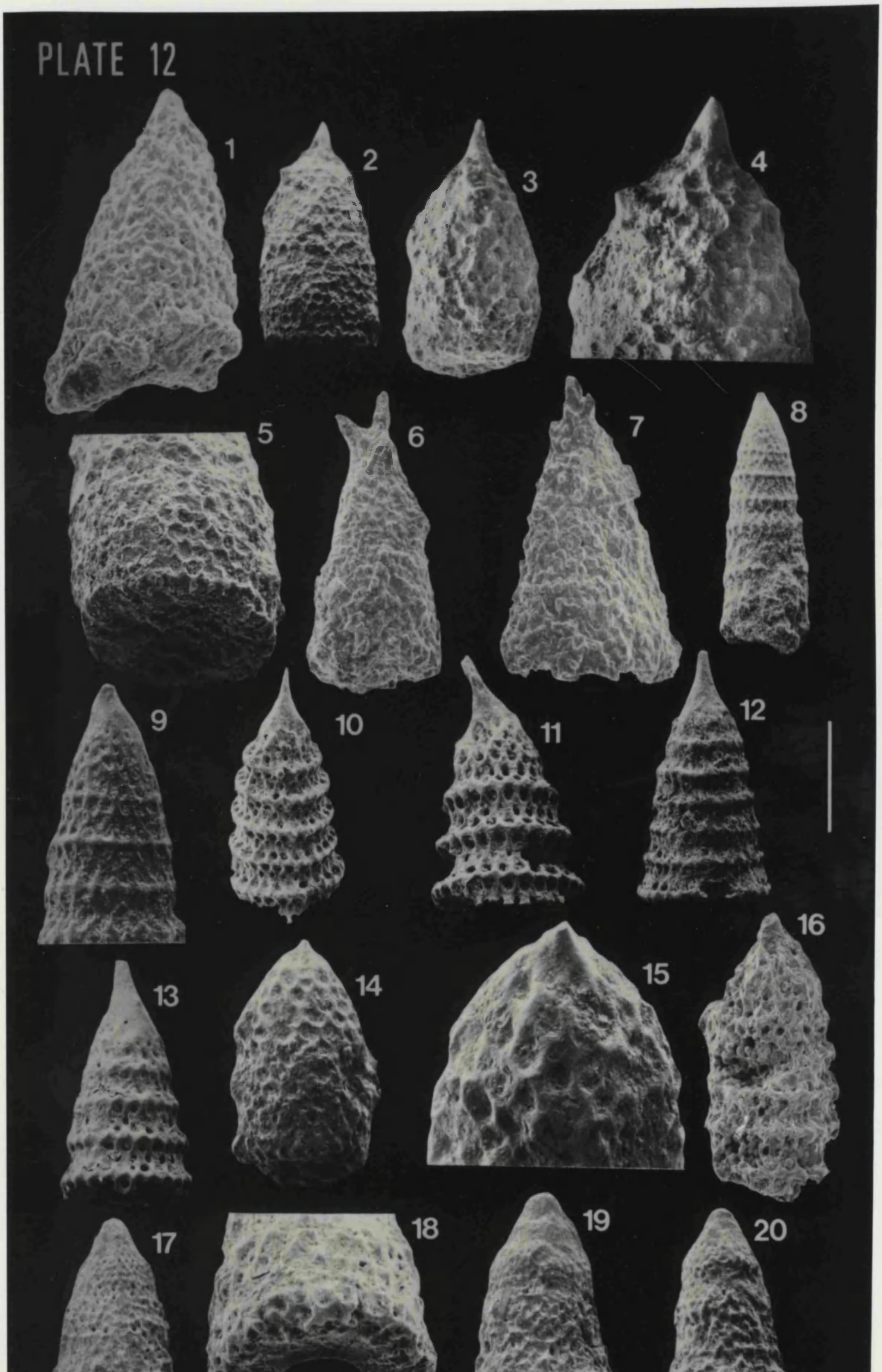
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PLATE 13

PLATE 13

1-4. *Spongocapsula*(?) sp. 3
1: CK 349, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 74.
2: CK 348, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 74.
3: detail of distal part and aperture of CK 349, sc. 49.
4: CK 347, UA 16; Ryazanian, Norwegian Sea, pyritised, detail of apical part of test, sc. 47.

5-12. *Stichocapsa decorata* Rüst
5: CK 354, UA 17-18; Ryazanian, Norwegian Sea, pyritised, sc. 80.
6: CK 377, UA 18; Ryazanian, North Sea, pyritised, sc. 76.
7: CK 369, UA 16; Ryazanian, Norwegian Sea, non-pyritised, sc. 89.
8: CK 370, UA 16; Ryazanian, Norwegian Sea, non-pyritised, vertical section, sc. 89.
9: CK 356, UA 16-17; Upper Volgian, North Sea, pyritised, sc. 75.
10: CK 368, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 90.
11: CK 568, UA 16; Ryazanian, Norwegian Sea, pyritised, detail of distal part, sc. 67.
12: CK 376, UA 18; Ryazanian, North Sea, pyritised, sc. 94.

13. *Stichocapsa* sp. A
13: CK 379, UA 4-17; Lower Volgian, North Sea, non-pyritised, sc. 70.

14-15. *Stichocapsa* sp. B
14: CK 380, UA 8-11; lowermost Middle Volgian, North Sea, non-pyritised, sc. 71.
15: CK 384, UA 11; Lower Volgian, North Sea, non-pyritised, sc. 78.

16. *Stichocapsa*(?) sp. C
16: CK 385, UA 9; Lower Volgian, North Sea, non-pyritised, sc. 87.

17-19. *Stichocapsa*(?) sp. E
17: CK 388, UA 8; Lower Volgian, North Sea, non-pyritised, sc. 67.
18: detail of apical part of CK 388, sc. 47.
19: CK 387, UA 8; Lower Volgian, North Sea, non-pyritised, sc. 57.

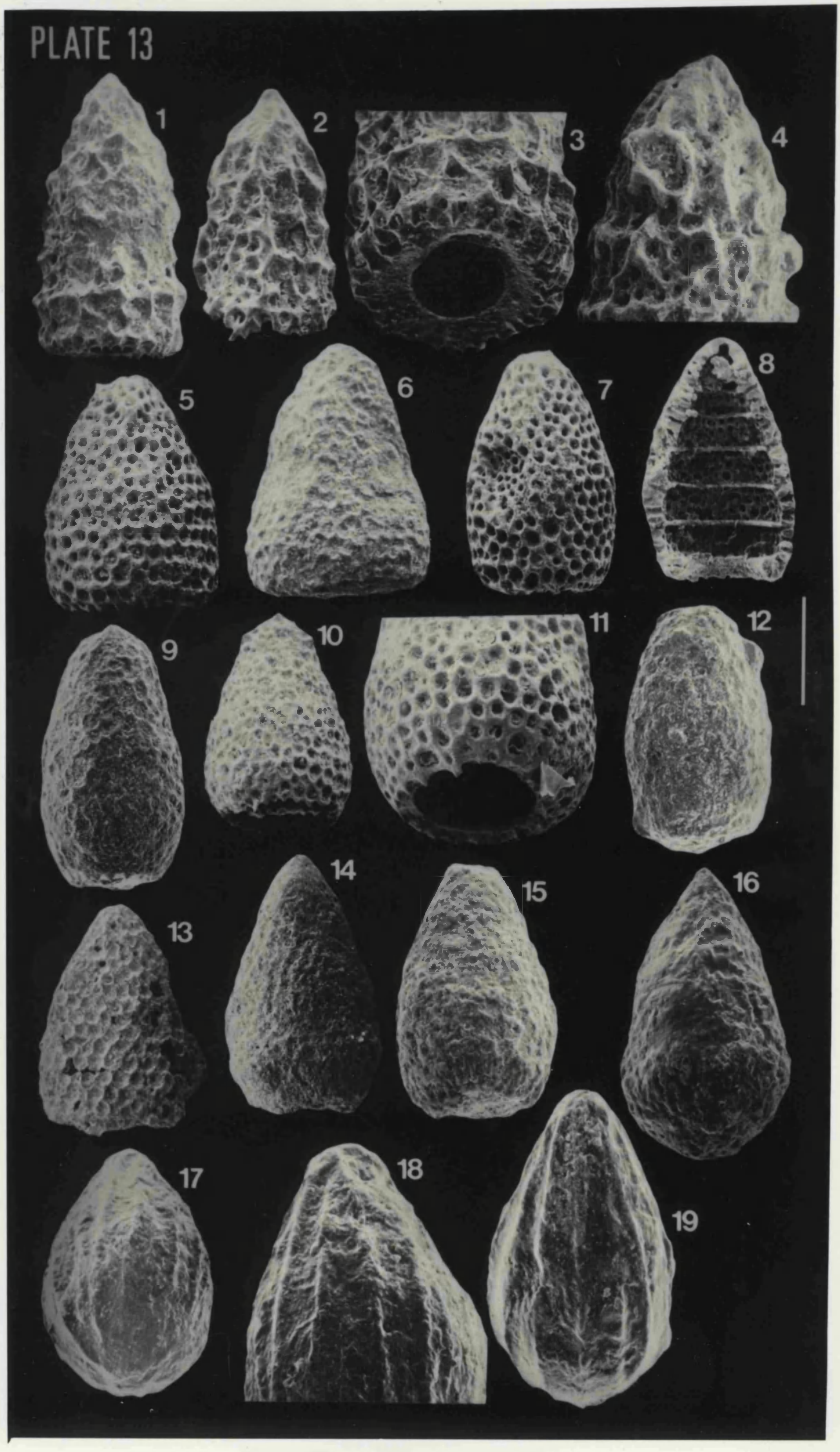
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PLATE 14

PLATE 14

1-2. *Stichocapsa*(?) sp. F

1: CK 391, UA not defined; middle Kimmeridgian, North Sea, non-pyritised, sc. 105.
2: detail of test surface and distal part of CK 391, sc. 77.

3. *Stichocapsa*(?) sp. G

3: CK 393, UA 11; Lower Volgian, North Sea, non-pyritised, sc. 51.

4-5. *Stichocapsa*(?) H

4: CK 395, UA 1; upper Callovian, North Sea, pyritised, sc. 51.
5: CK 394, UA 8; Lower Volgian, North Sea, non-pyritised, sc. 87.

6-7. *Stichocapsa*(?) sp. I

6: CK 396, UA 16-17; Ryazanian, North Sea, pyritised, sc. 89.
7: CK 398, UA 16-17; Ryazanian, North Sea, pyritised, sc. 88.

8-9. *Stichocapsa*(?) sp. indet.

8: CK 360, UA 16-17; Upper Volgian, North Sea, non-pyritised, sc. 112.
9: CK 569, UA 16-17; uppermost Middle Volgian, North Sea, non-pyritised, sc. 114.

10-14. *Tricolocapsa* sp. A

10: CK 410, UA 16-17; Ryazanian, North Sea, pyritised, sc. 73.
11: CK 408, UA 17-18; Ryazanian, Norwegian Sea, pyritised, sc. 73.
12: detail of aperture of CK 410, sc. 40.
13: CK 400, UA 17-18; Ryazanian, Norwegian Sea, pyritised, vertical section, sc. 61.
14: CK 403, UA 16-17; Upper Volgian/Upper Ryazanian, North Sea, non-pyritised, sc. 47.

15-19. *Tricolocapsa*(?) sp. B

15: CK 417, UA 16-17; Ryazanian, North Sea, pyritised, sc. 73.
16: CK 412, UA 16-17; Upper Jurassic/Lower Cretaceous, North Sea, pyritised, sc. 61.
17: CK 414, UA 17-18; Ryazanian, Norwegian Sea, pyritised, sc. 67.
18: detail of pore frames of CK 414, sc. 18.
19: CK 418, UA 16-17; Ryazanian, North Sea, detail of aperture, pyritised, sc. 60.

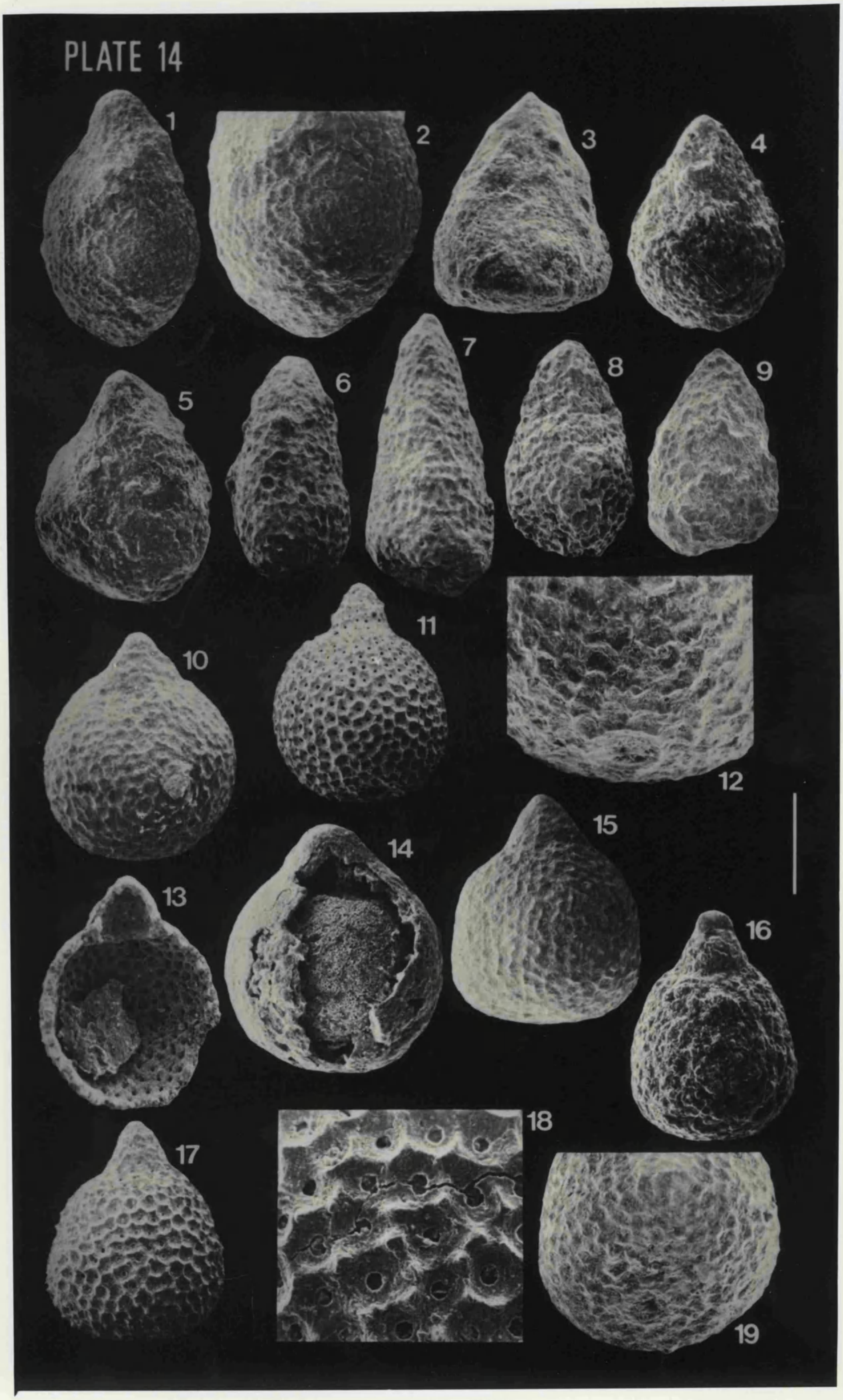
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PLATE 15

PLATE 15

1-2. *Tricolocapsa* sp. C
1: CK 419, UA 16-17; Upper Volgian/Upper Ryazanian, North Sea, non-pyritised, sc. 67.
2: CK 423, UA 17-18; Ryazanian, Norwegian Sea, pyritised, sc. 53.

3-6. *Tricolocapsa* sp. D
3: CK 424, UA 16-17; Upper Volgian, North Sea, pyritised, sc. 82.
4: CK 426, UA 18; Ryazanian, North Sea, pyritised, sc. 89.
5: detail of apical part of CK 426, sc. 54.
6: apical view of CK 426, sc. 76.

7. *Tricolocapsa*(?) sp. 1
7: CK 427, UA 17-18; Ryazanian, Norwegian Sea, pyritised, sc. 62.

8. *Tricolocapsa*(?) sp. 2
8: CK 428, UA 4-12; Lower Volgian, North Sea, non-pyritised, sc. 46.

9-12. *Tricolocapsa*(?) sp. 3
9: CK 429, UA 1; middle Callovian, North Sea, pyritised, sc. 59.
10: distal view of CK 429, sc. 59.
11: CK 431, UA 1-2; middle Callovian, North Sea, pyritised, sc. 57.
12: detail of pores of CK 431, sc. 25.

13, 15. *Tricolocapsa*(?) sp. indet.
13: CK 563, UA 16-17; Upper Volgian, North Sea, pyritised, sc. 57.
15: CK 564, UA not defined; Middle/Upper Oxfordian, North Sea, pyritised, sc. 46.

14. *Tricolocapsa*(?) sp. 4
14: CK 432, UA 11; Lower Volgian, North Sea, non-pyritised, sc. 70.

16. *Turanta*(?) sp. indet.
16: CK 433, UA 1; middle Callovian, North Sea, pyritised, sc. 83.

17. *Williriedellum*(?) sp. 1
17: CK 442, UA 14; ?Lower Volgian, North Sea, non-pyritised, sc. 68.

18. *Zhamoidellum*(?) sp. 1
18: CK 441, UA 16-17; Upper Volgian, North Sea, pyritised, sc. 49.

PLATE 15

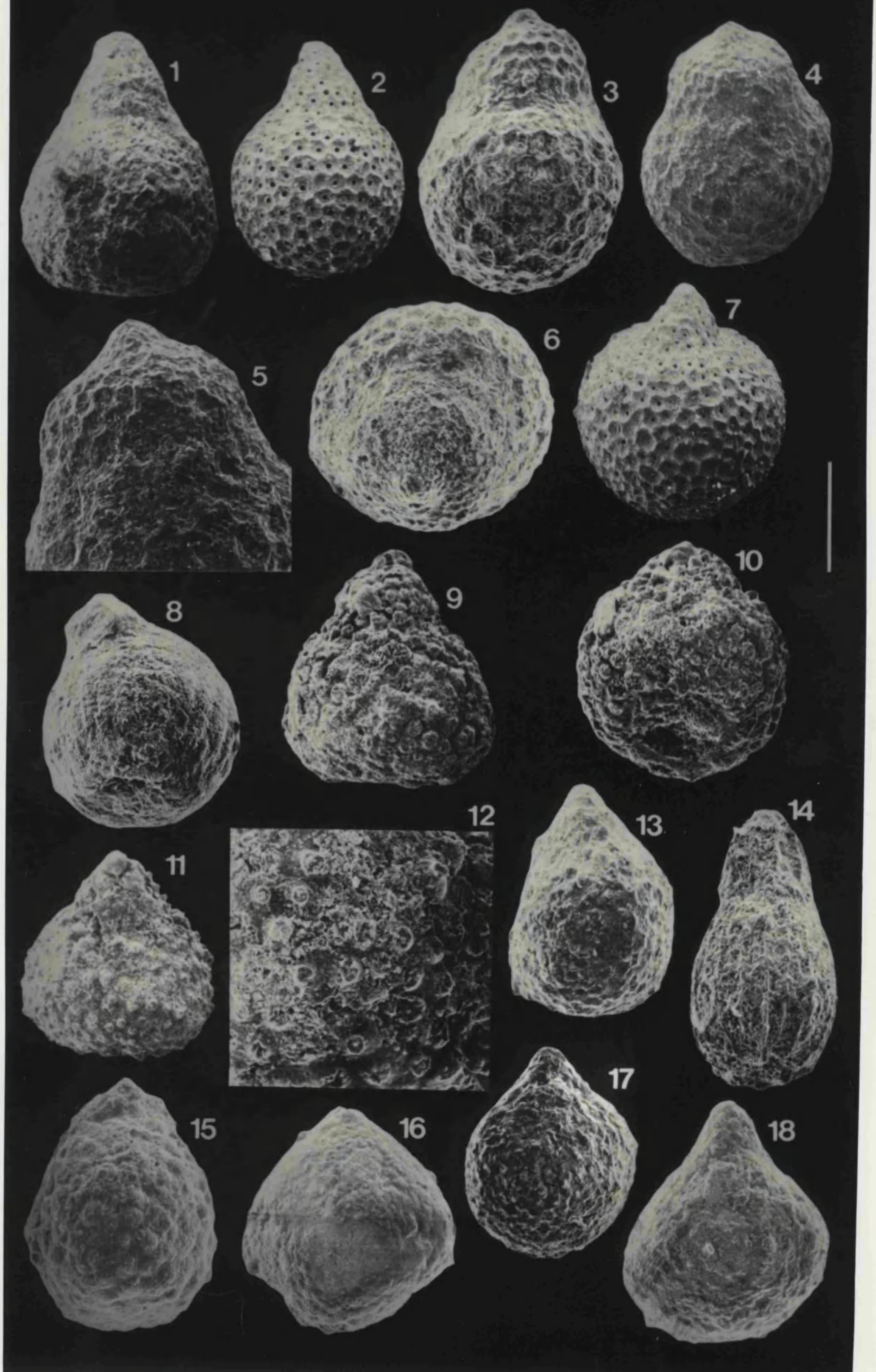

PLATE 16

PLATE 16

1-2. *Williriedellum*(?) sp. 1
1: CK 439, UA 14; uppermost Middle Volgian/Upper Volgian, North Sea, pyritised, sc. 68.
2: detail of apical part of CK 439, arrow shows possible sutural pore, sc. 25.

3. *Zhamoidellum*(?) sp. 1
3: CK 438, UA 16-17; Upper Volgian, North Sea, pyritised, sc. 51.

4. *Zhamoidellum*(?) sp. 2
4: CK 443, UA 14; ?Lower Volgian, North Sea, non-pyritised, sc. 57.

5. *Xitus*(?) sp. 1
5: CK 434, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 83.

6. Cryptothoracic Nassellaria sp. A
6: CK 228, UA 16-17; Ryazanian, North Sea, pyritised, sc. 94.

7-9. Cryptothoracic Nassellaria sp. B
7: CK 229, UA 14-17; uppermost Middle Volgian, North Sea, pyritised, sc. 71.
8: different view of CK 229, sc. 67.
9: detail of apical part of CK 229, sc. 28.

10. Cryptocephalic & Cryptothoracic Nassellaria sp. C
10: CK 230, UA 16-17; uppermost Middle Volgian, North Sea, pyritised, sc. 73.

11. Nassellaria sp. 1
11: CK 518, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 67.

12. Nassellaria sp. 2
12: CK 447, UA not defined; ?Upper Bathonian/lower Callovian, North Sea, pyritised, sc.105.

13-14. Nassellaria sp. 3
13: CK 448, UA 1; middle Callovian, North Sea, pyritised, sc. 48.
14: different view of CK 448, sc. 48.

15. Nassellaria sp. 4
15: CK 449, UA 1; middle Callovian, North Sea, pyritised, sc. 70.

16. Nassellaria sp. 5
16: CK 489, UA 1; middle Callovian, North Sea, pyritised, sc. 71.

17. Nassellaria sp. 6
17: CK 496, UA 16-17; uppermost Middle Volgian, North Sea, pyritised, sc. 91.

18. Nassellaria sp. 7
18: CK 452, UA 4-6; Lower Volgian, North Sea, non-pyritised, sc. 57.

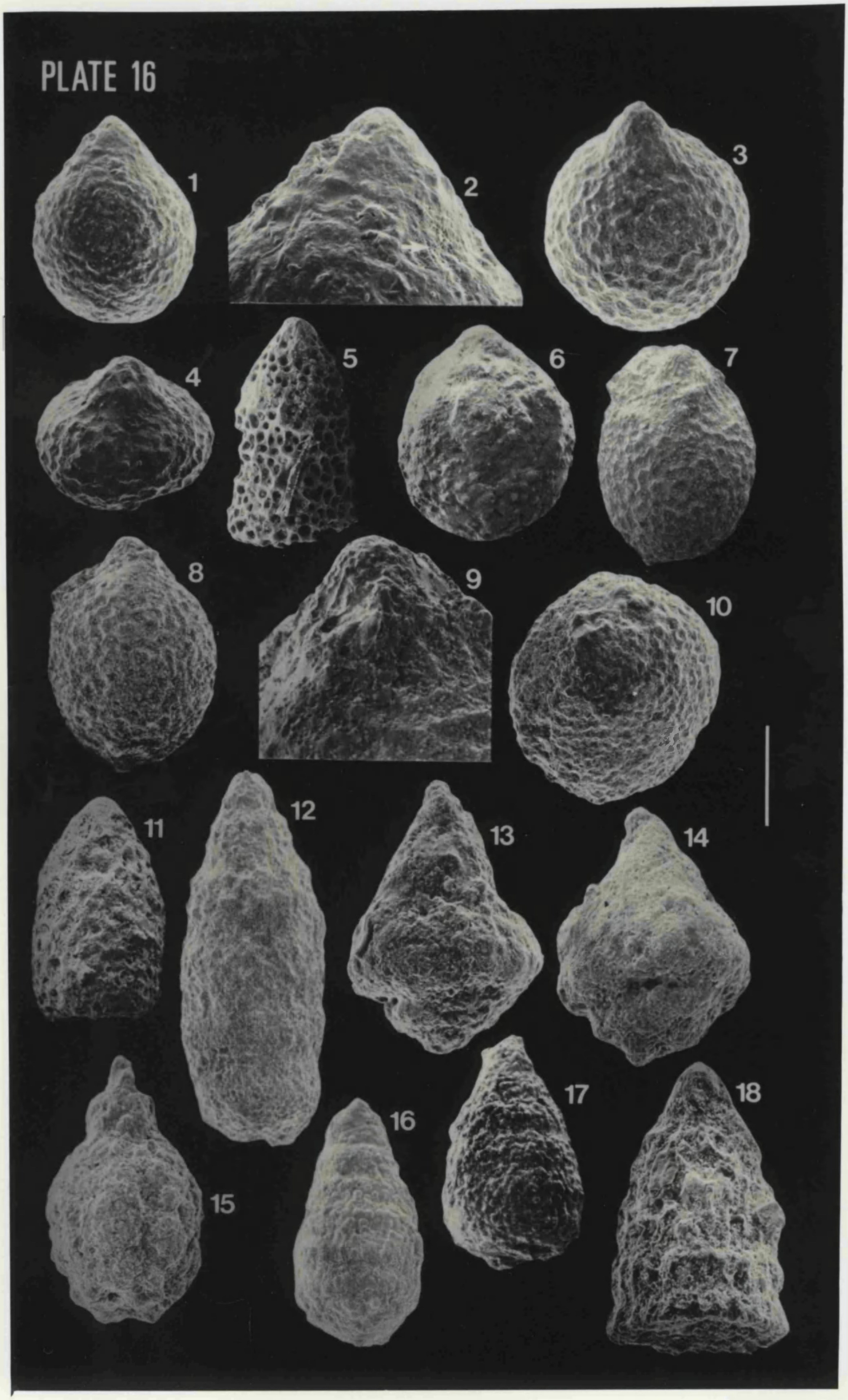
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PLATE 17

PLATE 17

1. Nassellaria sp. 8
   1: CK 450, UA 11; Lower Volgian, North Sea, non-pyritised, sc. 49.

2. Nassellaria sp. 9
   2: CK 483, UA 11; Middle Volgian, North Sea, pyritised, sc. 81.

3. Nassellaria sp. 10
   3: CK 454, UA 1-2; Lower Oxfordian, North Sea, non-pyritised, sc. 97.

4-5. Nassellaria sp. 11
   4: CK 457, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 98.
   5: detail of horns and apical part of CK 457, sc. 36.

6-9. Nassellaria sp. 12
   6: CK 446, UA 2-5; middle Kimmeridgian (*mutabilis* zone), North Sea, pyritised, sc. 83.
   7: detail of horns and apical part of CK 445, sc. 36.
   8: CK 445, UA 2-5; middle Kimmeridgian (*mutabilis* zone), North Sea, pyritised, sc. 83.
   9: detail of horns and apical part of CK 446, sc. 40.

10. Nassellaria sp. 13.
   10: CK 451, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, non-pyritised, sc. 77.

11-12. Nassellaria sp. 14
   11: CK 487, UA 13; Volgian, Barents Sea, pyritised, sc. 125.
   12: CK 488, UA 13: Volgian, Barents Sea, pyritised, sc. 105.

13-14. Nassellaria sp. 15
   13, 14: CK 497, UA 9; Lower Volgian, North Sea, non-pyritised, stereopair, sc. 119.

15. Nassellaria sp. 16
   15: CK 504, UA 13-18; Upper Volgian, North Sea, non-pyritised, sc. 87.

16-17. Nassellaria sp. 17
   16: CK 486, UA 18; Ryazanian, North Sea, non-pyritised, sc. 56.
   17: different view of CK 486, sc. 40.

18-20. Nassellaria group A
   18: CK 492, UA 1; middle Kimmeridgian (*cymodoce* zone), North Sea, pyritised, sc. 114.
   19: CK 494, UA 1; upper Callovian/Lower Oxfordian, North Sea, pyritised, sc. 112.
   20: detail of test surface of CK 494, sc. 37.

PLATE 17

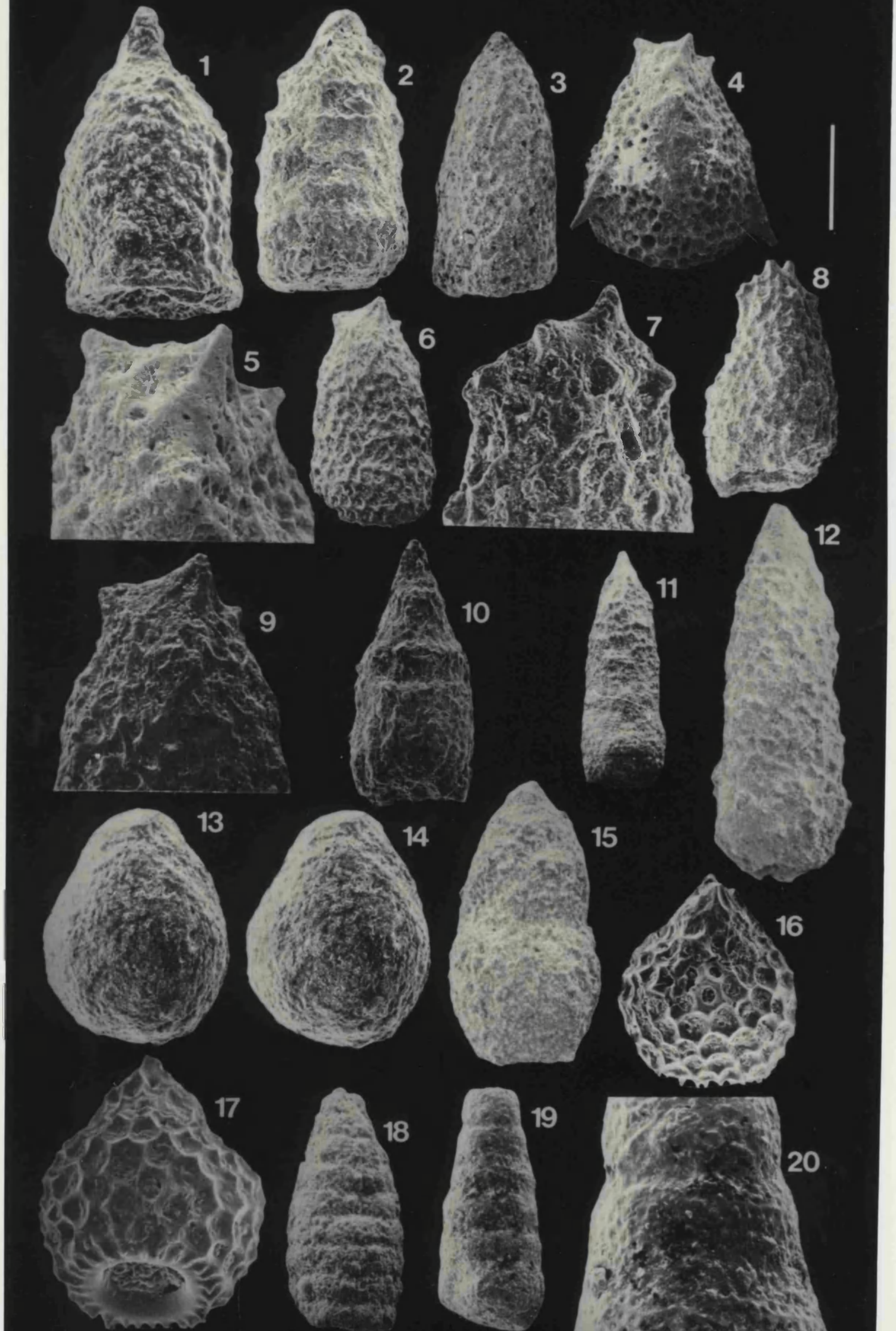

PLATE 18

PLATE 18

1. Nassellaria group A
   1: CK 490, UA 1; middle Callovian, North Sea, pyritised, sc. 83.

2-5. Nassellaria group B
   2: CK 460, UA 9; lowermost Middle Volgian, North Sea, non-pyritised, sc. 89.
   3: different view of CK 460, sc. 111.
   4: CK 480, UA 9; Volgian, Barents Sea, pyritised, sc. 89.
   5: CK 465, UA 9; Lower Volgian, North Sea, non-pyritised, sc. 103.

6-8. Nassellaria group C
   6: CK 505, UA 6; lowermost Volgian, North Sea, non-pyritised, sc. 123.
   7: detail of distal part of CK 505, sc. 58.
   8: CK 507, UA 7-8; lowermost Volgian, North Sea, detail of apical part, non-pyritised, sc. 57.

9-11. Nassellaria group D
   9: CK 513, UA 9-11; Lower Volgian, North Sea, non-pyritised, sc. 66.
   10: CK 514, UA 11; Lower Volgian, North Sea, non-pyritised, sc. 101.
   11: CK 511, UA 4-12; Lower Volgian, North Sea, non-pyritised, sc. 80.

12. *Rhaxella* group sponge spicule
   12: CK 547, UA 18; Upper Volgian/Lower Ryazanian, North Sea, pyritised, sc. 85.

13-17. Sterraster sp. 1
   13: CK 542, UA 16; Ryazanian, Norwegian Sea, non-pyritised, sc. 43
   14: CK 522, UA 16-17; Upper Volgian, North Sea, pyritised, sc. 52.
   15, 16: CK 528, UA 16-17; uppermost Middle Volgian, North Sea, non-pyritised, stereopair, sc. 63.
   17: CK 519, UA 16-17; Upper Volgian, North Sea, pyritised, sc. 56.

18. Sponge spicule (microcalthrops)
   18: CK 565, UA 16-17; uppermost Middle Volgian, North Sea, pyritised, sc. 77.

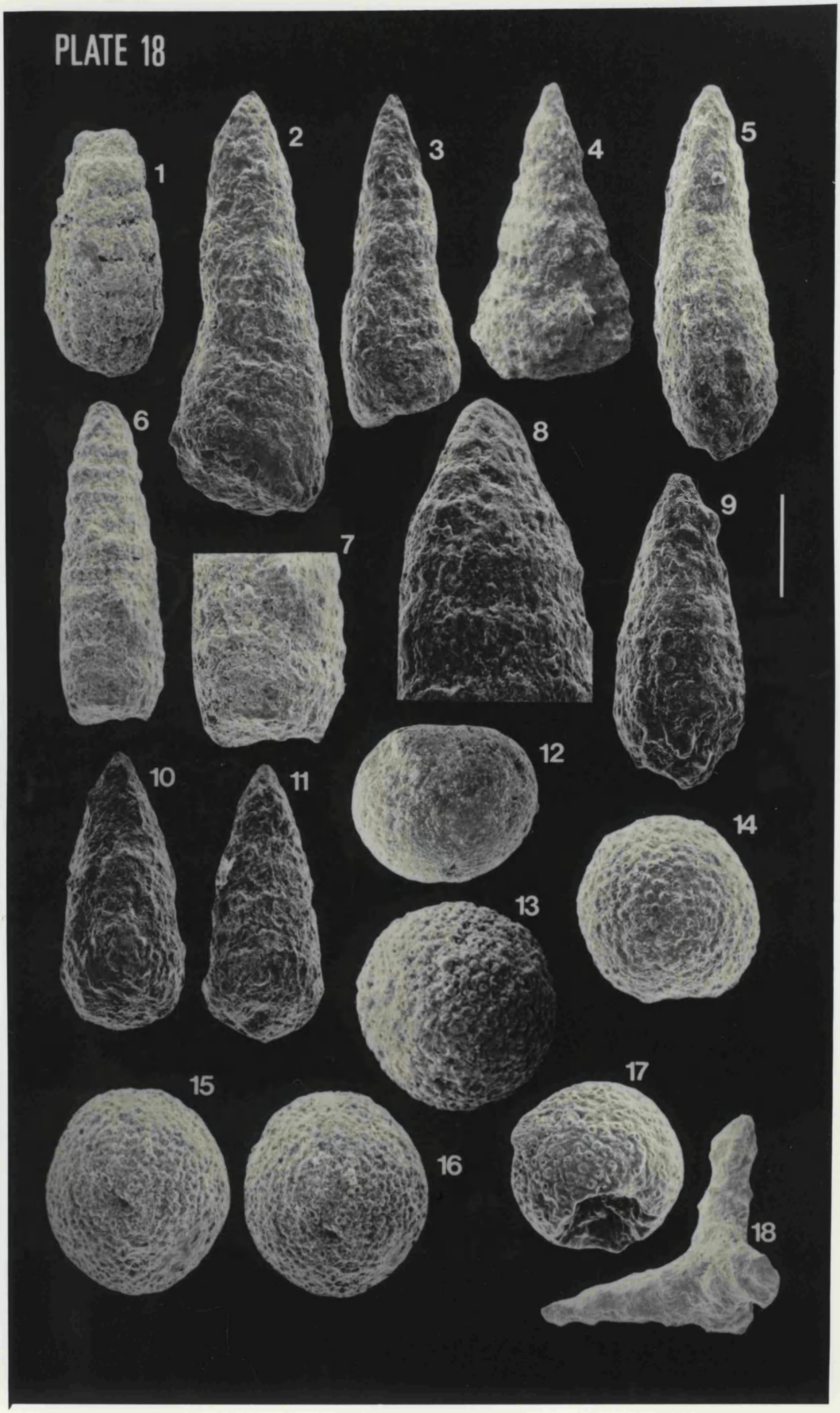
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PLATE 19

PLATE 19

1. *Archaeocenosphaera*(?) sp. 1
   1: CK 20, UA 4; Lower Volgian, North Sea, sc. 97.

2-3, 4. *Archaeocenosphaera*(?) sp. 5
   2: CK 32, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 165.
   3: CK 29, UA 4; upper Kimmeridgian/Lower Volgian, North Sea, sc. 186.
   4: CK 34, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, detail of pore frames, sc. 62.

5-6, 9. *Archaeocenosphaera*(?) sp. 6
   5: CK 550, UA 9-11; Lower Volgian, North Sea, detail of pore frames, sc. 62.
   6: CK 38, UA 11; Lower Volgian, North Sea, sc. 161.
   9: CK 36, UA 8-11; Lower Volgian, North Sea, detail of pore frames, sc. 87.

7. *Orbiculiforma* sp. 2
   7: CK 81, UA 2; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 137.

8. *Orbiculiforma mclaughlini* Pessagno
   8: CK 76, UA 16-18; Ryazanian, Norwegian Sea, sc. 128.

10-11. *Orbiculiforma* sp. 3
   10: CK 90, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 133.
   11: CK 95, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 138.

12-13. *Orbiculiforma* sp. 6
   12: CK 112, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 140.
   13: CK 111, UA 2; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 133.

14-15. *Porodiscus*(?) sp. 1
   14: CK 214, UA 16; Ryazanian, Norwegian Sea, sc. 83.
   15: CK 213, UA 16; Ryazanian, Norwegian Sea, sc. 79.

16. *Orbiculiforma* spp. indet.
   16: CK 98, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 171.

All specimens are non-pyritised.

PLATE 19

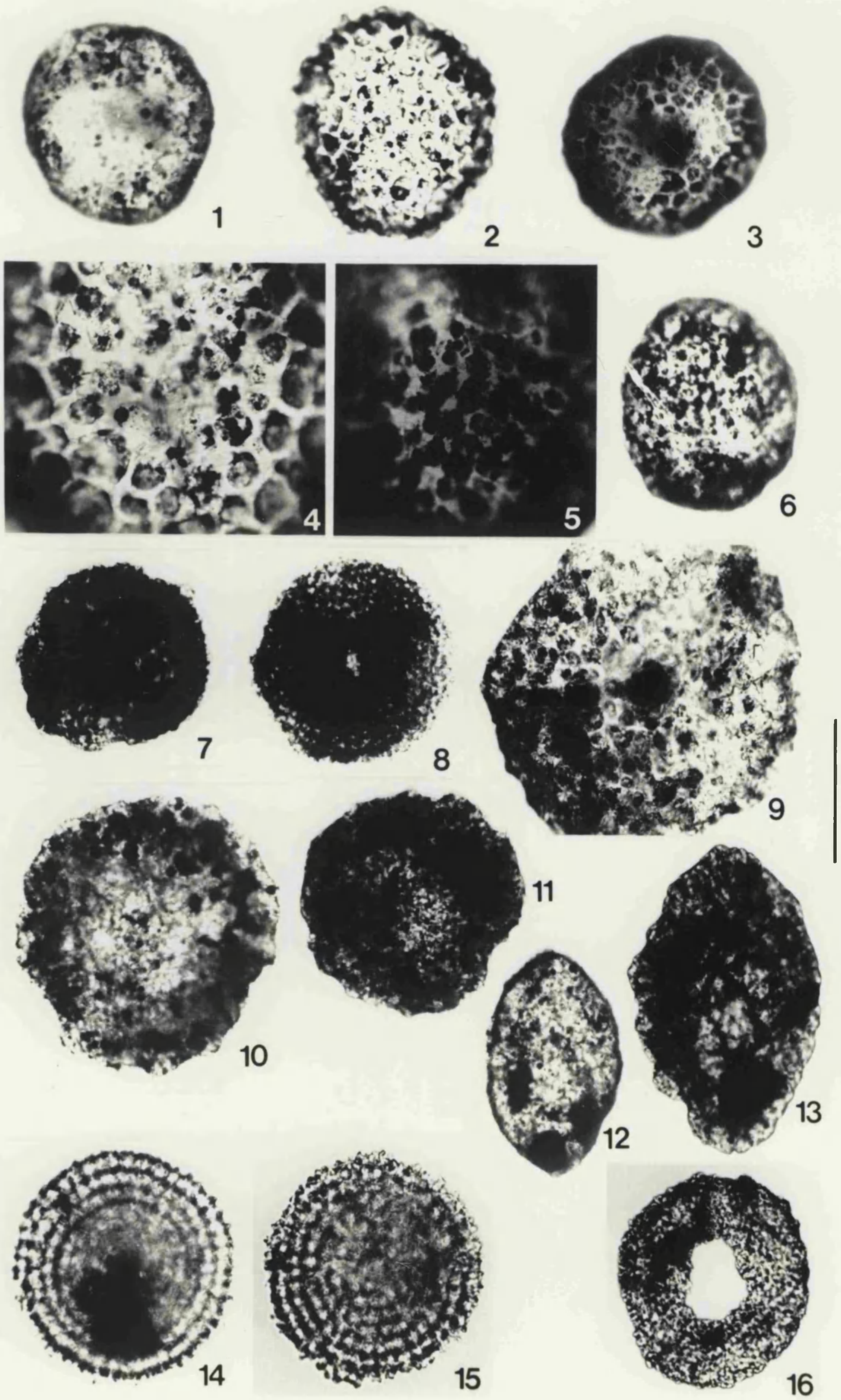


PLATE 20

PLATE 20

1-2. *Praeconocaryomma hexagona* (Rüst)
1: CK 140, UA 4; Lower Volgian, North Sea, sc. 110.
2: CK 567, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 123.

3. *Praeconocaryomma* sp. A
3: CK 153, UA 16-17; uppermost Middle Volgian, North Sea, sc. 81.

4. Actinommidae gen. et sp. indet.
4: CK 216, UA 17-18; Berriasian, Barents Sea, sc. 71.

5-6. Hagiastridae(?) group 2
5: CK 55, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 111.
6: CK 57, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 213.

7. Hagiastridae(?) group 6
7: CK 63, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 85.

8. Spongodiscidae sp. B
8: CK 189, UA 9-11; Lower Volgian, North Sea, sc. 125.

9-10. Spongodiscidae sp. A
9: CK 168, UA 11; lowermost Middle Volgian, North Sea, sc. 105.
10: CK 172, UA 11; Middle Volgian, North Sea, sc. 206.

11. Spongodiscidae sp. D
11: CK 202, UA 11; lowermost Middle Volgian, North Sea, sc. 112.

12-13. Spongodiscidae sp. C
12: CK 197, UA 9-11; lowermost Middle Volgian, North Sea, sc. 133.
13: CK 199, UA 4-17; Lower Volgian, North Sea, sc. 198.

14. Spumellaria gen. et sp. indet. C
14: CK 211, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 84.

15-16. Spumellaria gen. et sp. indet. D
15: CK 500, UA 7; Kimmeridgian/Lower Volgian, North Sea, sc. 167.
16: CK 498, UA not defined; Middle Volgian, North Sea, sc. 94.

All specimens are non-pyritised.

PLATE 20

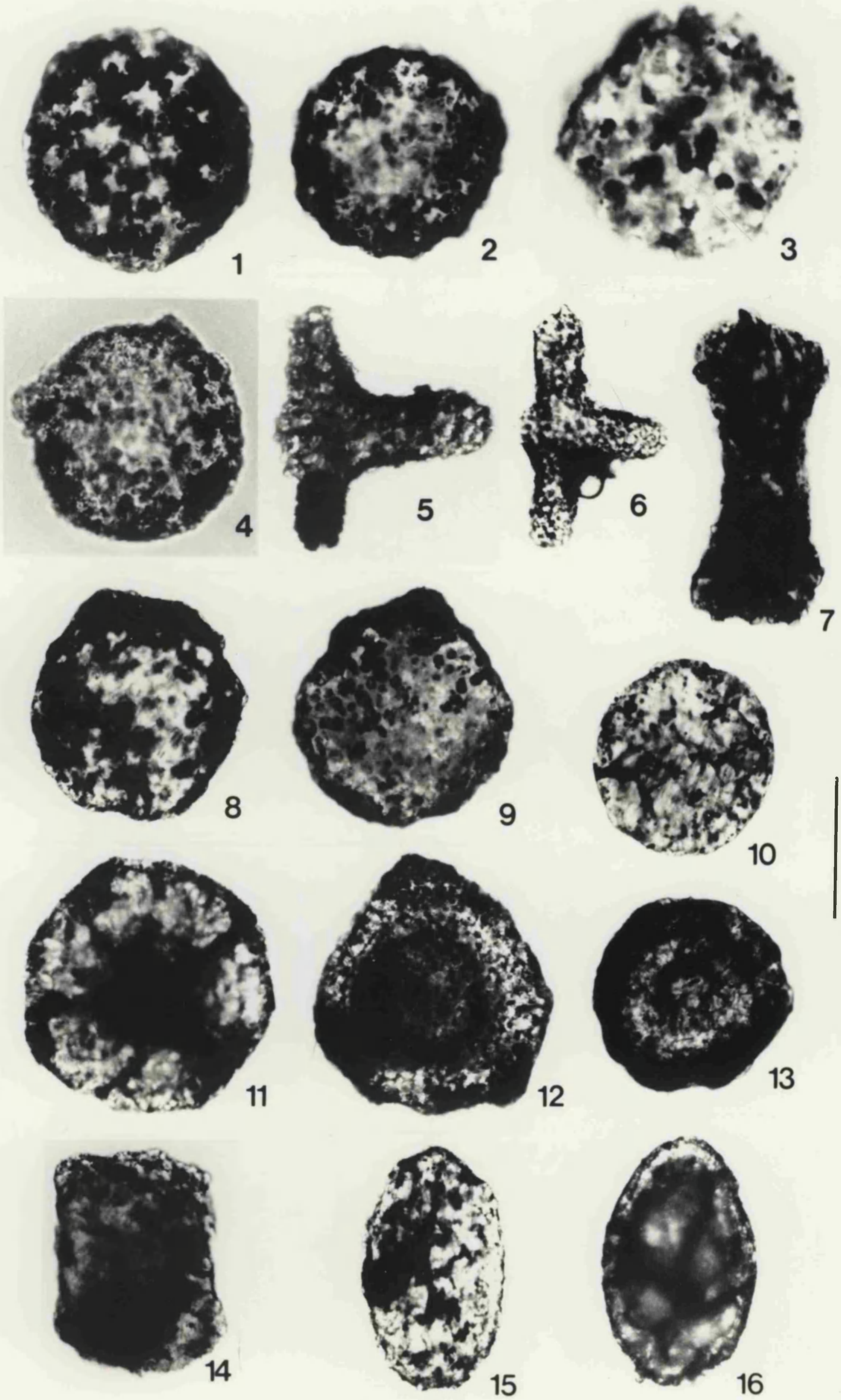


PLATE 21

PLATE 21

1. *Archaeodictyomitra rigida* Pessagno
   1: CK 218, UA 16; Ryazanian, Norwegian Sea, pyritised, sc. 86.

2. *Hsuum*(?) sp. A
   2: CK 236, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 120.

3. *Parvicingula*(?) cf. *P. jonesi* Pessagno
   3: CK 247, UA 16-17; Upper Volgian, North Sea, sc. 166.

4. *Parvicingula* sp. 1
   4: CK 249, UA 4; Lower Volgian, North Sea, sc. 113.

5. *Parvicingula* sp. 2
   5: CK 254, UA not defined; Lower Oxfordian, North Sea, sc. 130.

6-7. *Praeparvicingula* sp. 3
   6: CK 307, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 148.
   7: CK 306, UA 3; middle Kimmeridgian (*mutabilis* zone), North Sea, detail of apical part, sc. 75.

8. *Praeparvicingula* sp. 5
   8: CK 319, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 116.

9. *Praeparvicingula* sp. 7
   9: CK 326, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 123.

10. *Praeparvicingula*(?) sp. B
   10: CK 329, UA 16; Ryazanian, Norwegian Sea, sc. 68.

11. *Praeparvicingula*(?) sp. C
   11: CK 335, UA not defined; uppermost Middle Volgian, North Sea, pyritised, sc. 102.

12. *Spongocapsula*(?) sp. 1
   12: CK 344, UA 16; Ryazanian, Norwegian Sea, sc. 88.

13, 16. *Spongocapsula*(?) sp. 2
   13: CK 345, UA 4; upper Kimmeridgian, North Sea, sc. 89.
   16: CK 346, UA 2; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 86.

14-15, 17-19. *Stichocapsa decorata* Rüst
   14: CK 365, UA 16; Ryazanian, Norwegian Sea, sc. 91.
   15: CK 367, UA 16; Ryazanian, Norwegian Sea, sc. 120.
   17: CK 372, UA 18; Ryazanian, North Sea, sc. 103.
   18: CK 357, UA 16; Ryazanian, Norwegian Sea, sc. 126.
   19: CK 364, UA 16; Ryazanian, Norwegian Sea, detail of pore frames, sc. 64.

All specimens are non-pyritised except where stated

PLATE 21

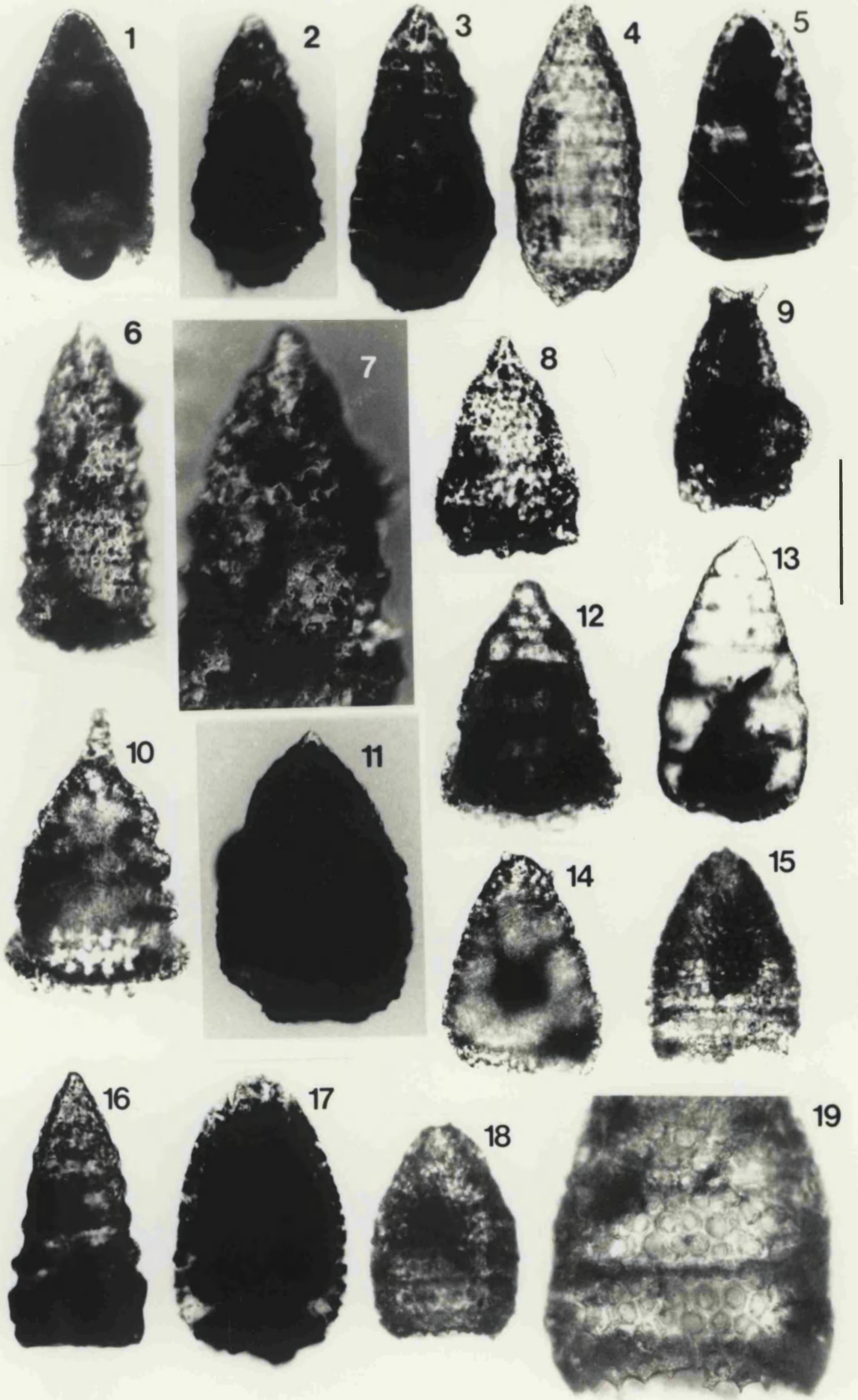


PLATE 22

PLATE 22

1. *Stichocapsa* sp. B
   1: CK 381, UA 8-11; Middle Volgian, North Sea, sc. 106.

2. *Stichocapsa*(?) sp. D
   2: CK 386, UA 8-11; lowermost Middle Volgian, North Sea, sc. 78.

3. *Stichocapsa*(?) sp. G
   3: CK 392, UA 11; Lower Volgian, North Sea, sc. 94.

4. *Stichocapsa*(?) sp. I
   4: CK 397, UA 16-17; Ryazanian, North Sea, sc. 97.

5-7. *Tricolocapsa* sp. A
   5: CK 406, UA 17-18; Ryazanian, North Sea, sc. 91.
   6: CK 399, UA 16-17; Upper Volgian, North Sea, sc. 68.
   7: CK 402, UA 17-18; Berriasian, Barents Sea, sc. 71.

8. *Tricolocapsa* sp. B
   8: CK 415, UA 17-18; Ryazanian, North Sea, sc. 101.

9-10. *Tricolocapsa* sp. C
   9: CK 422, UA 17-18; Ryazanian, North Sea, sc. 89.
   10: CK 421, UA 17-18; Berriasian, Barents Sea, sc. 70.

11-12. *Zhamoidellum*(?) sp. 1
   11: CK 436, UA 17-18; Ryazanian, North Sea, sc. 74.
   12: CK 435, UA 17-18; Ryazanian, North Sea, sc. 81.

13-15. Nassellaria sp. 10
   13: CK 456, UA 8; Middle Volgian, North Sea, sc. 77.
   14: CK 453, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 111.
   15: CK 455, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 75.

16. Nassellaria sp. 11
   16: CK 458, UA 16; Ryazanian, Norwegian Sea, sc. 93.

17. Nassellaria sp. 18
   17: CK 482, UA 16-17; uppermost Ryazanian/Lower Valanginian, North Sea, sc. 103.

18. Nassellaria sp. 19
   18: CK 485, UA 4-12; lowermost Volgian, North Sea, sc. 74.

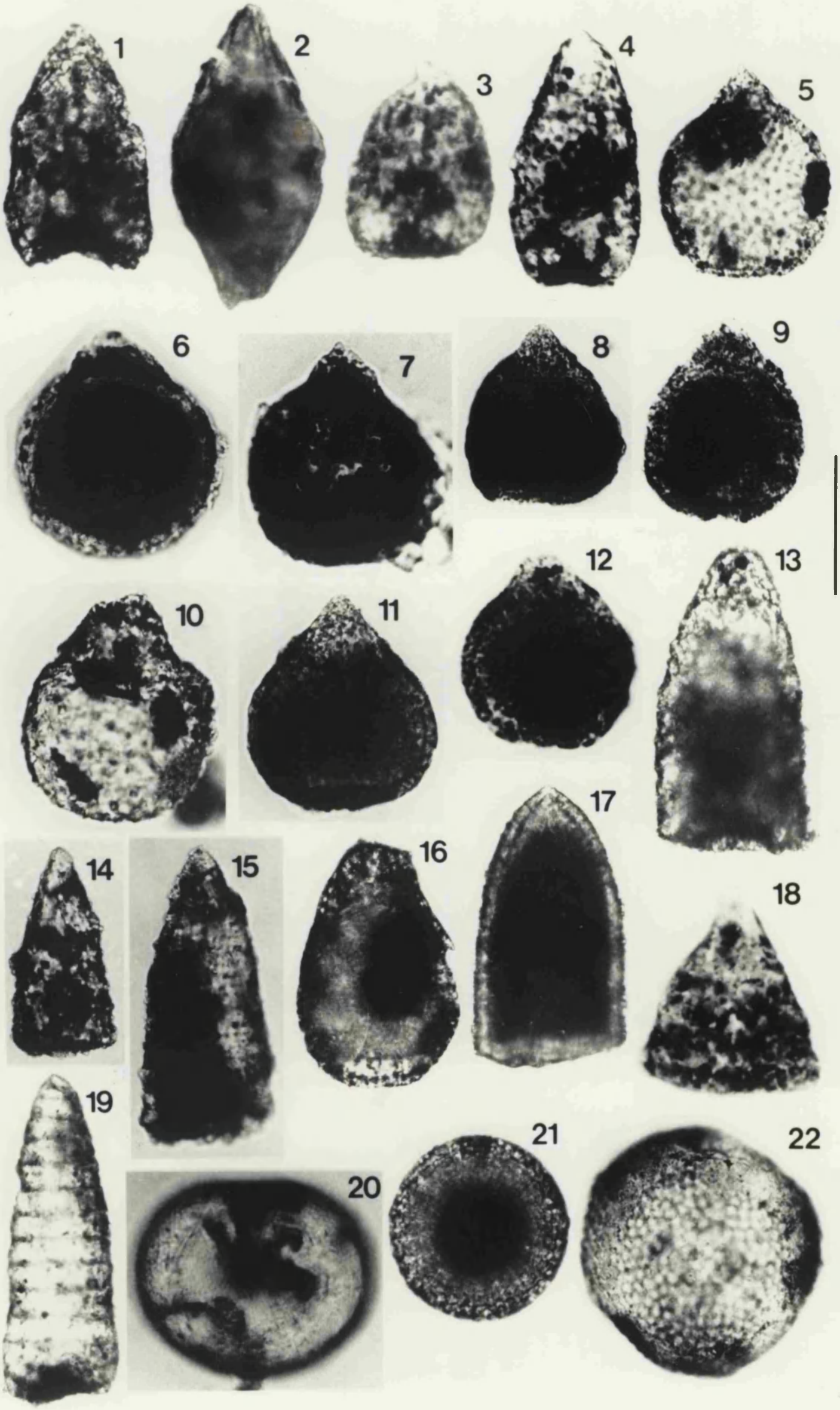
19. Nassellaria group C
   19: CK 510, UA 4; Lower Volgian, North Sea, sc. 150.

20. *Rhaxella* group sponge spicule
   20: CK 546, UA 5; middle Kimmeridgian (*mutabilis* zone), North Sea, sc. 87.

21-22. Sterraster sp. 1
   21: CK 544, UA 16; Ryazanian, Norwegian Sea, sc. 64.
   22: CK 540, UA 16-17; Middle/Upper Volgian, North Sea, sc. 74.

All specimens are non-pyritised.

PLATE 22



APPENDIX 1

Analyses of Mid Jurassic to Earliest Cretaceous published literature

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Abbate *et al.*	1986	Europe	Jurassic		SEM		Evolution of Tethys, ophiolites
Adachi & Kojima	1983	Japan	Mid Jurassic		SEM		Palaeozoic - Mesozoic Geology
Aita	1985	Japan	Callovian - Oxfordian		SEM	Yes	4 rad zones, range charts, correlation (in Jap. with English abstract)
Aita	1987	Japan, Italy	Mid Jurassic - Early Cretaceous	M, N	SEM, LM	Yes	New zonation for japanese area applicable to some european sequences, correlation with other zones
Aita & Grant-Mackie	1992	New Zealand	Late Jurasic		SEM		Dinoflagellates and other microfauna used for age assignment
Aita & Okada	1986	Japan, Europe	Late Jurassic - Early Cretaceous	M, N	SEM, LM	Yes	Introduction of a new zone, description of new species, nannofossils
Aita & Sporli	1992	New Zealand	Late Triasssic - Jurassic		SEM		Geology, paleobiogeography
Aliev	1961a	Russia (Azerbaidzhan)	Valanginian - Albian	N	D		Description of new nassellarian species (in Russian)
Aliev	1961b	Russia (Azerbaidzhan)	Valanginian, Albian, Cenomanian	N	D		Description of new Cyrtoidae species (in Russian)
Aliev	1965	Russia (Azerbaidzhan)	Valanginian - Cenomanian	M, N	D		Range charts (in Russian)
Aliev	1967	Russia (Azerbaidzhan)	Valanginian - Albian	N	D		Description of new species (*Tricolocapsa* etc.) (in Russian)
Aliev	1969a	Russia	Cretaceous (incl. Early)				Systematics of Cyrtoidea (in Russian)
Aliev	1969b	Russia (Azerbaidzhan)	Valanginian - Turonian				List of species, range charts (in Russian)
Aliev	1976	Russia (Azerbaidzhan)	Valanginian, Albian	N	D		Description of new species (in Russian)
Amon	1993	Russia	Berriasian - Maastrichtian			Yes	11 rad zones, correlation table
Aoki	1982	Japan	Late Jurassic	M	SEM, LM		List of species (in Japanese)
Aono	1985	Japan	Triassic, Jurassic				List of rad. species, conodonts
Bailey & McCallien	1953	Turkey	Mesozoic (incl. Late Jurassic), Cenozoic		D		Geology, rads mentioned, species given
Bailey *et al.*	1953	Gibraltar	Late Jurassic?				Geology, rad genera identified given
Bartenstein	1979	worldwide	Early Cretaceous		SEM, D		Discussion of the applicability of rads as index fossils (in German)
Basov & Vishnevskaya	1991	Russia	Late Jurassic - Cretaceous	M, N	SEM	Yes	Correlation of existing zonations, description of new species, forams (in Russian with English abstract)
Baumgartner	1980	Greece (Peloponnesus)	Late Jurassic	M, N	SEM, LM		Internal structure of Hagiastridae, Patulibracchiidae
Baumgartner	1983	Atlantic Ocean	Mid Jurassic - Early Cretaceous			Yes	Unitary Association (UA) zonation, correlation with other areas, DSDP Site

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Baumgartner	1984a	Europe, Atlantic Ocean, USA, Central America, Japan,Pacific Ocean, Oman	Mid Jurassic - Early Cretaceous	M, N	SEM	Yes	UA biozonation, correlation with other zonations, radiolarites
Baumgartner	1984b	Europe	Mid Jurassic - Early Cretaceous			Yes	UA method, comparison with probabilistic methods
Baumgartner	1985	Greece	Jurassic		SEM		Sedimentary evolution study
Baumgartner	1987a	Europe	Jurassic				Genesis of radiolarites, correlation of sections, stratigraphy
Baumgartner	1987b	Europe	Mid Jurassic - Early Cretaceous			Yes	UA biozones, correlation with other zonations, radiolarites
Baumgartner	1992	Indian Ocean (NW Australia)	Latest Jurassic - Barremian	M	SEM	Yes	Palaeobiogeography, palaeoceanography, ODP Site
Baumgartner	1993	Indian Ocean	Early Cretaceous		SEM	Yes	UA biozones, palaeoceanography, palaeogeography
Baumgartner & Bernoulli	1976	Greece	Berriasian - Valanginian	M	SEM, LM		Stratigraphy
Baumgartner & Murchey	1987	N. America, Europe	Jurassic - Early Cretaceous			Yes	Correlation of UA zonation with N. American zones
Baumgartner *et al.*	1980	Europe, Atlantic Ocean	Late Jurassic - Early Cretaceous	M, N	SEM, LM	Yes	First UA zonation, method of UA, correlation with other zonations
Baumgartner *et al.*	1981	worldwide	Mesozoic, Cenozoic		SEM, LM		EURORAD II, general paper
Baumgartner *et al.*	1992	Indian Ocean	Early Cretaceous				Palaeobiogeography, palaeoceanography, nannofossils, forams, ODP Site
Beck *et al.*	1984	Venezuela	Early Cretaceous				(in French)
Benson & Chapman	1938	New Zealand	Mesozoic (?Jurassic)				Note on rads, few species listed
Birkenmajer & Gasiorowski	1960	Poland (Carpathians)	Late Jurassic				Stratigraphy, rads mentioned
Blome	1984	Alaska, Oregon	Callovian	M, N	SEM, LM		Description of new genus and species
Blome	1992	Indian Ocean	Latest Jurassic - Early Cretaceous, Cenozoic	M	SEM, TS		Note on Jurassic/Early Cret. rads, taxonomy on Paleocene rads, ODP Site
Boyanov & Lipman	1973	Bulgaria	Early Cretaceous				Rads mentioned (species given) (in Russian)
Bragin	1992	Russia	Late Palaeozoic, Mesozoic (incl. Jurassic)				Stratigraphy, rads mentioned (in Russian)
Bragin *et al.*	1988	Russia	Triassic - Jurassic		SEM		One Late Jurassic species illustrated
Bralower	1992	Indian Ocean (NW Australia)	Berriasian - Valanginian		SEM		Sedimentology, few rad species illustrated, ODP Site

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Brouwer	1921	Indian Ocean (Rotti)	Mesozoic (incl. Jurasic),Cenozoic		TS		Geology, rads mentioned (in Dutch)
Brouwer	1925	Indonesia	Triassic, jurassic, Cretaceous		TS		Geology, rads mentioned
Campbell, A. S.	1954	worldwide	all		D		Radiolaria volume of the TREATISE ON INVERTEBRATE PALAEONTOLOGY
Campbell, H. J	1988	New Zealand					Comment on Foley *et al.* (1986) for age assignment
Carayon *et al.*	1984	USA (Oregon)	Kimmeridgian, Albian		SEM		Stratigraphy (in French)
Cayeux	1891	France	Jurassic (?Oxfordian), Eocene				Locations given (in French)
Cayeux	1896	France	Tithonian				Note on rads, 2 genera given (in French)
Cayeux	1897	Europe	Palaeozoic, Jurassic, Cretaceous				Sedimentation, list of few Cret. species (in French)
Chediya	1970	Middle Asia	Mesozoic (incl. Jurassic)				General paper (in Russian)
Cheng	1992	Philippines	Late Jurassic	M, N	SEM		Description of new species of Pantanelliidae
Cita	1964	Italy	Late Jurassic - Early Cretaceous	M, N	D, RM		Other microfauna studied (forams, nannofossils, calpionellids)
Cita & Pasquare	1959	Italy	Early Cretaceous	M	D, TS		Other microfauna studied (forams, etc.)
Conti	1986	Italy	Callovian - Tithonian		SEM		
Conti & Marcucci	1986	Italy	Late Jurassic	M	SEM		Ophiolites
Conti & Marcucci	1991	Italy	Mid Callovian	M, N	SEM		Description of new species
Conti & Marcucci	1992	Italy	Oxfordian - Berriasian		SEM		Ophiolites
Conti *et al.*	1984	Italy	Late Jurassic - Early Cretaceous				Short note on rad cherts & ophiolites
Conti *et al*	1985	Italy, Corsica	Mid, Late Jurassic				Ophiolites, rad species given
Conti *et al.*	1988	Italy	Callovian - Oxfordian		SEM		Range charts
Coomaraswamy	1902	India	?Jurassic		D		Few rad morphotypes mentioned (in French)
Cordey, De Wever *et al.*	1987	Canada	Early - Mid Jurassic				
Cordey, Mortimer *et al.*	1987	Canada	Late Triassic - Mid Jurassic		SEM		
Cornelius	1951	worldwide	Mesozoic (incl. Jurassic)				Paper on radiolarites (in German)
Crespin	1958	Australia, New Guinea	Early Cretaceous, Eocene				Brief note on rads
Dacque	1933	Europe	Jurassic	M	D		General paper, long list of species (in German)
Dal Piaz	1907	Italy	Jurassic (?Callovian)				Geology, list of species identified (in Italian)

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Danelian *et al*	1986	Greece	Callovian - Kimmeridgian				List of species (in French)
Davis	1950	Oman	Jurassic? - Early Cretaceous	M, N	D		
De Wever	1981a	Greece, Italy	Late Jurassic, Cretaceous	N	SEM		Description of new species (*Saitum*) (in French)
De Wever	1984	worldwide	Mesozoic	N			New classification of Saturnalidae, new genus (in French)
De Wever	1987	Greece	Mesozoic				Radiolarites as a cyclic sedimentation (in French)
De Wever	1989	Europe	Mesozoic (incl. Jurassic)				Radiolarites, their age & distribution, palaeogeography
De Wever & Caby	1981	France	Oxfordian - Kimmeridgian		SEM, TS		(in French)
De Wever & Cordey	1986	Greece	Bajocian - Tithonian		SEM		Radiolarites, range charts (in French)
De Wever & Dercourt	1985	Europe	Triassic - Jurassic				Rewiew of radiolarites (in French)
De Wever & Miconnet	1985	Italy	Oxfordian - Valanginian	M, N	SEM		Description of new species (in French)
De Wever & Origlia-Devos	1982	Greece	Oxfordian - Turonian				Table of species occurrence in samples (in French)
De Wever & Riedel	1979	Europe	Palaeozoic, Mesozoic, Cenozoic				EURORAD 1978, general paper, notes on sampling procedures, preparation of slides, reworking, taxonomy, etc.
De Wever & Thiebault	1981	Greece	Late Jurassic - Late Cretaceous	M, N	SEM		Range charts (in French)
De Wever, Duee & El Kadiri	1985	Marocco	Jurassic - Cretaceous		SEM		Stratigraphic study (in French)
De Wever, Azema *et al.*	1985	Costa Rica	Jurassic - Cretaceous				Table with stratigr. distribution of rads (in French)
De Wever, Geyssant *et al.*	1986	Italy (Sicily)	Late Jurassic - Early Cretaceous		SEM		Study with ammonites, nannofossils, calpionellids and radiolaria (in French)
De Wever, Ricou & Fourcade	1986	worldwide	Late Jurassic				Radiolarites (in French)
De Wever, Baumgartner & Polino	1987	Italy	Callovian		SEM		Re-examination of age (in French)
De Wever, Danelian *et al.*	1987	Europe (Corsica)	Callovian - Tithonian				List of species
De Wever *et al.*	1990	Oman	Mesozoic		SEM		Species are given
Degli Innocenti	1927	Italy	Jurassic	M	D		Range chart (in Italian)
Diersche	1980	Austria	Jurassic, Cretaceous		SEM		Study on radiolarites, species given
Donofrio & Mostler	1978	Austria	Triassic - Cretaceous	M, N	SEM		Classification of Saturnalidae (in German)

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Dosztaly	1986	Hungary	Oxfordian - Kimmeridgian		SEM		(in Hungarian with English abstract)
Downie	1956	North Sea Basin	Late Jurassic				Study on Kimmeridge Clay, rads mentioned
Dumitrica	1970	Romania	Mesozoic (incl. Jurassic & Early Cretaceous)	M, N	LM, D		Cryptocephalic & cryptothoracic nassellarians, taxonomy, new species
Dumitrica	1978	Italy, Romania	Triassic - Jurassic	N	LM, D		Description of new family Eptingiidae
Dumitrica	1982	Mesozoic, Cenozoic	Mesozoic, Cenozoic	M, N	LM, D		Description of new species, evolution of Centrocubidae
Dumitrica & De Wever	1991	Austria	Late Jurassic		SEM, D		Forams species re-assigned to radiolarians
Dumitrica & Mello	1982	Slovakia	Callovian - Oxfordian	N	SEM, TS		Description of new genus, list of species
Dun *et al.*	1901	Australia	Early Cretaceous		LM		List of species, diatoms
Dundo & Zhamoida	1963	Russia	Valanginian	M, N	D, TS		Description of new species (in Russian)
Dyer & Copestake	1989	North Sea Basin	Kimmeridgian - Ryazanian	M	SEM, RM	Yes	13 rad events recognised
Eicher	1960	N. America	?Early Cretaceous	N	LM		Stratigraphy, other fossils, one rad new species
Elliot	1959	Northern Iraq	Triassic, Jurassic, Cretaceous				List of genera identified
Etheridge & Dun	1902	Australia	Cretaceous (incl. Early)				List of species & their occurrence
Faure & Ishida	1990	Philippines	Mid - Late Jurassic		SEM		Geology (olistostrome), list of rad species
Feary & Hill	1978	New Zealand	Mesozoic (Early Cretaceous?)	M	SEM		Age assignment uncertain
Ferriere *et al.*	1988	Greece	Late Jurassic				Geology, radiolarites, ophiolites (in French)
Fischli	1916	Europe	Early Cretaceous		D		List of species (in German)
Flügel & Meixner	1972	Austria	Late Jurassic		LM		Few rads (genera given) & sponge spicules described (in German with English abstr.)
Foley *et al.*	1986	New Zealand	Mid Jurassic - Early Cretaceous	M	SEM		
Folk & McBride	1978	Italy	Late Jurassic		TS		Petrography of radiolarites, ophiolites
Foreman	1973	NW Pacific	?Late Jurassic - Cretaceous, Cenozoic	M, N	SEM, LM	Yes	3 rad assemblages, range charts, description of new species, DSDP Site
Foreman	1975	N. Pacific	Cretaceous (incl. Berriasian)	M, N	LM	Yes	DSDP Site, description of new species
Foreman	1977	Atlantic Ocean	Late Jurassic - Cretaceous		LM	Yes	New zones for Cretaceous, correlation, range charts
Foreman	1978a	Atlantic Ocean	Latest Jurassic - Early Cretaceous, Late Cretaceous	M, N	LM		DSDP Site, list of species

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Foreman	1978b	SE Atlantic	Cretaceous (incl. Early Cret.)	N	LM		Description of new species, DSDP Site
Fourcade *et al.*	1991	Turkey	Jurassic - Cretaceous				Rads mentioned (list of species), stratigraphy (in French)
Furukubo *et al.*	1985	Japan	Mid Jurassic			Yes	2 zones, correlation with other zonations, chart of rad distribution
Garison & Fisher	1969	worldwide	Mesozoic		TS		General paper for radiolarites
Geroch & Nowak	1963	Poland (Carpathians)	Valanginian - Albian		D		Stratigraphy, other fossils, rad list of species given (in Polish)
Geyer	1961	Germany	Late Jurassic		D		*Cenosphaera* morphotype illustrated (in German)
Gorican	1983	Slovenia	Late Callovian - Early Tithonian	M	SEM		(in yugoslavian with English summary)
Gorican	1987	Yugoslavia	Early Jurassic, Bathonian - Kimmeridgian, Albian - Cenomanian	M	SEM		Comparison of rad fauna with a fauna from Greece
Gorican & Kolar-Jerkovsek	1984	Slovenia	Triassic, Jurassic	M	SEM		
Grunau	1959	Europe	Jurassic, Cretaceous				Radiolarites & their deposition (in German)
Grunau	1965	worldwide	all				Distribution of radiolarian cherts
Guidi *et al.*	1984	Japan	Jurassic?		SEM		
Hanzawa *et al.*	1961	Japan	all				Catalogue with rad specimens
Hattori	1984	Japan	Mesozoic (incl. Jurassic)				Rads mentioned, geological evolution of area
Hattori	1993	Japan	Jurasic		SEM, TS		Diagenesis affecting rad preservation
Hayasaka *et al.*	1983	Japan	Late Jurassic		SEM		List of species, *M. mediodilatus* illustr. (in Japanese)
Heitzer	1930a	Europe (Carpathians)	Late Jurassic	M	D		(in German)
Heitzer	1930b	Europe (Alps)	?Middle Jurassic, all	M, N	D		*Cenosphaera* & *Tricolocapsa* morphotypes, general range chart of species (all ages)
Hinde	1894	N. America	?Early Cretaceous	M	D		
Hinde	1900a	Borneo	Jurassic - Cretaceous	M, N	D		
Hinde	1900b	worldwide	all				Paper on fossil radiolaria
Hiroi *et al.*	1987	Japan	Jurassic		SEM		Age cannot be well-defined, poorly preserved rads
Hisada & Kishida	1986	Japan	Late Carboniferous - Early Cretaceous			Yes	7 zones for the Jurassic, lists of species

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Hojnos	1916	Hungary	Palaeozoic, Mesozoic (incl. Early Cretaceous)	M, N	TS		List of species and occurrences (in German)
Holdsworth & Nell	1992	Antarctica	Late Jurassic - Early Cretaceous		SEM		Geology, palaeoceanography
Holzer	1980	Austria	Tithonian - Early Cretaceous	M	SEM		
Hudson *et al.*	1954	Oman	Tithonian - Early Cretaceous				List of species identified is given
Huzimoto	1938	Japan	?Jurassic		TS, D		
Iacob & Nicorici	1957	Romania	Late Jurassic - Early Cretaceous	M, N	D, TS		Description of new species, list of species (in Italian)
Ichikawa	1946	Japan	Mesozoic				List of species & occurrence (in Japanese)
Ichikawa & Yao	1973	Japan	Mesozoic, Cenozoic		SEM, LM		Study on pore patterns of nassellaria
Ichikawa & Yao	1976	Japan	Mesozoic (incl. Jurassic)	N	SEM, LM		Description of new genera (*Unuma* & *Protunuma)*
Igo *et al.*	1987	Japan	Valanginian		SEM		(in Japanese with English abstract)
Irwin *et al.*	1977	California	Late Triassic - Late Jurassic		LM		
Ishida	1983	Japan	Early Triassic - Late Jurassic		SEM	Yes	4 rad assemblages (in Japanese with English abstract)
Ishida	1985	Japan	Late Permian, Early - Mid Jurassic		SEM		Range chart of species, conodonts (in Japanese with English abstract)
Ishida	1986	Japan	Jurassic		SEM		Range chart (in Japanese)
Ishida	1987	Japan	Mid Jurassic - Late Cretaceous				Geology, list of species with ranges, conodonts (in Jap. with English abstract)
Ishida & Hashimoto	1991	Japan	Jurassic, Barremian - Albian	M	SEM	Yes	3 zones for the Barremian - Albian, reworked Jurassic rads (in Japanese with English abstract)
Ishida *et al.*	1992	Japan	Early Cretaceous	M	SEM	Yes	Assemblage zones, bivalves (in Japanese with English abstract)
Ishii & Takahashi	1993	Japan	Mid Jurassic- Paleogene				Geology, tectonics, rads mentioned
Ishizuka *et al.*	1983	Japan	Latest Jurassic		SEM, LM		
Ishizuka *et al.*	1984	Japan	Valanginian?		SEM		
Isozaki & Itaya	1990	Japan	Palaeozoic, Mesozoic				Rads mentioned, metamorphism
Isozaki *et al.*	1981	Japan	Late Jurassic		LM		List of species (in Japanese)
Isozaki *et al.*	1990	Japan	Permian - Cretaceous				Rads mentioned, accreted oceanic materials
Iwasaki *et al.*	1984	Japan	Early Cretaceous		SEM		Exact age not given (in Japanese)

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Iwasaki *et al.*	1989	Japan	Permian, Triassic, Jurassic, Cretaceous				Stratigraphy, lists of species (in Japanese with English abstract)
Iwata & Tajika	1989	Japan	Late Jurassic - Early Cretaceous, Late Cretaceous		SEM	Yes	3 rad assemblages
Jaccard	1909	Europe	Jurassic				List of genera (in French)
Jasin *et al.*	1985	Malaysia (Sabah)	Early Cretaceous				Assemblage identified is given
Jodot	1931	Europe (Corsica)	Tithonian, Albian				Few genera given (in French)
Johnson *et al.*	1991	Pacific Ocean (Mariana fore arc)	Early Cretaceous (Valanginian - Albian)				Geology, rads reported, table with zonation of Pessagno (1977a,b), range of species
Jones *et al.*	1992	Greece	Late Triassic, Mid - Late Jurassic, Mid - Late Cretaceous		SEM		Tectonic & sedimentary evolution of area, rads identified and given
Kaminski *et al.*	1992	Indian Ocean	Latest Jurassic - Cenozoic			Yes	Magnetobiostratigraphy, nannofossils, forams, ODP Site
Kamon & Nakazawa	1989	Japan	Permian, Triassic, Jurassic, Cretaceous		SEM		Bivalves (in Japanese with English abstract)
Kanamatsu *et al.*	1992	Japan	Tithonian, Late Cretaceous		SEM		(in Japanese with English abstract)
Kanie *et al.*	1981	Japan	Valanginian		SEM		List of species (in Jap. with English abstr.)
Kaplan	1984	California	Jurassic		SEM		Range chart, ophiolites, stratigraphy
Karakitsios *et al.*	1988	Greece	Callovian, Tithonian, Berriasian				Rad species given
Karitsky	1889	Russia	Early Cretaceous, Turonian				Short note (in Russian)
Karrer	1867	Austria (Alps)	Late Jurassic		D		Two rad species mistaken as foraminifera
Kato & Iwata	1989	Japan	Early Cretaceous (Berriasian? - Valanginian)		SEM		Re-evaluation of age, conodonts, stratigraphy
Kato *et al.*	1986	Japan	Early Cretaceous		SEM		(in Japanese)
Kawabata	1988	Japan	Latest Jurassic - Earliest Cretaceous	M, N	SEM, LM		Description of new species, list of species
Kawada	1953	Japan	Carboniferous, Jurassic, Cenozoic				List of species, geology, other fossils
Kazintsova & Lipman	1972	worldwide	all				List of publications from 1965-1971 (in Russian)
Khabakov	1932	Russia (Kamchatka)	Jurassic, Cretaceous	M, N?	D		Questionably new species given (in Russian)
Khabakov	1937	Russia	Late Jurassic, Early Cretaceous	M, N	D		Description of new species (in Russian)

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Khudayev	1931	Russia	Kimmeridgian - Early Cretaceous	M, N	D		Description of new species, many *Cenosphaera* morphotypes (in Russian)
Kido *et al.*	1982	Japan	Mid Jurassic		SEM	Yes	Notes on 1 rad assemblage (in Japanese with English abstract)
Kiessling	1992	Austria	Tithonian		SEM		Sponge spicules, stratigraphy & facies
Kiessling & Ziess	1992	Austria	Kimmeridgian - Tithonian	M, N	SEM		Description of new genus & species, ammonites
Kiminami *et al.*	1985	Japan	Late Valanginian - Early Barremian		SEM, TS with rads		List of species (in Japanese with English abstract)
Kimura	1944a	Japan	Triassic, Jurassic	M	TS, D		Some *Cenosphaera* & *Tricolocapsa* morphotypes given
Kimura	1944b	Japan	Triassic, Jurassic	M	TS, D		List of species with occurrence
Kishida & Hishida	1986	Japan	Late Carboniferous(?) - Earliest Cretaceous		SEM	Yes	18 rad assemblages, range charts, correlation (in Jap. with English abstract)
Kito	1987	Japan	Late Jurassic - Early Cretaceous		SEM	Yes	3 rad zones, correlation of zones, long list of species
Kito & De Wever	1990	worldwide	Mesozoic				Cladistic analysis, phylogeny of Hagiastridae (in French)
Kito & De Wever	1992	Italy (Sicily)	Mid Jurassic	N	SEM		Description of new genus & species (Hagiastridae) (in French)
Kito *et al.*	1990	Italy (Sicily)	Bathonian - Early Berriasian	M, N	SEM		Range charts, list of species, description of new species
Kling	1971	Pacific Ocean	?Late Jurassic - Cenozoic	M, N	LM		Range charts of Cenozoic species, few Mesozoic ones, DSDP Site
Kling	1982	Pacific Ocean	?Early Cretaceous - Cenozoic	M, N	SEM, LM		Mainly cenozoic forms, DSDP Site
Kobayashi	1935	Japan	Late Jurassic				Short list of species
Kobayashi	1941	Japan	Late Jurassic				Note on rads
Kobayashi	1944	Japan, Australia	Palaeozoic, Mesozoic				Radiolarian rocks
Kobayashi & Kimura	1944	Japan, worldwide	all				List of species with occurrence, composition of rad. rocks
Kojima	1984	Japan	Early Permian, Mid Jurassic				Occurrence chart, fusulinids (in Japanese with English abstract)
Kojima	1989	China	Triassic, Jurassic		SEM		Geology, list of species
Kojima & Mizutani	1987	Japan	Late Triassic, Bathonian - Callovian	M	SEM		List of rad species
Kojima *et al.*	1991	Russia, Japan	Triassic, Jurassic		SEM		Comparison with japanese assemblages
Kozlova	1971	Russia	Early Kimmeridgian		D		(in Russian)

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Kozlova	1973	Russia	Early Kimmeridgian	N	D		Same rad fauna as in Kozlova (1971), description on species (in Russian)
Kozur	1979	worldwide	?Mid Triassic, Late Triassic - Mid Jurassic, ?Late Jurrasic	N			Description of new genus *Pessagnosaturnalis* (in German)
Kozur	1984	worldwide	Triassic, Jurassic	N	SEM		Description of new genus, discussion of taxonomic position of *Hagiastrum*
Kozur	1991	Central Europe	Triassic, Jurassic		SEM		Geological evolution of the area, conodonts
Krasheninnikov (ed)	1981	Russia	Mesozoic, Cenozoic		TS		General paper on rads (in Russian)
Kumon *et al.*	1986	Japan	Latest Jurassic - Cretaceous		SEM, LM	Yes	8 rad assemblages recognised (in Jap. with English abstract)
Kurimoto	1992	Japan	Jurassic (Mid?)		SEM		*Tricolocapsa conexa* (in Japanese)
Lawson	1895	California	Jurassic, Cretaceous				Geology, note on radiolarian chert
Le Grand & Glen	1993	America	Palaeozoic, Mesozoic				Radiolarian cherts, D. Jones work
Leischner	1961	Austria	Jurassic		D		3 rad morphotypes (in German)
Leong	1975	Malaysia (Sabah)	Early Cretaceous				Table with rad species
Li	1986	China	Early Tithonian	M, N	SEM		Description of new species (in Chinese with English summary)
Lipman	1953	Russia	Mesozoic (incl. Jurassic)	M	TS, D		(in Russian)
Lipman	1969	Europe	Mesozoic				General paper (in Russian)
Lipman & Boyanov	1976	Bulgaria	Valanginian - Hauterivian		LM		(in Russian)
Lloyd	1968	Australia	Early Cretaceous	M	TS		
Lozynyak	1969	Russia (Carpathians)	Early Cretaceous	M, N	D		(in Russian)
Lozynyak	1975	Russia (Carpathians)	Cretaceous (incl. Early)	N	D		(in Russian)
McLaughlin & Pessagno	1978	California	Jurassic, Cretaceous				Stratigraphy, tectonics, list of rad localities, table of zonation
MacLeod	1988	Oregon	Toarcian - Callovian	M, N	SEM, LM		Paper on *Perispyridium*
Marcucci & Passerini	1991	Italy	Jurassic, Cretaceous				General paper on siliceous sediments in the area
Marcucci-Passerini & Marri	1990	Italy	Oxfordian - Kimmeridgian		SEM		Rad species given
Matsuoka	1982a	Japan	Late Jurassic	N	SEM, LM		Description of new species
Matsuoka	1982b	Japan	Mid - Late Jurassic		SEM, LM	Yes	3 rad assemblages, range chart (in Japanese with English abstract)
Matsuoka	1983a	Japan	Triassic, Jurassic		SEM, LM		Conodonts (in Japanese)
Matsuoka	1983b	Japan	Mid - Late Jurassic	M, N	SEM, LM	Yes	3 assemblage zones, description of new species

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Matsuoka	1984a	Japan	Jurassic, Early Cretaceous				Zonations mentioned, range charts of rad species (in Jap. with English abstract)
Matsuoka	1984b	Japan	Late Jurassic	M, N	SEM, LM		Description of new species
Matsuoka	1985	Japan	Mid Jurassic		SEM		List of species (in Jap. with English abstr.)
Matsuoka	1986a	Japan	Jurassic - Early Cretaceous		SEM	Yes	Summary of zonation (in Japanese with English abstract)
Matsuoka	1986b	Japan	Late Jurassic	N	SEM, LM	Yes	Description of 1 assemblage, new species
Matsuoka	1986c	Japan	?Mid Triassic - ?Early Cretaceous				Stratigraphy, geology, use of Jap. rad zones for age assignment (in Japanese with English abstract)
Matsuoka	1986d	Japan	Mid Jurassic		SEM	Yes	On the boundary of 2 *Tricolocapsa* zones, (in Japanese with English abstract)
Matsuoka	1987	Japan	Late Tithonian - Earliest Cretaceous		SEM		(in Japanese with English abstract)
Matsuoka	1988	Japan	Jurassic		SEM	Yes	*Tricolocapsa conexa* biozone, correlation
Matsuoka	1989	Japan	Berriasian		SEM		Illustrations of *Achaeodictyomitra* & *Holocryptocanium* morphotypes (in Japanese with English abstract)
Matsuoka	1990	Western Pacific	Bathonian/Callovian		SEM		List of species, ODP Site
Matsuoka	1992a	Western Pacific	Bajocian - Barremian		SEM	Yes	ODP Leg 129, 7 rad zones, correlation, long list of species
Matsuoka	1992b	Japan	Jurassic - Early Cretaceous			Yes	Japanese rad zones used in tectonic evolution
Matsuoka	1993	Japan	Jurassic		SEM	Yes	Summary of Japanese biostratigraphy, long range chart, localities
Matsuoka & Oji	1990	Japan	Mid Jurassin		SEM		List of rad species (in Japanese)
Matsuoka & Yao	1985	Japan	Latest Jurassic (Tithonian)	N	SEM, LM		Description of new species
Matsuoka & Yao	1986	Japan	Jurassic		SEM, LM	Yes	8 rad zones, correlation with other zonations
Mattson & Pessagno	1979	Puerto Rico	Jurassic, Early Cretaceous		SEM		Tectonics
Mizutani	1981	Japan	Tithonian	M, N	SEM		List of species & occurrence, geology, description of new species in english, biostratigraphic note (in Japanese with English abstract)
Mizutani & Kido	1983	Japan	Mid Jurassic		SEM		Description of new species
Mizutani & Kojima	1992	Japan, East Asia	Triassic, Jurassic		SEM		Tectonics
Mizutani & Shibata	1983	Japan	Late Jurassic - Early Cretaceous				Paper on diagenesis, list of species.

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Mizutani & Yao	1991	Japan	Palaeozoic, Mesozoic		SEM	Yes	Summary of zonation, geology
Mizutani *et al.*	1981	Japan	Jurassic		SEM	Yes	3 rad assemblages, general biostratigraphy
Mizutani *et al.*	1982	Japan	Mid Triassic - Late Cretaceous	M	SEM	Yes	Summary of biostratatigraphy in Japan, geology
Mizutani *et al.*	1984	Japan	Mid Jurassic		SEM		
Mizutani *et al.*	1986	China	Triassic, Jurassic		SEM		
Mizutani *et al.*	1990	Japan, East Asia	Triassic - Jurassic				Geology, rads used , some species given
Moore	1973	Pacific Ocean	Latest Jurassic - Late Cretaceous	M	LM	Yes	7 zones recognised, range chart, DSDP Site
Murata	1987	Japan	Mesozoic (incl. Jurassic)				Radiolarians mentioned
Murchey	1984	California	Early Jurassic - Late Cretaceous		SEM	Yes	7 assemblages recognised, range charts, stratigraphy
Murchey & Jones	1984	California	Mesozoic			Yes	7 rad assemblages recognised, species are given
Murchey *et al.*.	1983	Western N. America	Palaeozoic, Mesozoic (incl. Jurassic)				Rad cherts in N. America (distribution, age & depositional environments)
Nagai	1989	Japan	Jurassic		SEM		Effect of supersonic vibration on test surface of rads
Nagai & Mizutani	1990	Japan	Mid - Late Jurassic	M, N	SEM		Paper on *Eucyrtidiellum*
Nagy	1971	Hungary	Late Jurassic				Rad mentioned, few genera given, other fossils (in Russian)
Nakae	1991	Japan	Latest Jurassic		SEM		(in Japanese)
Nakagawa & Nakaseko	1977	Japan	Late Jurassic - Early Cretaceous		SEM		List of species (in Japanese with Esperanto abstract)
Nakaseko & Nishimura	1981	Japan	Tithonian - Campanian	M, N	SEM, LM	Yes	7 rad assemblages recognised
Nakaseko *et al.*	1982	Japan	Cretaceous (incl. Early)		SEM, LM	Yes	6 rad assemblages, correlation, summary of zonations, list of species (in Japanese with English abstract)
Nakazawa *et al.*	1983	Japan	Tithonian - Late Cretaceous		SEM, LM	Yes	6 assemblages recognised
Nekrasova	1973	worldwide	all		TS, D		General paper, other fossils
Neviani	1900	Italy	Late Jurassic, Early Cretaceous	M, N	D		(in Italian)
Nozzoli	1986	Italy	Oxfordian, Kimmeridgian				Rad species given
O'Dogherty *et al.*	1989	Spain	Mid - Late Jurassic			Yes	UA biozones (in Spanish)
Obradovic & Gorican	1989	Yugoslavia	Triassic, Jurassic		SEM		Siliceous sediments in the area
Okada *et al.*	1989	Japan	Late Jurassic - Early Cretaceous		SEM		Lists of species, nannofossils

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Okamura	1980	Japan	Cretaceous (incl. Early)		SEM		Range charts (in Japanese)
Ormiston	1993	wordlwide, Russia	all				Rads in relation to hydrocarbon source rocks
Otsuka	1985	Japan	Permian, Triassic, Late Jurassic				List of species (in Japanese with English abstract)
Ozvoldova	1975	Slovakia	Late Jurassic - Early Cretaceous	M, N	SEM		Description of new genera, species
Ozvoldova	1978	Slovakia (West Carpathians)	Mid - Late Jurassic		SEM		Summary paper (in Czech with English abstract)
Ozvoldova	1979	West Carpathians	Late Jurassic - Early Cretaceous	M, N	SEM		Decsription of new species
Ozvoldova	1988	Slovakia (West Carpathians)	Late Oxfordian - Early Tithonian	M, N	SEM, LM		Description of a new species
Ozvoldova	1990	Slovakia	Oxfordian	M, N	SEM		Range charts, description of new species
Ozvoldova	1992	Slovakia (Western Carpathians)	Callovian	M	SEM		
Ozvoldova & Petercakova	1987	Slovakia (Carpathians)	Oxfordian - Tithonian	M	SEM		
Ozvoldova & Sykora	1984	Slovakia	Berriasian	M, N	SEM, LM		Description of new species
Pantanelli	1889	Italy	Jurassic, Cenozoic				Rads mentioned (in Italian)
Parona	1890	Italy	Early Cretaceous	M, N	D		Description of new species (in Italian)
Partington *et al.*	1993	North Sea Basin	Kimmeridgian - Ryazanian			Yes	7 microfossil biozones (incl. rads), correlation with ammonites, palynology
Pavsic & Gorican	1987	Western Slovenia	Late Berriasian - Valanginian	M	SEM		Nannofossils used for age assignment
Pessagno	1969	Atlantic Ocean	Late Jurassic - Cretaceous		SEM		Report on rads & forams, DSDP Site
Pessagno	1971	Atlantic Ocean, California	Tithonian, Late Cretaceous	M, N	SEM		Paper on Hagiastridae, description of new genera and species
Pessagno	1973a	California	Late Jurassic - Early Cretaceous		SEM		Age of rad cherts in the studied area
Pessagno	1977a	California	Late Jurassic	M, N	SEM, LM	Yes	First zonation for Jurassic of N. America
Pessagno	1977b	California	Late Jurassic - Cretaceous	M, N	SEM, LM	Yes	Biozonation , description of new taxa
Pessagno	1977c	worldwide	Mesozoic (incl. Jurassic)	M	SEM, LM	Yes	General paper, zonation summary of Late Cretaceous, techniques
Pessagno & Blome	1982	North America	Mid - Late Jurassic	M, N	SEM, LM		Paper on *Turanta* (n. gen.) and *Perispyridium*

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Pessagno & Blome	1986	North America	Jurassic				Geology, palaeobiogeography
Pessagno & Blome	1990	North America	Oxfordian - Kimmeridgian			Yes	Revision of a part of existing zonation, chronostratigraphy
Pessagno & Mizutani	1992	North America, Japan	Jurassic		SEM	Yes	Ementation of N. American zonation, correlation with japanese zonation
Pessagno & Whalen	1982	North America	Early - Mid Jurassic	M, N	SEM, LM		Description of new genera & species, phylogeny of families
Pessagno *et al.*	1984	Western North America	Late Jurassic	M, N	SEM, LM	Yes	Revised zonation, description of new genus and species
Pessagno *et al.*	1986	North America	Jurassic	M, N	SEM, LM		Description new genera and species of nassellarians, palaeobiogeography, stratigraphy
Pessagno, Longoria, MacLeod & Six	1987a	North America	Jurassic	M, N	SEM, LM		Description of new genera and species, palaeobiogeography
Pessagno, Blome, Carter *et al.*	1987b	North America	Jurassic			Yes	Preliminary rad zonation for entire Jurassic
Pessagno *et al.*	1989	North America	Jurassic	M, N	SEM	Yes	Revised zonation, description of new family, genera and species
Pessagno *et al.*	1993	California, Oregon	Mid - Late Jurassic	M, N	SEM	Yes	Revised rad zonation, correlation with European & Japanese zonations
Picchi	1985	Italy	Late Jurassic - Early Cretaceous				Stratigraphy & ophiolites
Price *et al.*	1993	North Sea Basin	Late Jurassic			Yes	Some rads events, lithostratigraphy
Protescu	1936	Romania	Callovian - Oxfordian, Kimmeridgian, Cretaceous		TS		Geology, list of species, other fossils (in French)
Pujana	1989	Argentina	Late Jurassic - Early Cretaceous	M, N	SEM		Range chart
Pujana	1991	Argentina	Tithonian	M, N	SEM		Description of new species of Pantanelliidae
Rangin *et al.*	1981	Mexico	Late Triassic, Late Jurassic - Early Cretaceous				Study on geochemistry of rad chert, rads species given
Ransome	1894	California	Cretaceous, ?Jurassic				Note of radiolarian chert, geology
Richter	1925	Germany	Cretaceous, ?L. Jurassic	M, N	D		Description of new species (in German)
Riedel & Schlocker	1956	California	?Early Cretaceous	M	D		
Routhier	1946	Europe	Mesozoic				Radiolarites, short note (in French)
Rüst	1884	Europe	Jurassic				Rads mentioned (in German)
Rüst	1885a	Europe	Jurassic	M, N	D		Description of new species (in German)
Rüst	1885b	Europe	Jurassic, Early Cretaceous				List of families (in German)

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Rüst	1888	Europe	Cretaceous (incl. Early)	M	D		
Rüst	1897	Europe	Mesozoic				Catalogue with species and occurrence (in German)
Rüst	1898	Europe	Cretaceous (incl. Early)	M, N	D		Description of new species
Sacco	1905	Europe	Cretaceous (?Early)				Genera given, other fossils (in French)
Saida	1987	Japan	Triassic, Jurassic		SEM		(in Japanese)
Saito	1989	Japan	Permian,Triassic, Jurassic		SEM		Conodonts (in Jap. with English abstract)
Saito & Tsukamoto	1993	Japan	Mid Triassic - Mid Jurassic		SEM		Chert breccia (in Jap. with English abstr.)
Salvador *et al.*	1992	Mexico	Jurassic - Cretaceous				Rads mentioned, species are given
Sanfilippo & Riedel	1985	worldwide	Latest Jurassic - Cretaceous	M	SEM, LM	Yes	General paper, biostr. zones for Cretaceous, preparation techniques, publications, etc.
Sano *et al.*	1992	Japan	Jurassic		SEM		Japanese zonation used for tectonostratigraphy
Sashida *et al.*	1982	Japan	Jurassic				Table with distribution of samples
Sashida *et al.*	1984	Japan	Permian - Maastrichtian				Long list of species
Sashida *et al.*	1989	Japan	Late Jurassic - Cretaceous				List of species
Sato	1992	Southeast Asia, Japan	Palaeozoic, Mesozoic				Geology, stratigraphy, Japanese rad zonation mentioned
Schaaf	1981	worldwide	all, Eocene				Morphology, phylogeny, skeleton of rads, etc. (in French)
Schaaf	1984	worldwide	Early - Mid Cretaceous	M	SEM, LM		General on rads, taxonomy
Schaaf	1985	Atlantic, Pacific, and Indian Oceans, Italy	Latest Jurassic - Cretaceous			Yes	21 zones, correlation with other zonations, range of species
Schaaf *et al.*	1985	Italy	Late Oxfordian - Early Kimmeridgian		SEM		(in French)
Schmidt-Effing	1979	Central America	Late Jurassic - Eocene		SEM, TS		Geology, general paper (in German)
Schrivenor	1912	Indian Ocean	Mesozoic (incl. Jurassic)				General paper, rad.iolarian rocks
Sedlock & Isozaki	1990	Mexico	Early Jurassic - Early Cretaceous			Yes	7 rad assemblages recognised, correlation with other zonations, geology
Seiders & Blome	1984	California	Triassic - Early Cretaceous				Study on conglomerates, rads used for age
Seiders *et al.*	1979	California	Mesozoic (incl. Jurassic)				List with rad. localities, conglomerates
Sido & Sikabonyi	1953	Hungary (Carpathians)	Jurassic				Rads mentioned, radiolarites (in Hungarian)
Smith, W. D.	1913	Philippines	?Jurassic, Cretaceous, Cenozoic		TS		Stratigraphy, list of species given, other fossils
Smith, W. D.	1916	Oregon	Mesozoic (?Jurassic)				Note on radiolarians
Spörli & Aita	1988	New Zealand	Triassic - Late Jurassic		SEM		Fieldwork guide, list of species

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Spörli *et al.*	1989	New Zealand	Late Triassic - Late Jurassic		SEM		
Squinabol	1912	Europe	Jurassic, Cretaceous	M, N	TS		Description of new species (in Italian)
Squinabol	1914a	worldwide	all	N			Catalogue with all publications up to that date, taxonomy (in Italian)
Squinabol	1914b	Italy	Jurassic, Cretaceous	M, N	D		List of species, description of new species (in Italian)
Stais *et al.*	1990	Greece	Triassic, Late Jurassic - Early Cretaceous				Geology, some rad species given
Steiger	1981	Austria	Late Jurassic		SEM		Study on turbidites, part on rads, list of species
Steiger	1992	Austria, Germany	Oxfordian - Valanginian	M, N	SEM	Yes	4 rad zones, taxonomy, description of new genera & species, palaeoecology
Suyari	1984	Japan	Berriasian - Barremian, Cenomanian		SEM		List of species (in Japanese with English abstract)
Suyari & Kuwano	1986	Japan	?Barremian - Cenomanian		SEM		Re-evaluation of previous Kimmeridgian in age strata, forams
Suyari *et al.*	1982	Japan	Palaeozoic, Mid Jurassic - Early Cretaceous		SEM		Stratigraphy (in Japanese with English abstract)
Suyari *et al.*	1983	Japan	Palaeozoic, Triassic - Mid Jurassic		SEM		Range chart, other fossils (in japanese with English abstract)
Suzuki	1939	Japan	Palaeozoic, Jurassic, Cretaceous		TS		List of species
Tajika & Iwata	1983	Japan	Early Cretaceous		SEM		*A. apiarum* illustrated (in Japanese)
Takemura	1986	Japan	Jurassic (Mid?)	M, N	SEM		Description of new families, genera and species, classification of nassellarians
Takemura & Nakaseko	1982	Japan	Late Jurassic	N	SEM		Description of new genera
Takemura & Nakaseko	1983	Japan	Mid Jurassic	N	SEM		Description & phylogeny of new genus *Perseus*
Takemura & Nakaseko	1986	Japan	Jurassic	M, N	SEM		Study on *Eucyrtidium*
Taketani & Kanie	1992	Japan	Berriasian - Early Albian		SEM		
Tan	1978	Malaysia (Sarawak)	Early Cretaceous				List of species
Tan Sin Hok	1927	Indian Ocean	Mesozoic (incl. Jurassic, Cretaceous)	M, N	D		Description of new species (in Dutch)
Tan Sin Hok	1931	worldwide	Mesozoic, Cenozoic				List of species from various publications, stratigraphy
Tan Sin Hok	1935	Indian Ocean	Mesozoic (incl. Jurassic), Cenozoic				List of some species (in Dutch)

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Tanaka *et al.*	1985	Japan	Late Jurassic		SEM, LM		(in Japanese)
Termier & Maury	1928	Europe	Jurassic				Note on radiolarites (in French)
Thiebault *et al.*	1981	Greece	Mid Jurassic - Late Cretaceous				Table with rad ranges (in French)
Tikhomirova	1975	Russia	Jurassic, Cretaceous	M, N	TS		Paper on cryptocephalic nassellarians, description of new species (in Russian with English summary)
Tikhomirova	1983	Russia (Carpathians)	Late Jurassic - Early Cretaceous	N	TS		Description of new species, range charts (in ussian with English abstract)
Tikhomirova	1984	Europe, Russia	Late Jurassic - Cretaceous			Yes	9 zones recognised, range charts of species (in Russian with English abstract)
Tikhomirova	1986	Russia	Jurassic - Early Cretaceous			Yes	Correlation of zones (in Russian)
Tikhomirova	1987	Bulgaria, Russia	Jurassic	M, N	TS		Description of new genera & species
Tikhomirova	1988	Russia (Far East)	Jurassic - Early Cretaceous			Yes	12 zones, correlation with Japanese zonations, range charts of species
Tonielli	1992	Italy	Mid - Late Jurassic	N	SEM		Description of 2 new species (*Andromeda*, *Monotrabs*)
Trauth	1948	Europe (Alps)	Jurassic				Rads mentioned (in German)
Tromp	1948	Turkey	Jurassic				Paper on radiolarites
Tumanda	1989	Japan	Valanginian - Coniacian or Santonian?	M	SEM, LM	Yes	4 rad assemblages, correlation with other zonations, range charts, description of new species
Tumanda & Sashida	1988	Japan	Valanginian - Barremian, Cenomanian - Turonian	M, N	SEM	Yes	3 assemblage zones for the Late Cret., list of species, bivalves (in Japanese with English abstract)
Turner	1965	France	Berriasian		TS		Rads mentioned, few illustrated
Vialov *et al.*	1967	Russia	all				report on fossil rads, (in russian)
Vinassa de Regny	1898a	Italy	Mesozoic (?Jurassic)	N			Short note (in Italian)
Vinassa de Regny	1898b	Italy	?Tithonian	M, N			List of species given (in Italian)
Vinassa de Regny	1899	Italy	?Tithonian	M, N	D		Description of new species (in Italian)
Vinassa de Regny	1900	Italy	?Jurassic, Cretaceous	M, N	D		Description of new species (in Italian)
Vishnevskaya	1984	Russia, Europe, Cuba	Late Jurassic - Early Cretaceous				Radiolarites, short note
Vishnevskaya	1985	Russia	Late Jurassic - Cretaceous			Yes	Existing zonal schemes compared (in Russian with English absstract)
Vishmevskaya	1988	Russia	Jurrasic - Cretaceous	N	SEM		Range charts of species (in Russian)
Vishnevskaya	1992a	Russia	Jurassic - Cretaceous	N	SEM		General paper on rads from Russia

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Vishnevskaya	1993	Russia	Jurassic - Cretaceous		SEM	Yes	13 rad zones for Caucasus area, 11 rad zones for Pacific rim area, correlation table
Vogler	1941	Central America	Jurassic - Cretaceous		D		Geology, other fossils, list of species (in German)
Wakita	1982	Japan	Jurassic (?Mid)		SEM		Table of occurrence of species (in Japanese with English abstract)
Wakita	1987	Japan	Late Jurassic - Early Cretaceous		SEM		List of species (in Japanese)
Wakita	1988a	Japan	Triassic - Cretaceous	N	SEM		Geology, description of new species, summary of Japanese zonation
Wakita	1988b	Japan	Early Jurassic - Early Cretaceous				Biostr. zones mentioned, table of diagnostic species
Wakita & Okamura	1982	Japan	Permian - Triassic, Jurassic		SEM		(in Japanese with English abstract)
Wakita *et al.*	1994	Indonesia	Cretaceous (incl. early Cret. up to Barremian)		SEM		5 rad assemblages distinguished
Wang & Sheng	1982	China	Early Permian, Late Triassic, Late Jurassic	M, N	LM, TS		Description of new genus (in Chinese with English abstract)
Waterston	1951	North Sea Basin	Kimmeridgian				Stratigraphy, rads mentioned
Widz	1991	Poland (West Carpathians)	Oxfordian - Kimmeridgian	M	SEM		Age assignment using UA (in French)
Widz & De Wever	1993	Poland (West Carpathians)	Oxfordian - Kimmeridgian	M, N	SEM		Description of new nassellarian genus, new species (in French)
Wisniowski	1889	Poland	Late Jurassic	M, N	D		Paper on rads & forams (in German)
Wu	1993	China (Tibet)	Late Kimmeridgian - Late Valanginian	M, N	SEM		Description of new genera & species
Wu & Li	1982	China (Tibet)	Berriasian?, Turonian	M, N	SEM		Description of new species (in Chinese with English abstract)
Yamagata	1992	Japan	Jurassic (Mid?)		SEM		*Tricolocapsa conexa* (in Japanese)
Yamakita	1986	Japan	Mid Jurassic				Table with rad occurrence, geology, conodonts
Yamakita	1988	Japan	Triassic - Jurassic				List of rads, structural geology, conodonts
Yamamoto	1983	Japan	Late Jurassic		SEM		(in Japanese)
Yamamoto	1985	Japan	Late Permian, Jurassic		SEM		Geology (in Japanese with English abstr.)
Yamamoto *et al.*	1985	West Atlantic Ocean	Callovian		SEM, TS		List of species (with notes)
Yanai	1983	Japan	Latest Jurassic - Cretaceous				Rad assemblage mentioned (in Japanese)
Yang & Mizutani	1991	China	Triassic, Early Jurassic, Jurassic	N	SEM		Mention Jurassic radiolarian assemblages of Japan, emend. of Parasaturnalidae

AUTHOR(S)	DATE	LOCALITY	AGE	TAXON.	ILLUSTRAT.	BIOS.	COMMENTS
Yang & Pessagno	1989	Mexico	Late Tithonian	M, N	SEM		Description of new genera and species
Yang & Wang	1990	China	Late Kimmeridgian - Early Tithonian	M, N	SEM		Description of new family, genera and species
Yao	1979	Japan	Late Jurassic - Cretaceous	M, N	SEM, LM		Description of new species
Yao	1983	Japan	Permian - Cretaceous		SEM	Yes	Summary of rad assemblages of Japan
Yao	1984	Japan	Mid Triassic - Late Cretaceous		SEM, LM	Yes	13 rad assemblages recognised, geology
Yao	1990	Japan	Triassic, Jurassic		SEM	Yes	Review of existing japanese zonations, correlation
Yao *et al.*	1980	Japan	Triassic - Mid Jurassic		SEM, LM	Yes	4 rad assemblages, list of species
Yao *et al.*	1982	Japan	Ladinian - Late Jurassic		SEM, LM	Yes	11 rad assemblages recognised (in Japanese with English abstract)
Yehara	1926	Japan	Late Jurassic - Late Cretaceous	M	D		Stratigraphy
Yehara	1927	Japan	Palaeozoic, Triassic, Late Jurassic	M	D		List of species given
Zagorcev & Tikhomirova	1986	Bulgaria	Early - Late Jurassic	M	TS		(in Russian with English abstract)
Zakariadze *et al.*	1983	Russia (Caucasus)	?Late Jurassic - Early Cretaceous				Study on ophiolites, rads mentioned, short list of species is given
Zhamoida	1960a	Russia	Palaezoic, Mesozoic (incl. Jurassic)				General paper (in Russian)
Zhamoida	1961	Russia	Early Cretaceous	N	D		Stratigraphy (in Russian)
Zhamoida	1968a	worldwide	all		D		Systematic discussions, general paper, review of rad publications (in Russian)
Zhamoida	1968b	Russia	Triassic, Jurassic	N	D, TS		(in Russian)
Zhamoida	1969	Russia	Mesozoic (incl. Jurassic)		D		Preliminary results of rad study
Zhamoida	1972	Russia	all	M, N	D, TS		Stratigraphy, range charts, methods of study (in Russian)
Zhamoida	1973	worldwide	Palaeozoic, Mesozoic				General paper on rads (in Russian)
Zhamoida	1975	Russia	all				Discussion on taxonomy, systematics, etc. (in Russian)
Zhamoida	1984	worldwide	all				General paper on biostratigraphy, systematics
Zhamoida *et al.*	1976	Russia	?Early - Late Cretaceous				general note on rads, list of species (in Russian)

Total number of entries: 445

APPENDIX 2

Catalogue numbers of radiolarian specimens and their details

CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME
CK 1	7B	92.52	3800/19,20	CK 2	7B	92.52	3800/17,18	CK 3	12/28-1	5800	3240/2
CK 4	9/18A-4	10760	3277/3	CK 5	9/18A-4	10760	3385/20	CK 6	28/5-1	6470	3384/12
CK 7	22/21-2	12610	3583/6	CK 8	22/21-2	12650	3577/28	CK 9	22/21-2	12650	3577/27
CK 10	EATHIE A	10430	3382/19	CK 11	22/21-2	12650	3577/29	CK 12	12/28-1	5960	3240/21
CK 13	12/28-1	5820	3240/8,9	CK 14	22/21-2	12660	3577/6	CK 15	EATHIE B2	10512	3745/32
CK 16	28/5-1	6490	3532/17	CK 17	14/18-2	7840	3719/23	CK 18	22/21-2	13190	3372/21
CK 19	22/21-2	12210	3351/21	CK 20	22/21-2	12650	3597/30	CK 21	7B	86.94	3799/1
CK 22	EATHIE A	10423	3381/24	CK 23	16/17-5	14130	3509/26	CK 24	16/17-5	14150	3509/22
CK 25	22/21-2	12360	3366/6	CK 26	22/21-2	12660	3389/12,13 3389/14	CK 27	29/12-1	6680	3389/15,16
CK 28	22/21-2	13040	3370/26	CK 29	22/21-2	12660	3577/4,5 3583/23 3597/28	CK 30	12/28-1	6280	3536/3,5
CK 31	EATHIE B2	10512	3745/33	CK 32	EATHIE B2	10512	3725/14	CK 33	EATHIE B2	10512	3733/18,19
CK 34	EATHIE B2	10512	3726/25	CK 35	EATHIE B2	10512	3733/33	CK 36	14/18-2	8270	3745/34
CK 37	22/21-2	12190	3733/34,35	CK 38	22/21-2	12190	3725/29	CK 39	23/27-4	10550	3385/28,29 3302/3
CK 40	23/27-4	10580	3305/4	CK 41	23/27-4	10600	3589/27	CK 42	29/12-1	8190	3245/24,25
CK 43	9/18A-4	10760	3279/33	CK 44	22/21-2	12300	3365/9	CK 45	9/18A-4	11030	3279/22
CK 46	EATHIE A	10423	3381/3	CK 47	EATHIE A	10430	3382/7	CK 48	EATHIE A	10430	3382/22
CK 49	EATHIE B1	10404	3371/19	CK 50	EATHIE A	10430	3382/15	CK 51	EATHIE A	10430	3382/3
CK 52	EATHIE A	10423	3381/2	CK 53	EATHIE A	10430	3382/10, 11	CK 54	EATHIE B1	10419	3380/9
CK 55	EATHIE A	10430	3416/29	CK 56	EATHIE A	10423	3745/28	CK 57	EATHIE B2	10512	3725/18
CK 58	EATHIE A	10423	3381/4	CK 59	EATHIE A	10423	3381/5,6	CK 60	EATHIE A	10430	3382/6
CK 61	EATHIE A	10430	3382/9	CK 62	14/18-2	8040	3719/7	CK 63	EATHIE B2	10512	3725/25,26 3726/34
CK 64	EATHIE A	10430	3382/23	CK 65	9/18A-4	10760	3277/23,32	CK 66	EATHIE A	10430	3382/5
CK 67	EATHIE A	10423	3381/20	CK 68	EATHIE B2	10512	3726/20	CK 69	7B	86.94	3798/15
CK 70	9/18A-4	10880	3283/18	CK 71	9/18A-4	10800	3279/24	CK 72	7B	86.94	3798/15-17
CK 73	16/17-5	12040	3589/19,10	CK 74	9/18A-4	10760	3283/21	CK 75	7B	92.52	3814/10 3800/12,13
CK 76	7B	92.52	3807/1,24	CK 77	9/18A-4	10760	3281/1	CK 78	7B	85.14	3798/25,26
CK 79	9/18A-4	10760	3282/17	CK 80	16/17-5	12000	3509/7	CK 81	EATHIE B2	10509	3726/15 3745/13

CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME
CK 82	9/18A-4	10930	3282/24	CK 83	EATHIE B2	10509	3718/	CK 84	EATHIE B2	10509	3718/10,11
CK 85	9/18A-4	11030	3385/5,6 3279/4	CK 86	9/18A-4	10930	3589/21,22 3285/25	CK 87	16/17-5	14230	3532/2-4
CK 88	EATHIE A	10430	3416/27	CK 89	EATHIE A	10430	3381/29	CK 90	EATHIE B1	10404	3546/2
CK 91	23/27-4	10650	3312/22	CK 92	EATHIE A	10423	3381/16,17	CK 93	EATHIE B1	10404	3416/13
CK 94	EATHIE B1	10404	3371/17	CK 95	EATHIE B1	10419	3416/21	CK 96	23/27-4	10650	3312/32
CK 97	23/27-4	10650	3312/26	CK 98	EATHIE B2	10512	3745/12	CK 99	7B	92.52	3807/15,31
CK 100	23/27-4	10650	3386/4	CK 101	7B	86.94	3799/18,19	CK 102	EATHIE B2	10514	3726/16
CK 103	EATHIE B2	10509	3726/3	CK 104	7B	92.52	3800/14-16	CK 105	7B	92.52	3800/14
CK 106	9/18A-4	10930	3282/22	CK 107	16/17-5	14150	3509/23	CK 108	EATHIE B1	10404	3371/18
CK 109	12/28-1	6360	3532/29,30	CK 110	22/21-2	12190	3351/10	CK 111	EATHIE B2	10509	3725/10
CK 112	EATHIE B2	10512	3725/16,17	CK 113	EATHIE A	10423	3725/27	CK 114	EATHIE B2	10512	3717/23
CK 115	EATHIE B2	10512	3717/15-18	CK 116	EATHIE A	10430	3395/23,24	CK 117	EATHIE A	10430	3395/25
CK 118	EATHIE B2	10512	3726/33	CK 119	22/21-2	11840	3814/8,9	CK 120	22/21-2	11840	3591/28-30
CK 121	16/17-5	12200	3589/8	CK 122	16/17-5	12100	3589/6	CK 123	28/5-1	6520	3200/23
CK 124	EATHIE A	10423	3383/3	CK 125	23/27-4	10650	3314/23	CK 126	7B	86.94	3798/20
CK 127	23/27-4	10550	3304/15	CK 128	23/27-4	10560	3304/21	CK 129	23/27-4	10560	3385/34,35
CK 130	23/27-4	10920	3331/5	CK 131	23/27-4	10500	3303/12	CK 132	23/27-4	10520	3332/26
CK 133	23/27-4	10520	3303/27	CK 134	23/27-4	10550	3304/17	CK 135	23/27-4	10550	3385/33
CK 136	23/27-4	10500	3332/25	CK 137	23/27-4	10580	3386/3 3304/29	CK 138	22/21-2	10700	3583/5
CK 139	22/21-2	12650	3577/25	CK 140	22/21-2	12650	3707/29	CK 141	22/21-2	12700	3546/17
CK 142	14/18-2	8040	3719/22	CK 143	7B	85.14	3798/30,31	CK 144	22/21-2	13170	3372/13
CK 145	23/27-4	10500	3303/14	CK 146	22/21-2	12390	3366/14	CK 147	22/21-2	12550	3367/5
CK 148	22/21-2	12340	3366/4	CK 149	22/21-2	12240	3352/6	CK 150	22/21-2	13110	3370/32
CK 151	22/21-2	12550	3387/17	CK 152	16/17-5	12060	3532/1,27	CK 153	28/5-1	6490	3583/21,22 3546/33 3707/34
CK 154	28/5-1	6470	3201/15	CK 155	28/5-1	6470	3383/23	CK 156	28/5-1	6470	3198/10
CK 157	23/27-4	10220	3732/26	CK 158	28/5-1	6470	3383/24	CK 159	28/5-1	6470	3389/10
CK 160	7B	85.14	3798/32,33	CK 161	16/17-5	14170	3508/12	CK 162	16/17-5	14150	3591/17 3589/11
CK 163	7B	86.94	3799/4	CK 164	23/27-4	10550	3304/16	CK 165	9/18A-4	10800	3295/11
CK 166	22/21-2	12290	3352/21	CK 167	22/21-2	12060	3344/19	CK 168	12/28-1	5840	3577/12

CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME
CK 169	22/21-2	12120	3589/25,26	CK 170	22/21-2	12060	3344/18	CK 171	22/21-2	12120	3350/20
CK 172	23/27-4	10650	3577/16	CK 173	23/27-4	10700	3324/5	CK 174	22/21-2	12150	3589/29
CK 175	23/27-4	12610	3733/28	CK 176	22/21-2	12150	3733/27	CK 177	22/21-2	12100	3733/26
CK 178	22/21-2	12210	3745/17	CK 179	7430/10-U-01	168.94	3800/30	CK 180	12/28-1	5840	3733/29,30
CK 181	12/28-1	5840	3733/31	CK 182	7430/10-U-01	168.94	3792/10,11	CK 183	22/21-2	12610	3367/13
CK 184	22/21-2	12120	3589/23	CK 185	22/21-2	12120	3589/24	CK 186	22/21-2	13970	3509/17
CK 187	12/28-1	5980	3240/24	CK 188	7B	86.94	3807/6	CK 189	22/21-2	12210	3707/28
CK 190	12/28-1	6120	3536/9,10 3240/30,31	CK 191	22/21-2	12100	3350/7	CK 192	16/17-5	13990	3509/15,16
CK 193	23/27-4	10610	3589/28	CK 194	23/27-4	10650	3332/28	CK 195	22/21-2	12120	3745/18
CK 196	7430/10-U-01	221.78	3800/27 3792/30	CK 197	12/28-1	5860	3707/27	CK 198	12/28-1	5840	3589/17,18
CK 199	12/28-1	5960	3725/1	CK 200	22/21-2	12120	3725/31	CK 201	12/28-1	5840	3240/14
CK 202	12/28-1	5840	3745/23	CK 203	7B	91.86	3800/24,25	CK 204	7B	92.52	3800/22,23
CK 205	7B	92.52	3800/21	CK 206	7430/10-U-01	168.96	3792/3,4,32	CK 207	7B	91.86	3800/8
CK 208	7B	86.94	3799/13,14	CK 209	12/28-1	5840	3240/16	CK 210	22/21-2	11740	3368/4 3908/34
CK 211	EATHIE B2	10512	3726/9,10,30	CK 212	7B	86.94	3807/7	CK 213	7B	86.94	3807/17
CK 214	7B	86.94	3807/19	CK 215	7B	91.84	3800/9,10	CK 216	7430/10-U-01	153.54	3807/12
CK 217	7B	86.94	3798/32	CK 218	7B	86.94	3807/20,21	CK 219	9/18A-4	11180	3291/12,13,30
CK 220	7B	86.94	3798/24,25	CK 221	7B	86.94	3798/27	CK 222	7B	86.94	3795/33
CK 223	7B	86.94	3798/28,29	CK 224	7B	86.94	3798/30,31	CK 225	7B	86.94	3798/34,35
CK 226	16/17-5	14170	3508/10,11,16	CK 227	9/18A-4	11050	3289/27,28 3385/16,17	CK 228	23/27-4	10200	3732/9
CK 229	23/27-4	10300	3732/8-11	CK 230	28/5-1	6470	3384/14	CK 231	7430/10-U-01	168.96	3792/17-20
CK 232	29/12-1	8010	3241/11	CK 233	29/12-1	8010	3240/19	CK234	EATHIE A	10430	3589/13-16
CK 235	EATHIE B1	10404	3416/10	CK 236	EATHIE A	10430	3745/26,27 3546/5 & 3416/16	CK 237	9/18A-4	10930	3590/16-19
CK 238	EATHIE A	10430	3382/16 3389/9	CK 239	EATHIE B2	10507	3717/26,27	CK 240	9/18A-4	11030	3278/32 3385/2
CK 241	9/18A-4	11020	3278/24 3384/34	CK 242	9/18A-4	11020	3278/26	CK 243	9/18A-4	11020	3278/25
CK 244	9/18A-4	10930	3590/14,15,21	CK 245	9/18A-4	11050	3289/29 3385/18	CK 246	23/27-4	10220	3302/5

CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME
CK 247	22/21-2	11770	3745/32,35	CK 248	EATHIE B1	10404	3380/1	CK 249	22/21-2	12650	3725/34,35
CK 250	EATHIE B1	10404	3371/26,27	CK 251	EATHIE B1	10404	3380/2	CK 252	16/17-5	13970	3509/20,21
CK 253	16/17-5	13970	3508/4 3509/19	CK 254	16/17-5	13970	3577/18	CK 255	EATHIE B2	10507	3718/27-29
CK 256	7430/10-U-01	217.03	3792/26,27	CK 257	7430/10-U-01	155.84	3792/2 & 3800/29	CK 258	23/27-4	10200	3732/17,18
CK 259	22/21-2	11840	3343/28	CK 260	23/27-4	10650	3312/29	CK 261	16/17-5	14170	3508/14-15
CK 262	16/17-5	14090	3508/5	CK 263	9/18A-4	11050	3385/14,15	CK 264	9/18A-4	11050	3389/23
CK 265	9/18A-4	11180	3291/26	CK 266	9/18A-4	11080	3290/15	CK 267	9/18A-4	11080	3290/18
CK 268	9/18A-4	11020	3278/12	CK 269	9/18A-4	11280	3292/12	CK 270	9/18A-4	11020	3278/11
CK 271	9/18A-4	11180	3291/27	CK 272	9/18A-4	11020	3278/13	CK 273	9/18A-4	11340	3295/4
CK 274	9/18A-4	11080	3290/16	CK 275	9/18A-4	11030	3385/3,4	CK 276	9/18A-4	11030	3279/2
CK 277	9/18A-4	11030	3279/3	CK 278	9/18A-4	11230	3292/1	CK 279	9/18A-4	11050	3289/24
CK 280	23/27-4	10260	3302/10	CK 281	23/27-4	10260	3302/12 3385/30	CK 282	23/27-4	10320	3302/20
CK 283	23/27-4	10200	3732/12,13	CK 284	23/27-4	10200	3732/14,15	CK 285	23/27-4	10320	3385/31,32
CK 286	23/27-4	10200	3732/19	CK 287	23/27-4	10200	3732/16	CK 288	23/27-4	10200	3732/20,21
CK 289	23/27-4	10220	3732/35,36	CK 290	23/27-4	10240	3733/4,5	CK 291	23/27-4	10610	3301/8
CK 292	23/27-4	10680	3323/20	CK 293	23/27-4	10600	3305/19	CK 294	23/27-4	10600	3305/20
CK 295	23/27-4	10720	3322/15	CK 296	23/27-4	10600	3305/13	CK 297	23/27-4	10600	3305/18
CK 298	23/27-4	10620	3387/27	CK 299	16/17-5	13920	3509/2-4	CK 300	EATHIE B2	10512	3726/8
CK 301	EATHIE B2	10512	3717/19-22	CK 302	EATHIE A	10423	3381/21	CK 303	EATHIE B2	10512	3725/19
CK 304	EATHIE B2	10512	3725/20	CK 305	EATHIE B2	10512	3725/21	CK 306	EATHIE B1	10419	3416/28
CK 307	EATHIE A	10423	3416/7,8	CK 308	EATHIE A	10423	3381/7	CK 309	EATHIE A	10423	3389/2
CK 310	EATHIE B1	10419	3380/22	CK 311	EATHIE B1	10404	3371/6	CK 312	EATHIE A	10430	3382/8
CK 313	23/27-4	10600	3305/10	CK 314	23/27-4	10600	3305/11	CK 315	22/21-2	12100	3344/28
CK 316	23/27-4	10600	3386/1,2	CK 317	22/21-2	12100	3386/22,23	CK 318	EATHIE B1	10419	3383/2
CK 319	EATHIE B2	10512	3745/10	CK 320	EATHIE B2	10512	3733/20,21	CK 321	23/27-4	10970	3278/22,23 3384/33
CK 322	EATHIE A	10430	3382/17	CK 323	7430/10-U-01	168.96	3792/13,14	CK 324	7430/10-U-01	168.96	3792/6-9
CK 325	EATHIE B1	10404	3371/29	CK 326	EATHIE B2	10512	3745/15,16 3726/6	CK 327	EATHIE A	10423	3381/12
CK 328	EATHIE B2	10507	3718/24-26	CK 329	7B	86.94	3807/3	CK 330	7B	86.94	3798/7,8
CK 331	7B	86.94	3798/11	CK 332	7B	86.94	3798/9	CK 333	7B	86.94	3798/10
CK 334	7B	86.94	3798/6	CK 335	23/27-4	10320	3726/17,31	CK 336	23/27-4	10320	3733/12-14

CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME
CK 337	23/27-4	10320	3733/16	CK 338	7B	86.94	300/4,5	CK 339	7B	86.94	3800/2
CK 340	7B	86.94	3800/1	CK 341	7B	86.94	3799/23	CK 342	7B	86.94	3798/5-7
CK 343	7B	86.94	3798/16	CK 344	7B	86.94	3798/16	CK 345	22/21-2	12700	3725/36 3726/22
CK 346	EATHIE B2	10509	3725/11,12	CK 347	7B	86.94	3798/13,14	CK 348	7B	86.94	3800/3
CK 349	3799/21,22	86.94	3799/21,22	CK 350	28/5-1	6440	3200/3	CK 351	28/5-1	6520	3200/19
CK 352	28/5-1	6520	3383/29	CK 353	29/12-1	8010	3240/28	CK 354	7B	64.14	3798/17
CK 355	7B	86.94	3798/35	CK 356	22/21-2	11770	3386/17,18 3342/18	CK 357	7B	86.94	3807/4,5
CK 358	29/12-1	8040	3243/3	CK 359	7B	91.86	3807/10	CK 360	28/5-1	6440	3200/7
CK 361	29/12-1	8040	3243/6	CK 362	22/21-2	11840	3342/26	CK 363	28/5-1	6440	3383/17,18
CK 364	7B	91.86	3807/28	CK 365	7B	86.94	3807/27	CK 366	7B	86.94	3807/26
CK 367	7B	91.86	3807/25	CK 368	7B	86.94	3798/1,2	CK 369	7B	91.86	3800/6
CK 370	7B	91.86	3800/7	CK 371	7430/10-U-01	168.94	3792/24	CK 372	22/21-2	11740	3726/1,2
CK 373	7B	85.14	3798/27	CK 374	23/27-4	10200	3732/10,11	CK 375	23/27-4	10200	3732/7,8
CK 376	22/21-2	11740	3719/4	CK 377	22/21-2	11740	3719/5,6	CK 378	14/18-2	7780	3719/31
CK 379	12/28-1	5960	3240/22,23	CK 380	12/28-1	5800	3240/6,7	CK 381	14/18-2	8060	3725/3,4
CK 382	7B	91.86	3807/11	CK 383	7B	85.14	3798/28	CK 384	22/21-2	12120	3388/5
CK 385	23/27-4	10760	3313/20	CK 386	12/28-1	5800	3577/10 3583/20	CK 387	29/12-1	8260	3262/22
CK 388	29/12-1	8260	3591/20-22	CK 389	22/21-2	12210	3591/25	CK 390	14/18-2	8160	3719/12,13
CK 391	22/21-2	13080	3536/18,19	CK 392	22/21-2	12100	3583/10 3745/24	CK 393	22/21-2	12190	3343/18
CK 394	29/12-1	8260	3591/18,19	CK 395	9/18A-4	10930	3590/24	CK 396	23/27-4	10240	3733/3
CK 397	23/27-4	10200	3726/18	CK 398	23/27-4	10200	3732/6	CK 399	22/21-2	11770	3577/20,22,23 3546/20
CK 400	7B	64.14	3798/20	CK 401	14/18-2	7740	3707/2	CK 402	7430/10-U-01	153.54	3807/13,30
CK 403	14/18-2	7740	3719/29	CK 404	29/12-1	7920	3745/5	CK 405	22/21-2	12030	3344/6
CK 406	29/12-1	7920	3745/7,30	CK 407	7B	64.14	3798/11,12	CK 408	7B	64.14	3798/9,10
CK 409	7B	64.14	3798/23	CK 410	23/27-4	10200	3732/22-25,33,34	CK 411	7B	64.14	3798/19
CK 412	9/18A-4	10760	3590/3-5	CK 413	9/18A-4	10760	3377/9	CK 414	7B	64.14	3798/21,22
CK 415	29/12-1	7920	3745/2,19	CK 416	29/12-1	7920	3745/9	CK 417	23/27-4	10220	3732/27-29
CK 418	23/27-4	10220	3732/31,32	CK 419	16/17-5	12040	3508/21	CK 420	16/17-5	12040	3509/32,33
CK 421	7430/10-U-01	153.54	3807/14,29	CK 422	29/12-1	7920	3745/6	CK 423	7B	67.03	3798/24

CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME
CK 424	22/21-2	11770	3350/11 3342/16 3344/32	CK 425	29/12-1	7950	3235/10	CK 426	22/21-2	11740	3718/14-17 3719/35,36
CK 427	7B	64.14	3798/18	CK 428	22/21-2	12390	3366/18 & 3387/8	CK 429	9/18A-4	11050	3590/25-28
CK 430	9/18A-4	11080	3589/3	CK 431	9/18A-4	11050	3590/29-32	CK 432	22/21-2	12120	3350/25
CK 433	9/18A-4	11520	3289/12	CK 434	7B	86.94	3799/12	CK 435	29/12-1	7920	3745/1
CK 436	29/12-1	7920	3745/3,4,28,29	CK 437	29/12-1	7920	3745/20	CK 438	22/21-2	11770	3342/10 3386/14,15
CK 439	23/27-4	10260	3302/15,16	CK 440	22/21-2	12030	3368/6	CK 441	22/21-2	11770	3386/16
CK 442	22/21-2	12030	3368/7	CK 443	22/21-2	12030	3368/5 & 3344/4	CK 444	22/21-2	12030	3367/9
CK 445	EATHIE B2	10507	3718/5-7	CK 446	EATHIE B2	10507	3718/2-4	CK 447	9/18A-4	11340	3295/1 3385/22,23
CK 448	9/18A-4	11030	3279/20,21 3385/9	CK 449	9/18A-4	11030	3279/19 & 3385/8	CK 450	22/21-2	12100	3344/29
CK 451	EATHIE B1	10419	3380/28,30	CK 452	22/21-2	12300	3365/10	CK 453	EATHIE B2	10512	3725/23 3726/24
CK 454	16/17-5	14150	3508/6	CK 455	EATHIE B2	10512	3725/24	CK 456	14/18-2	8160	3725/7,8
CK 457	7B	86.94	3798/3,4	CK 458	7B	91.86	3807/16	CK 459	23/27-4	10700	3324/8
CK 460	23/27-4	10700	3393/4-6 3324/8	CK 461	23/27-4	10700	3324/7	CK 462	23/27-4	10760	3313/25
CK 463	23/27-4	10760	3313/22	CK 464	23/27-4	10750	3313/7	CK 465	23/27-4	10720	3324/29
CK 466	23/27-4	10750	3313/14	CK 467	23/27-4	10750	3389/19	CK 468	23/27-4	10750	3389/20,21
CK 469	23/27-4	10700	3324/9	CK 470	23/27-4	10960	3331/25	CK 471	23/27-4	10740	3325/17
CK 472	23/27-4	10750	3386/5	CK 473	23/27-4	10680	3323/27	CK 474	23/27-4	10750	3386/6
CK 475	23/27-4	10750	3313/6	CK 476	23/27-4	10760	3313/24	CK 477	23/27-4	10740	3325/18
CK 478	23/27-4	10640	3301/33	CK 479	7430/10-U-01	221.78	3800/26	CK 480	7430/10-U-01	221.78	3792/29
CK 481	7430/10-U-01	221.78	3792/31	CK 482	16/17-5	12000	3546/27	CK 483	23/27-4	10600	3305/27
CK 484	14/18-2	7840	3726/29 3707/3,4	CK 485	22/21-2	12270	3707/35 3583/8,19	CK 485	22/21-2	11740	3342/5,6 3368/3
CK 487	7430/10-U-01	168.96	3792/21	CK 488	7430/10-U-01	168.96	3792/22,23	CK 489	9/18A-4	11030	3279/18 3385/7
CK 490	9/18A-4	11020	3278/27	CK 491	EATHIE B2	10504	3718/23	CK 492	EATHIE B2	10504	3718/22
CK 493	EATHIE B2	10504	3718/20,21	CK 494	9/18A-4	10930	3590/13,20	CK 495	9/18A-4	10930	3590/11,12
CK 496	9/18A-4	10780	3590/9,10	CK 497	23/27-4	10750	3591/31-33	CK 498	14/18-2	7860	3707/19

CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME	CAT. NO.	WELL/ EXPOSURE	DEPTH/ SAMPLE	FILM/FRAME
CK 499	14/18-2	7900	3707/12	CK 500	14/18-2	8060	3745/11	CK 501	14/18-2	7900	3719/25
CK 502	14/18-2	7920	3590/1,2 3591/34	CK 503	23/27-4	10880	3726/19	CK 504	14/18-2	7800	3719/32,33
CK 505	22/21-2	12630	3367/15 3387/13-15	CK 506	23/27-4	10860	3386/10	CK 507	22/21-2	12630	3326/32 3386/11
CK 508	EATHIE B2	10509	3745/21	CK 509	12/28-1	6280	3240/32	CK 510	22/21-2	12630	3725/33
CK 511	22/21-2	12390	3366/9	CK 512	22/21-2	12190	3351/2	CK 513	22/21-2	12060	3344/12
CK 514	22/21-2	12150	3350/12	CK 515	23/27-4	10650	3314/11	CK 516	22/21-2	12300	3387/1,2
CK 517	22/21-2	12390	3387/4	CK 518	7B	86.94	3798/36	CK 519	28/5-1	6450	3201/8,9 3384/3,4
CK 520	28/5-1	6450	3196/8 3384/11	CK 521	28/5-1	6450	3196/8 & 3295/9	CK 522	22/21-2	11770	3388/18
CK 523	9/18A-4	10790	3278/4	CK 524	29/12-1	7980	3383/14	CK 525	9/18A-4	10780	3277/27
CK 526	29/12-1	7980	3235/27	CK 527	29/12-1	8010	3240/18	CK 528	29/12-1	7980	3261/18,19
CK 529	29/12-1	7980	3235/32	CK 530	29/12-1	8010	3241/12	CK 531	29/12-1	7980	3235/28
CK 532	29/12-1	7980	3235/30	CK 533	29/12-1	8010	3583/3	CK 534	29/12-1	8010	3583/2
CK 535	29/12-1	8010	3597/27	CK 536	29/12-1	8010	3577/19	CK 537	16/17-5	12060	3589/5
CK 538	16/17-5	12060	3508/24	CK 539	29/12-1	8010	3546/19	CK 540	16/17-5	12060	3546/22
CK 541	14/18-2	7820	3707/8,9	CK 542	7B	86.94	3799/2	CK 543	7B	86.94	3807/9
CK 544	7B	86.94	3807/22,23	CK 545	14/18-2	7740	3719/27,28	CK 546	EATHIE A	10423	3726/35
CK 547	29/12-1	7950	3235/9	CK 548	EATHIE A	10423	3416/19	CK 549	12/28-1	5900	3546/25
CK 550	22/21-2	12210	3726/23	CK 551	16/17-5	12060	3508/1	CK 552	EATHIE A	10430	3382/1
CK 553	7430/10-U-01	168.96	3792/12	CK 554	7B	91.86	3800/11	CK 555	7430/10-U-01	168.96	3792/5
CK 556	EATHIE A	10430	3382/2	CK 557	7B	85.14	3798/29	CK 558	9/18A-4	11180	3292/3
CK 559	EATHIE B2	10507	3718/1	CK 560	7430/10-U-01	217.03	3792/28	CK 561	EATHIE A	10423	3381/22
CK 562	28/5-1	6630	3194/19	CK 563	22/21-2	11770	3718/18	CK 564	9/18A-4	10830	3279/30
CK 565	9/18A-4	10780	3278/1	CK 566	EATHIE B1	10419	3546/1	CK 567	EATHIE B2	10512	3726/12
CK 568	7B	86.94	3798/1,2	CK 569	29/12-1	8010	3241/3				