UPPER CRETACEOUS RADIOLARIA FROM THE ATLANTIC OCEAN
AND CYPRUS

BY

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Thesis submitted for the degree of
Doctor of Philosophy
in the
University of London
For my parents

"I must, however, confess at the close of my work that my original intention is far from having been fulfilled". Haeckel, 1887, p. ii.
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>1</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>3</td>
</tr>
<tr>
<td>CHAPTER 1  INTRODUCTION</td>
<td>5</td>
</tr>
<tr>
<td>CHAPTER 2  PRODUCTION AND PRESERVATION OF SILECEOUS MICROFOSSILS</td>
<td>13</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>13</td>
</tr>
<tr>
<td>2.2 The Silica Cycle</td>
<td>13</td>
</tr>
<tr>
<td>2.3 Water Chemistry</td>
<td>13</td>
</tr>
<tr>
<td>2.4 Biogenic Silica</td>
<td>16</td>
</tr>
<tr>
<td>2.5 Solution</td>
<td>18</td>
</tr>
<tr>
<td>2.6 Deposition</td>
<td>20</td>
</tr>
<tr>
<td>2.7 Diagenesis</td>
<td>21</td>
</tr>
<tr>
<td>2.8 Discussion</td>
<td>26</td>
</tr>
<tr>
<td>CHAPTER 3  PREPARATION TECHNIQUES AND METHODS</td>
<td>29</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>29</td>
</tr>
<tr>
<td>3.2 General Aims and Objectives</td>
<td>29</td>
</tr>
<tr>
<td>3.3 Sample Selection</td>
<td>30</td>
</tr>
<tr>
<td>3.4 Sample Collection</td>
<td>32</td>
</tr>
<tr>
<td>3.5 Examination of raw samples</td>
<td>33</td>
</tr>
<tr>
<td>3.6 Extraction of Microfossils</td>
<td>34</td>
</tr>
<tr>
<td>3.6.1 Contamination</td>
<td>34</td>
</tr>
<tr>
<td>3.6.2 Sample evaluation</td>
<td>36</td>
</tr>
<tr>
<td>3.6.3 Universal techniques</td>
<td>36</td>
</tr>
<tr>
<td>3.6.4 Disaggregation of sediments</td>
<td>37</td>
</tr>
<tr>
<td>3.6.5 Dissolution of sediments</td>
<td>39</td>
</tr>
<tr>
<td>3.7 Concentration of fossils from residue</td>
<td>43</td>
</tr>
<tr>
<td>3.7.1 Methods</td>
<td>43</td>
</tr>
<tr>
<td>3.7.2 Discussion</td>
<td>47</td>
</tr>
<tr>
<td>3.7.3 Future work</td>
<td>48</td>
</tr>
<tr>
<td>3.8 Mounting concentrated residues</td>
<td>49</td>
</tr>
<tr>
<td>3.8.1 Examination with the S.E.M.</td>
<td>49</td>
</tr>
<tr>
<td>3.8.2 Examination with reflected light</td>
<td>53</td>
</tr>
<tr>
<td>3.8.3 Mounts prepared for viewing in transmitted light</td>
<td>54</td>
</tr>
<tr>
<td>3.8.4 Preparation for viewing the same specimen in S.E.M. and transmitted light</td>
<td>56</td>
</tr>
<tr>
<td>3.9 Sorting and cataloging of specimens</td>
<td>56</td>
</tr>
<tr>
<td>3.10 Recording fossil occurrence</td>
<td>58</td>
</tr>
<tr>
<td>3.11 Comparison of published material with specimens recovered from samples</td>
<td>61</td>
</tr>
<tr>
<td>3.12 Data storage of observation of specimens</td>
<td>61</td>
</tr>
<tr>
<td>3.13 Discussion</td>
<td>61</td>
</tr>
</tbody>
</table>
### CHAPTER 4
#### THE SELECTION OF STUDIED SECTIONS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 Introduction</td>
<td>63</td>
</tr>
<tr>
<td>4.2 DSDP/IPOD Locations</td>
<td>63</td>
</tr>
<tr>
<td>4.2.1 Publications contained within DSDP/IPOD Reports</td>
<td>63</td>
</tr>
<tr>
<td>4.2.2 Tabulation of occurrence of siliceous and calcareous microfossils</td>
<td>64</td>
</tr>
<tr>
<td>4.2.3 Discussion</td>
<td>64</td>
</tr>
<tr>
<td>4.3 Onshore and Continental Shelf Locations</td>
<td>65</td>
</tr>
<tr>
<td>4.3.1 Radiolaria</td>
<td>65</td>
</tr>
<tr>
<td>4.3.2 Diatoms</td>
<td>66</td>
</tr>
<tr>
<td>4.4 Discussion</td>
<td>66</td>
</tr>
</tbody>
</table>

### CHAPTER 5
#### CYPRUS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Introduction</td>
<td>75</td>
</tr>
<tr>
<td>5.1.1 General Geology</td>
<td>75</td>
</tr>
<tr>
<td>5.1.2 Geological Succession</td>
<td>77</td>
</tr>
<tr>
<td>5.1.3 Autochthonous Units</td>
<td>77</td>
</tr>
<tr>
<td>5.1.4 Allochthonous units</td>
<td>83</td>
</tr>
<tr>
<td>5.1.5 Discussion</td>
<td>85</td>
</tr>
<tr>
<td>5.2 Sections Studied</td>
<td>87</td>
</tr>
<tr>
<td>5.2.1 Akamas peninsula</td>
<td>90</td>
</tr>
<tr>
<td>5.2.2 Phiti</td>
<td>96</td>
</tr>
<tr>
<td>5.2.3 Kritou Marottou Borehole</td>
<td>101</td>
</tr>
<tr>
<td>5.2.4 Anadhiou - Sarama</td>
<td>106</td>
</tr>
<tr>
<td>5.2.5 Paleomylon Valley</td>
<td>111</td>
</tr>
<tr>
<td>5.2.6 Kithasi</td>
<td>123</td>
</tr>
<tr>
<td>5.2.7 Pano Arkhimandrita</td>
<td>127</td>
</tr>
<tr>
<td>5.2.8 Petra tou Romiou</td>
<td>130</td>
</tr>
<tr>
<td>5.2.9 Kuoka</td>
<td>134</td>
</tr>
<tr>
<td>5.2.10 Perapedhi</td>
<td>137</td>
</tr>
<tr>
<td>5.2.11 Trimiklini</td>
<td>144</td>
</tr>
<tr>
<td>5.2.12 Ayios Mamas</td>
<td>147</td>
</tr>
<tr>
<td>5.2.13 Kapillo</td>
<td>149</td>
</tr>
<tr>
<td>5.2.14 Mangaleni Mine</td>
<td>151</td>
</tr>
<tr>
<td>5.2.15 Moni</td>
<td>156</td>
</tr>
<tr>
<td>5.2.16 Kalavassos</td>
<td>159</td>
</tr>
<tr>
<td>5.2.17 Dhrapia</td>
<td>161</td>
</tr>
<tr>
<td>5.2.18 Layia</td>
<td>164</td>
</tr>
<tr>
<td>5.2.19 Kambia</td>
<td>166</td>
</tr>
<tr>
<td>5.2.20 Paralimni</td>
<td>171</td>
</tr>
<tr>
<td>5.3 Conclusions</td>
<td>191</td>
</tr>
<tr>
<td>5.3.1 Inter-lava sediments</td>
<td>191</td>
</tr>
<tr>
<td>5.3.2 Perapedhi Formation</td>
<td>192</td>
</tr>
<tr>
<td>5.3.4 Kannaviou Formation</td>
<td>196</td>
</tr>
<tr>
<td>5.3.5 Lefkara Formation</td>
<td>198</td>
</tr>
<tr>
<td>5.3.6 Moni Formation</td>
<td>199</td>
</tr>
<tr>
<td>5.3.7 Discussion</td>
<td>200</td>
</tr>
<tr>
<td>FIGURE</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>Figure 1.1</td>
<td>Graph showing the quantity and dates of publication of Palaeozoic, Mesozoic and Cenozoic radiolarian papers between 1834 - 1988</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>Occurrence of Mesozoic radiolarians from selected publications (1876 - 1990)</td>
</tr>
<tr>
<td>Figure 2.1</td>
<td>The Silica Cycle - major sinks, processes and routes</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Location of onshore and continental shelf regions with recorded occurrence of radiolarians and co-occurrence of calcareous and siliceous microfossils in Tertiary material, in research published between 1972 and 1986</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Locations of DSDP/IPOD/ODP Sites with recorded co-occurrence of calcareous and siliceous microfossils in the Tertiary</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Locations of onshore and continental shelf regions with recorded occurrence of radiolarians and co-occurrence of calcareous and siliceous microfossils in Cretaceous material, in research published between 1972 and 1986</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Locations of DSDP/IPOD/ODP Sites with recorded co-occurrences of calcareous and siliceous microfossils in the Cretaceous</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>Locations of DSDP/IPOD/ODP Sites where Cretaceous age sediments have been dated</td>
</tr>
<tr>
<td>Figure 4.6</td>
<td>Occurrence of radiolarians and co-occurrence of radiolarians, diatoms, foraminifera and calcareous nannofossils from research published between 1972 - 1986 from onshore and continental shelf sites</td>
</tr>
<tr>
<td>Figure 5.1</td>
<td>Composite Stratigraphic Column of the Cretaceous - ?Neogene part of the Circum-Troodos Sedimentary Succession</td>
</tr>
<tr>
<td>Figure 5.2</td>
<td>Outline Geology of Cyprus showing Location of Sites Studied</td>
</tr>
<tr>
<td>Figure 5.3</td>
<td>Summary of samples analysed from Cyprus sections</td>
</tr>
<tr>
<td>Figure 5.4</td>
<td>Summary of lithological units sampled from Cyprus</td>
</tr>
<tr>
<td>Figure 5.5</td>
<td>Map showing the location of the base of the Akamas section</td>
</tr>
<tr>
<td>Figure 5.6</td>
<td>Generalised lithological and biostratigraphical summary of the Akamas section</td>
</tr>
<tr>
<td>Figure 5.7</td>
<td>Akamas - distribution chart showing radiolaria</td>
</tr>
</tbody>
</table>
Figure 5.8 Akamas - distribution chart showing calcareous nannofossils ................................................................. 93

Figure 5.9 Akamas - distribution chart showing miscellaneous fossils ........................................................................ 93

Figure 5.10 Map showing the location of the base of the Phiti section ................................................................. 97

Figure 5.11 Generalised lithological and biostratigraphical summary of the Phiti section .................................................. 98

Figure 5.12 Phiti - distribution chart showing calcareous nannofossils ................................................................. 99

Figure 5.13 Phiti - distribution chart showing radiolaria ................................................................................. 99

Figure 5.14 Phiti - distribution chart showing miscellaneous fossils ........................................................................ 99

Figure 5.15 Map showing the location of the Kritou Marottou Borehole ................................................................. 102

Figure 5.16 Generalised lithological and biostratigraphical summary of the Kritou Marottou Borehole ......................... 103

Figure 5.17 Kritou Marottou - distribution chart showing calcareous nannofossils ................................................................. 104

Figure 5.18 Kritou Marottou - distribution chart showing miscellaneous fossils ................................................................. 104

Figure 5.19 Kritou Marottou - distribution chart showing radiolaria ................................................................................. 105

Figure 5.20 Map showing the Base of the Anadhiou-Sarama section ........................................................................... 107

Figure 5.21 Generalised lithological and biostratigraphical summary of the Anadhiou-Sarama section ......................... 108

Figure 5.22 Anadhiou-Sarama - distribution chart showing calcareous nannofossils ................................................................. 109

Figure 5.23 Anadhiou-Sarama - distribution chart showing radiolaria and miscellaneous fossils ................................. 110

Figure 5.24 Map showing the location of the base of the Paleomylon Valley section .................................................. 112

Figure 5.25 Generalised lithological and biostratigraphical summary of the Paleomylon Valley section ......................... 115

Figure 5.26 Paleomylon Valley - distribution chart showing miscellaneous fossils ................................................................. 119
Figure 5.27 Paleomylon Valley - distribution chart showing calcareous nannofossils ................................................................. 119

Figure 5.28 Paleomylon Valley - distribution chart showing radiolaria ................................................................. 121

Figure 5.29 Map showing the location of the Kithasi section ................................................................. 123

Figure 5.30 Generalised lithological and biostratigraphical summary of the Kithasi section ................................................................. 124

Figure 5.31 Kithasi - distribution chart showing radiolaria and miscellaneous fossils ................................................................. 125

Figure 5.32 Map showing the location of the base of the Arkhimandrita section ................................................................. 127

Figure 5.33 Generalised lithological and biostratigraphical summary of the Pano Arkhimandrita section ................................................................. 128

Figure 5.34 Pano Arkhimandrita - distribution chart showing radiolaria ................................................................. 129

Figure 5.35 Map showing the location of the base of the Petra tou Romiou section ................................................................. 131

Figure 5.36 Generalised lithological and biostratigraphical summary of the Petra tou Romiou section ................................................................. 131

Figure 5.37 Petra tou Romiou - distribution chart showing radiolaria and miscellaneous fossils ................................................................. 132

Figure 5.38 Map showing the Location of Sampling Points in the Kuoka Section ................................................................. 135

Figure 5.39 Kuoka - distribution chart showing miscellaneous fossils ................................................................. 136

Figure 5.40 Map showing the location of the base of the Perapedhi section ................................................................. 138

Figure 5.41 Generalised lithological and biostratigraphical summary of the Perapedhi section ................................................................. 139

Figure 5.42 Perapedhi - distribution chart showing radiolaria ................................................................. 141

Figure 5.43 Map showing the location of the base of the Trimiklini section ................................................................. 144

Figure 5.44 Generalised lithological and biostratigraphical summary of the Trimiklini section ................................................................. 145

Figure 5.45 Trimiklini - distribution chart showing radiolaria ................................................................. 145

Figure 5.46 Map showing the location of the Ayios Mamas sections ................................................................. 147
Figure 6.11 DSDP Site 369A - distribution chart of calcareous nannofossils ............................................................... 218
Figure 6.12 Location map of DSDP/IPOD Site 612 .......................................................... 221
Figure 6.13 Cross-section showing the location of DSDP/IPOD Site 612 .......................................................... 222
Figure 6.14 Generalised lithological and biostratigraphical summary of cores analysed from DSDP/IPOD Site 612 .......................................................... 223
Figure 7.1 Chart showing 73 radiolarian species from Cyprus which have all or part of their ranges within the respective zonal intervals defined by co-occurring calcareous nannofossils .......................................................... 242
Figure 7.2 Chart showing 31 radiolarian species recorded from Atlantic DSDP Site 152 and DSDP/IPOD Site 369A which have all or part of their ranges within the respective zonal intervals defined by co-occurring calcareous nannofossils .......................................................... 243
Figure 7.3 Co-occurring radiolarian species and calcareous nannofossil species and their relative distribution in Cyprus sections .......................................................... 245
Figure 7.4 Correlation of Upper Cretaceous radiolarian zonation schemes .......................................................... 249
Figure 7.5 Comparative ranges of synonymous species used in published Upper Cretaceous radiolarian zonation schemes .......................................................... 259
Figure 7.6 Publications recording synonymous forms with selected species from this study .......................................................... 261
Figure 7.7 Upper Cretaceous radiolarian ranges compiled from publications and plotted in order of lowest occurrence .......................................................... 263
Figure 7.8 Upper Cretaceous radiolarian ranges compiled from publications and plotted in order of highest occurrence .......................................................... 263
Figure 7.9 Tie-Line correlation diagram showing the stratigraphic distribution of 108 radiolarian species in 6 Cyprus sections .......................................................... 267
Figure 7.10 Chart showing radiolarian species diversity and distribution in relation to calcareous lithologies in 13 Cyprus sections and 2 Atlantic sections .......................................................... 270
Figure 7.11 Chart showing the distribution of radiolaria in 13 Cyprus sections and 2 Atlantic sections .......................................................... 271
Figure 7.12 Upper Cretaceous ranges of selected calcareous nannofossils (adapted from Sissingh, 1977, Perch-Nielsen, 1985 and Burnett, 1990) .......................................................... 275
Figure 7.13 Upper Cretaceous ranges of selected planktic foraminifera (from Caron, 1985) .......................................................... 275
Figure 8.1 Palaeogeographical Map (c.80Ma) showing locations of studied sites .......................................................... 281
Figure A1 Correlation chart of fossil and mineral components compiled from 255 sediment samples analysed during this project.
ACKNOWLEDGEMENTS

I would like to thank the following for their contributions to the production of this thesis and to the research behind it.

The research was financed by Simon-Robertson, Llandudno, North Wales who also allowed me the use of their microscopes. Sincere thanks are due to Abda Futyan and Richard Attewell for their support at the outset of this project.

Alan Lord of University College London was responsible for the initial conception of the theme of this work and introduced me to the potential of siliceous microfossils. He has followed this with stoical supervision throughout the duration and the text on page A269 is dedicated entirely to him, in appreciation. The project was carried out at University College London where laboratory space, computing facilities and microscopes were provided. Thanks for help and advice are due to the staff of the Department of Geological Sciences and to Leisa, Trisha and Jamie for administrative support.

Fieldwork was undertaken with the guidance of the Director and officers of the Geological Survey Department of Cyprus with particular help from Dr. G. Constantinou, Dr. A. Panayiotou, Dr. C. Xenophontos and Mr. G. Panyides. I am also grateful to the Geological Survey Department of Cyprus for permission to reproduce the geology maps included in this work. DSDP/IPOD samples were provided by the Ocean Drilling Program at Texas A. & M. University.

The processing techniques used benefited from discussions with Rick Battarbee, Ted Bianco, John Catt, Klaus Kemp, Annette Kreiser, Atsushi Matsuoka, Carol Parsons, Pat Sims and Torsten Steiger. Taxonomic assistance came from Peter Baumgartner, Patrick De Wever, Paulian Dumitrica and Jurgen Thurow. Residue for comparative taxonomic use was donated by Paulian Dumitrica, Alastair Robertson, Chris McCleod and Peter Mears.

Graeme Burnett, Alan Deacon and Danuta Kaminski came to my aid where computing problems were concerned (and there were many) whilst machine data analyses were performed with the help of John Athersuch, Peter Baumgartner, Paul Britton and Jean Guex. David Forbes was almost constantly available for help and advice on word processing problems which is greatly appreciated. Advice and ideas on design and creation of a database were received from Peter Baumgartner, Patrick De Wever, Dave Lazarus, Bill Riedel and Annika Sanfilippo.

Calcereous analyses were mainly carried out by Jackie Burnett with contributions from Ted Finch and Dave Rutledge all of University College London. Geological and biostratigraphical discussions were entered into at various stages with Peter Baumgartner, Paul Bown, Jackie Burnett, Dave Ince, Martin Jakubowski, Mike Kaminski, Sue Matthews, Emile Pessagno, Alastair Robertson, Annika Sanfilippo, Jurgen Thurow and the members of the Geological Department of Cyprus.

Photographic processing was expertly handled by Mike Gray and Toby Stiles at University College London. The graphics incorporated in this thesis benefited from the assistance of Janet Baker, Paul Bown, Glynn Ellis, Spencer Roberts and Graham Rose.

I am particularly grateful to the "Lausanne Team" for including me in their workshop meetings, for making me feel welcome and for their infectious enthusiasm. Finally, but importantly, endless general support and encouragement was provided by many people but most notably my parents together with Jackie Burnett, Fiona Mackinlay and Carol Parsons.

- 1 -
ABSTRACT

Micropalaeontological analyses, with special reference to radiolaria, have been carried out on 255 samples of Campanian-Maastrichtian sediments from 3 sections encountered at offshore DSDP/IPOD Sites in the Atlantic Ocean and 20 onshore sections in Cyprus in the Mediterranean sea. Radiolarian assemblages recorded here are integrated with calcareous nannofossils where possible, the studied sections having been carefully chosen in order to test existing biostratigraphical schemes using radiolaria and calcareous microfossils.

Of the published zonation schemes for the Late Cretaceous, seven are discussed and their application to material recorded here considered. A number of interesting biostratigraphical observations confirmations and conclusions have been made in relation to the geological history of Cyprus, whilst the radiolarian biostratigraphical database from DSDP Sites 152 and 369A has been amended.

A taxonomic atlas has been compiled, with extensive synonymy lists and the geographical and stratigraphical occurrence patterns both for published species and for new forms recorded exclusively in this study. The stratigraphical occurrences recorded here are correlated with co-occurring calcareous nannofossils. The taxonomic atlas includes 141 taxa and 47 genera which are described and/or figured. Of these morphotypes, 59 are left in open nomenclature, many of which represent new and undescribed species to be formally described when their occurrence patterns are fully researched. Eighty-two of the species recorded have published ranges which include the Campanian whilst the ranges of a further 11 species are here extended into the (stratigraphically higher) Campanian stage. Published radiolarian ranges are confirmed and extended.

The organisation and storage of the lithological and micropalaeontological data from this study on a computer database allowed for rapid searches for correlative and inversely correlative sample characteristics. Equally, future rapid selection of samples for purposes such as refining zonation schemes or selection of particularly well-preserved specimens for photography or specific reappraisal is facilitated.

Controls on production and preservation of siliceous microfossils are discussed and applied to the interpreted depositional conditions in the Late Cretaceous. The effects of these controls, as interpreted for the Late Cretaceous, are discussed in relation to biostratigraphical utilization of the group. A comprehensive assessment of sample processing and analytical techniques and a discussion on the technical problems encountered, together with their impact on recorded data, is included.

Finally, future research areas have been defined in relation to the following:
1. developing/refining radiolarian biozonation;
2. standardization of preparation techniques, data production and storage;
3. advancement of stored computerised data to include pictorial representation of taxa;
4. more extensive work on Cyprus involving correlation with DSDP/ODP material.
CHAPTER 1

INTRODUCTION

1.1 Objectives

This project involved radiolarian micropalaeontological analysis of samples from selected Upper Cretaceous sections (Cenomanian - Maastrichtian stages). The sediment samples analysed have been collected from cores drilled at DSDP/IPOD Sites 152, 369A and 612 in the Atlantic Ocean and from onshore sections in Cyprus.

The primary aims of the project are to record the occurrence of radiolaria, i.e.

a) to identify the forms encountered,

b) record their abundance and preservational state,

c) to record their association with other microfaunal and -floral elements present, and

d) to record the host lithology.

Further, to:

i interpret the geological history of the areas studied, and

ii correlate and calibrate the data recorded on a global scale by incorporating previously published information.

An account of the sample preparation techniques, the methods of study and a discussion of the technical problems encountered are included. Further chapters discuss current published ideas on production and preservation of siliceous organisms, with particular reference to the Late Cretaceous, and the biostratigraphical use of siliceous microfossils; ideas which are then applied to the findings of this study. The biostratigraphical interpretations and correlations of the Senonian samples analysed are calibrated, where possible, by the integration of age and range data provided by calcareous planktic microfossils. The thesis is illustrated by location maps, lithological sections and correlations and range charts, and includes taxonomic descriptions with photographic plates illustrating examples of the species described.
1.2 History of Research

Research into radiolaria began in the first part of the 19th century, one of the earliest papers being by Meyen in 1834 describing low-latitude Cenozoic radiolarians from the Atlantic Ocean. In the latter part of the 19th century work was undertaken, notably by Rust, Haeckel and Parona whose interests were not only confined to radiolarians but to all fossil and Recent micro-organisms. Several monographs concerning radiolarians were published during this period, probably the most extensive being that by Haeckel (1887) documenting the specimens collected during the voyage of H.M.S. Challenger [1873 to 1876].

Work carried out in the latter part of the 19th century was by men of independent means who, judging by the volume of work produced, regarded their studies with great enthusiasm.

Although the early scientists did not have the technology to recover the specimens, record them or store the data as efficiently as present workers, the value of this early work (mainly monographic) should not be underestimated. In many cases, it is easier to improve on established work than to initiate it.

Prior to the development or availability of adequate photographic techniques, many of the earlier illustrations were hand-drawn and without a scale. Even so, these drawings are still valuable now, as they have the advantage of emphasising morphological features considered important which may not be noticed on a photographic illustration. An excellent recent example of the use of hand-drawn illustrations is a paper published by Dumitrica in 1970. International communications were poorly established during the early years of radiolarian study and resulted in many species being described and, more importantly, named by two or more different authors with resulting taxonomic confusion. Such problems are only now being resolved, largely due to efforts by workers such as Baumgartner and Riedel, and their respective associates, to standardize taxonomical schemes by international communication, and by encouraging the use of electronic storage and management facilities.
Following Haeckel's monumental work on the *Challenger* material a period of consolidation followed. After the First World War and with the advent of the use of microfossils for oil exploration, more people became interested in micropalaeontology and this is reflected in the rate of publication of papers concerned with radiolarians (see Fig. 1.1).

A growing interest in Mesozoic radiolarians accompanied the proliferation of micropalaeontological publications after the Second World War. In 1944, Campbell and Clark published a paper on "Radiolaria from the Upper Cretaceous of Middle California" and later, in 1954, Campbell produced a treatise on radiolarians. The early 1950's onwards saw the advent of work by Riedel, later joined by Pessagno (1962). Lipman (1960-1962) proposed the first zonation scheme for Mesozoic radiolarians, using Valanginian - Maastrichtian assemblages from Western Siberia. Since then a number of zonation schemes have been proposed and these are further discussed in detail in Chapter 7.

By the early 1970's, the more general availability of the scanning electron microscope made study of microfossil morphology easier.

In 1968, the first voyage of the *Glomar Challenger* for the Deep Sea Drilling Project (Leg 1) marked the start of an extensive exploration programme of the ocean basins and margins for purely scientific reasons, (142 Legs to date). This programme has made sections, often of a more complete geological succession which had previously been inaccessible, available for study. The organization of the DSDP/IPOD/ODP projects, and the co-operation of different nations, has resulted in a large inter- and multi-disciplinary dataset in such fields as sedimentology, geochemistry and biostratigraphy. These data are available in a comprehensive, accessible form to non-specialists of these disciplines and enables them to integrate this multi-disciplinary information with their own data, thereby aiding interpretations.

Recorded occurrences of Mesozoic radiolarians both from DSDP/IPOD/ODP and land-based sections show that the distribution of these fossils is global and that they have been identified from a wide
variety of host sediments. This occurrence pattern is discussed in more detail in Chapter 4.

In the last 20 years, industrial micropalaeontology has developed rapidly as a tool for the sub-surface mapping of formations, and the geometry and extent of potential source and reservoir rocks can be determined by means of palaeoenvironmental interpretations. Momentum is still growing in this field, as more-refined zonations, more accurate interpretation of palaeoenvironmental conditions and more cost-effective analyses are demanded in an increasingly competitive market.

A graph showing the quantity and dates of publication of Palaeozoic, Mesozoic and Cenozoic radiolarian papers is shown in Fig. 1.1.

Fig. 1.2 is a map showing the occurrence of Mesozoic radiolarians as recorded from selected papers with a key listing the author, date of publication and approximate geographical location of samples. The position of the sampling sites is approximate and simplified here because, for example, analyses of the DSDP Legs involve several sites from one area. The publications (63) which have been used to construct this distribution map are those which figured specimens synonymous with the material recovered during this study (described and illustrated in Appendix 2).
Figure 1.1 Graph showing the quantity and dates of publication of Palaeozoic, Mesozoic and Cenozoic radiolarian papers between 1834 - 1988.

Cumulative number of publications

Year of publication

1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990

KEY

- Palaeozoic Radiolarian Publications
- Mesozoic Radiolarian Publications
- Cenozoic Radiolarian Publications

World War I
World War II
First DSDP Leg
Figure 1.2 Occurrence of Mesozoic Radiolarians from Selected Publications (1876 - 1990).
INDEX

1. Abin, 1988........................................... Cuba
2. Bione & Irwin, 1985............................ Cyprus
3. Campbell & Clark, 1944....................... California
4. De Wever, 1988.................................... Oman
5. Dunkleman, 1973................................. Central Pacific; DSDP Leg 16
6. Dumitrica, 1970..................................... Romania
7. Dumitrica, 1973..................................... Central Atlantic; DSDP Leg 13
8. Dumitrica, 1975..................................... Romania
10. Emsen Moris, 1982.............................. Composite
11. Emsen Moris, 1984.............................. Composite
12. Foreman, 1966..................................... Composite
14. Foreman, 1971..................................... Central Pacific; DSDP Leg 7
15. Foreman, 1973a.................................... Gulf of Mexico; DSDP Leg 10
16. Foreman, 1973b.................................... North Pacific; DSDP Leg 20
17. Foreman, 1973c.................................... North Pacific; DSDP Leg 32
18. Foreman, 1977..................................... Atlantic Basin - Composite
19. Foreman, 1978a.................................... South Atlantic; DSDP Leg 40
20. Foreman, 1978b.................................... Central Atlantic; DSDP Leg 41
21. Goricam, 1987..................................... Yugoslavia
22. Hasek, 1877........................................ Composite
25. Kling, 1971....................................... North Pacific; DSDP Leg 6
26. Kling, 1982....................................... North Pacific; DSDP Leg 60
27. Koutsoukos & Hart, 1990...................... Brazil
29. Kuhnt et al., 1986.............................. Morocco, Gibraltar Arch
30. Lipman, 1952...................................... Russian Platform
31. Lipman, 1962...................................... Russian Platform
32. Nakaokeko et al., 1979....................... Japan
33. Nakaokeko & Nishura, 1981................... Japan
34. Okamura, 1980..................................... Japan
35. Pessagno, 1962.................................... Puerto Rico
36. Pessagno, 1963.................................... Puerto Rico
37. Pessagno, 1971..................................... California
38. Pessagno, 1973..................................... California
39. Pessagno, 1975..................................... Tasman Sea
40. Pessagno, 1976..................................... California
41. Pessagno, 1977..................................... California
42. Pessagno, 1977a................................. California
43. Pessagno, 1977b................................. California
44. Petrushovskaya & Kozlova, 1972............. Central Atlantic
45. Renz, 1974........................................ Indian Ocean; DSDP Leg 27
46. Riedel & Sanfilippo, 1970..................... Central Atlantic; DSDP Leg 4
47. Riedel & Sanfilippo, 1973..................... Caribbean, DSDP Leg 15
48. Riedel & Sanfilippo, 1974..................... Indian Ocean; DSDP Leg 26
49. Rust, 1898......................................... Germany
50. Sanfilippo & Riedel, 1985.................... Composite
51. Schaf, 1981....................................... North Pacific; DSDP Leg 62
52. Schaf, 1984....................................... Composite
53. Schaf, 1986....................................... Oman
55. Squinabol, 1903.................................. Italy
56. Squinabol, 1904.................................. Italy
57. Squinabol, 1914.................................. Italy
58. Taketani, 1982................................. Japan
59. Tan Sin Huk, 1927.............................. Rotti
60. Thurov, 1988a................................. North Atlantic; DSDP Leg 93
61. Thurov & Khant, 1986....................... Gibraltar Arch
62. White, 1924...................................... Mexico
63. Zittel, 1876....................................... Germany
CHAPTER 2

PRODUCTION AND PRESERVATION OF SILICEOUS MICROFOSSILS

2.1 Introduction
The recovery of fossil radiolarians from marine sediments is intermittent and less predictable than, for instance, the recovery of foraminifera or calcareous nannofossils. This chapter examines some of the reasons behind the occurrence patterns and analyses the relative causes for the distribution patterns, i.e. whether these patterns are a function of production or of preservation. There is, however, less information on the preservation of silicon in the oceans than for calcium.

2.2 The Silica Cycle
The silica cycle is by definition dynamic and the interactive complexities have here been simplified. Only part of the cycle is discussed in any detail, i.e. uptake of silica by siliceous organisms, pre-burial dissolution after the death of the organism, and post-burial diagenesis and mineralogical change within a host sediment. A discussion of the pathways or routes taken by biogenic silica is difficult to undertake without reference to non-biogenic silica as, although the formation of authigenic siliceous deposits is still not fully understood, the relationships between biological and mineralogical sources and respective sinks and processes are inter-connected. These major sinks, routes and processes of the natural silica cycle are simplified in figure 2.1 (adapted, in part, from Reynolds, 1986, p. 270, fig. 17.1) and are discussed below. The discussion is primarily concerned with the marine cycle although brief references are also made to non-marine organisms.

2.3 Water Chemistry
In ocean water, silica naturally occurs as $\text{H}_4\text{SiO}_4$ (monosilicic acid) (Reynolds, 1986). Its concentration is limited by precipitation of amorphous silica which in turn is governed by the pH value of the environment. At the present day, sea water is undersaturated with respect
to amorphous silica and cristobalite (Kastner, 1981). Biological fixation (by radiolaria and diatoms) of silica in surface waters accounts for these being the most depleted. Calvert (1974), suggests that the concentration of dissolved silicon in sea-water increases with depth because in surface waters it is removed by the silica-secreting phytoplankton and is then only released by dissolution as the dead phytoplankton fall through the water column.

Most of the amorphous silica budget of oceanic waters is at any one time fixed in the photic zone by silica-secreting organisms and nowhere in the ocean, above the sediment/water interface, is there more than 10%
saturation with respect to amorphous silica. Dissolved silica is then taken back into the cycle by siliceous organisms or is directly chemically precipitated in mineral form.

The amount of time dissolved silica would remain in a stationary state ocean before being precipitated was estimated by Wollast (1974) at c. 13,000 years. Kastner (1981) considers that, with the intervention of the silica-fixing biota, the figure is more like 100 - 300 years.

A figure by Calvert (1974, p. 275, fig. 1) shows dissolved silicon concentrations to vary between oceans. He explained this as being brought about by deep water circulation between the oceans (silicon-bearing waters from the Atlantic flow into the Pacific and are returned as surface water depleted with respect to silicon). A balance is brought about, however, because the Atlantic receives relatively more dissolved silicon from runoff than does the Pacific.

The sources of dissolved silica $\text{H}_4\text{SiO}_4$ in oceanic waters are primarily from the continents via rivers, reaction of clay minerals, the pre-burial or post-burial dissolution of siliceous organisms, and submarine volcanic activity. The submarine diagenesis of clay minerals, such as the alteration of smectite to hydrous mica or chlorite, would release silica. Smectite zeolite and opal-A may also be produced by the alteration of volcanic detritus (Keene, 1976). Gibson and Towe (1971) suggested that volcanic glass was a source of silica for planktic\(^1\) skeletogenesis, and could produce sporadic increased productivity. However, summarising the work done by Stefansson (1966), Elderfield (1972) and Vidal et al. (1978), Kastner (1981) commented that submarine eruptions do not affect plankton blooms. Farinacci (1989) disagrees with this view and suggests that with regard to the Late Jurassic Tethyan Ophiolite event great proliferation of siliceous organisms is connected with submarine volcanism but poorly substantiated in modern environments. The most important source of dissolved silica in modern waters, however, is thought to be the re-cycling of siliceous organisms after death and this was probably the case in Late Cretaceous oceans where diatoms were present with radiolaria as in modern oceans.

\(^1\)The terms planktic and benthic (as opposed to planktonic and benthonic) are used in this work, following the recommendations of Emiliani (1991). It is acknowledged, however, that this view is not necessarily generally acceptable to all readers.
2.4 Biogenic Silica

The organisms of special interest in this discussion are the siliceous microfossils, i.e. radiolaria, diatoms and silicoflagellates, although it should be noted that other biospheric components, e.g. sponges, must also contribute to the dynamic state of the silica budgets of both marine and non-marine waters.

Riech and von Rad (1979) report that most of the dissolved oceanic silica is taken up for skeletogenesis by siliceous plankton in the photic zone; Jerlov (1968) suggests that diatoms and radiolaria thrive in the euphotic zone (10 - 30 metres in the ocean); Kirk (1983) observed a preferential depth of 2 - 25 metres in lakes by non-marine diatoms.

The distribution of marine siliceous organisms in life is not laterally or vertically homogeneous in the oceans. According to Kastner (1981), there are four areas of upwelling (or divergence) constituting present day areas of biogenic siliceous sediment formation comprising three belts: 1). equatorial Pacific and Indian Oceans (radiolaria, diatoms); 2). discontinuous in the northern Pacific (diatoms); 3). Antarctic (diatoms); and 4). western continental coasts (diatoms). Siliceous sediments are very much diluted in the equatorial Atlantic Ocean by calcareous oozes. Outside these four areas, biogenic silica is being deposited but dissolves at an approximately equivalent rate and is thus not preserved (Riedel, 1971). Calvert (1974) summarised the pattern that organic productivity is high where surface nutrient supply and concentration is high, due to upwelling currents bringing the nutrients to the surface (e.g. in the Antarctic) and where there is an abundance of sunlight for photosynthesis. Another area of high productivity is along the western continental, mid-latitude coasts, caused by seasonal upwelling of water where surface water is being transported away from the coasts.

Biogenic silica is, by definition, silica produced by secretion of living organisms. These organisms - radiolaria and diatoms (and silicoflagellates, sponges, etc.) - utilize dissolved silicon from the oceans to construct skeletons because biomineralisation is a method of imparting strength to an organism's organic skeleton. This strengthening of the test is the reason
why such forms can then be preserved in the fossil record (Lowenstam and Weiner, 1989).

The resultant test (skeleton) constructed via the uptake of monosilicic acid by silica-secreting organisms such as radiolaria is made of hydrated amorphous silica known as opal-A. Diatom walls are also primarily composed of hydrated amorphous cryptocrystalline polymers of silica (opal) with high porosity (Lewin, 1961; Reynolds, 1986).

Some species of diatoms (in particular freshwater forms) are relatively easy to culture in the laboratory and therefore a great deal is known about how silicon is extracted and deposited by them, and of their physiology, i.e. that the major component of the cell walls of diatoms is opaline silica, which is also needed to aid cell division (Calvert, 1974). Low silicon concentrations in the culture medium inhibits metabolic reactions in the diatoms, and in cell-wall construction. The concentration of silicon in a culture medium affects the rate of division of a cell and the amount of silicon in the cell, so that this can vary within a species: the less silicon in the medium, and the faster the rate of cell division, the thinner the cell wall (Lund, 1950; Jørgensen, 1955).

Diatoms still constitute one of the densest microplankton groups even although evolution has progressed along the lines of increasing buoyancy (Reynolds, 1986). The larger the diameter of the cell, the slower the sinking rate: spines and webs composed of chitinous fibres increase resistance, and the formation of chains (common in some species of diatoms), whilst increasing volume, also increases surface area, which allows greater elemental and light uptake and inhibits predation (Reynolds, 1986). Radiolaria have followed a similar evolutionary path, i.e. a decrease in weight and mass and an increase in buoyancy and surface area, at least from the Triassic to Recent. This is further discussed in Chapter 8.

In the present day oceans, diatoms (because of the greater number of individuals) are the dominant group responsible for removal of dissolved silica from sea water, with lesser contributions from radiolaria, silicoflagellates and sponges (Maliva et al., 1989). The evolution of
silica-secreting groups of organisms and their effect on the biogenic silica sinks have changed with time. The way in which this affected silica distribution during the Late Cretaceous is referred to in Chapter 8, p. 291.

2.5 Solution

An equilibrium between silica uptake by siliceous organisms and silica availability in the oceans is maintained by dissolution of their sinking dead skeletons and only a fraction of organic remains are deposited on the ocean floor (Calvert, 1974). Reynolds (1986) noted that c. 40% of deposited biogenic silica is returned directly to the system by pre-depositional dissolution or mechanical liberation, however, some authors claim that this figure is as high as 98%.

During life, the mineral skeletons of plankton are protected by the protoplasm of the cell. In certain stress conditions radiolaria have been observed to retract this protective covering therefore leaving part of the skeleton exposed and prone to dissolution (De Wever, pers. comm., 1989). The question of contemporaneous pre-mortem dissolution and regeneration of siliceous organisms is considered to have only a relatively minor impact on the silica cycle and is not considered further here. Removal or disintegration of this protective coating after death exposes the skeleton to chemical attack. Dissolution of fragile dead diatom frustules is relatively rapid in the water column after removal of the organic coating (Lewin, 1961). This was demonstrated in studies undertaken to determine the decrease of skeleton numbers (Gilbert and Allen, 1943; Round, 1968), differences in the floral composition (Calvert, 1966) and decrease in suspended biogenic silica concentrations with depth (Lisitzin et al., 1967). Radiolaria, with generally larger, more robust skeletons than diatoms, tend to suffer less destruction during post-mortem sinking.

It should also be considered that species of radiolaria are thought to inhabit a variety of depths in the water column and not all are restricted to surface waters. The depth travelled to the ocean floor must also therefore be taken into account when monitoring dissolution rates. Interpretations based on fossil assemblages must take into account that the
thanatocoenoses of siliceous microfossils represented in preserved sediments do not reflect the biocoenoses (Calvert, 1974), but are potentially composites of superposed assemblages from several depths.

In areas where biogenic productivity is high (and therefore sedimentation rates are likely to be high) opaline silica is better preserved because of the presence of high concentrations of dissolved silica in the sediment's pore waters (Kastner, 1981). Of the skeletons which survive dissolution in the water column (possibly aided, for example, by transport and protection by faecal pellets), diatoms tend to be better preserved than radiolaria. This may also be a function of size, a parallel being drawn with calcareous organisms in that calcareous nannofossils are usually better preserved in calcareous sediments than the larger, contemporaneous planktic foraminifera.

Recycling of silica in lake environments is slightly different from open ocean conditions in that the water column in a lake is often not extensive enough to allow dissolution of the dead skeletons. Extensive dissolution may then, however, take place on the lake floor, aided by resuspension brought about by wind and wave turbulence, and bioturbation, thus allowing more opportunity for solution to take place.

The results of Goto (1958), van Lier et al. (1960), Hurd (1973), Lawson et al. (1978) and Wirth and Gieskes (1979) show that dissolution of amorphous silica is a function of a chemical surface reaction rather than being diffusion-controlled, so that sediments rich in opaline silica can still accumulate on the ocean floor despite the water being undersaturated with respect to opaline silica (Kastner, 1981).

The rate of return of biogenic silica to the system depends upon temperature, pressure, pH of the host medium, and organic remains coating the skeleton (Reynolds, 1986). Wollast (1974) indicated that between 0 - 1000 metres of the water column, 40% of siliceous material is dissolved.
2.6 Deposition

Biogenic silica is much discussed in the literature as the source of silica for the formation of nodular and bedded cherts, and for the partial silicification of other sediments.

Calvert (1974) noted that radiolaria and diatoms provide a large amount of the solid silica being deposited in the oceans, other sources including pyroclastic volcanic deposits and terrigenous debris. Maliva, Knoll and Siever (1989) suggest that biogenic oozes are mostly made up of robust siliceous skeletal material which reaches the sea floor via faecal pellets and marine snow (flocculated empty shells).

Nodular cherts were originally believed to have formed by inorganic precipitation of globules of silica gel from sea water (Tarr, 1917). However, years of research have shown no deposits of such a gel on or below the present ocean floors (Wise and Weaver, 1974). Another theory of chert formation involved the replacement of carbonates by silica (Barton, 1918; van Tuyl, 1918). It is now generally accepted that nodular cherts have a predominantly biogenic origin. Hypotheses on bedded chert formation have also been forthcoming since Davis (1918) suggested that the silica gel was provided by volcanic activity which trapped radiolarian skeletons and solidified. In 1946, Bramlette noted that porcellanite was formed by conversion of biogenic opal.

The environment of deposition of biogenic oozes is a critical factor in determining the resultant type of chert or silicified rock. Depositional conditions at the sediment/water interface and during shallow burial have a significant impact because, as Calvert (1974) suggests, biogenic silica is very prone to chemical change (e.g. dissolution by pore water, recrystallisation) during diagenesis. (Opaline) silica accumulates on the modern ocean floor where siliceous microfossils are not entirely dissolved in the water column, and where the ocean floor lies above the critical level for dissolution of silica. Solubility of deposited opaline silica decreases (i.e. siliceous microfossils have a greater chance of preservation) in regions where surface productivity is high and the calcite compensation depth is deep, so that the carbon dioxide released from the
sediments accumulating beneath these areas depresses the sea water pH (Ramsay, 1971).

At the present day, biogenic ooze deposits are deposited in two main pelagic environments:-
1. open ocean, where terrigenous dilution is minimal but biogenic carbonate, pelagic clay and volcanic ash may be present (Maliva et al. 1989) - in this environment, the sedimentation rate is millimetres/centimetres per thousand years; and
2. in basins formed at the edges of active continental margins, e.g. Gulf of California (Calvert, 1966), where upwelling is strong, creating ideal conditions for high productivity - these sediments tend to be diluted with clays, phosphorites and terrigenous material and dissolved silica is provided by circulating oceanic water and weathering of basalt.

As Ramsay (1971) stated, biogenic silica-rich deposits are not geographically widespread in the present day Atlantic Ocean, although they do appear relatively extensively in the stratigraphical record there, as described in numerous DSDP volumes, in regions of palaeo-upwelling.

The source of silica deposited on ocean and lake floors is a controversial topic. Whilst it is accepted that organic debris is a major source, the question of whether silica is also precipitated inorganically directly from ocean and lake waters is still poorly understood.

2.7 Diagenesis

Since diagenesis destroys some of the palaeoenvironmental indicators, any interpretation or reconstruction of events renders it necessary to:-
1. identify silica sources,
2. determine the relationship between the depositional environment and the present diagenetic facies, and
3. attempt to identify the nature and causes of the silicification processes (Riech and von Rad, 1979).
Throughout each stage of diagenesis, skeletons are susceptible to partial or total destruction and the more delicate skeletons are selectively removed from the geological record. It has been estimated that only about 2% of the siliceous organisms living in high-productivity surface waters are permanently removed from the oceanic silica cycle and are permanently preserved in the fossil record.

Diagenesis results in alteration of skeletal material starting with skeletal corrosion (often commencing during transport in the water column, which is undersaturated with respect to silica, and also at the sediment/water interface). Pore waters can thus locally, become oversaturated with respect to silica (Riech and von Rad, 1979). Porcellanite becomes chert when opal-CT transforms into quartz with time and increased burial, i.e. increased pressure and temperature.

Riech and von Rad (1979) consider that these geologically preserved siliceous plankton also amount to only c. 2% of the original deposited population. Diagenesis of biogenic silica often results in, among other things, dissolution and disassociation of siliceous skeletons, decrease in surface area and solubility, loss of water from the skeleton and increased test density (Hurd and Theyer, 1975, 1977); thus reduction in volume of siliceous sediments and decrease in porosity (80% in siliceous ooze, 10% in chert) results.

The different phases of opal (A, C and CT) can be distinguished by their X-ray diffraction patterns (Kastner, 1981, p. 920, fig. 1). Opal-CT can occur as radiolarian test casts. Opal-C is the phase associated with volcanic sediments. Deep-sea chert and porcellanite are mostly formed by biogenic silica diagenesis but this authigenic silica accounts for only 1 - 2% of the original biogenic remains (Kastner, 1981).

Opal-A is the first of the three principal pure silica phases in a transition series through which post-mortem siliceous skeletons can be transformed, the other main phases being Opal-CT and finally quartz. Opal-A is a metastable, hydrous, amorphous, silica form. The first stages of alteration or aging of this is recognisable with scanning electron microscopy by its globular surface appearance. Should this skeleton, post-mortem, reach the
ocean floor without significant dissolution and become buried, it then stands a chance of preservation in the geological record. After shallow burial, however, there is still the possibility of dissolution by the action of pore waters and a subsequent return of Si(OH)$_4$ to the ocean waters. Smaller and thinner-walled organisms are more susceptible to dissolution at this stage, the input of this silica to the pore waters then consequently favouring preservation of more robust skeletons. If the skeleton survives morphologically in-situ, the next metastable phase is the replacement of opal-A with opal-CT.

Opal-CT is an abbreviated term for metastable, undimensionally disordered, low temperature cristobalite/tridymite. This is commonly recognisable with the S.E.M. as replacement of the skeletal wall-structure by lepispheres (hemispherical shaped growths of intersecting, bladed crystals showing irregular, ragged edges). During this stage in the diagenesis the skeleton may, if there is no significant mobilization of silica, be replaced in-situ by opal-CT. Should there be local mobilization of silica, then skeletons may be partly or selectively dissolved. Undersaturation with respect to silica of the diagenetic environment at this stage results in the formation of zeolites and phyllosilicates such as smectite, if sufficient aluminium, alkali and alkaline-earth ions are available in the pore water. Siliceous skeletons can also be replaced by (Na, K, Ca)$_6$ (Si, Al)$_{36}$ O$_{72}$ 20H$_{2}$O) the zeolite clinoptilolite at this stage, recognisable with the S.E.M. as euhedral crystals. Oversaturation with respect to silica in the pore waters results in the formation of porcellanite or porcelaneous sediments.

Under the influence of factors such as temperature, time, pressure and host lithology, plus other, as yet indeterminate, factors, the opal-CT is changed to more stable quartz. It is generally considered that quartz cherts were never formed from biogenic silica without an intermediary opal-CT phase (e.g. Riech and von Rad, 1979; Afanasieva, 1990). However Kastner (1981) suggests that biogenic silica (opal-A) can, rarely, be altered straight to quartz or, more commonly, to quartz via opal-CT by diagenesis and that these are the major constituents of cherts (mainly authigenic quartz) and porcellanites (mainly opal-CT).
Kastner (1981, p. 916, table 1) summarised the reactions leading to production of authigenic (i.e. formed in-situ within the sediment) silicates in deep-sea sediments, and noted that such sediments "start out as a mixture of stable and metastable phases" (Kastner, 1981, p. 915) and are transformed by diagenetic reactions into a mixture of stable phases.

As Kastner (1981) commented, both experimental and field observations have shown that biogenic silica changes within the sediment with age, e.g. the Monterey Formation, California: from siliceous ooze (opal-A) to porcellanite (opal-CT; step 1) to chert (chalcedony and quartz; step 2) (Bramlette, 1946). The first step involves solution (Carr and Fyfe, 1958; Mizutani, 1966; Kastner et al., 1977) which does not disturb fine morphological detail, whilst the second step occurs with both a solid state and a solution phase (Ernst and Calvert, 1969; Heath and Moberly, 1971; Stein and Kirkpatrick, 1976; Carr and Fyfe, 1958; Murata and Larson, 1975; Murata et al., 1977). Thus, the reverse stratigraphical sequence should be:- siliceous ooze → porcellanite → chert, indicating that temperature and pressure control this transformation. Many exceptions have been observed from DSDP cores and onshore sections, however, and these may be due to presence/absence of argillaceous/carbonate sediment (Millot, 1970; summarised in Kastner, 1981).

A study by von Rad and Rosch (1974) on central Atlantic cherts from DSDP Leg 14 revealed four types of chert in different stages of maturation, ranging from immature, poorly-crystallised to mature, highly-crystallised cherts, showing a decrease in opal-A and a corresponding increase in opal-CT and quartz from young to old. Biogenic remains were also seen to become rarer with increased maturity.

Kakuwa (1984) defined six grades of preservation of siliceous microfossils based on the degree of diagenetic alteration to pore structure, their visibility and the inter-granular cement in the tests/frustules, which he related to stages of silica preservation. Where opal-A only was detected in a diatomite, preservation of the microfossils was good; where opal-CT appeared, compaction and dissolution of delicate diatom species had resulted. In the opal-A to opal-CT transition zone, dissolution of large diatoms and internal cementation had occurred, whilst radiolaria were still
well-preserved. Within the zone of opal-CT, only diatom moulds were present with uniform silica granules surrounding the mould. Where opal-CT changes to quartz, dissolution of diatoms was complete and radiolaria were partially preserved. Diatoms and radiolaria in porcellanite are usually replaced by moulds and rarely preserved as casts.

The role of the host lithology is also thought to play a contributory part in the maturation process, although this is also not a conclusive factor. It is generally accepted that bedded silica is characteristic of environments with a high clay content while nodular cherts or flints are characteristic of calcareous sediments. Predominantly carbonate sediments are thought to slightly accelerate the transformation of opal-A to opal-CT, while a clay facies significantly retards the transformation of opal-CT to quartz. Riech and von Rad (1979) and Thein and von Rad (1987) agree that the presence of carbonates increases the transformation rates, whereas Isaacs (1982), during a study of the Monterey Formation (Miocene), demonstrated that the presence/absence of carbonate minerals had no significant effect on the rate of silica diagenesis. All phases of transformation, however, are to be found in both carbonate and clay facies. In general, nodular cherts/porcellanites represent replacement of carbonate matrix in carbonate sediments, whilst those that are bedded have replaced biogenic amorphous silica (Kastner, 1981).

Sedimented biogenic silica forms beds of chert/porcellanite when deposited below the calcite compensation depth, and nodular chert/porcellanite when deposited above (Kastner, 1981). Porcellanite is more frequently associated with argillaceous sediments, and chert with carbonate sediments. Where cherts are associated with carbonates, the rate of change of opal-A to opal-CT is increased (Kastner et al., 1977), the radiolaria/diatoms being protected from dissolution by an opal-CT coating.

Problems encountered in the interpretation of the geological history of sediments and phases of change in siliceous components are hindered by a lack of understanding of the physical and temporal conditions needed to trigger each phase of diagenesis and the conditions controlling the rate of diagenesis. This is illustrated by Riech and von Rad (1979), who report
that all phases of the biogenic silica maturation process have been found preserved in similar conditions, i.e. the stability fields of opal-A, opal-CT and quartz overlap. For example, opal-A can be present at depths of more than 1000 metres in younger sediments, e.g. of Miocene age, whereas it is not found at shallower depths in older sediments, e.g. Early Cretaceous and older. Younger, post-Miocene opal-CT is extremely rare but has been recorded at burial depths of less than 50 metres. It would appear also that the minimum age and burial depth of quartz cherts and the maximum age and burial depth of opal-A overlap.

During a study of radiolarian petrographic preservation types in the cherts of Costa Rica, Gursky (1990) observed approximately 40 preservation types. He suggests that types and grades of radiolarian preservation represent an important aid in the reconstruction of the post-depositional diagenetic and thermal history of the Costa Rican cherts.

Although this discussion has been concerned only with the diagenesis of biogenic silica preserved as silica it should also be noted that silica-secreting microfossils, such as radiolaria, diatoms and silicoflagellates can also be diagenetically altered, post-mortem, to $\text{CaCO}_3$ in post-burial environments oversaturated with respect to calcium carbonate, and to sulphides, e.g. pyrite, in reducing diagenetic environments.

2.8 Discussion

Distribution of ancient biogenic cherts in association with different facies gives an insight into the evolution of the habitats of the biota and highlights silica sinks through time. The silica cycle evolved through geological time in conjunction with the evolution of a silica-secreting biota (sponges, radiolaria and diatoms) which form the main sink for silica on burial (Maliva et al., 1989).

Distribution patterns would therefore seem to be a function of both sufficient biogenic production (i.e. areas of high production, such as upwelling zones, where deposition exceeds dissolution) and favourable preservational conditions (i.e. low pH values, lack of bottom-water
turbulence, etc.) at the site of deposition. Regional conditions affecting the post-burial history (e.g. depth-controlled temperature and pressure conditions) could be expected to have only a localised influence on global distribution patterns. Probably the most important influencing factor, however, is the state, during any one period in time, of the silica budget and the distribution of Si(OH)$_4$ during that period. The interaction of major global conditions such as continental position, climate and sea-level change, etc., and the rate of change in these conditions will undoubtedly have had significant effect on the evolution of the silica cycle. The global distribution patterns of production and preservation of siliceous microfossils through time, or during any one period of time, should take into account the interpreted state of the silica cycle at that time. The impact of global conditions in the Late Cretaceous on silica production and preservation is considered in Chapter 8.
CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction
In analysing the occurrence patterns of Late Cretaceous radiolaria it was intended to compare their biostratigraphy with that of calcareous plankton to produce an interpreted Si and Ca biozonation scheme. Thus, sample selection and also techniques were approached with the need to isolate both Si and Ca microfossils in mind. This chapter discusses the materials and methods used in pursuit of the general aims outlined in Chapter 1.

The probability of there being no form of life present in any particular marine or terrestrial environment during any time interval from at least late Pre-Cambrian times is extremely low. The likelihood of the evidence being preserved in the fossil record is considerably less but the probability of, at present, being unable to recognise this evidence is much higher. The envisaged scale of investigations is immense so therefore the current investigations have been confined to the search for evidence of radiolarians with skeletal remains measuring, at the minimum dimension or latitudinal axis, over 5μm. The interval to be studied has also been confined to the Upper Cretaceous period.

3.2 General Aims and Objectives
The general aims of the following investigation are:-
a). to define a universal processing technique, applicable to all lithologies and to all sample types, e.g. field samples or ditch cuttings, which is cost-effective, needs little specialised equipment, is portable for use at rig site, which meets all health and safety standard requirements, and which, most importantly, does not destroy, remove or damage any contained microfossils;
b). to gain technical experience in both experimental processing, observational and data management techniques and in previously documented methods;
c). to assess the effects of different techniques and methods on the data acquired and ultimately on its geological interpretation;
d). to present data gathered during this project in a comprehensive manner so that any part of the investigations can be easily repeated, or the data re-interpreted by other workers.

3.3 Sample Selection
Certain criteria were considered in the sample selection process for this project. These are interdependent and are listed in the order in which they were considered:-

a. Reasons for analysis, e.g. palaeoenvironmental interpretation, biostratigraphical interpretation, broader correlation studies;
b. Time available for analysis;
c. Stratigraphical framework;
d. Sample spacing; and
e. Lithological type.

a. Reasons for analysis - these can vary greatly between extremes; for example, the aim may be to establish an approximate age of the uppermost part of a section by the use of a minimum number of index species. Alternatively, a detailed analysis of the section using all available data may be required. In this study, preliminary decisions were taken as to the reason for analysing samples for each section. These were designed partly to save time and effort but equally to ensure that enough data would be generated for the required interpretations.

b. Time available - this factor influences the choice of lithology, the sample spacing, the method of processing and the method of analysis. The quantity of data produced will be proportional to the time spent collecting it (within a maximum limit) but the quality of the data will be variable.

c. Stratigraphical framework - if a section has previously yielded comprehensive data for another fossil group, such as foraminifera, then this can be employed in the selection of samples for siliceous analysis. For example, although it is preferable to calibrate the occurrences of calcareous and siliceous microfossils by using specimens recovered from the same sample valid results can be obtained by using closely-spaced,
alternating samples which contain either calcareous or siliceous microfossils.

d. Sample spacing - samples need to be closely enough spaced to give optimum distribution data or refine a zonation if necessary. Initially, quite wide spacing can be employed and more samples analysed later to refine ranges for zonation purposes as considered necessary. Obviously, the samples for the refined zonation must be readily available. The accessibility of more closely-spaced samples must be balanced against shipment costs and storage facilities. In reconnaissance analysis, closely-spaced samples of not more than 1 metre should normally yield even short-ranging species but much depends on the sedimentation rate and compaction history of the sequence. When a biostratigraphical framework for the microfossil group has been established, such as in the case of planktic foraminifera effective sample spacing can usually be reliably predicted. No ideal universal spacing can be dictated, as each section is different.

e. Lithological type - previous experience has shown that some lithologies are more suitable for the extraction of particular fossil groups than others. Lithologies can be divided into three broad categories:-

i). suitable for recovery of microfossils, e.g. fossiliferous mudstones easily yield foraminifera, ostracods, palynomorphs, nannofossils but not calpionellids, which originally needed the support of the host lithology to remain intact;

ii). suitable for selective recovery of microfossils, e.g. chalks are suitable for recovery of nannofossils, siliceous microfossils (unless replaced by CaCO\textsubscript{3}) and, if soft enough, foraminifera - foraminifera and nannofossils recovered from chalks tend to be overgrown with CaCO\textsubscript{3}; and

iii). unsuitable for recovery of microfossils, e.g. coarse sands, evaporites, dolomite, red beds, etc..

These categories are only regarded as a broad generalization and are subject to exceptions. For example, in practice it is often found that unfossiliferous halite will be intercalated with thin beds of fossiliferous mudstone. Also, whilst it is relatively easy to recover fossiliferous palynological and micropalaeontological residues from reasonably soft,
fossiliferous mudstones other lithologies have their own, sometimes prohibitive, characteristics. For example, hard limestones yield palynomorphs and siliceous microfossils (by acid digestion), but make recovery of isolated foraminifera difficult because the latter (unless silicified) are dissolved by the HCl used to remove the limestone matrix.

Discussion - from previous experience, it is apparent that an effective analysis programme requires careful sample selection. The criteria considered during the selection process can greatly influence the final results obtained, both in respect of the quality and quantity of data gathered, and subsequently in the value of the final interpretation.

During the course of this project, not only have the previously perceived effects of sample selection been re-established but additional factors have become apparent. These include the distortion of assemblage composition and the subsequent incompatibility of different global zonation schemes. More detailed discussion of these effects is included in the conclusions of this chapter and in Chapters 5, 6, and 7.

3.4 Sample Collection
Samples used in this project were collected in two different ways, i.e. from DSDP cores and by field sampling. The method of collection is an important consideration in interpretation, e.g. for identification of possible contamination. The method of collection, and subsequently the amount of material available, directly affects the size of the residue available for analysis. DSDP/IPOD samples were restricted to a maximum size of c.25cc per sample whilst c.500cc of material was collected in the field.

Samples collected by DSDP expeditions are cores and detailed recovery methods for each site are given in the respective 'Initial Reports of the Deep Sea Drilling Project'. Common factors of all drilled and cored sections are: i) the discrepancy between drillers' and loggers' depth measurements, and ii) to a greater or lesser degree, downhole contamination. These factors are considered in subsequent interpretations in this report. Contamination from drilling mud is considered of minimal importance with regard to samples used in this study, as they are all core samples as opposed to ditch cuttings.
Field samples from Cyprus were collected in the following way. The section was identified, measured, sample spacing was decided upon and suitable lithologies chosen. Sub-samples were examined with a hand lens and tested with HCl. acid. Elaborate field examination of samples with a field microscope and HF (as described in Baumgartner et al., 1981) was not employed, partly due to import difficulties and partly due to the health hazards involved in the use of HF in the field. Field relations were considered to a greater or lesser degree, depending on the situation. Chosen sampling points were examined in-situ for macrofossils and sedimentary features, such as slumping, burrowing, laminations, etc.. Samples were collected from the base to the top of the section to reduce risk of contaminating older material with younger material. Care was taken to clean implements between each successive sample. Samples were placed in numbered cloth bags and logged in a field book. A field sketch and photographs were recorded at each section, as was the exact location and the height above present sea level.

3.5 Examination of Raw Samples

Prior to laboratory examination, all samples were completely dried. They were dried for several reasons, including: a). to limit bacterial action within the sample which, apart from other destructive action, causes rotting of the sample bags and potential contamination from adjacent stored samples, b). standardize observations of colour, hardness and fissility, c). removal of pore fluids speeds chemical treatment, and d): dry samples are more easily crushed. Each sample was then examined primarily for macrofossils and sedimentary structures (N.B. temporary wetting of the sample surface can make these features clearer. A summary report of the sample was then made, documenting all features apparent at this stage. These included lithological type, colour, hardness, fissility, calcareous or non-calc当地orous nature, accessory minerals, and sedimentary features together with the microfossil content (group, abundance, diversity and preservation) of each sample, recorded when the processed residue was examined. These observations are summarised in Appendix 1 and the complete data set is stored on floppy disc, deposited in the Department of Geological Sciences, University College London.

- 33 -
A small amount of sample was then used to make a simple smear slide to enable further evaluation of appropriate processing techniques and fossil content. The sample was then split into several parts: a control portion, a sub-sample for nannofossil analysis, and sub-samples for each of the processing techniques to be applied for the extraction of siliceous fossils.

In the evaluation of the processing technique(s) to be used, the following points were considered:

1. the mineral components and their relative proportions;
2. the organic components, including microfossils, kerogen and amorphous organic material (AOM);
3. successful removal of unwanted constituents may adversely affect the presence or preservation of the microfossils sought; and
4. each sample will have been subjected to different degrees of compaction, dehydration, pressure, temperature and related diagenetic processes during burial history which will have produced individual characteristics within the sample, making it more or less susceptible to the processing techniques applied.

During each stage of the preparation, the samples were inspected and modifications made, if necessary, to the processing technique.

3.6 Extraction of Microfossils

3.6.1. Contamination

Before the samples were processed, careful consideration was given to the danger of contamination. The mixing of microfossils from different assemblages (either environmentally different or stratigraphically different) is regarded as contamination. This can occur as a result of two sets of influences: by natural processes, or human influence. The natural influences can occur at any time between death of the microfossil and sampling of the host sediment, i.e.

i). Co-deposition at the sediment-water interface of vertically different and/or laterally transported life assemblages;
ii). Reworking in the uppermost layers of sediment by burrowing organisms;
iii). Downslope movement of material, either by solifluction or mass slumping, in both submarine and subaerial situations.
iv). Erosion and redeposition of sediments (and contained microfossils),
thereby mixing older sediments into younger formations;

v). Washing of sediment into desiccation or tectonic fissures thereby mixing younger material into older formations (e.g. sample Perapedhi 89-1, Chapter 5.2, has been interpreted as a fissure deposit).

Contamination during and after the sampling process is attributable to human influence and, unlike the previous category, measures can be taken to prevent, minimise or identify 'displaced' microfossils. The main sources of contamination in well and borehole samples include drilling mud, circulation material and downhole caving. In the case of sidewall core or core samples, much of the influence of drilling mud and circulation material can be eliminated by cleaning the surface of the sample before processing. The effects of caving can be predicted by taking operational conditions into consideration (e.g. casing points, hole conditions, etc.) and minimised by using 'tops' or last appearances of fossils as datum levels. The main sources of contamination in field samples are dirty collecting implements, dirty hands, insecure sample bags and downslope movement of material at the time of collection. All these risks were minimised during the collection of Cyprus material. In the laboratory, cross-contamination can occur between samples from one or more studies. The causes include dirty utensils and airborne material. During preparation of samples for this study, all glassware and sieves were thoroughly washed between samples. For calcareous analyses, glassware was first soaked in 10% HCl and for the siliceous preparations the glassware and sieves were rinsed with methylene blue dye. Also, for the siliceous preparations only, a set of 20 numbered beakers was used. By processing the samples in batches of 20, the beaker used for a particular sample and the other samples which had previously been prepared in this same beaker can be identified in the case of interpretational problems. Distilled water was used rather than tap water for preparations containing smaller fossils, i.e. <20 microns, to prevent aquifer contamination. The nature of material from other workers' projects being prepared in the same laboratory was noted for reference and identification of contamination during sample analyses. Further discussion on the identification of contamination (caused either by natural or human
influences) found in samples during this project is included in the biostratigraphical interpretations in later chapters.

3.6.2. Sample evaluation
The examination of the raw sample, and the observations made from the preliminary smear slide, made it possible to decide which processing method(s) to use. The decision was governed by the type of lithology to be processed in conjunction with the required result, e.g. the group of fossil, the size range of these fossils, the amount and diversity of fossils, balanced by the time available. These factors obviously varied between samples, and the combinations of requirements and techniques which can be applied are large. Only the general methods used are documented here, because of the large permutation available and the necessity to evaluate each sample individually.

3.6.3. Universal techniques
Some parts of sample treatment were common to all of the samples prepared and are as follows:-
  a). Sub-samples were always used for processing in case any of the following problems arose, i. the sample was inadvertently lost in the sink, or ii. the initial lithological evaluation was inaccurate, or iii. the siliceous microfossils had undergone mineral replacement and were dissolved by the acid used.
  b). Samples were completely dried before processing because it makes it easier to crush the rock into small pieces, e.g. mudstone, and also because subsequent chemical treatments are more effective if pore fluids have been removed.
  c). The exterior surfaces of the samples were cleaned before crushing to reduce the risk of contamination. Hard limestones and cherts were scrubbed with a small brush under running water and softer lithologies, such as mudstones, were cleaned by scraping the exterior surfaces with a knife.
  d). In each stage of the processing, the samples were treated in strict rotational order. For example, in the case of well or borehole material, where caving is likely, samples were treated in the order of the youngest or stratigraphically highest first. Field samples were treated in the reverse
order, i.e. the lowest samples in a section were treated first. This helps to
avoid unnecessary artificial reworking or contamination.
e). Each sample was mechanically crushed or broken into small pieces,
about 1cc, in order to produce a large surface to volume area for
chemicals to act on (water is here included as a chemical).

The ultimate aim of the processing techniques applied is to remove all
non-biological mineral components from the sediments, leaving a residue
which consists of an un-biased assemblage of undamaged microfossils,
which accurately represents the content of the original sample. The degree
of success achieved can be greatly influenced by the methods used.
Mineral components can be removed from the sediment by using their
chemical and physical properties, either by dissolution or physical means.
Unfortunately, the methods used can also partially or totally eliminate the
microfossils, depending on their degree of chemical and physical
similarity to the host sediment. The methods of chemical and physical
attack available, and their advantages and disadvantages, are discussed
below.

3.6.4 Disaggregation of sediments
a) Freeze/Thaw
The sediment is immersed in a small amount of water in a plastic
container and placed in a domestic freezer. When the mixture is
completely frozen, the sample is allowed to thaw at room temperature.
The process is then repeated up to twelve times. Sediment disaggregation
is caused by the expansion of the freezing water forcing the sediment
particles apart, as ice between 0 and -4°C has a greater volume than water
above or ice below these temperatures. Thawing of the mixture then
allows the water to redistribute in pore spaces and the process is repeated.
Theoretically, damage to the fossils might be expected but no systematic
damage has been observed to date. This method is documented by
Ableman (1989).

b) Paraffin
The crushed sediment is warmed in an oven and then immersed in
paraffin. After a few minutes, when the sediment is completely saturated,
the remaining liquid is decanted and replaced with boiling water. This
method is particularly useful on mudstones and normally reduces the sediment to liquid mud immediately. The smaller sediment particles can then be removed by washing through a 63μm mesh sieve. The advantages of this method are rapid disaggregation and no observed fossil damage. Petrol can also be used but has the disadvantages of being explosive and of dissolving the nylon and glue components of the sieves after a time. A variation of this method is described by Ferguson (1968).

c) Sodium hexametaphosphate, \((\text{NaPO}_3)_n \text{Na}_2\text{O}\) (Calgon, a commercial water softener)
The chemical is dissolved in water, and the sediment is boiled in this solution for between five minutes and six hours. The length of time needed for breakdown of the material depends on the nature of the sample. The main function of this solution is as a deflocculent for clay minerals. It is effective because the ionic radius of Na is larger than that of Ca. Substitution by the Na ions results in disaggregation and dispersion of the clay minerals.

d) Sodium carbonate, \(\text{Na}_2\text{CO}_3\) (washing soda)
This is used in the same way, and acts in approximately the same way, as Calgon but is less expensive.

e) Ultrasonic vibrations
Various authors discuss the use of ultrasonics for disaggregation of sediments (Pessagno, 1976, 1977a; Sanfilippo and Riedel, 1985) and for the cleaning of already freed specimens. During this project, several experiments using ultrasonics were carried out. Sediment samples immersed in water in a beaker were placed in the tank. The water level in the tank was raised as high as possible without causing the beaker to float and without exceeding the level of water in the beaker. The tank was run for an initial period to allow the water to de-gas. The tank available has a fixed (but unknown) frequency. The ultrasound was switched on for periods of between 30 seconds and 1 hour. Disaggregation of sediments was found to be considerably slower than by using other methods described here. Cleaning of already freed specimens was also found to be unsatisfactory. It is extremely difficult to judge the point in time between optimum cleaning and disintegration of the specimen. Those specimens
which survived the technique were not appreciably cleaner than other untreated specimens from the same sample and survival time of specimens varied between samples. This lack of success may be partly due to the recrystallised infilling of Mesozoic specimens and the technique may be more useful for Tertiary microfossils. Additionally, a bath with a frequency regulator may be an advantage.

3.6.5 Dissolution of sediments
The following chemicals can be used to remove unwanted mineral and organic components by changing their state to liquid and gas. The removal of these components also helps disaggregation of the remaining particles.

a) Hydrogen peroxide (H$_2$O$_2$)
Samples were treated with hydrogen peroxide in a variety of ways. Some were immersed in cold 20 vol. solution and left to soak for several days. Others were boiled in either 20 vol. or 30 vol. solution (repeatedly replenished) for between 1 hour and six hours until oxidization was considered complete.

The purpose of treating samples with hydrogen peroxide is to oxidise the organic matter and also to induce disaggregation of clay minerals. Pyritised fossils may be dissolved or damaged by the acidic action induced (2FeS$_2$ + H$_2$O$_2$ → 4H$_2$SO$_4$ ≠ Fe$_2$O$_3$ + H$_2$O) although Thurow (1988a) maintains that this can be counteracted by the addition of chalk as a buffer. In past studies, pyritised Tertiary microfossils have been seen to become partially dissolved or changed to a reddish colour by brief (5 - 15 minutes) immersion in 20 vol. H$_2$O$_2$, whilst Mesozoic pyritised microfossils have remained unchanged. In this study no completely pyritised specimens were recovered either from material treated with hydrogen peroxide or from material treated in any other way. Some partially pyritised specimens from Cyprus, subjected to boiling in 30 vol. H$_2$O$_2$ for 6 hours, show no signs of alteration.

b) Nitric acid (HNO$_3$)
This acid also produces an oxidising effect and should eliminate unwanted organic matter. The reaction produced is more violent than that with hydrogen peroxide and it will also have an adverse effect on pyritised
microfossils. Samples from this project which were treated with nitric acid did not show any significant improvement compared to those treated with hydrogen peroxide. Although faster results were obtained using nitric acid, when balanced against the additional risk of destroying assemblage components it was decided that hydrogen peroxide was more suitable for the routine processing.

c) Hydrochloric acid (HCl)

Samples prepared for the extraction of siliceous microfossils were soaked in concentrated HCl whether or not they showed signs of a reaction. The acid was repeatedly replenished for those samples which did show a positive reaction, either by effervescence or colour change. The purpose of treating a sample with hydrochloric acid is to remove all carbonate material. The amount and form of this carbonate may vary from minor amounts of calcareous cement, bonding together argillaceous particles, as in calcareous mudstones, to the majority of the sample, as in chalks and limestones. There are several advantages in using HCl as it helps disaggregate particles insoluble in HCl. Also, the acid removes calcareous microfossils such as calcareous foraminifera which otherwise, if present in a great enough relative abundance, may mask the occurrence of radiolaria. HCl also removes unwanted CaCO$_3$ mineral components thus reducing the amount of unwanted residue to be treated by other techniques. In some cases, such as pure/clean limestones, the residue consisted of only siliceous microfossils.

There are, however, disadvantages to this method. Sometimes the radiolaria have been wholly or partly replaced by calcite, in which case they will be destroyed or severely damaged by this method. In other cases (e.g. samples from DSDP Site 152) the calcareous foraminifera have been found to be partly replaced by silica, which means that they will not be totally removed from the residue. Also, although some very small, apparently delicate radiolaria have been collected using this method, recovery of the total assemblage cannot be guaranteed.

The removal of the calcareous material renders the preparation useless for calcareous foraminiferal and calcareous nannofossil analyses, and an initial sub-sample of each sample was retained for separate processing.
None of the samples processed during this study contained siliceous microfossils which had been replaced by calcium carbonate, as none were observed in samples processed by other, non-dissolution methods. If CaCO₃ replacement of fossils occurs, then they can be extracted by first soaking the rock in hydrofluoric acid, thus replacing the calcium carbonate with fluorite (Pessagno, 1977a). Alternatively, a method described by Knitter (1979, 1980) was used on a test sample of U.K. Cenomanian chalk and found to be successful. The method involves floating HCl on top of chloroform in a beaker and then suspending the sample in a coarse mesh sieve (c. 1000μm) in the acid. The freed calcareous microfossils then sink into the chloroform and are protected from further attack. For the experiment carried out during this project, glycerine was used instead of chloroform (Steiger, pers. comm., 1989) for safety reasons, and was found to be a suitable substitute.

Basically, the idea of using HCl is to dissolve the CaCO₃ in the sample, leaving a non-calcareous residue.

For details of techniques used see Baumgartner (1980). Baumgartner demonstrated one of his methods in 1989, at a meeting in Lausanne University. This demonstration involved suspending a small piece of limestone in a plastic kitchen sieve with a large mesh (c. 1000μm) and holding a piece of sieve material (Mesh c. 60μm and approx. 1m square) over a collecting dish but under the sieve containing the piece of sample. 10% HCl was then poured over the sample and when the reaction was complete the acid and freed residue washed through into the second, smaller mesh sieve. The acid continued down into the collecting dish and the residue above 60μm was held in the smaller mesh material. The residue, still held in the material, was then washed under a gentle water jet. The wet residue was then examined to assess the recovery of radiolaria, before drying either with chemicals or by heat induced evaporation (Baumgartner, pers. comm., 1989). Matsuoko (pers. comm., 1990) favours the use of a smaller mesh sieve, i.e. c. 40μm, as the species diversity in the residue is greater.

During this project, specimens of radiolaria recovered from samples treated with concentrated (38%) HCl appear to have suffered little
damage. However, recovery of the potentially complete assemblage cannot be guaranteed.

d) Hydrofluoric acid (HF)
Chert and silicified samples were immersed in cold hydrofluoric acid for periods of up to 48 hours. The treatment time intervals were varied, as was the strength of the acid used. The results show that the resistance of the cherts to dissolution, and also the resistance of contained radiolarian specimens, varies greatly between samples. Some radiolarians showed signs of etching after a few minutes in very dilute (0.5%) acid, whilst other samples yielded specimens after soaking in 40% acid for 24 hours. In the latter case a c.5cc sample was immersed in 150cc of acid, which was not periodically renewed. The experiments showed that each sample should be treated individually, with careful monitoring of the reaction over short time intervals. The strength of the acid should be very gradually increased to reduce the risk of total loss of specimens. To reduce the risk of breakage of very delicate specimens, the sample can be suspended in a sieve so that the freed specimens can fall clear of the more turbulent reaction area, (cf. c) above). The method of floating acid on glycerine, as described above for HCl, can also be applied with HF, making sample monitoring less critical when large batches of samples are being routinely processed.
Treatement with hydrofluoric acid is essentially to free radiolarian tests from a wholly siliceous matrix, i.e. pure chert, or a partly silicified matrix, such as argillaceous chert or silicified limestone. The use of the HF for freeing radiolarians has been employed for several decades - Wetzel in 1933, Lejeune in 1936, Bolli in 1950, Dumitrica, 1970 and De Wever et al. in 1979. The method followed here is that described in detail by Pessagno and Newport (1972). The method works on the principle that the chemical bonding in the precipitated silica of the rock is weaker than the biologically precipitated radiolarian tests. This applies especially to impure or argillaceous cherts. If the acid is used in too strong a concentration, or for too long, then eventually the radiolarian tests will also dissolve.
This method of processing is extremely time-consuming and hazardous. However, radiolarian assemblages recovered from cherts can have a much higher species diversity than non-chert samples and yield specimens with
excellent preservation. Processed residue from Campanian chert from Cyprus (lent by A.H.F. Robertson) are almost 100% more diverse, with much better preservation, than any of assemblages recovered from coeval mudstone, siltstone, sandstone or chalk samples from Cyprus analysed during this project.

e) Sulphuric acid (H\textsubscript{2}SO\textsubscript{4})
Organic matter can be removed from mudstone and shale samples by boiling in concentrated sulphuric acid (Kemp, pers.comm., 1989; Bachmann and Ichikawa, 1962). Radiolarian specimens recovered from samples treated in this seemingly harsh way show no signs of damage and the assemblages recovered have a much higher diversity (>30%) than samples treated with only water and Calgon.

f) Oxalic acid (COOH\textsubscript{2} (ethanedioic acid)
Oxalic acid can be used as a bleaching agent for freed radiolarian skeletons. Examination of specimens treated in this way did not reveal any signs of damage or etching as a result of this process.

g) Water (H\textsubscript{2}O)
The acidity of the water must be considered, as the dissolution of small delicate siliceous (and calcareous) forms can be measured in minutes rather than hours. N.B. tap water in North Wales has a much lower pH value, i.e. is more acidic, than tap water in S.E. England. Tap water also tends to contain contaminants, e.g. diatoms, so wherever possible only distilled or filtered water should be used.

3.7 Concentration of fossils from residues
3.7.1 Methods
As outlined in the previous section, the chemical properties of the fossils have been utilised in order to separate the required components from the unwanted ones. In this stage of the process, the physical properties of specimens are exploited, i.e. size, shape, volume, weight, specific gravity, magnetic susceptibility, etc..

a) Sieving
The disaggregated samples over 1cc in volume were wet-sieved through a
63 μm mesh sieve. A gentle water flow was used to minimise breakage of specimens. When the sample was clean, usually after about 5 minutes, the residue was transferred to an evaporating dish and dried in a warm oven. When the residues were completely dry, they were dry-sieved into four size fractions (i.e. 63 -150μm, 150 - 250μm, 250 - 500μm, and >500μm).

To isolate the sub-63μm components of a sample, the material washed through the 63μm mesh sieve was collected and re-sieved through a 10μm mesh sieve. This method is extremely time consuming and only small amounts of sample, i.e. 0.5cc, can be introduced to the sieve at any one time or the meshwork becomes clogged. An attempt was made to accelerate the sieving process by the use of a vacuum pump, powered by water pressure, and a Buchner flask. This method did not appreciably speed up the flow of material through the sieve and the time needed to dismantle, assemble and clean the apparatus rendered the method inappropriate.

b) Settling, decanting and swirling
The most efficient way to separate smaller (c.10 - 63μm) microfossils from both larger and smaller mineral grains was found to be by repeatedly allowing the sediment to settle and then decanting off a fraction of the liquid. The settling times and the fraction retained (i.e. the liquid or the sediment) are varied according to the result desired. Every fraction was examined before being discarded. A detailed account of experiments involving settling times for diatom species is given by Fenner (1982).

The lighter components of a sediment, such as diatoms, silicoflagellates and palynomorphs, can sometimes be isolated by swirling in a watch glass but this is not totally reliable (see section 3.7.2).

Experiments to investigate isolation of specific particle size ranges by means of the Andreasen's Pipette Apparatus were also conducted. This apparatus is designed for the determination of particle size distribution. By means of a pipette, samples are removed from a constant depth over different time intervals and a determination can then made as to the rate at which the concentration of a substance decreases. This apparatus was used
to find the optimum time at which the highest concentration of siliceous microfossils of a particular size range could be withdrawn from solution, from the predetermined depth in the pipette. Results showed that for a water-suspended sample of disaggregated mudstone the optimum time for extraction was 30 seconds after suspension. At this time, the most concentrated assemblage of fossils was obtained but the size range from 10 - 100\(\mu\text{m}\) was represented rather than the more restricted size range required, (i.e. c.10 - 20\(\mu\text{m}\) intervals). The main reason for this was because all the sediment particles cannot be effectively introduced into the liquid at precisely the same moment without producing turbulence and thereby biasing settling rates.

c) Centrifugal action
This method is only useful for further cleaning of small portions of disaggregated sample (i.e. of about 1cc or less) because of the capacity of the centrifuge tubes. Hydrogen peroxide, acids and clay particles can be removed in this way. To remove hydrogen peroxide, the sample suspended in peroxide was poured into the centrifuge tube. A small drop of HCl was added to stop any further reaction (and subsequent mixing of the sample and supernatant) before spinning. The sample was then spun at 1000 r.p.m. for 4 minutes and a brake applied to the centrifuge. The supernatant was poured away and the sample re-suspended in distilled water. A small drop of ammonia was added to the test tube to encourage suspension of the clay particles. The sample was then spun again at 1000 r.p.m. for a further 4 minutes. This last step was repeated until the supernatant remained clear. The sample was then stored in a small glass phial. Removal of acids was carried out by the same procedure but the reaction was arrested by adding a small drop of acetone instead of HCl. This method is useful for removal of most of the clay particles but not larger mineral grains. The greatest disadvantage of the technique is that only a small volume of sample can be treated. The main advantage is that it accelerates the processing procedure when the small size fraction of microfossils is required, as these are the ones that take the longest to settle when the settling/decanting method is used.

d) Picking
A concentration of microfossils can be collected in a gridded or single cell
storage slide by picking them individually from disaggregated sediment with a fine, damp paint brush. Usually only particles over 63 μm are picked in this way. Smaller individual specimens (5 - 63μm), required for S.E.M. studies, can be successfully picked using a pigs eyelash (Sims, *pers. comm.*, 1989).

e) Magnetic separation
This method of separating one fraction of mineral grains and microfossils from another, one of which is magnetically susceptible, is described in detail by a number of authors, including Schmidt (1948), Dow (1960), Eckert *et al.* (1961) and Rosenblum (1958). As picking individual microfossils by hand is time-consuming, particularly when the sample is poorly fossiliferous, the technique as described by Eckert *et al.* (1961) was tested. A poorly fossiliferous sample of pink, bentonitic, silty mudstone (sample 9819 from Cyprus) was selected for the test. The processed residue from the size fraction 63 - 150 μm was hand-picked for one hour, resulting in the recovery of 19 specimens of radiolaria and foraminifera. A fraction of the remaining residue was then poured through the magnetic separator. The forward slope of the separator was set at 25 degrees, the side slope at 20 degrees and the current at 1.5 amperes. This resulted in two fractions of residue of approximately equal volume. To test the efficiency of the apparatus each fraction was poured through again; apart from a few grains (usually <10 grains of a variety of minerals) the results were the same. The two fractions of residue were then examined to determine which contained the highest concentration of microfossils. The selected fraction was then picked for one hour resulting in the recovery of 63 specimens of radiolaria and foraminifera. This significant increase is, however, relative to the original ratio of microfossils to mineral grains and makes the technique only valid for poorly fossiliferous or seemingly barren samples. For samples with common to abundant microfossils, the possible time saved is variable in direct correlation to the percentage of magnetic mineral grains (iron, glauconite, iron micas) and percentage of microfossils and must be offset against the time taken to clean (approximately 15 minutes) and operate (approximately 5 minutes) the separator. In this 20 minutes, a large number of microfossils could be picked from the residue of a reasonably fossiliferous sample which had not been processed with the magnetic separator.
separator. The technique is also only feasible for larger size fractions, i.e. over 63μm.

3.7.2 Discussion
A test sample (Cyprus 9827) was chosen for experimentation purposes because it was known to contain an abundant and diverse radiolarian fauna in the 63 - 150μm range. This same sample was subjected to all the various chemical and concentration techniques, in various combinations, that are outlined above in sections 3.6 and 3.7. The magnetic separation procedure and HF treatment were excluded. Very different results were obtained from the different techniques and combinations of techniques, and methods which theoretically would have been expected to recover a particular group of fossils sometimes did not, but instead yielded exceptionally abundant and diverse assemblages of a different group. One example of this concerned use of a standard technique for the recovery of diatoms (Bachmann and Ichikawa, 1962) which produced an excellent assemblage of radiolaria but no diatoms or silicoflagellates which were present in the sample. Another test using the same sample disaggregated only in cold distilled water and then swirled in a watch glass produced a good palynological preparation but again no diatoms or silicoflagellates. As these latter two fossil groups often appear pyritised in North Sea Tertiary palynology preparations, it was expected that the lighter non-pyritised forms from this sample would be associated with palynological specimens.

The range of experiments carried out were successful in recovering diatoms, silicoflagellates, palynomorphs, agglutinated foraminifera and radiolaria. However, these preparations result in differences in presence/absence and in diversity and abundance of groups and species.

It is also important to record the amount of initial sample prepared. For example, assuming a homogeneous distribution of microfossils within a sediment sample (which is highly unlikely), then there is much less chance of recovering abundant, larger microfossils of say 250 - 300μm from a 1cc sample than from a 200cc sample. A distortion of assemblage species diversity may influence the results of comparative analyses of samples prepared when using non-standard sample sizes. This was proved during
the experiments. A larger sample, however, may represent a longer interval of deposition (if from a longer vertical interval) and this may, although not necessarily, contribute to a higher diversity of species.

A record of the weight or volume of samples also allows computation of statistics of abundances, e.g. \( n \) species per 100g etc., although no detailed quantitative analyses of this kind have been undertaken in this study.

Detailed accounts of individual experiments are not given here, partly for space reasons, but mostly because it became apparent that the degree of success is directly related to the experience and skill of the operator.

3.7.3 Future work
The human factor, influencing preparation and taxonomy mentioned above, accounts for lack of consistency in results of different workers. This inconsistency can be a significant disadvantage in terms of comparative analyses, and emphasises the fact that confident interpretations can be made by only using positive evidence. For example, the absence of a group or species is not necessarily biostratigraphically, palaeoenvironmentally or preservationally significant. One solution to this problem is to prepare samples using automated processes standard to each group of microfossils. The development of such a system in this project, although in progress, is far from complete.

Other processes used in various scientific and manufacturing fields have been investigated to see if their methods and applications could be adapted for micropalaeontological purposes. Two possibly suitable applications have been discovered to date. The first involves inducing an electric charge into the disaggregated sediment and then, by utilizing the selective uptake of this charging by the different sediment components, concentrating the required microfossils. The second method involves the use of a F.A.C.S. machine (Fluorescent-Activated Cell Sorter). One of the current uses of this machine is to identify diseased blood cells on the basis of shape and to then sort the cells into concentrations of normal and abnormal cells by passing them through a forward-light scattered laser beam.
Both these methods show potential for rapid concentration of microfossils but the capital equipment costs are currently prohibitive.

A successful method developed by B.P. Research collects images of palynomorphs on videotape. The processed slides are searched by an image analyser using a microscope with automated stage and when a possible palynomorph is located, the image is stored for subsequent identification. The advantages of this method, apart from time saved with poor samples, include the fact that any image can be retrieved for comparison at any later date. The data gathered and stored electronically could also be integrated into a more complex artificial intelligence system. The main disadvantages are i) the cost of the equipment, and ii) the restricted views of the specimens. This use of the method is a good example of an alternative approach, in that it concentrates data and speeds assessment by the scientist.

3.8 Mounting concentrated residues
Because of the nature of the morphology of radiolarians, and the reliance of taxonomy on both internal and external features, it is necessary for detailed taxonomical studies to examine specimens in both transmitted and reflected light and with the scanning electron microscope. A variety of viewing methods is necessary to establish the presence/absence of features only visible using one particular method of viewing and to make a comparative evaluation of the appearance of these features when viewed by different methods. The combination of these varied techniques is necessary for taxonomic understanding and subsequent phylogenetic interpretations.

When a certain degree of understanding has been achieved, the subsequent routine biostratigraphical logging of samples can be carried out with the use of either dry, picked residues using reflected light, or with permanent slide mounts using transmitted light microscopy.

Different methods of observation require a variety of methods of mounting the specimens. These are described below.
3.8.1. Examination with the S.E.M.

Two types of preparation were used for the scanning electron microscope, 
a) individual specimens, and b) strewn preparations.

a) For mounting individual specimens the aims are:
   i) to mount the specimens quickly and easily on a
      background which would appear smooth and black on
      photographs;
   ii) to observe and photograph the specimens from a
      maximum variety of angles; and
   iii) to be able to remove specimens from the stubs for
      safe storage.

The materials and methods used are discussed below.

Initially a Jeol T200 S.E.M. and a Polaron sputter-coater were used for 
these investigations. Double-sided adhesive tape was stuck directly onto 
the stub and the individual specimens were then mounted onto the tape 
using a fine, damp paint-brush. Specimens and the surface of the stub 
were then coated with gold. Coating was carried out in a sputter-coater for 
two successive exposures of 3 minutes each. Longer exposure may have 
resulted in over-heating and specimen damage. The specimens observed 
and photographed were not subject to charging but some tended to sink 
into the adhesive on the tape and a smooth, black background surrounding 
the specimens photographed was not achieved.

To try to counteract the specimens sinking into the tape, and also to 
provide a smoother and aesthetically improved background, it was decided 
to mount un-exposed film, matt emulsion side upwards, onto the double-
side tape. This initially worked well and achieved the desired results. 
When the specimens are mounted with a damp paint-brush, the emulsion 
on the film becomes a shallow, temporary gel to which the specimens stick, and the film surface provides a uniform background for 
photography.

After several months of successfully mounting specimens in this way, 
problems with charging appeared in the form of areas of bright light and 
dark shadows on and around the specimens. These features, together with 
scan lines, appeared on the photographs and obscured parts of the
specimens. This problem was not, at the time, affecting preparations of foraminifera, ostracods or calcareous nannofossils.

Discussion with other radiolarian workers (including Baumgartner, De Wever, Gorican) revealed that charging was a common problem. During attempts made to try and reduce this phenomenon, several theories as to the cause of charging were examined, which include:

1. The specimen did not make a good electrical contact with the stub to allow electrons to be conducted away due either to the shape of the specimen not allowing sufficient surface area to stick directly to the adhesive on the stub, or to the adhesive not being an efficient conducting medium. Different adhesives were tried and specimens were 'sunk' into the glue to increase contact area but charging was not reduced.

2. The size or shape of the specimens influenced the likelihood of charging, i.e. those at the extreme ends of the size range or those with rounded or pointed (Chapman, 1986) shapes were more susceptible to charging. Detailed observations of specimens of different shapes, from a size-range of 60 - 300 microns, revealed no significant correlation between charging susceptibility and size or shape of specimen;

3. The chemical composition of radiolarians was having some adverse effect on either the gold coating or the operation of the S.E.M. in some way;

4. The specimens were not being evenly coated with gold, i.e. perhaps the under-sides of the specimens were not being coated or only receiving a thinner coating. Baumgartner (pers. comm., 1989) experimented with a stub-holder which gyrates during the coating process but he reported little success. In this investigation, specimens were repeatedly re-coated, some for a total of 16 minutes. This resulted in specimens with concentrations of gold (see Plate 24, figs. 10, 12) but no reduction in charging;

5. Specimens with relatively smooth surfaces, such as *Phaseliforma* spp., produced more charging;

6. Specimens with particularly complex surface texture, such as *Mirifusus* spp., reacted adversely and inhibited the dispersal of electrons. Detailed observations of specimens with various wall-structures, both complex, such as in *Mirifusus* spp., and smoother, such as in
Phaseliforma spp., revealed no significant correlation between surface wall-structure and charging susceptibility;

7. Spherical, hollow specimens with large pores allowed electrons to pass inside the specimens easily but then become trapped. Again, detailed observations of species such as Gongylothorax spp., with infilled pores, and ?Actinomma sp. A, which has a wall-structure of open lattice work, showed no significant correlation between the different potential 'traps' for electrons;

8. A strong electromagnetic field from nearby plant or machinery was influencing the operation of the S.E.M.;

9. Atmospheric dust intensity had increased and was encouraging charging effects;

10. The shape of the stubs used could influence electron dispersal. Stubs with a flat surface are commonly used but discussion with A.H.F. Robertson revealed that he successfully used mushroom-shaped stubs when examining and photographing specimens included in his doctoral thesis (1974). Also, he used no adhesive but mounted the specimens onto the stubs with a paint brush dampened with distilled water. The specimens remained in place only by static electricity after the moisture had evaporated and before coating with gold. This method was followed in this investigation but charging was still present;

11. The position, i.e. higher or lower, of the stub in the stub holder could influence electron behaviour. The height of the stubs in the holder was adjusted but no reduction in charging occurred; and

12. The spacing of specimens on a stub was too dense. Stubs were prepared with fewer, more widely-spaced specimens but negligible improvement with regard to charging was noted.

During these lengthy investigations it was also noted that rotation and tilting of the stub holder, whilst in operation, induced differential charging, exaggerated in certain positions. Lowering of the accelerating voltage from 15KV to 10KV also slightly reduced charging effects but adversely affected the quality of the photographed image.

Approximately a year after this problem had begun to impair radiolarian studies, foraminiferal specimens, a previously unaffected group, also began to show similar effects. This development indicated an equipment
fault and an alternative sputter-coater (Biorad, model E5100, Series 2) and S.E.M. (Hitachi S530) were used. Radiolarian specimens were coated for 120 seconds in the Biorad coater and examined with the Hitachi S.E.M.. No problems with charging were encountered. The same stubs were then examined with the Jeol T200 S.E.M. and negligible charging problems occurred. Further experiments, including the mounting of specimens on stubs with only static electricity (as described above) showed that charging problems are most likely to occur because of an air leak into the argon atmosphere of the coating unit.

b) Strewn preparations
A drop of processed residue was dropped onto a 13mm diameter cover-slip and gently dried in a warm oven. The cover-slip was then glued to a flat S.E.M. stub with colloidal silver and the preparation coated with gold. Initially these preparations were affected by charging but this was also then eliminated as described above.

3.8.2. Examination with reflected light
The residue was dry-sieved into four size fractions: 63-150 \( \mu \text{m} \), 150-250 \( \mu \text{m} \), 250-500 \( \mu \text{m} \), and \( > 500 \mu \text{m} \). Residue was then spread thinly on a picking tray and microfossils picked. Everything organic was picked and stored on a gridded slide. The fossils are lined in rows and stuck to the slide with water-soluble paper-glue. (N.B. It is important to wash this off thoroughly before photography, as unusual 'morphological' features may be created by the glue). The specimens are aligned in rows because it makes it easier to search for a particular species or specimen in this way. They could be sorted into species but this is extremely time-consuming and usually there are more species than squares. Each sample was picked for a minimum of two hours, including apparently barren samples. The aim was to recover approximately 200 - 300 specimens, which is considered to be a statistically representative sample for a planktic foraminiferal assemblage, and from which an average species diversity of between 20 - 30 would be expected. The problem of how many specimens are representative in a radiolarian assemblage subsequently became apparent. The potential number of radiolarian species in the Upper Cretaceous (i.e. the cumulative total of species reported in publications) exceeds 300, which is approximately ten times greater than the number of
planktic foraminiferal species potentially present. Radiolarian workers, however, seem to record only a fraction of this number per sample. For example, some of the more diverse assemblages reported by Pessagno (1976), Foreman (1978b), Empson Morin (1981) and Taketani (1982) do not exceed 60 species, and usually the number recorded does not exceed 30 species per sample. The implications of species diversity for biostratigraphical interpretation are discussed in Chapter 7.

To maximise diversity of species recovered from samples analysed in this project, variable picking time was spent on samples where new radiolarian morphological types kept appearing. Samples could also be logged by sprinkling the residue onto slightly damp photographic paper to which they would adhere. This is a technique used by Baumgartner and described in Schmidt-Effing (1981). This method eliminates picking but requires a repetition of the whole logging process should a subsequent query arise. For example, if a particular species is split taxonomically at a later date the whole sample would need to be re-examined to determine whether one or more of the newly classified species or subspecies were present.

It has been found advantageous to permanently mount some of the 63-150 μm fraction onto clear glass slides for transmitted light microscopy (see page 55).

The remainder of the dry-picked and unpicked residues are stored either in glass phials or in paper envelopes.

3.8.3 Mounts prepared for viewing in transmitted light

Two types of preparation were mounted for viewing in transmitted light: sediment smears and processed residue. Several types of mounting medium were tried: Petropoxy (RI = 1.54mm), Norland Optical Adhesive 61 (RI = 1.56mm) and Naphrax (RI unknown). The refractive index of the mounting medium is important as specimens may become invisible or unclear if the refractive index is similar to, or lower than, that of the fossils being examined. Siliceous microfossils are normally found to be preserved as opal-A (SiO₂·nH₂O, hydrated silica containing cristobalite, RI = 1.435 - 1.455mm), or replaced by phase change opal-CT
(cristobalite/tridymite, RI of cristobalite = 1.485mm; RI of tridymite = 1.468mm), or quartz (RI = 1.544mm - 1.553mm), or replacement calcite (RI = 1.658 - 1.486mm). These mineral states each have slightly different refractive indices. Radiolarian skeletons replaced by pyrite appear opaque in transmitted light and are difficult to identify unless they have a distinctive shape.

To prepare smear slides, a small fraction of the sample material (approximately 2mm³) was placed on the slide and a drop of distilled water added. The sample and water were mixed together with a small, disposable wooden stick (tooth pick) and smeared evenly down the length of the slide, which was then placed on a hot-plate to dry. The hot-plate was set at a low temperature so that the moisture would evaporate gently and not cause damage to, or movement of, fossils or sediment by boiling or thermal current action. Steam has 1800 times the volume of water at 1 atm. according to the Petropoxy technical manual, and therefore is potentially destructive if trapped inside specimens. When the preparation had completely dried and cooled, the selected mounting medium was added. Cover-slips (22mm x 50mm) were lowered gently onto the mounting medium to minimise the risk of sediment movement or breakage, and also to reduce the potential entrapment of air bubbles. The medium was then cured in accordance with the manufacturer's instructions. Smear-slides were made so that the whole sediment and fossil content could be evaluated before any component was lost through processing. These slides are naturally less fossiliferous than slides made from processed residues.

The preparation procedure for permanent mounts of processed residues was subject to a few minor refinements of technique. Polished glass slides were first cleaned with a fine-grained abrasive household cleaner to slightly roughen the surface. This process was gentle enough not to scratch the surface of the slide but the roughening permitted a more even dispersal of wet preparations. The material to be mounted on the slide was then transferred from the storage phial to a test tube using a disposable plastic pipette. The sediment was then diluted with distilled water to the required concentration suitable for viewing and examination of specimens, and a small drop of liquid detergent or ammonia was added as a dispersal
agent. The material was then strewn onto the glass slide with a pipette, and dried and mounted as described above for the smear slides.

It was also found useful in some cases to permanently mount the 63 - 150 \( \mu \text{m} \) dried and sieved fractions onto clear glass slides rather than pick the sample. This depended on the success of the preliminary processing method in terms of fossil abundance and preservation. Some specimens were found to have a halo of sediment around them and were not identifiable as microfossils using reflected light (see discussion of samples from DSDP Site 369A in Chapter 6).

It is important in all stages of slide preparation to continually monitor the results. In the case of a poor preparation, it was found to be much more time-effective to make a new slide than to log a poorly fossiliferous preparation or one in which the fossils are partially obscured by mineral matter.

3.8.4 Preparations for viewing the same specimen in both S.E.M. and transmitted light

As discussed in the introduction to this section, it is often necessary and desirable to view the same specimen in both transmitted light and with the scanning electron microscope. This applies equally to other groups of microfossils, e.g. Gallagher (1988) and Varol (1989) describe methods for viewing the same calcareous nannofossil specimen in both transmitted light and the S.E.M.. During taxonomical investigations carried out for this project, selected specimens were first viewed in transmitted light by placing them in a small drop of immersion oil on a glass slide. The same specimens were then washed with methylated spirit and mounted onto S.E.M. stubs. The stubs were then coated with gold in the usual way and the specimens examined with the S.E.M.. Selected specimens were photographed using both types of microscopy and a large number of these dual illustrations are included in Appendix 2.

Viewing the same specimen in both transmitted light and S.E.M. enables comparison and greater appreciation of the appearance of morphological features when viewed by different methods. A disadvantage of the process, apart from the fact that it is time consuming, is that specimens
are sometimes broken during immersion in methylated spirit, or lost during transference.

3.9 Sorting and cataloguing of specimens
Initial sorting of material was confined to picked specimens because it is possible to physically manipulate these specimens, i.e. it is possible to turn the specimens over and also to group similar morphologies into different parts of the slide. Green food colouring was used to enhance morphological features of less than well-preserved specimens. The isolated specimens were sorted into morphological groups and representatives were examined and photographed using the S.E.M. and light microscope.

Subsequent analyses, using permanent mounts prepared for transmitted light studies, revealed that some genera and species, even when not replaced with pyrite or some other opaque mineral, are difficult to study. This can be due to internal infilling by sediment, or to re-crystallization, or because the internal structures form a dense pattern, or because the C-dimension is relatively large. In the latter two cases, it is possible to study the internal structures in accidentally or deliberately broken specimens. Mesozoic radiolarians in this category include spherical and sub-spherical forms such as Holocryptocanium spp. and Cryptamphorella spp., which are relatively large in the C-direction (studied by Dumitrica, 1970) and hagiastrids, which have a dense internal structure (studied by Baumgartner, 1980). Publications concerning methods used for internal examination were consulted, e.g. Nomura (1983). Attempts to examine the internal structures of specimens in this project have not been totally successful. Initially it was decided to examine the internal structure of members of the genus Pseudoaulophacus. Ten specimens of Pseudoaulophacus lenticulatus were selected for examination because of their size, c. 300 μm in planar view, and because they were well-preserved externally. The specimens were set, orientated in a planar view and cured in a mounting medium (Norland 61) on an S.E.M. stub, then photographed. This was not entirely successful because the surface of the surrounding Norland is very smooth and produces a halo of reflected electrons around the specimen. The next stage involved slicing through the base of the tholus on the uppermost side of the specimen with a scalpel. It
was expected that the specimens would be brittle and that an uneven breakage would occur, however, this was not the case and the skeletons appeared to be quite soft. It had been intended to disperse any cutting debris with either air or fluid but the 'elastic' debris adhered to the incised surface. Investigations into methods for viewing internal structures are continuing.

Initially, an informal taxonomic catalogue was compiled giving each morphological variant (i.e. subdivisions of species groups) a different code number and including photographs and descriptive remarks. The specimens photographed are stored in numbered reference slides.

No attempt to correlate the specimens with published species was made at this stage. This "stamp collecting" method was considered necessary partly because of the current state of radiolarian taxonomy and partly because of lack of personal experience of this group of microfossils. Specimens were compared with published descriptions and illustrations at a later stage in the project and names assigned to the specimens. The initial numbering and sorting method is still used, however, when unfamiliar morphotypes are encountered.

Final evaluation of species was considered in light of the stratigraphical distribution of the respective forms, i.e. if specimens of a form which showed only negligible morphological variation, such as different sized pore-frames, had consistent occurrence patterns, then they were grouped into one species. These points are discussed more fully in the introduction to the systematic palaeontology section in Appendix 2.

3.10 Recording fossil occurrence
Having established a catalogue of morphological types, further samples were analysed and the specimens logged by their code numbers. Samples were analysed using both transmitted and reflected light methods.

Samples were logged in sequence and entered by hand on a chart showing the presence/absence and relative abundance of radiolaria and other fossil groups. Barren samples are defined as such when no microfossils were
observed after the examination of two complete transmitted light slides (20mm x 50mm) or after examination of all size fractions of dry residue for a total of two hours per dry sample. Observations were also recorded concerning the following criteria:

a) The external and internal morphological features of the radiolarians. This information is necessary to classify the species. Particular attention was given to intra-specific morphological variation to try to identify: i) environmental adaptation, or ii) variations due to the reproductive cycle. These observations are described more fully in Appendix 2. The specimens illustrated in Appendix 2 were measured in reflected light using an ocular micrometer. Measurements taken by using the S.E.M. can be subject to aberration depending on the tilt angle of the stub and the height of the stub in the holder. The appearances of the size and shape of specimens viewed in transmitted light vary depending on the height of the focal plane.

b) The size range of the specimens. A normal Upper Cretaceous population of radiolarians would be expected to have a size range of individuals of at least 63 - 250 $\mu$m. If the recovered specimens in an assemblage are all of similar size, it could indicate current sorting of the material, peculiar environmental conditions, selective dissolution or processing bias.

c) The diversity of the assemblage. The interpretations described in the previous paragraph could equally apply to unusually low species diversity in an assemblage of radiolarians.

d) The abundance of each species. The relative abundance of each radiolarian species and other fossil groups is symbolised on the charts. The categories chosen follow those of Thurow (1988a) and are:- 1 specimen = Present; 2-5 specimens = Rare; 6-20 specimens = Common and more than 20 specimens = Abundant. Broken specimens are counted as one when more than 50% of the specimen is preserved. Unusually large numbers of a particular species, i.e. a flood or acme, were recorded. Knowledge of radiolarians, and the published data available, has not yet reached a stage where absolute numbers and accurate diversity counts can
be significantly interpreted, either in biostratigraphical interpretation on a global scale, or in quantitative palaeoecology. It is considered desirable, however, to include this data from other studies where consistent sample preparation procedures have been used. A relative abundance technique was applied in this study because the original raw samples were not weighed (as discussed in section 3.7.2), and the samples were processed by different methods, including being picked for different lengths of time. Some form of abundance assessment was considered necessary, however, as this information can be invaluable in the interpretation of palaeoenvironmental events, burial history and species range. Species might be expected to be less numerous at extremes of their stratigraphical and geographical range.

e) The preservation of the radiolaria. The preservational state of the specimens can provide information about the damage caused by the processing method, the environment of deposition, the reworking and transport of specimens, and the post-burial history of the sediments.

f) The association with other fossil groups, such as calcareous nanofossils, foraminifera, diatoms, silicoflagellates, fish teeth, sponge spicules, ostracods, bryozoans, shell debris and occasionally palynomorphs. This information can provide evidence about the environment of deposition and possibly on the palaeoecological stress factors involved in competition with these other groups. Interpretations of the diagenetic history of the sediment, including the influences on the chemical processes induced or facilitated by calcium carbonate (see Chapter 2), may benefit from this data. Perhaps, more importantly, the other groups can provide biostratigraphical correlation horizons and may enable the erection of integrated zonation schemes.

g) The character and size of associated mineral grains. Analyses of these components can provide indications of palaeogeography, environment of deposition, reworking and post-burial diagenesis.

All analyses recorded on the hand-drawn charts are stored on computer disc and can be used with a range-plotting software package "Checklist II". This program enables range and occurrence charts to be manipulated.
and produced quickly in a wide variety of different formats, e.g. total range, species order, first occurrence, last occurrence, relative abundance, etc..

The observations recorded are summarised in Appendix 1, and all the text from this project is stored in an electronically manageable form. The text therefore can be 'word searched' so that correlation theories can be readily tested.

### 3.11 Comparison of published material with present data

A hard copy version of a "cut and paste" catalogue was compiled from photocopies of published Mesozoic literature. A more sophisticated and efficient way to do this would have been to use a computer and text scanner but the hardware was not available. A file was established for each named species containing a published figure together with descriptions and remarks included. This made it easy to compare different authors' concepts of a species and also facilitated allocation of a morphotype to a species. It was found difficult to compare species which had been illustrated in different ways, i.e. drawings, S.E.M. photographs, views of low magnification or from only one angle, and transmitted light photographs. Ideally, for true comparison of assemblages, a standard processing method and standard viewing methods should be applied.

### 3.12 Data storage of observations of specimens

A computer database has been constructed, in addition to the photographic catalogue (3.9) and catalogue of published species (3.11). This database includes an extensive synonymy for each named species included in this project, together with remarks and the original description of the genus and type species, and any subsequent published emendations. This information is stored on floppy discs to facilitate access in the future.

### 3.13 Discussion

The extent to which the general aims stated in section 3.2 have been achieved are discussed below.

a) **Definition of a universal processing technique** - One of the advantages of the use of radiolarians as a biostratigraphical tool is that they can be recovered from many types of sediment. The variety of sediment types, however, precludes the use of a single processing method for all
sediments. Faunal assemblages adequate for the purposes of routine biostratigraphical analyses can be recovered by minimal processing. The use of hazardous chemicals, such as hydrofluoric acid, can be substituted by the use of thin-sections in circumstances such as at rig sites. Processing techniques for routine analyses can also be accelerated by generalising the initial evaluations of sediment type. The abundance and diversity of the faunal assemblage may be reduced but can be balanced against time saved. For detailed taxonomical, phylogenetical and palaeoenvironmental studies, however, the maximum recovery of specimens is desirable.

b) Assessment of effects of different techniques - During these investigations an appreciation has been acquired of how slight differences in sample preparation, viewing, data recording and data presentation techniques can result in exaggerated differences in results. This experience has produced a greater understanding of possible causes of discrepancies among published reports by different authors. Any interpretations made from collated information must take into account possible assemblage distortion caused by the processing methods.

c) Data presentation - Some detail has been omitted due to lack of space but all the information essential for repeating any part of this work, from section locations to sample preparation techniques used, has been included.
CHAPTER 4

THE SELECTION OF STUDIED SECTIONS

4.1 Introduction
In the past both industrial and academic biostratigraphers have held the view that siliceous microfossils were of limited value in stratigraphical and palaeoenvironmental interpretation. In order to effectively challenge this view, careful selection of sections suitable for such a demonstration was necessary.

The first logical step was to identify the geographical locations and the stratigraphical occurrence of sediments containing either siliceous microfossils or the co-occurrence of siliceous and calcareous microfossils. A comprehensive literature survey was conducted in order to create a database. Global occurrences were recorded from a review of published material of Mesozoic - Cenozoic siliceous microfossils and the co-occurrence of calcareous microfossils. The results are summarised in Figures 4.1 - 4.6 and are discussed in two parts, i) DSDP/IPOD locations, and ii) onshore and continental shelf locations.

4.2 DSDP/IPOD Locations
4.2.1. Publications contained within the DSDP/IPOD reports:
A card-index database was created, documenting all publications contained within volumes 1 - 96 of the DSDP/IPOD Initial Reports relating to calcareous and siliceous planktic microfossils from the Mesozoic and Cenozoic.

Although this database will prove invaluable in providing easy access to supplementary information for further research, the reports do not represent an exhaustive analysis of microfossils present in material recovered on these voyages.

Generally, the authors provide a brief discussion on occurrence of fossils, methods of preparation, and specimens recorded within each sample examined. Frequently only selected samples have been analysed routinely...
unless the "theme" of the DSDP/IPOD/ODP leg dealt with a special topic where microfossils had significant value, e.g. investigations of the Cretaceous/Tertiary boundary.

Papers published on DSDP/IPOD/ODP material subsequent to the issue of the reports are incorporated in the results.

4.2.2 Tabulation of occurrence of siliceous and calcareous microfossils:
A tabulated database was constructed using the detailed core logs published in each volume of the DSDP/IPOD reports, volumes 1 - 96. As stated in many of the reports, this information was collated on-board with limited time and is therefore liable to inaccuracy.

A complete tabulation of these records was compiled which includes occurrences within each stage from Albian to Pliocene of foraminifera, calcareous nannofossils, radiolaria, diatoms and silicoflagellates. The results are shown in Figures 4.2 and 4.4, although the database is not included within this volume, partly for reasons of space and partly because the information has subsequently become available on CD-ROM from ODP.

4.2.3 Discussion
The general impression gained from the survey of the DSDP/IPOD reports is that the analysts were primarily concerned with recording the presence of foraminifera and calcareous nannofossils, with usually only secondary regard to siliceous fossils. It would therefore seem reasonable to assume that where siliceous fossils are recorded they are present and that they are not necessarily absent when unrecorded. When cross reference to the database of publications, outlined above (in section 4.2.1), was made, such omissions became increasingly apparent. One of the reasons for these inconsistencies may be that, although smear slides were used in the core analyses, the size range of radiolaria reported in the specialist chapters tended to be above 44 µm and usually above 63 µm.

The tabulated occurrences from the core logs give an overall picture of sites most likely to be suitable for correlation between siliceous and
calcareous microfossils but are somewhat misleading in that occurrences are grouped within series rather than stages. Ideal material would contain calcareous and siliceous microfossils within each sample. Figures 4.2 and 4.4 show the locations of DSDP/IPOD/ODP sites where calcareous and siliceous microfossils are recorded within the same series within the Tertiary and Cretaceous. The majority of sites with co-occurrence relate to Tertiary material. However, reference to figure 4.5 shows that this is largely due to the artificial bias resulting from the smaller number of sites where Cretaceous lithologies have been penetrated. Comparison of Figures 4.4 and 4.5 shows that calcareous and siliceous planktic microfossils often co-occur in Cretaceous sites.

4.3 Literature survey of onshore and continental shelf locations
The aim of this part of the survey was to establish the occurrence of radiolaria and diatoms and the co-occurrence of calcareous and siliceous microfossils from onshore and continental shelf locations, recorded in research published between 1972 and 1986.

4.3.1 Radiolaria
Of approximately 1400 radiolarian papers published between 1972 and 1986, 790 concern onshore or continental shelf material of ages ranging from Jurassic to Tertiary. These 790 papers have been reviewed to determine whether calcareous microfossils have been recorded with siliceous microfossils. The results are shown in Figures 4.1, 4.3 and 4.6.

Examination of Figures 4.1 and 4.3 reveals no clear pattern of geographical restriction or patterns attributable to obvious geological events or conditions with respect to the occurrence of radiolaria as a group, or to the co-occurrence of siliceous and calcareous microfossils, either in the Cenozoic or in the Mesozoic. It is possible, however, that if patterns of occurrence were plotted on palaeogeographical maps, and if better resolution of time slices could be achieved, that the results may be different. Restricted occurrences of those microfossils recorded are in some cases artificial, i.e. determined by the pattern of previous publications, rather than negative results. The influence exerted by the authors' work pattern and geographical base is also suggested by the fact
that an approximately equal number of sites, in the same or proximal locations, have been investigated in publications relating to both Tertiary and Mesozoic material.

It should be noted that the onshore and continental shelf literature survey differs from the DSDP/IPOD/ODP literature survey in that the latter recorded occurrences at each site, thereby identifying barren sections, whereas the survey of onshore and continental shelf published material shows only the sites with radiolaria and diatoms, and the co-occurrence of calcareous and siliceous microfossils, i.e. positive results.

4.3.2. Diatoms
Research published between 1972 and 1986 concerning diatoms totals approximately 1500 papers. This survey shows that 502 relate to Tertiary material whilst only 30 relate to Cretaceous material. All 532 papers were reviewed to determine whether calcareous microfossils have been recorded with diatoms. A summary of the results is tabulated in Figure 4.6.

Examination of these results shows that whilst records of the co-occurrence of diatoms and calcareous microfossils are moderately common in Tertiary material, the co-occurrence of these groups in the Mesozoic is confined to the U.S.S.R.. It is suggested, therefore, that these patterns of occurrence and co-occurrence are, as previously suggested for the radiolarian distribution, influenced by the authors' work pattern and base.

A large proportion of current and recent diatom research, i.e. approximately 70% of papers published between 1972 and 1986, is concerned with Recent and Quaternary material, which, although of minimal use for dating older sediments, should prove invaluable for palaeoenvironmental interpretation.

4.4 Discussion
It is apparent from the literature survey that there are no unusual global or stratigraphical parameters controlling the occurrence of siliceous microfossils and that their presence in sediments examined is governed by the same factors as for other groups of microfossils, i.e. primarily palaeoenvironmental conditions and diagenetic history. In any attempt to
demonstrate the potential biostratigraphical and palaeoenvironmental use of siliceous microfossils it is therefore necessary to be selective in the identification of sections which will predictably provide a variety of data in order to construct a broad basis for comparative investigations.

The nature and time limits imposed on this project, together with the amount of data found to be potentially available, necessitated further restrictions on site selection in that only a limited geographical and stratigraphical range could be considered. It was initially decided to concentrate on the Atlantic Ocean and Cyprus and to limit the age range to the Late Cretaceous.

Sections were therefore selected on the following criteria:
1. Those likely to contain calcareous (either planktic foraminifera or nannoplankton) microfossils together with siliceous microfossils. Evidence for co-occurrence varied in quality, from in-house fossiliferous residues to DSDP/IPOD core barrel logs reporting traces of siliceous microfossils in smear slides. Late Cretaceous, mostly Campanian sequences, were selected, the age being the most significant constant control applied in the total selection process.

2. A broad present-day latitudinal range from approximately 50 degrees S. to 40 degrees N. and a longitudinal range of 73 degrees W. to 35 degrees E.

3. Sections varied from field sections, e.g. Cyprus, which are exposed above present sea level, to DSDP sections which are assumed to have always remained below sea level since deposition, which may affect the later pore water chemistry with diagenetic implications. DSDP sites studied here represent a more complete section as they may have always been submerged and not subject to periods of sub-aerial erosion. They are less likely to have been subjected to periods of non-deposition by localised regression, i.e. the nearer a site is to a mid-ocean ridge then the more likely that the site has always been submerged. The disadvantage of drilled sections in comparison with field sections is that field relations cannot be studied.
4. Sections of contrasting lithologies, e.g. Site 612 is mainly calcareous mudstone, sections in Cyprus consist of cherts, bentonitic mudstones and umbers, whilst Site 369A consists of chalk.

5. Lithologies deposited under various sedimentary regimes, e.g. pelagic (Site 369A), hemipelagic (Site 612), and siliclastic origin (Paleomylon Valley, Cyprus, in part).

6. Sites representative of variable post-burial history and water depth, e.g. DSDP Site 152 (deep sea) and DSDP Site 369A (continental shelf).

7. Sections were chosen with and without proximity to, or contact with, basaltic rocks, e.g. Paleomylon and Akamas sections in Cyprus show the contact with pillow lavas, DSDP Site 152 occurs just above the contact with basalt, while sediments in the section from DSDP Site 369A are recorded with no proximity to basalt. (The possible effects of volcanic activity on the production and preservation of siliceous microfossils are further discussed in Chapters 2 and 9.)

8. Sections not previously analysed for siliceous microfossils, e.g. Akamas section in Cyprus, together with a section from DSDP 369A, which had been analysed in detail by Foreman (1978).

Twenty eight sections, eight from the Atlantic and twenty from Cyprus were selected for analysis during this project. However, it was only possible to analyse three of the eight Atlantic sites due to shortage of time. The aims in selection were to provide as many variable conditions as possible for both comparison of fossil occurrence and extraction techniques.

The results from Cyprus are discussed in Chapter 5 and results from the Atlantic in Chapter 6.
Figure 4.2 Locations of DSDP/IPOD/ODP Sites with recorded co-occurrence of calcareous and siliceous microfossils in the Tertiary.
Figure 4.3 Locations of onshore and continental shelf regions with recorded occurrence of radiolaria and co-occurrence of calcareous and siliceous microfossils in Cretaceous material, in research published between 1972 and 1986.
Figure 4.4 Locations of DSDP/IPOD/ODP Sites with recorded co-occurrences of calcareous and siliceous microfossils in the Cretaceous.
Figure 4.5 Locations of DSDP/IPOD/ODP Sites where Cretaceous age sediments have been dated.
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Figure 4.6 Occurrence of radiolarians and co-occurrence of radiolarians, diatoms, foraminifera and calcarious nanofossils from research published between 1972 - 1986 from onshore and continental shelf sites.
5.1 Introduction

Sections for analysis from Cyprus were selected because the sediments were known to contain co-occurring Mesozoic calcareous and siliceous microfaunas and -floras and a primary aim of this study is to produce an integrated calcareous and siliceous biozonation. A secondary aim is to use the micropalaeontological data gathered to complement and support the work of many other workers who are trying to unravel the history of this tectonically complex island.

5.1.1 General Geology

The island is dominated by a NW - SE orientated mountainous region, the Troodos Massif, composed of igneous rocks interpreted as an ophiolite sequence. The ophiolite is surrounded and overlain by younger autochthonous sediments, which to the south-west are associated with rocks of the allochthonous Mamonia Complex. In the northernmost part of the island is an approximately east-west aligned mountain chain, the Kyrenia Range, which is structurally related to mainland Turkey and has a stratigraphic sequence very different from the rest of Cyprus. Between the Troodos and Kyrenia ranges is a low-lying area, the Mesaoria Plain, of Pliocene to Recent sediments which cover the suture between these two major tectonic elements. The piecing together of evidence from all of these broadly-defined, major units or areas is important in a reconstruction of the geological history of the region, i.e. Troodos and surrounding autochthonous sediments, Kyrenia, Mesaoria Plain, and the area of allochthonous Mamonia Complex. This study, however, is only concerned with a very small part of the evidence, i.e. the Mesozoic autochthonous sedimentary formations. The sections studied here are located to the south-west and the south of the Troodos Massif, with two exceptions. These exceptions are at Kambia on the northern edge of the Troodos massif and at Paralimni at the extreme eastern end of the island.
Figure 5.1 Composite Stratigraphic Column of the Cretaceous - Neogene part of the Circum-Troodos Sedimentary Succession

Legend on page 177
5.1.2 Geological Succession
Given below, and illustrated in Figure 5.1, is a simplified account of the relationships between the Mesozoic rocks, in reality a very complex association, due to the emplacement of allochthonous rocks, which provides a context for the present study. The micropalaeontological analyses are concerned with microfaunal and -floral assemblages and their utilization, via global biozonation schemes, to provide overall ages.

5.1.3 Autochthonous Units
The oldest rocks in-situ consist of the ophiolite complex forming the Troodos Massif. These are overlain by successive extrusive sequences of the Lower Pillow Lavas (LPL), inter-lava sediments and the Upper Pillow Lavas (UPL). On top of the UPL are the umbers (Fe/Mn mudstones) and then radiolarian mudstones of the Perapedhi Formation. Swarbrick and Robertson (1980, p. 560, Fig. 3) suggest that this formation is conformably overlain by the Kannaviou Formation (when present) e.g. at localities on the Akamas Peninsula and near Arkhimandrita and Marathounda villages. The bentonitic clays and volcaniclastic sediments of the Kannaviou Formation are exposed, in fragmentary sections, to the south and west of the Troodos Mountains, and are overlain by the chalks and marls of the Lefkara Formation. The Lefkara Formation is overlain by a generally shallowing sequence of Miocene-Recent sediments, which will not be discussed here.

Each unit is described in more detail below:

Ophiolite Complex: consists of harzburgites, dunites, etc. overlain by pillow lavas, typical of a Tethyan ophiolite complex (Moores, 1982). These rocks are of particular interest because they were the first to be identified as oceanic crust produced at a spreading centre and preserved at the surface. The Troodos Massif has been interpreted as an in-situ spreading axis (Robertson and Woodcock, 1980) and as tectonically emplaced/subduction-related (Cameron et al., 1980).

The Lower Pillow Lavas: are characterised petrographically by celadonite-rich basalts and comprise a sequence of pillow lavas and brecciated lava flows.
The Upper Pillow Lavas: are characterised petrographically by olivine-rich basalts and comprise a sequence of mainly pillowed lavas with a few debris flows.

Inter-lava sediments: occur between the Upper and Lower Pillow Lavas and are also intercalated with the lava flows. In some places the sediments are represented by red "Haematitic" shales as at the section near Layia village (Pantazis, 1967) and this study, by ochreous deposits, as at Kambia (Mantis, 1971a) and this study, and Kalavasos (this study), or by dark red, baked, siliceous mudstone, as exposed at Ayios Mamas (this study). Three types of inter-lava sediments were described by Boyle and Robertson (1984), who interpreted them as hydrothermally oxidised sediments deposited during a break in volcanic extrusion.

The inter-lava sediments, as described above, are interpreted by Moores (1982) as typical of sedimentary rock sequences overlying the igneous and metamorphic rocks of ophiolite complexes and are thought to reflect abyssal to bathyal environments of deposition.

Mantis (1971a) has dated inter-lava sediments from the MR 35/66 Borehole, to the west of the village of Kambia, as Cenomanian on the basis of the occurrence of the agglutinated foraminifer *Thomasinella aegyptia* Omara. This species has also been recovered from Albian - Lower Senonian sediments in Venezuela, and Cenomanian sediments in Egypt, France and Jordan (Basha, 1978). Weidich and Al-Harithi (1990) suggest that *Thomasinella* Schlumberger is a common foraminiferal genus in Cenomanian shallow and warm waters in the Tethyan realm and that *Thomasinella punica* Schlumberger (synonymous with *T. aegyptiaca* (sic) Omara) is common in some Albian? and Cenomanian samples from Jordan.

Using radiometric K-Ar measurements, Delaloye and Desmet (1979), dated the Troodos Pillow Lavas as 75±5Ma. (Campanian) and Delaloye *et al.* (1980), dated the sheeted dykes of the Troodos ophiolite as 83±Ma. (early Campanian).
Perapedhi Formation: sediments of the Perapedhi Formation conformably overlie the Upper Pillow Lavas (Elderfield et al., 1972; Constantinou et al., 1972; Robertson and Hudson, 1973) and are thought to have been deposited in the later stages of volcanic activity in hollows in the Upper Pillow Lavas (Robertson, 1977b). There is no type section but Wilson (1959) who first assigned these rocks to the Perapedhi Formation, designated a type area which is located in the vicinity of Perapedhi village.

The sediments of this formation form the basal component of a circum-Troodos sedimentary succession and are exposed in discontinuous outcrops around the margins of the Troodos Massif (Robertson and Hudson, 1973). The formation comprises two distinct lithologies: a) stratigraphically lower umbers and manganiferous deposits; and, b) overlying, generally non-calcareous, radiolarian mudstones:

a) The umbers consist of metalliferous mudstones which vary both regionally and locally in composition. The umbers and overlying manganiferous mudstones are often bedded, and towards the top of the succession is a locally-developed, thin, salmon-pink coloured bed of partially-silicified mudstone/serpentinite (Robertson, pers. comm., 1990). Pantazis (1967) divided the metalliferous sediments into three categories (terra umbra, yellow ochre and terra verte). The silica content varies, which is important for commercial mining and, in the case of this analysis, for the siliceous microfossil content. Robertson and Hudson (1973), after consideration of other generic theories, such as the origin of the sediments being the result of freshly erupting basalt mixing with seawater (Elderfield et al., 1972), and the sediments being derived from weathering of the pillow lavas (Constantinou et al., 1972), suggest that the most likely origin of these iron-rich mudstones was precipitation from hydrothermal solutions produced by deep leaching of the pillow lavas. Robertson and Hudson (1973) also conclude that, from field data, the absence of terrigenous material, sparsity of siliceous microfossils and variable thicknesses, the sedimentation of these lithologies was rapid in relation to normal pelagic sedimentation and formed, at most, within a single stage, probably during the Campanian.
Robertson and Hudson (1974) extracted radiolaria from pink radiolarites of the Perapedhi Formation, recovering a very diverse fauna, including *Crucella espartoensis* and *Patulibrachium lawsoni*, which they interpret to be diagnostic of the Campanian.

Irwin *et al.* (1980) described a radiolarian assemblage from a small sample collected from the basal umbers of the Mangaleni Mine. Blome and Irwin (1985) analysed this same sample and concluded that, as the fauna included morphotypes not elsewhere recorded from material younger than Turonian, the umbers were of Turonian age.

b) Conformably overlying the umbers, and forming the stratigraphically higher lithologies of the Perapedhi Formation, are non-calcareous, radiolarian-rich mudstones. These mudstones are sometimes slightly silty and characteristically have manganese banding. The colour varies from yellowish gray, grayish orange, light brown and moderate brown.

Mantis (1971b) analysed material from 14 sections of argillaceous strata distributed round Troodos mountains which he assigned to the Perapedhi Formation and dated as Campanian on the basis of the radiolarian faunas, in particular the presence of *Dictyomitra multicostata* Zittel.

**Kannaviou Formation:** the Perapedhi Formation appears to grade into the overlying Kannaviou Formation, although this transitional boundary is not often seen in the field. According to Swarbrick and Robertson (1980), this gradation can be seen in the Akamas Peninsula, Arkhimandrita and Marathounda. The Kannaviou Formation was defined by Lapierre (1968) and a river section in the Paleomylon Valley was designated as the type section.

The lithologies of the type Kannaviou are described by Ealey and Knox (1975, p. 92) as mudstones, marls and poorly-sorted tuffaceous sandstones ("the tuffaceous deposits of the...Kannaviou Formation were...introduced by mass movement into (an)...abyssal environment") and by Robertson (1977b) as bentonitic clays, volcanlastic siltstones and sandstones. These "volcanlastic sediments were derived from a Late Cretaceous volcanic pile which was probably a volcanic arc generated by a period of Late...
Cretaceous subduction of an area of oceanic crust of which the Troodos Massif now forms one surviving fragment" (Robertson, 1977b, p. 269). Swarbrick and Robertson (1980) suggest that deposition of the Kannaviou was as influxes of volcaniclastic sediment, implying the presence of a contemporaneous Late Cretaceous volcanic arc.

Robertson (1977b), reports that the Kannaviou volcaniclastic sediments crop out in two main areas: in south-west Cyprus and in the east around the updomed perimeter of the Troodos Massif. In south-west Cyprus, the sediments occur in two main SW-NE orientated belts, one on either side of the Polis Graben, in a series of what Robertson (1977b) describes as tectonic windows through the overthrust, allochthonous Mamonia Complex. Due to the tectonically complex structure of Cyprus, a study of the Kannaviou sediments must be compiled from fragmented sedimentary successions. Field exposures are frequently obscured by the overlying Mamonia Complex or by land slips. Considerable facies variation within the formation, and the lack of easily distinguishable marker horizons make field correlations between the exposed sections difficult. Interpretation is further complicated by periods of submarine erosion and non-deposition during the history of sedimentation. Sections, particularly in the north of the region, have been subject to extensive erosion since the Oligocene (Robertson, 1977b).

According to Cleintuar et al. (1977) and Robertson (1977b), the sediments of the Kannaviou Formation were deposited probably during Campanian times, after initial uplift of the Troodos Massif and associated volcanic activity. Basal sediments either rest directly on top of volcanic rocks or on older sediments of the Perapedhi Formation.

The top of the Kannaviou Formation is overlain at Petra tou Romiou (south-west Cyprus) by the Lefkara Formation, without any perceptible lithological break (Robertson, 1977b) and in other parts of south-west Cyprus by normal contact with either the Kathikas or Lefkara Formations (Swarbrick and Robertson, 1980, p. 560).

Micropalaeontological analyses by Mantis (1970), assigned a Campanian age to these sediments on the basis of a radiolarian fauna which included
the species *Dictyomitra multicostata*, *Pseudoaulophacus gallowayi* (here = *Alievium gallowayi*), *Pseudoaulophacus pargueraensis*, *P. floresensis*, *P. lenticulatus* and *Stylospongia verteroensis* (here = *Patellula verteroensis*). Ealey and Knox (1975, p. 92) state that "the deposition of the Kannaviou Formation (and the emplacement of the overlying Mamonia allochthonous complex) must have been complete before, or probably within, Lower Maastrichtian times because the oldest sediments of the post-Mamonia carbonate cover (Lefkara Formation) are Upper Maastrichtian" in south-west Cyprus.

**Lefkara Formation:** (synonymous with the Lapithos Group) was named by Pantazis (1967), who designated the type section by the road to Pano Lefkara. Gass (1960) first subdivided these circum-Troodos chalks into three units (lower, middle and upper) based on palaeontological rather than on lithological criteria. Pantazis (1967) describes the lithological characteristics of the units as:- a) the Lower Marl - pink marls and grey tuffaceous marls (Maastrichtian), b) the Chalk-Chert - flaggy chalks interbedded with cherts (Palaeocene - Eocene), and c) the Upper Chalks comprising a Massive-Chalks Member overlain by a Cleaved-Chalks Member (Upper Eocene - Lower Miocene). Robertson (1976) suggests that the upper part of the formation is mostly chert free marls and chalks.

Robertson (1976) describes the Lefkara Formation as a laterally variable sequence of: 1) *in-situ* deposits on topographic highs in south-west Cyprus, 2) highly condensed ferruginous chalks along the northern margin of Troodos, 3) pelagic calciturbidites in south Cyprus - chalk with calcareous nanofossils, planktic foraminifera and radiolaria with rare redeposited benthic foraminifera. He reports that the inter-turbiditic beds have no benthic foraminifera (probably due to a deep environment of deposition) which distinguishes them from the turbiditic beds. Robertson (1976) suggests that these calciturbidites flowed from the north-east down a regional paleoslope which was previously developed by deformation of the southern margin of the Troodos massif.

Palaeontological evidence for the dating of the Lefkara Formation suggesting that these sediments are Maastrichtian to Lower Miocene in
age is provided by Thalmann (in Pantazis, 1967) and by Allen (in Pantazis, 1967). Analyses by Mantis (1977) of ditch cuttings from a borehole at the southernmost onshore limits of the formation near Moni village also suggest an age of Maastrichtian to Lower Miocene for these sediments. Mantis (1977) assigns the chalks and marls of the Lower Lefkara to the Maastrichtian planktic foraminiferal G. gansseri Zone and the overlying chalk marl and cherts to the Upper Palaeocene (planktic foraminiferal, G. velascoensis Zone) to Lower Eocene. He therefore proposes an unconformity, and the absence of the Cretaceous/Tertiary boundary and the Lower Palaeocene, between the chalky marl of the Lower Lefkara and the Chalk and chert of the Middle Lefkara. The uppermost sediments of the Lefkara Formation examined by Mantis (1977) which represent part of the Upper Lefkara Formation were assigned to the Lower Miocene, planktic foraminiferal, Globigerinita dissimilis Zone.

5.1.4 Allochthonous units - The Mamonia Complex
Swarbrick and Robertson (1980) divide the Mamonia Complex into 5 parts (the Ayios Photos Group, Dhiarizos Group, Ayia Varvara Formation, the Kathikas Formation and the Moni Formation). Robertson and Woodcock (1979) suggest that the timing of the emplacement of the Mamonia Complex is established by the presence of Maastrichtian Lefkara above and Maastrichtian Kannaviou below the allochthon. Fold geometry in the complex, together with the regional geological setting, suggests an origin from the west-south-west of the island, allowing for the 90° palaeorotation suffered by the island since the Late Cretaceous, which would indicate a provenance in the present day north-west, i.e. Turkey. Swarbrick and Robertson (1980, p.562) suggest that a major phase of deformation in the Maastrichtian "resulted in the emplacement of the Ayios Photios group as a series of allochthonous sheets, and of the Moni Formation as a sedimentary mélange". They also suggest that the Dhiarizos group of rocks were emplaced soon afterwards, and that the Kathikas Formation was then laid down as a series of submarine debris flows. Swarbrick and Naylor (1980) suggest that the Kathikas mélange immediately post-dates an episode of major deformation of the Kannaviou Formation in the Maastrichtian, and state "that the age of the mélange in bracketed by the underlying Campanian/early Maastrichtian Kannaviou
Formation (Mantis, 1970; Ealey and Knox, 1975), and the overlying late Maastrichtian and Cenozoic chalk sequences. An internal report from University College London dates pelagic interbeds of the Kathikas Formation as calcareous nannofossil zones CC25/26 (Late Maastrichtian).

The only part of the Mamonia Complex which has been analysed for radiolaria content in this study is the mélangé matrix of the Moni Formation. This was first defined as the Moni Formation (later recognised as a mélangé unit by Robertson (1977c)) and was described by Pantazis (1967) as a series of gypsum-rich clays with intercalations of radiolarian, siliceous, chalky and tuffaceous beds. The type locality is near Parekklisha, east of Moni village. The formation is restricted to an area of outcrops "along the southern flanks of the Troodos Massif from near Yerasa in the W to Cape Dolos in the E, a distance of c.30km" (Swarbrick and Robertson, 1980).

The clays were dated as Campanian or younger by Allen (in Pantazis, 1967) on the basis of planktic foraminifera and radiolaria. Robertson (1977c) suggests that the matrix of the mélangé is contemporaneous with Kannaviou sediments deposited further to the west in the Paphos district but that the former was deposited below the CCD, i.e. the matrix is Kannaviou non-calcareous clays and siltstones, and that they are in-situ. He further suggests that the allochthonous components of the olistostrome were "emplaced by sliding into an in-situ matrix of Upper Cretaceous bentonitic clays and radiolarian siltstones of deep-water, hemipelagic facies". Robertson and Woodcock (1979) suggest that the Moni Mélange is allochthonous and as it has a matrix of Campanian mudstones (dated by radiolarian assemblages) and is overlain by Maastrichtian Lefkara chalks and marls, it was emplaced during a brief period in the Maastrichtian. These authors also suggest that palaeocurrent analyses of the matrix and orientation of the olistoliths suggest that it was emplaced from the west-south-west, i.e. in the pre-palaeorotation setting (and comparable with main Mamonia units), the olistoliths probably originated in Turkey to the north-west of their present position.
Robertson and Woodcock (1979) suggest that outcrops of allochthonous rocks in the east of the island, near Paralimni, appear to be comparable with Moni Mélange.

Mantis (1977) analysed material from the Moni Formation encountered in a borehole to the south-west of Moni village and reports an apparent thickness of approximately 2130ft of bentonitic clays with silica sand bands. He dated the formation as Campanian, based on the occurrence of *Dictyomitra multicostata*, and records 17 other species of radiolaria from these sediments, including *Alievium gallowayi*, *Pseudoaulophacus floresensis*, *P. pargueraensis* and *Dictyomitra formosa*. He observed that the Perapedhi Formation appeared to be absent from this site and that the Moni clays rested directly over the Upper Pillow Lavas. The Moni clays are overlain here by chalk, marl and chert of the Lower Lefkara, dated as Upper Palaeocene on the presence of *Globorotalia velascoensis* (Mantis, 1977).

5.1.5 Discussion
This brief account of the geological succession is based on an interpretation of the work of many other authors. Previous work is based on detailed field work and analyses of the structural relationships and sedimentological content, petrographical, chemical and radiometric dating methods etc. The field work associated with this study was limited to three weeks, one week in each successive year from 1988 to 1990, in which suitable sections were identified, sampled and, in some cases reappraised after laboratory analyses of collected samples. The study therefore relies heavily on the published descriptions and interpretations of others. A discussion of how the data gathered from the analyses in this study relates to work previously carried out by others is presented in Chapter 5.3.
Figure 5.2 Outline Geology of Cyprus showing Locations of Sites Studied (adapted from Zomenis et al., 1988)
5.2 Sections studied

General locations of the sections are shown on the map in Figure 5.2. More detailed regional locations are illustrated in the geological maps relevant to each section. A lithological column showing sample positions is also given for each section. These columns show the measurements of the section in the field and are not adjusted for dip, repeated sequences, etc.. The grid references and heights above sea level given refer to the base of each section and are taken from 1:50000 maps of the area shown on Series K717 Edition 1-GSGS.

180 samples from twenty field sections in Cyprus have been collected and analysed for microfaunal and lithological content. Calcareous nannofossil analyses have been carried out on 57 of these samples.

The samples analysed and a summary of results are shown in Figure 5.3 below.
For radiolarian and miscellaneous microfaunal analyses all the samples have been split, the lithologies recorded, a smear slide examined and each processed using at least two different methods, i.e. a). Hydrogen peroxide, and b). Hydrochloric acid (methods described in Chapter 3). Each sample fraction has been analysed using both transmitted and reflected light methods. The sample numbers are given in the relevant section details below. Sections sampled are representative of one or more lithological unit(s). Figure 5.4 tabulates the unit, or combination of units, sampled in each section.

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<tr>
<th>LITHOLOGICAL ASSOCIATION</th>
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<td>Kapilo</td>
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<td>Kambia</td>
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<td>Paralimni</td>
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Figure 5.4 Summary of lithological units sampled from Cyprus

Calcareous nannofossil preparation, analyses and interpretations are mainly the work of Dr. J. A. Burnett, Dr. E. M. Finch, Dr. L. T. Gallagher and D. Rutledge (University College London). The zonation scheme used is that of Sissingh (1977) modified by Perch-Nielsen (1985) and Burnett (1990). A total of 57 spot samples were selected for
calcareous nannofossil analyses and these are indicated on the relevant charts and sections and results summarised in the text. The age determinations and correlation of calcareous nannofossil and radiolarian occurrences are limited by the fact that only spot samples have been used as a calcareous control and samples have not been compared on a one by one (siliceous/calcareous) basis.

Age determination of samples based on radiolarian data is limited by the fact that only 82 of the 141 species recovered have been recorded by other authors. These 82 species do not have well established ranges, e.g. reference to the synonymy lists in Appendix 2 shows that rarely are species reported by more than ten authors, the number usually being much less. For this reason, the species recorded here which are not compatible with their respective age assessments are also mentioned in the relevant sections and not interpreted as reworked/contamination because they may have extended ranges. A full discussion of the methods used to determine radiolarian ranges in this work is given in Chapter 7.

Explanation of Symbols
Legends for the Geological Maps* and lithological sections are given at the end of this Chapter on pages 177 - 190. The references in the text to FO and LO indicates First and Last Occurrences respectively. The symbols used on the faunal analyses charts represent the following abundances: / = Present = 1 specimen; X = Rare = 2 - 5 specimens; O = Common = 6 - 20 specimens; • = Abundant = 21+ specimens. Calcareous nannofossils are recorded as ■ = Present; † = not recorded.

General Aims
1. to analyse the occurrence, abundance, diversity and preservation of faunal, floral and sedimentological characteristics of collected samples. All microfaunal/floral biota recorded is presented on the charts under the groupings of radiolaria, calcareous nannofossils and miscellaneous fossils. The abundance, diversity and preservation of all groups has been taken into account in subsequent interpretations. Macrofossils were absent from all samples analysed with the exception of Inoceramus prisms, fish teeth and shell debris;

*Although the geology maps reproduced here are the most recent publications available interpretations have, in part, been subject to subsequent re-evaluation by other workers.
2. to determine the age, environment of deposition and regional context of umbers, non-calcareous mudstones and bentonitic mudstones referred to in the published literature as the Perapedhi Formation and the Kannaviou Formation; and
3. to use this information, together with sedimentation rates, diagenetic history and provenance data to correlate the different sections studied and to use the information in a regional and global context.

5.2.1 Location 1 - Akamas Peninsula

Grid Ref.: VD 392721, 180m a.s.l.

Samples: UCL10105A - UCL10107A; UCL10121 - UCL10130; EAK1 - EAK5. Total 18.

Location: Akamas Peninsula, NW Cyprus approximately 1.75 km. SW of Vlambouros (prominent hill). Section trends NW-SE with base (stratigraphically lowest sediments) to north-west. Complete section not measured in detail but c.250m thick with general dip c.30° SE.

Figure 5.5 Map Showing the Location of the Base of the Akamas Section (1)
Figure 5.6 Generalised lithological and biostratigraphical summary of the Akamas section.
Description: This section consists of pillow lavas at the base, directly overlain by umbers, and on top of these a section of gray, brown and red, generally non-calcareous mudstones. The upper part of the sequence is represented by yellowish gray and olive gray, sometimes silty, calcareous mudstones with siltstone and sandstone horizons. The top of the sequence is overlain by the Mamonia Complex. Samples UCL10105A - UCL10130 were collected from the umbers and non-calcareous mudstones at the base of the section; sample UCL-EAK 1 represents a spot sample from a sandstone ridge - c.120m to the south-east of the base of the section; samples UCL-EAK 2 to UCL-EAK 5 were collected from the stratigraphically higher part of the section c.250m to the south-east of the base of the section. Sample collection in the mid part of the section was inhibited by cultivation. Details of sample positions and lithologies are shown on Figure 5.6.

Aims: To date the oldest sediment above the pillow lavas and the youngest sediment below the Mamonia Complex. To record the history of deposition of the sediments between these points and determine the relative positions of occurrence of calcareous and siliceous microfossils.

Biostratigraphy: Eighteen samples were analysed for microfaunal content from this section. The lowermost thirteen samples yielded faunal assemblages dominated by well-preserved, abundant and diverse radiolaria, together with common agglutinated foraminifera. With few exceptions (see Figures 5.8, 5.9) calcareous components are generally absent from these samples. The spot sample (EAK1) from the mid part of the section, yielded a sparse, low-diversity assemblage of radiolaria, rare planktic foraminifera and rare sponge spicules. In the uppermost part of the section, sample EAK2 yielded sparse radiolarian and calcareous nannofossil assemblages, together with rare agglutinated foraminifera, calcareous benthic foraminifera, sponge spicules and fish teeth. Common, poorly-preserved planktic foraminifera are also present in this sample.

Calcareous nannofossils: Four samples were analysed from this section.
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<th>Foraminifera</th>
<th>Distribution Chart for Cretaceous Foraminifera</th>
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<tr>
<td>Lituolidae</td>
<td>Fish teeth, sponge spicules, mollusk shell debris</td>
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<td>Xylophilidae</td>
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Samples 10107A and 10130 are barren of calcareous nanofossils. Sample EAK2: late Late Campanian to earliest Maastrichtian, CC22A? (FO *Quadrum trifidum*) to CC23B? (LO *Q. trifidum*). The sparse and extremely badly preserved occurrence of *Q. trifidum* in this sample, and the absence of any other Late Cretaceous marker species, makes this age assignment questionable. Sample EAK5: late Late Campanian to latest Campanian/earliest Maastrichtian, CC22A (FO *Q. trifidum*) to CC23A (LO Broinsonia parca).

Radiolaria: The presence of *Amphipyndax tylotus* and *Patellula verteroensis* in sample 10105A (umber) at the base of this section indicate an age no older than Campanian for this sample. Other species recorded from the sample are also consistent with this age assignment. The stratigraphically highest sample in this section (EAK5) yielded the species *Patellula verteroensis*, *Pseudoaulophacus lenticulatus*, *P. parqueraensis*, *Diacanthocapsa acuminata* and *Crucella esparroensis*, all of which are considered to have last occurrences within the Campanian. Throughout the section, the majority of species recorded have been previously recorded by authors either as Campanian-restricted forms (e.g. *Patulibracchium californiaensis*, *Phaseliforma laxa*, *Novixitus* sp.B, *Septinastrum dogeli*) or as forms with ranges which include the Campanian. Species identified here which have not been previously recorded from the Campanian are as follows:

*Hexapyramis pantanelli* Aptian - Turonian
*Mita gracilis* Cenomanian - Turonian
*Alievium praegallowayi* Turonian - Santonian
*Amphipyndax conicus* Cenomanian - Santonian
*Crucella cachensis* Turonian - Coniacian
*Dictyomitra sagitafera* Cenomanian - Turonian
*Paronaella venadoensis* Turonian - Coniacian
*Diacanthocapsa euganea* Cenomanian - Coniacian

An acme of both "*Cenosphaera*" spp. and *Novixitus* sp.B in sample 10121 is noted as a potential biostratigraphic marker horizon.
The presence of *Amphipyndax tylotus* in the lowermost samples suggests that this horizon and the sediments stratigraphically above are in the *Amphipyndax tylotus* Zone (Late Campanian - Maastrichtian) of Foreman (1977).

**Palaeoenvironment:** The agglutinated foraminiferal species recovered, i.e. *Bathysiphon* spp. and *Ammodiscus* spp., suggest deposition in deep-marine conditions. The lithologies, together with the absence of calcareous microfauna and -flora in the lower part of the section, suggest either deposition below the CCD or post-depositional diagenetic destruction of calcareous microfossils. Sediments are hemipelagic with very minor arenaceous input and together with the faunal evidence, this suggests deposition in a deep-marine, outer shelf/upper slope environment. Lithologies in the upper part of the section are calcareous, lack botryoidal manganese and have a locally higher silt/sand content. The microfaunal and -floral assemblages are characterised by poorly-preserved calcareous microfossils and sparse, poorly-preserved radiolaria. There is, however, no evidence to suggest any shallowing of water depth.

**Discussion:** The stratigraphical relations of the distinct lithological units suggest that the section is younging to the south although there is no biostratigraphical evidence to support this theory. The lithologies, and the radiolarian and miscellaneous fossil assemblages of the lowermost part of the section are similar to the sections analysed from Perapedhi (Location 10), and the lower part of the Paleomylon Valley section (Location 5).

**Age:** Oldest sediments dated as Late Campanian on the basis of radiolarian fauna; Youngest sediment dated as Late Campanian - ?earliest Maastrichtian on the basis of calcareous nannofossil floras and Late Campanian on the basis of radiolarian faunas.

5.2.2 Location 2 - Phiti

**Grid Ref.:** VD579661, 540m a.s.l.

**Samples:** UCL10158 - UCL 10161. Total 4
Location: c.1km. NW Phiti (village). Comprises several small exposures beside small, steep track leading (northwards) towards Evretou.

Description: The section consists of mudstones and siltstones of the Kannaviou Formation, directly overlain by a mélange (possibly part of the Mamonia Complex) consisting of boulder size, and smaller, lumps of yellowish gray mudstone in a matrix of light olive gray mudstone. The mélange is overlain by Lefkara chalk.

Aims: To determine the age and depositional environment of the three distinct lithological units exposed in this section by analyses of the sedimentological and palaeontological evidence in relation to their structural position, and to integrate biostratigraphical occurrences of calcareous and siliceous microfossils.
**Biostratigraphy:** Sample 10159, from the Kannaviou Formation at the base of the section, contains a moderately diverse assemblage of radiolaria together with abundant calcareous nannofossils and common planktic foraminifera. A sample from the overlying siltstone (10058) is barren of radiolaria but yielded abundant and diverse calcareous nannofossils. Fractions of a sample from the matrix and the clasts of the mélangé (10160) contain similar assemblages of common Campanian radiolaria such as *Amphipyndax pseudoconulus*, *A. tylotus* and *Patellula verteroensis* (suggesting a disturbance of the unit during, or shortly after, deposition) but is barren of calcareous nannofossils. The sample from the Lefkara chalk (10161) yielded calcareous nannofossils of (? Late) Miocene age and has not been analysed for radiolaria. Radiolaria are moderately well-preserved when present while calcareous nannofossils and planktic foraminifera are generally poorly-preserved.

**Calcareous nannofossils:** Four samples from this section were analysed.
Figure 5.12 Phiti - distribution chart showing calcareous nannofossils

Figure 5.13 Phiti - distribution chart showing radiolaria

Figure 5.14 Phiti - distribution chart showing miscellaneous fossils
Sample 10159: late Late Campanian, CC22A (FO *Q. trifidum*) to CC22B/22C (see below).

Sample 10158: late Early Campanian to late Late Campanian, CC20 (FO *Ceratolithoides aculeus*) to CC22B/22C (presence of *Reinhardtites anthophorus*, absence of *R. levis*. However, *R. levis* may not be present due to preservation, etc., thus the youngest age would be CC22C, LO *R. anthophorus*).

10160: barren of calcareous nannofossils.

10161: Tertiary nannoflora, (?late) Miocene.

**Radiolaria:** Twenty species of radiolaria have been recovered from sample 10159 at the base of the section, 15 of which are recorded by other authors. Four are Campanian-restricted, (*Amphipyndax(?) pyrgodes, Patellula verteroensis, Pseudoaulophacus vielseitigus* and *Rhopalosyringium kleinum*), one first occurs in the Campanian (*Amphipyndax tylotus*) and nine range into the Campanian. The stratigraphically higher sample (10160) from the mélange/conglomerate yielded Campanian-restricted forms from both the clast and the matrix including *Amphipyndax pseudoconulus*, together with *Amphipyndax tylotus*. The co-occurrence of these forms suggests deposition during the lower part of the Amphipyndax tylotus Zone (Late Campanian - Maastrichtian) (Foreman, 1977).

Radiolarian species identified here which are not consistent with a Campanian age are as follows:

*Hexapyramis pantanellii* Aptian - Turonian
*Orbiculiforma maxima* Cenomanian.

**Palaeoenvironment:** The rich and diverse assemblages of radiolaria, the presence of keeled planktic foraminifera, rare ostracods and common calcareous benthic foraminifera suggest deposition above the CCD and in an outer shelf setting (>200m).

**Discussion:** The Campanian age and the lithological characteristics of the mudstone, siltstone and mélange/conglomerate sediments in the lower part of the section suggest that they should be assigned to the Kannaviou Formation. The mélange/conglomerate unit is not recorded from other sections in this study and possibly is the result of localised slumping or
other tectonic disruption. The chalk unit in the upper part of the section is consistent in colour and sedimentological characteristics with the Upper Chalk Member (Pantazis, 1967) of the Lefkara Formation and analyses of the calcareous nanofossil assemblage of sample 10161 suggests a Tertiary, probably Miocene age for these sediments. An unconformity between the mélangé/conglomerate unit and the chalk unit is therefore proposed.

**Age:** Mudstones and siltstones - Late Campanian based on radiolarian and calcareous nanofossil evidence; Mélangé/Conglomerate - Late Campanian, based on radiolarian assemblages recovered from both clasts and matrix; Chalk - (?Late) Miocene, based on calcareous nanofossil evidence.

### 5.2.3 Location 3 - Kritou Marottou Borehole

**Grid Ref.:** 595647, 467m a.s.l.

**Samples:** (core) BH01 - BH012. Total 12.

**Location:** Borehole (D1) drilled by Cyprus Geological Survey Department in 1984, c.0.75km SW of Kritou Marottou village.

**Description:** The section consists of inter-bedded, generally greenish gray mudstones, siltstones and sandstones. Sediments are variably calcareous and contain varicoloured lithic fragments, probably representing weathered volcanics, near the base of the section.

**Aims:** To record comparative calcareous and siliceous microfossil content of selected samples.

**Biostratigraphy:** Generally throughout the section, sediments contain rare to common, moderately well- to poorly-preserved radiolaria, with the exception of samples BH04, BH05 and BH06, which are barren of siliceous microfossils. Miscellaneous microfossils recovered also record a barren section in approximately the same position in the core but
elsewhere include locally abundant, poorly-preserved planktic foraminifera and locally abundant, poorly-preserved calcareous nannofossils.

Calcareous nannofossils: Two samples from this section were analysed.
Sample BH03: late Early Campanian to late Late Campanian, CC20 (FO *Ceratolithoides aculeus*) to CC22B/22C (see comments for sample 10158 above).
Sample BH10: barren of calcareous nannofossils.

Radiolaria: All radiolarian species recovered from this section are considered to be Late Cretaceous in age. The sample at the base of the section (BH01) contains three radiolarian species (*Pyramispongia*?) sp.A, *Heliocryptocapsa* sp.A and *Patellula verteroensis* which
are restricted to the Campanian. The first occurrence of *Amphipyndax tylotus* in sample BH03 places this sample, and stratigraphically higher samples, in the Amphipyndax tylotus Zone (Late Campanian - Maastrichtian) of Foreman (1977).

Radiolarian species recorded from this section which are not consistent with a Campanian age are as follows:

*Diacanthocapsa euganea* Cenomanian - Coniacian

*Dictyomitra sagitafera* Cenomanian - Turonian

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*GENERALISED BIOSTRATIGRAPHICAL SERIES STAGE*

*LITHOLOGY ASSEMBLAGES*

- **MUDSTONE**:
  - greenish gray, pale olive gray and grayish yellow, moderately hard, blocky and variably calcareous. Locally silty and sandy with common mica and rare glauconite.
  - Common, moderately well-preserved radiolaria. Common to abundant, poorly-preserved planktic foraminifera and rare calcareous benthic foraminifera. Rare fish teeth and common to abundant sponge spicules.

- **MUDSTONE**:
  - yellowish gray, hard, blocky and calcareous with common mica.
  - Sparsey fossiliferous to barren. Locally rare radiolaria and abundant, poorly-preserved planktic foraminifera.

- **MUDSTONE**:
  - grayish yellow green, moderately hard, blocky and calcareous with rare to common mica.
  - Rare to common, poorly-preserved radiolaria. Locally abundant planktic foraminifera and calcareous nannofossils.

**Figure 5.16** Generalised lithological and biostratigraphical summary of the Kritou Marottou Borehole
**Figure 5.17** Kritou Marottou - distribution chart showing calcareous nannofossils

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- Amphiugus brooksi
- Brainosia parca
- Calculites obscurus
- Ceratolithoides sculeus
- Chiaptozegus bifiarius
- Chiaptozegus platyrhethus
- Cretarhabdus conicus
- Discorhabdus ignotus
- Eiffellithus eximius
- Eiffellithus gorcke
- Eiffellithus furrievei
- Manivitella pessatoidea
- Micula concava
- Micula cubiformis
- Prediscosphaera cretacea
- Prediscosphaera ponticula
- Reinhartites anthophorus
- Repagulus parvidentatus
- Retepetra angustiformis
- Retepetra crenulata
- Staurothites meiicnensis
- Tranolithus orionatus
- Watznaueria barnesae
- Watznaueria biporta
- Watznaueria fossacincta
- Watznaueria manivitae
- Barren of calcareous nannofossils

**Figure 5.18** Kritou Marottou - distribution chart showing miscellaneous fossils

- X - Planktic foraminifera
- O - Sponge spicules
- X - Agglutinated foraminifera
- X - Calcareous benthic foraminifera
- Fish Teeth
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<td>O. aegtenis</td>
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<td>P. aegtenis</td>
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<tr>
<td>P. aegtenis</td>
<td></td>
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</tbody>
</table>

**Figure 5.19 Kritou Marottou -distribution chart showing radiolaria**
Palaeoenvironment: The abundance and diversity of the radiolarian, planktic foraminiferal and calcareous nannofossil assemblages, when recorded, suggest deposition above the CCD in a deep marine environment with open circulatory conditions.

Discussion: As this section is a sub-surface borehole, field relations have not been recorded. The microfossil content of the samples, lithological characteristics of the sediment and the location of the borehole (i.e. SW Cyprus) confirm that this section represents part of the Kannaviou Formation.

Age: Campanian, based on radiolarian fauna; Sample BH03 - late Early Campanian to late Late Campanian based on calcareous nannofossils.

5.2.4 Location 4 - Anadhiou-Sarama

Grid Ref.: VD590679, 380m a.s.l.

Samples: UCL9809 - UCL9814. Total 6.

Location: On S side of road from Anadhiou to Sarama, c. 1.5km NW of Anadhiou village.

Description: This exposure was sampled and described by Mears (1986) as an outcrop of Kannaviou which contains bedding and laminations, and also as exposing volcanogenic sandstone and laminated, olive green-brown mudstones. Re-examination of the section in 1989 showed that the section is somewhat tectonically disrupted and no field relations with other units are evident.

Aims: To record comparative siliceous and calcareous microfossil content of sediments with a view to locating the position of the exposure within the Kannaviou Formation.

Biostratigraphy: Samples from this section yielded common, moderately well-preserved radiolaria throughout the lower part of the
Rare to common, poorly-preserved planktic foraminifera and abundant, poorly-preserved calcareous nannofossils were recovered from sediments in the upper part of the section. Common fish teeth, rare calcareous benthic foraminifera, rare agglutinated foraminifera and rare sponge spicules are also present in samples above sample 9810.

Calcareous nannofossils: One sample from this section was analysed.
Sample 9812: early Early Campanian to late Late Campanian, CC18 (FO Broinsonia parca) to CC22B/22C (see comments above for sample 10158).

Radiolaria: The stratigraphically lowest sample in this section (9809) contains specimens of Amphipyndax tyloitus and Amphipyndax pseudoconulus which together indicate a Campanian age in the lower part of the Amphipyndax tyloitus Zone (Late Campanian - Maastrichtian) of Foreman (1977). Patellula verteroensis, a Campanian-restricted form, also occurs in sample 9809. Throughout the remainder of the section several other Campanian restricted forms are present, including
### Generalised Lithology and Biostratigraphical Assemblages

<table>
<thead>
<tr>
<th>Series</th>
<th>Stage</th>
<th>Formation/Unit</th>
<th>Lithology</th>
<th>Sample Point</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Cretaceous</td>
<td>Kannaviou</td>
<td></td>
<td></td>
<td>9814</td>
<td><strong>Argillaceous Sandstone</strong>: yellowish gray, hard, blocky, non-calcareous and micaceous. Fine-grained with abundant, angular and subrounded quartz grains. Rare agglutinated foraminifera, rare sponge spicules and very rare, poorly-preserved, indeterminate radiolarians.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9813</td>
<td><strong>Siltstone/Sandstone</strong>: yellowish gray, hard, blocky and calcareous. Abundant, poorly-sorted, fine angular quartz grains, common mica and rare pyrite. Common radiolarians and rare to common planktic foraminifera. Rare calcareous benthic foraminifera and rare sponge spicules. Abundant, poorly-preserved calcareous nannofossils.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9812</td>
<td><strong>Mudstone</strong>: light olive gray to yellowish gray, moderately hard, blocky to subbimodal and non-to moderately calcareous. Common to abundant botryoidal manganese fragments and rare pyrite. Common to abundant, moderately well-preserved radiolarians and common fish teeth.</td>
</tr>
</tbody>
</table>

**Figure 5.21** Generalised lithological and biostratigraphical summary of the Anadhiou - Sarama section
Figure 5.22 Anadhiou-Sarama - distribution chart showing calcareous nannofossils
Figure 5.23 Anadhiou-Sarama - distribution chart showing radiolaria and miscellaneous fossils
Comutella californica, Novixitus sp.A, Bisphaerocephalina (?) heros, Patulibracchium californiaeensis and Phaseliforma laxa. Species recovered which have previously not been considered to range into the Campanian are as follows:

*Mita gracilis* Cenomanian - Turonian
*Orbiculiforma maxima* Cenomanian
*Crucella cachensis* Turonian - Coniacian
*Dictyomitra sagitafera* Cenomanian - Turonian

**Palaeoenvironment:** The abundance and diversity of both radiolarians and calcareous nannofossils suggests deposition in open marine conditions above the CCD. The relatively high input of arenaceous material in this section is considered to be the result of turbiditic/mass flow processes associated with regional uplift and submarine erosion of the ophiolite complex. The mass flow may have carried the nannofossils to below the CCD.

**Discussion:** The absence of some of the calcareous nannofossil marker species and the difficulty in defining ranges of radiolarian species which would enable a finer zonation of the section (see further discussion of this problem in Chapter 7) makes it impossible here to locate the position of this exposure within the Kannaviou Formation.

**Age:** Campanian, based on radiolarian assemblages and co-occurring radiolarian and calcareous nannofossil assemblages.

### 5.2.5 Location 5 - Paleomylon Valley

**Grid Ref.:** VD 644645, 560m a.s.l.

**Samples:** UCLPV1 - UCLPV9; UCLSS1; UCL10087 - UCL10120; UCLKR1 - UCLKR2; UCLPV89-1 - UCLPV89-2; UCL9816 - UCL9830. Total 65.

**Location 5:** Paleomylon river valley trending approximately E-W between Mamoundali and Kannaviou villages. c. 3 km. long and includes
the Type Section of Lapierre (1968) at base. Dip c.30° - 40° WSW. Section sampled in two parts, i) stratigraphically lower to E and ii) stratigraphically higher to W (middle part obscured by cultivation). Two spot samples KR1 and KR2, collected from a roadside exposure c. 1km N of Kannaviou village.

**Description:** The stratigraphically lower part of the section consists of pillow lavas (UPL) at the base, immediately overlain by a calcareous, brecciated sandstone which is subsequently overlain by generally non-calcareous, sometimes silty/sandy mudstone. The mudstones near the base of the section are obscured by recent slumping. Approximately 40m above the UPL, a resistant, bedded sandstone (2 m. thick) forms a prominent ridge. This sandstone horizon is described by Robertson (1977b, p.275 ), as "a major volcaniclastic sandstone horizon with two stringers containing rounded pebble- to cobble-sized clasts of basalt and diabase not seen elsewhere in the Kannaviou Formation ". Stratigraphically above this sandstone ridge is a sequence of calcareous mudstones occasionally inter-
bedded with argillaceous siltstones and argillaceous sandstones. The stratigraphical top of the section was marked by the juxtaposition of sediments and pillow lavas which may reflect the very irregular surface of the U.P.L.. These pillow lavas are assumed to be the same age as those at the base of the section. The two spot samples, KR1 and KR2 are tentatively placed in the youngest part of the section although field relations were not observed.

Although the sediments in this section have been subject to local fault movements (see map, Figure 5.24) field evidence for repeated sequences has not been recorded.

**Aims:** To analyse the oldest sediments overlying the pillow lavas and to determine the age range and the depositional history of the Kannaviou sediments at this locality. To attempt identification of possible repeated sequences using microfaunal evidence.

**Biostratigraphy:** In the lower part of the section, i.e. above the pillow lavas and below the prominent sandstone ridge located by sample 10087, the varicoloured, locally silty mudstones are generally non-calcareous with abundant and diverse, well-preserved radiolaria, common sponge spicules, common to abundant agglutinated foraminifera and common palynomorphs. One specimen of *Classopollis* spp. (LO late Cenomanian - earliest Turonian, and therefore probably reworked) was recovered from sample 9827. Sample 9817 was analysed for calcareous nannofossils and proved to be barren. Immediately below the sandstone ridge samples 9833 and 9830 are slightly calcareous with rare planktic and rare calcareous benthic foraminifera.

The section between samples 9830 and 10090 yielded a moderately rich, moderately diverse radiolarian assemblages, rare to common sponge spicules, rare to common agglutinated foraminifera, rare to common fish teeth and common *Inoceramus* prisms. Between sample 10090 and sample 10098, near the top of this first section the faunal assemblages become impoverished and consist of rare, moderately well-preserved radiolaria, rare to common indeterminate radiolaria, rare planktic foraminifera, common, poorly-preserved calcareous nannofossils, rare to
common sponge spicules, rare agglutinated foraminifera, rare fish teeth, rare calcareous benthic foraminifera and rare *Inoceramus* prisms. The stratigraphically highest part of the Paleomylon section yielded rich and diverse radiolarian assemblages, rare to abundant planktic foraminifera, rare to abundant sponge spicules, rare to common agglutinated foraminifera, rare fish teeth, rare to common calcareous benthic foraminifera and common to abundant calcareous nannofossils between samples 10100 and 10111.

A flood of the agglutinated foraminiferal species *Trochammina globigeriniformis* (Parker and Jones) is recorded from sample 9821, which may prove to be correlatable marker horizon although no specimens have been recovered from any other samples in this study.

**Calcereous nannofossils:** Twelve samples from this section were analysed.

Sample 9817: barren of calcareous nannofossils
Sample 10090: barren of calcareous nannofossils
Sample 10094: Campanian
Sample PV8: barren of calcareous nannofossils
Sample 10098: late Early Campanian to late Late Campanian or latest Campanian/earliest Maastrichtian, CC20 (FO *Ceratolithoides aculeus*) to CC22C/23A (LO *Eiffellithus eximius*, which is not a very reliable marker but has to be used in determining the age of other samples herein, or LO *Broinsonia parca*).
Sample 10102: Campanian
Sample 10106: barren of calcareous nannofossils
Sample 10110: Campanian
Sample 10113: late Early Campanian to early Early Maastrichtian, CC19? (based on the approximate FO of *Watznaueria quadriradiata* (Rutledge, *pers. comm*, 1991)) to CC23B (LO *Tranolithus orionatus*).
Sample 10112: late Late Campanian, CC22C (co-occurrence of *Reinhardtites anthophorus* with R. *levis*).
Sample 10111: Late Cretaceous
Sample KR1: Late Cretaceous
Figure 5.25 Transect over c.1500m, only 20% of the Paleomylon Valley that tectonic influence on the upper area and up to 750m estimated estimates c.454m of sediment in this of c.40° W, this represents 900m of exposed. Allowing for a general dip

<table>
<thead>
<tr>
<th>Sample</th>
<th>Generalised Lithology</th>
<th>Biostratigraphical Assemblages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PILLOW LAVA</td>
<td>RARE plastic foraminifera, rare calcareous benthic foraminifera, rare to common radiolarians and common (agglutinated) foraminifera.</td>
</tr>
<tr>
<td></td>
<td>MUDSTONE: yellowish grey, hard, blocky and calcareous</td>
<td>Abundant radiolaria, abundant sponge spicules, rare calcareous benthic foraminifera and common calcareous radiolarians.</td>
</tr>
<tr>
<td></td>
<td>ARGILLACEOUS SILTSTONE</td>
<td>Locally common mollusca, abundant sponge spicules, rare plastic foraminifera and rare, calcareous and agglutinated benthic foraminifera.</td>
</tr>
</tbody>
</table>

Transect over c.1500m, only 20% exposed. Allowing for a general dip of c.40° W, this represents 900m of sediment. Robertson (1977) estimates 454m of sediment in this area and up to 750m estimated thickness of the Karroo Formation. This supports the view that tectonic influence on the upper area and up to 750m estimated estimates c.454m of sediment in this area. Allowing for a general dip of c.40° W, this represents 900m of exposed. Allowing for a general dip of c.40° W, this represents 900m of exposed.
Radiolaria: The presence of *Amphipyndax tylotus* in sample PV1 near the base of the section and the co-occurrence of *Amphipyndax tylotus* with *Amphipyndax pseudoconulus* in sample 10114 near the top of the section places these samples and the intervening sediments in the Amphipyndax tylotus Zone (Late Campanian - Maastrichtian) of Foreman (1977). Species recovered from this section which are considered to be Campanian restricted are as follows: *Amphipyndax*(!) pyrgodes, *Novixitus* sp.B, *Patellula verteroensis*, *Phaselliforma laxa*, *Amphipyndax pseudoconulus*, *Diacanthocapsa acuminata*, *Foremanina schona*, *Bisphaerocephalina*(?) heros, *Heliocryptocapsa* sp.A, *Protoxiphotractus kirbyi*, *Rhopalosyringium kleinum*, *Cornutella californica*, *Patellula euesseei*, *Praeconocaryomma*(?) dauerhafta, *Amphipyndax mediocris*, *Eostichomitra warzigita*, *Acaeniotyle starka*, *Actinomma*(?) douglasi, *Alievium zartum*, *Novixitus* sp.A, *Praestylosphaera hastata*, *Archaeospongoprunum andersoni*, *Diacanthocapsa acanthica*, *Orbiculiforma sacramentoensis*, *Pseudoaulophacus riedeli*, *Pseudoaulophacus vielseitigus* and *Pyramispongia* sp.A. Species recovered from this section which have not previously been reported from Campanian age sediments are as follows: *Crucella cachensis* Turonian-Coniacian *Amphipyndax conicus* Cenomanian-Santonian *Orbiculiforma maxima* Cenomanian *Diacanthocapsa euganea* Cenomanian-Coniacian *Pseudodictyomitra iodogenaensis* Cenomanian *Crucella irwini* Turonian-Coniacian *Dictyomitra sagitafera* Cenomanian-Turonian *Orbiculiforma persenex* Coniacian Other species recorded from this section have either FO's, LO's or range through the Campanian.

Palaeoenvironment: The non-calcareous hemipelagic sediments at the base of this section which are barren of calcareous microfossils but yielded abundant and diverse radiolaria, rare to abundant agglutinated...
foraminifera and common fish teeth are interpreted as being deposited in deep marine conditions, probably below the CCD, with normal open ocean circulation which were hospitable to both non-calcareous benthos and to near surface pelagic faunas and floras. Some evidence of diagenetic, post-burial alteration and dissolution is provided by the presence of botryoidal manganese and by partly pyritised radiolaria in these sediments.

Sediments between samples 9830 and 10098 become more arenaceous, with silty/sandy mudstones and relatively thick beds of volcanioclastic sandstones, and calcareous with initially poor calcareous faunas recorded. These sediments are interpreted as being deposited in a gradually shallowing, open marine environment of deposition, possibly also associated with a lowering of the lysocline.

Sediments above sample 10098 are calcareous, bentonitic mudstones interbedded with siltstones and sandstones, yielded calcareous and siliceous benthic and planktic microfossils and are considered to have been deposited in open marine conditions under normal circulatory conditions, probably associated with active phases of extrusive volcanism.

Discussion: The non-calcareous sediments at the base of the section, i.e. above the pillow lavas and below sample 9830 yielded similar faunas to those recorded from the Perapedhi Formation of the Akamas section (Location 1) and the Perapedhi Formation of the Perapedhi section (Location 10). In particular all three sections have horizons of unusually abundant *Cenosphaera* spp., usually coincident with unusually high numbers of *Novixtus* sp.B, in the same sample or in stratigraphically close samples. These occurrences may mark a laterally traceable horizon, due possibly to regional aberrant environmental conditions at the time of deposition. The general similarity of faunas and the similarity of the lithological characteristics suggests that all three sections have sediments assignable to the Perapedhi Formation (as revised by Swarbrick and Robertson (1980) and that each section has a transitional upper boundary grading into the overlying Kannaviou sediments. Because of susceptibility to dissolution and because most of the radiolarian species range through the Late Campanian (further discussed in Chapter 7). A lack of faunal
Figure 5.28 Palaeomylon Valley, distribution chart showing radiolaria
marker species also makes it impossible at this stage to identify repeated sequences in this highly faulted and disturbed section.

**Age:** Samples including, and stratigraphically above, sample PV1 are assigned a Campanian (?)late) age on the basis of radiolarian faunas. This is confirmed by calcareous nannofossil assemblages where recovered.

### 5.2.6 Location 6 - Kithasi

**Grid Ref.:** VD 739531, 320m a.s.l.

**Samples:** Kithasi-1. Total 1.

![Figure 5.29 Map showing the Location of the Kithasi Section (6)](image-url)

Location: Working quarry c.1.25km N of Kithasi village on W bank of Dhiarizos River.

Description: Yellowish gray, bentonitic mudstones with manganiferous beds were exposed in this working quarry and one spot sample was collected.

![Lithological and Biostratigraphical Summary of the Kithasi Section]

![Biostratigraphy: This sample yielded a moderately rich, diverse assemblage of well-preserved Campanian radiolarians together with rare agglutinated foraminifera. The sample is barren of calcareous microfossils.]

Calcareous nanofossils: One spot sample was analysed.
Sample Kithasi-1: barren of calcareous nanofossils.
Figure 5.31 Kithasi - distribution chart showing radiolaria and miscellaneous fossils
Radiolaria: Specimens recovered from this sample are consistent with a Campanian age and include forms restricted to the Campanian including *Amphipyndax pseudoconulus*, *Diacanthocapsa acuminata*, *Eostichomitra warzigita*, *Novixitus* sp.A, *Novixitus* sp.B and *Patellula verteroensis*. The co-occurrence of *Amphipyndax tylotus* and *A. pseudoconulus* suggest that these sediments are of Late Campanian age from the lower part of the Amphipyndax tylotus Zone (Late Campanian - Maastrichtian) of Foreman (1977). Species recovered which have not previously been recorded by other workers from Campanian sediments are as follows:
*Orbiculiforma maxima* Cenomanian.

Palaeoenvironment: The abundance and diversity of radiolaria recovered suggest deposition in open marine conditions with normal oceanic circulation. The absence of calcareous microfossils may indicate that the depositional site was below the CCD or may be the result of diagenetic destruction of these forms induced by the presence of manganese. Alternatively, as the sample is intensely burrowed, the calcareous components may have been removed, after shallow burial, by chemical action produced by sediment feeders.

Discussion: Although this section is located near the extreme eastern extent of the Kannaviou Formation of SW Cyprus, as mapped by Robertson (1977b), the lithological characteristics, and the nature of the radiolarian assemblage recorded, suggest that these sediments are part of, or are a lateral equivalent of, the Kannaviou Formation. Conversely, however, the absence of calcareous nannofossils and planktic foraminifera and the fine grained nature of the sediments are similar to those found in the Moni Mélange. The presence of agglutinated foraminifera and of trace fossils of burrowing organisms may suggest however that these sediments are less likely to have been deposited under mass flow, rapidly depositing slump conditions as suggested for the Moni Mélange by Robertson (1977c). Although it is possible that the bentonitic sediments exposed in the Kithasi section may form part of the Moni Mélange no exotic blocks were observed. (see Discussion in 5.3).

Age: Late Campanian, based on the radiolarian fauna.
5.2.7 Location 7 - Pano Arkhimandrita

Grid Ref.: VD 704458, 420m a.s.l.

Samples: UCL10111A - UCL10112A; PAEU1 - PAEU2. Total 4.

Location 7: Beside small track, c. 0.5 km. NW of Pano Arkhimandrita village.

Figure 5.32 Map showing the Location of the Base of the Arkhimandrita Section (7)

**Description:** The sediments exposed show the boundary between yellowish gray mudstones of the Kannaviou Formation and above pinkish gray chalk of the lower Lefkara Formation. These lower Lefkara chalks are overlain by more lithified, partly silicified, light gray limestone, consistent with the Palaeocene - Eocene Chalk-Chert Member of the Lefkara Formation as described by Pantazis (1967). One sample was collected from the top of the exposed Kannaviou sediments and three samples were collected from the Lefkara Formation. (see Figure 5.33).

<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>Formation</th>
<th>Calc. Nann.</th>
<th>Lithology</th>
<th>Sample Points</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td>PAEU1</td>
<td>MUDSTONE: yellowish gray, moderately hard, blocky and non-calcareous.</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.33** Generalised lithological and biostratigraphical summary of the Pano Arkhimandrita section

**Aims:** To record comparative calcareous and siliceous microfossil assemblages and to determine the age of the uppermost Kannaviou and the lowermost Lefkara sediments.

**Biostratigraphy:** Rare, moderately well-preserved Cretaceous radiolarians were recovered from the mudstones of the lowermost sample (PAEU1) in this section. Radiolarians, (not examined in detail), recovered from stratigraphically higher chalks and marls are rare and very poorly-preserved. Age-diagnostic calcareous nannofossils were recovered from only one sample (10112A) of Tertiary chalk. This latter chalk sample also yielded rare calcareous benthic and rare planktic foraminifera.
Calcareous nannofossils: Four samples from this section were analysed.
Sample PAEU1: barren of calcareous nannofossils.
Sample PAEU2: non age-diagnostic
Sample 10112A: an Early Eocene age (NP11/12 of Martini, 1971), is suggested for this sample on the basis of the association of *Discoaster kuepperi* and *Discoaster lodoensis*.
Sample 10111A: barren of calcareous nannofossils.

**Radiolaria:** A low-diversity, moderately well-preserved assemblage was recovered from only one sample in this section. Species identified all have previously recorded ranges which include the Campanian; two species, *Pseudoaulophacus lenticulatus* and *P. pargueraensis*, have previously recorded LO's within the Campanian; one species, *Archaeodictyomitra lamellicosta* first occurs in the Campanian; two species *Foremanina schona* and *Rhopalosyringium kleinum* are Campanian restricted species.

![Figure 5.34 Pano Arkhimandrita - distribution chart showing radiolaria](image-url)
Palaeoenvironment: The moderately diverse assemblage of radiolaria recovered from the mudstone in the lower part of the section suggests deposition in an offshore marine environment subject to normal oceanic circulation. The nature of the lithologies in this part of the section suggest hemipelagic deposition below the CCD. Lithologies in the upper part of the section i.e. chal克斯 and limestones, together with the presence of planktic foraminifera, calcareous benthic foraminifera, calcareous nannofossils and radiolaria suggest deposition in a relatively shallower marine offshore environment above the CCD.

Discussion: The paucity of microfaunas and -floras recovered, probably due to non-preservation, limits more precise age assignments. The poor recovery from samples PAEU1 and PAEU2 also makes positive identification of a potential unconformity/depositional hiatus at the mudstone-chalk boundary, based on micropaleontological evidence, impossible.

Age: Mudstone - Campanian, based on radiolaria; Chalk - Campanian? - Eocene (Calcareous nannofossil NP11 - NP12 Zone of Martini, 1971), based on field evidence, stratigraphical position, lithological characteristics and calcareous nannofossil assemblage.

5.2.8 Location 8 - Petra tou Romiou

Grid Ref.: VD663367, 80m a.s.l.

Samples: PTREU0 - PTREU2. Total 3.

Location 8: c. 800m to 30°N from Aphrodite's Birthplace above small track near top of hill (Figure 5.35).

Description: The section shows a boundary between yellowish gray, bentonitic mudstones of the Kannaviou Formation and the overlying grayish pink chalk marl of the Lower Lefkara Formation. Samples were collected from 1.8m below the boundary and from immediately below and immediately above the boundary (Figure 5.36).
Figure 5.35 Map showing the Location of the Base of the Petra tou Romiou Section (8)


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**Figure 5.36 Generalised lithological and biostratigraphical summary of the Petra tou Romiou section**

<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>FORMATION</th>
<th>Calc. Nanos</th>
<th>Lithology</th>
<th>Sample Point</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TERTIARY</td>
<td>PALAEO</td>
<td>LEFKARA</td>
<td>‘Ca’ Pli</td>
<td>PTR-EU2</td>
<td>1m</td>
<td>CHALK: grayish pink, moderately hard and blocky with common manganese.</td>
<td>Abundant, moderately well-preserved calcareous nanofossils. Abundant planktic foraminifera and common calcareous benthic foraminifera. Rare radiolarians.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PTR-EU1</td>
<td>MUDSTONE: yellowish gray, blocky and non-to very slightly calcareous. Common botryoidal manganese and rare, poorly sorted, angular quartz grains.</td>
<td>Abundant poorly-preserved radiolarians with an acme of ?Ctenospherites spp. Rare keeled planktic foraminifera and rare agglutinated foraminifera.</td>
<td></td>
</tr>
</tbody>
</table>

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Aims: To record coeval calcareous and siliceous microfossil assemblages and to determine the ages of the uppermost Kannaviou and the lowermost Lefkara sediments at this locality.

Biostratigraphy: The Kannaviou sediments yielded abundant poorly-preserved radiolaria, rare planktic foraminifera, rare agglutinated foraminifera and rare fish teeth but are barren of calcareous nannofossils. One sample from the Lefkara Formation contains rare indeterminate radiolaria, common calcareous nannofossils, abundant planktic foraminifera and common calcareous benthic foraminifera (Figure 5.37).

Figure 5.37 Petra tou Romiou - distribution chart showing radiolaria and miscellaneous fossils
Calcareous nannofossils: Two of the samples, PTREU0 and PTREU1, analysed from the Kannaviou Formation of this section are barren. Sample PTREU2 from the Lefkara Formation yielded moderately well-preserved Late Palaeocene calcareous nannofossils including *Fasciculithus* spp., *Sphenolithus anarrhopus* and *Discoaster mohleri*.

Radiolaria: Sample PTREU0, from the base of this section, contains the species *Amphipyndax tylotus* thereby placing this sample within the Late Campanian - Maastrichtian Amphipyndax Zone of Foreman (1977). Other species recovered from this sample include Campanian-restricted forms such as *Novixitus* sp.B, *Patellula verteroensis* and *Phaseliforma laxa*. The Campanian-restricted species *Protoxiphotractus kirbyi* is recorded from the higher sample of the Kannaviou Formation (PTREU1) just below the boundary with the overlying chalk-marl unit of the Lefkara Formation. Sample PTREU2 from this chalk-marl yielded indeterminate radiolaria.

Palaeoenvironment: The fine grained hemipelagic character of the mudstones in the lower part of the section, together with a moderately diverse radiolarian assemblage, rare planktic foraminifera and rare fish teeth suggest deposition in a deep marine, offshore environment above the CCD. The presence of agglutinated foraminifera suggests bottom conditions suitable for benthos. The paucity of the planktic foraminiferal assemblage recovered and the absence of calcareous nannofossils and calcareous benthic foraminifera together with the presence of botryoidal manganese suggests post-burial diagenetic destruction of calcareous forms rather than deposition below the CCD. Abundant, moderately well-preserved calcareous nannofossils, abundant planktic foraminifera and common calcareous benthic foraminifera, together with the hemipelagic nature of the lithologies suggests an offshore depositional environment with normal marine circulatory conditions for the deposition of the chalks and marls in the upper part of this section.

Discussion: An unconformity or depositional hiatus is proposed at the boundary between the Kannaviou sediments and the sediments of the
Lefkara Formation, as no biostratigraphical evidence of Maastrichtian or Early Palaeocene sediments is present.

This section, at the southern limits of the Kannaviou exposures, is overlain unconformably by pink chalk marl of the Lefkara Formation which is Late Palaeocene in age. According to Pantazis (1967), this pink chalk marl is the characteristic lithology of the lowermost Lefkara sediments. Lowermost Lefkara sediments have previously been thought to be Maastrichtian in age (Pantazis, 1967). However the calcareous nannofossil evidence recorded here suggests that the lower member of the Lefkara Formation is at least Maastrichtian - Late Palaeocene in age.

**Age:** Mudstone - Campanian, based on radiolarian evidence; Chalks and marls - Late Palaeocene, based on calcareous nannofossil evidence.

### 5.2.9 Location 9 - Kuoka

**Grid Ref.:** VD898565, 750m a.s.l.

**Samples:** Kuoka 89-1 (9a), Kuoka 89-2 (9b), Kuoka 89-3 (9c), Kuoka 89-4 (9d), Kuoka 89-5 (9e). Total 5.

**Location:** Section sampled in two parts. One sample collected from umbers 10cm. above pillow lavas in quarry 0.75 km N of Kuoka village (Grid Ref.: 896574). Remaining four spot samples collected from Lefkara chalks and marls S of Kuoka village along Kuoka to Silikou road (Figure 5.38).

**Description:** At the quarry locality to the north of Kuoka, the section consists of pillow lavas at the base, overlain by approximately 6m. of umber. Quartz lenses measuring c. 5cm. by 0.5 cm. were observed in the umber. Above the umbers, at the top of the exposure, was a reworked deposit of chalk and umber.

The second part of the sampling was carried out from the exposures of Lefkara chalks and marls along the road-cut sections to the south of
Kuoka village. These exposures showed a general dip of about 10° to the south-west. The sediments exposed represent the pink marls and siliceous chalks of the Lower to Mid Lefkara, overlain by the massive chalk of the Middle Lefkara which in turn are overlain by the cleaved chalk transitional zone from Middle Lefkara Chalk to Upper Lefkara Marl (Pantazis, 1967).

**Figure 5.38** Map Showing the Location of Sampling Points in the Kuoka Section (9a - 9e)

Reproduced from G.S.D. (Geol.) 1, Sheet 1, Xeros - Troodos Area, (accompanies Memoir No. 1, Bishopp, D. W., Wilson, R. A. M., Burdon, D. J. and Carr, J. M., 1958). Geological Survey Department, Cyprus; Scale 2" : 1 mile. Relevant legend shown on page 180.

**Aims:** To determine the age and the siliceous and calcareous microfossil association in the umber sample (Kuoka 89-1) and to establish the position of the Cretaceous/Tertiary boundary in the Lefkara Formation.

**Biostratigraphy:** The stratigraphically lowest sediments in this section, the umbers, are barren of microfauna and -flora. The chalks and marls of the Lefkara Formation yielded poorly-preserved Palaeogene radiolaria which have not been examined in detail here. Common to abundant
Eocene planktic and calcareous benthic foraminifera are also recorded from the Leleka sediments together with rare ostracods and rare sponge spicules (Figure 5.39).

![Figure 5.39 Kuoka - distribution chart showing miscellaneous fossils](image)

**Calcareous nannofossils** - Five samples were analysed from this section.
Sample Kuoka 89-1: barren of calcareous nannofossils.
Sample Kuoka 89-2: Early-Middle(?) Eocene with Palaeocene and Late Cretaceous reworking.
Sample Kuoka 89-3: Early-Middle Eocene.
Sample Kuoka 89-4: Late(?) Eocene with Palaeocene and Late Cretaceous reworking.
Sample Kuoka 89-5: Late Eocene with minor Late Cretaceous reworking.

**Radiolaria**: No determinable Late Cretaceous radiolaria were recovered from this section.

**Palaeoenvironment**: The presence of common to abundant calcareous benthic foraminifera, abundant planktic foraminifera and calcareous nannofossils in the chalks and marls of the Leleka Formation at this locality suggests deposition in an offshore marine environment hospitable to both pelagic and benthic organisms. The presence of rare to common Tertiary radiolaria supports this interpretation. Poor preservation of microfossils is attributed to post-burial diagenesis.
Discussion: Following the interpretations of Robertson (1976), the presence of abundant calcareous benthic foraminifera in these sediments suggests that they are in-situ, deposited on topographic highs. Lithologies he assigns to pelagic calciturbidites he identifies partly on the basis of the occurrence of only rare redeposited calcareous benthic foraminifera. Alternatively the high incidence of reworked calcareous nannofossils in samples analysed in this project suggest either the influence of localised slumping or of mass flow movement down a regional palaeoslope.

Age: Umber - Campanian or ?older, based on lithological characteristics and geographical context; Chalks and Marls - Early-Middle(?) Eocene to Late Eocene, based on calcareous nannofossil analyses.

5.2.10 Location 10 - Perapedhi

Grid Ref.: VD 894577, 780m a.s.l.

Samples: UCL10163 - UCL10180; PERA 89-1 - PERA 89-3. Total 21.

Location: Approximately E-W trending road cutting c. 0.75 km. E of Perapedhi village (Figure 5.40).

Description: The section consists of pillow lavas at the base immediately overlain by umbers. Approximately 1m below the top of the umbers is a thin bed (20cm) of sandy mudstone. Immediately above the pillow lavas is a succession of non-calcareous to slightly calcareous mudstone intercalated with thin (0.5cm) manganiferous bands at the base. The mudstones were sampled at 10m intervals along the section.

The section trends approximately E-W, younging to the west, with a general dip of the sediments c. 30° in the lower part of the section (c. Samples 10179 - 10177). When the samples were first collected and
analysed in 1988-1989 it was assumed that the section had a dip of c.30° along the entire length. A subsequent inspection during late 1990 revealed a newly cut track through the section showing a change in dip of c.40° to the north for sediments situated (at least) to the west of sample position 10176. All samples shown on the section in Figure 5.41, and on the chart, Figure 5.42 are now therefore considered to be from stratigraphically close horizons and not, as previously interpreted, younging upwards. The fault is questionably marked on the section above the position of sample 10177 but the exact position (somewhere between sample point 10177 and sample point 10176) is not exposed.
<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>Formation</th>
<th>Calc. Nannos</th>
<th>Lithology</th>
<th>Sample Point</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.P.L.</td>
<td></td>
<td>PERAPEDHI</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

|        |       |           |             |           |              |                      |                                |


| MUDSTONE: yellowish gray and pale orange, moderately hard, blocky to subfissile and locally slightly calcareous. Minor arenaceous content, abundant angular and botryoidal manganese. Flood of Cenosphera spp. and Novititus sp. B. | Abundant, moderately well-preserved radiolaria, rare agglutinated foraminifera and rare to common planktic foraminifera. |

| MUDSTONE: yellowish gray, light brown and dark yellowish brown, moderately hard, blocky to subfissile and locally slightly calcareous. Rare angular quartz, common to abundant manganese and rare chert. Common, rounded umber fragments. Flood of Cenosphera spp. and Novititus sp. B. | Abundant radiolaria, rare to common agglutinated foraminifera. |

| MUDSTONE: grayish orange, yellowish gray and moderate brown, moderately hard, blocky and locally very slightly calcareous. Flood of Cenosphera spp. and Novititus sp. B. | Rare to abundant radiolaria, common agglutinated foraminifera, rare ostracods and rare fish teeth. |


**Figure 5.41 Generalised lithological and biostratigraphical summary of the Perapedhi section**

-139-
**Aims:** To analyse sediments immediately overlying the pillow lavas and to analyse as much of the younger succession of mudstones as is exposed.

**Biostratigraphy:** The sandy mudstone-sample within the umbers and the mudstones above the umbers yielded abundant radiolaria of Campanian age. Towards the top of the section, samples 10166 and 10165 yielded planktic foraminifera but are barren of calcareous nannofossils.

**Calcareous nannofossils:** Four samples were analysed from this section, 10163, 10166, 10177 and PERA 89-1. All are barren of calcareous nannofossils.

**Radiolaria:** The stratigraphically lowest sample in this section (PERA 89-1) contains *Diacanthocapsa acanthica*, a species previously reported only from the Campanian. However the presence of this species is here considered as irrelevant as the sample is interpreted as a fissure deposit (see above). Sample 10179 contains the Campanian restricted form, *Novixitus* sp.B, and the lowermost mudstones between sample points 10179 and 10177 are therefore assigned a Campanian age.

As discussed above, samples 10176 - 10163, because of a sampling strategy error, are from stratigraphically close horizons. The relative order of the samples is, however, uncertain. For this reason the assemblages from these samples are considered together (as one assemblage) for biostratigraphical purposes. Radiolarian species recovered from these combined assemblages include the Campanian restricted forms *Novixitus* sp.B, *Patellula verteroensis*, *Novixitus* sp.A, *Patulibracchium californiaensis*, *Phaselliforma laxa*, *Pyramispongia (?)* sp.A, *Septinastrum dogeli*, *Amphipyndax (?)* pyrgodes, *Foremanina schona*, *Eostichomitra warzigita*, *Pseudoaulophacus riedeli* and *P. vielseitigus*. These sediments are therefore assigned a Campanian age.

Radiolarian species not previously reported as being consistent with a Campanian age assignment which have been recorded from this section are as follows:
**Figure 5.**

<table>
<thead>
<tr>
<th>RADIODARIA</th>
<th>ARCHAEODECTIDUMOSA</th>
<th><strong>CITALIFER</strong></th>
<th>CANCEPHA</th>
<th>GPSS</th>
<th>OPAQUUS</th>
<th>KITUS</th>
<th>CITALIFERCA</th>
<th>CITALIFERCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<td>O</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**MISCELLANEOUS FOSSILS**

- Bioclastic foraminifera
- Planktic foraminiferan
- Fish teeth
- Ostracods
- Calcareous benthic foraminifera
- Indurated prisms
- Shell debris
An acme of both "Cenosphaera" spp. and Novixitus sp.B in sample 10175 and another similar acme event recording these two species in unusual abundance in sample 10169 are noted as potential biostratigraphic marker horizons.

**Palaeoenvironment:** The presence of abundant and diverse radiolarian assemblage within hemipelagic host sediments together with fish teeth, agglutinated foraminifera in the stratigraphically lower part of the section suggests deposition in an environment of deep open marine conditions, possibly below the CCD, but with well-oxygenated bottom conditions. The absence of calcareous faunas and floras may however be a diagentic characteristic due to post-burial alteration of calcium carbonate. In the higher part of the section common to rare planktic foraminifera are recorded, although calcareous nannofossils are absent. Lithologies in these upper sediments also have a higher arenaceous content and a slightly shallower, outer shelf, open marine environment of deposition is proposed.

**Discussion:** The thin bed of sandy mudstone within the pillow lava at the base of the section is interpreted as a fissure deposit on the basis of a microfaunal assemblage showing mixed preservational states and including well-preserved specimens of the planktic foraminifera, *Heterohelix striata* (Ehrenberg), (Campanian - Maastrichtian).

The mudstones immediately above the umbers are varicoloured, non-calcareous and non-silty. These mudstones and the umbers below are interpreted as belonging to the Perapedhi Formation.
Mudstones higher in the section, particularly above the fault (marked on Figure 5.41), are generally yellowish gray, sometimes slightly calcareous and locally slightly silty with rare to common planktic foraminifera. These lithologies are interpreted as a transitional unit between the Perapedhi and Kannaviou Formations (see discussion on p. 195).

Age: Umber - Late Cretaceous; Mudstone - Campanian, dated on radiolarian evidence.

5.2.11 Location 11 - Trimiklini

Grid Ref.: VD 916565, 540m, a.s.l.

Samples: Trimiklini 89-1. Total 1.

Location: Disused quarry c.150m W of Trimiklini village.

Figure 5.43 Map showing the Location of the base of the Trimiklini Section (11)

Reproduced from G.S.D. (Geol.) 1, Sheet 1, Xeros - Troodos Area, (accompanies Memoir No. 1, Bishopp, D. W., Wilson, R. A. M., Burdon, D. J. and Carr, J. M., 1958). Geological Survey Department, Cyprus. Scale 2":1 mile. Relevant legend shown on page 180
Description: Pillow lavas, overlain by umbers, are exposed on the western face of a disused quarry. A spot sample was collected from the umber, approximately 1m above the contact with the pillow lavas (Figure 5.44).

<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>Formation</th>
<th>Calc. Name</th>
<th>Lithology</th>
<th>Sample Points</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ + +</td>
<td>1m</td>
<td>PILLOW LAVA</td>
<td>Not sampled</td>
</tr>
</tbody>
</table>

Figure 5.44 Generalised lithological and biostratigraphical summary of the Trimiklini section

Aims: To analyse the oldest sediments overlying the pillow lavas at this locality.

Biostratigraphy: The only microfossils recovered from these sediments were a poorly-preserved, sparse assemblage of radiolaria (Figure 5.45).

Figure 5.45 Trimiklini - distribution chart showing radiolaria.
Calcareous nannofossils: One spot sample was analysed from this section, Trimiklini 89-1, and is barren of calcareous nannofossils.

Radiolaria: The radiolarian assemblage recovered from this sample is of low-diversity and consists of the following species:

- *Alievium gallowayi* Cenomanian-Maastrichtian
- *Dictyomitra formosa* Cenomanian-Maastrichtian
- *Orbiculiforma maxima* Cenomanian
- *Pseudoaulophacus floresensis* Cenomanian-Maastrichtian
- *Pseudoaulophacus lenticulatus* Cenomanian-Campanian

Although it may appear feasible to assign a Cenomanian age to this sample on the basis of the occurrence of *Orbiculiforma maxima* this form has also been recovered from other samples in this study which are younger than Cenomanian. A ?Cenomanian-Campanian age is therefore assigned, based on the occurrence of *Pseudoaulophacus lenticulatus*.

Palaeoenvironment: The presence of a radiolarian fauna in these sediments is consistent with the environment of deposition proposed by Robertson and Hudson (1973, 1974) for the umbers of the region, i.e. rapid sedimentation close to ocean-ridge vulcanicity in open ocean, well-oxygenated waters.

Discussion: The biostratigraphical results from this section are encouraging in that this is the only sample of umber in this project to yield identifiable radiolaria. It is unfortunate that the assemblage recovered cannot define the age of the sediment more precisely at this stage in radiolarian biozonation studies. Chert horizons were observed in the umbers in other parts of this sampling area but were not collected. Future collection and analyses of these chert horizons may yield more diverse radiolarian faunas which include reliable marker species.

Age: ?Cenomanian - Campanian, based on radiolarian evidence.
5.2.12 Location 12 - Ayios Mamas

Grid Ref.: VD 956559, 560m a.s.l.

Samples: UCL10038 - UCL10042A. Total 6.

Location: c.0.5 km S of Ayios Mamas village. Samples 10038-10042 were collected from E side and sample 10042A from W side of road.

Figure 5.46 Map Showing the Location of the Ayios Mamas Sections (12a-d)

Reproduced from D.O.S. (Geol.) 1103, Agios - Apsiou Area, (accompanies Memoir No. 7. Bear, L. M. and Morel, S. W., 1960). Geological Survey Department, Cyprus; Scale 2":1 mile. Relevant legend shown on page 182

Description: Exposures at this locality are fragmented into four parts. The lithologies exposed show lava flows intercalated with grayish red to moderate brown, ?baked mudstones. In Section 1 a younger dyke can be seen cutting across the inter-bedded lavas and mudstones. Section 2 shows mudstones interbedded with chert bands. Field relations are difficult to
interpret and the relative position of the outcrops shown in Figure 5.47 is only a tentative suggestion.

<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>Formation</th>
<th>Calc. Nano.</th>
<th>Lithology</th>
<th>Sample Points</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPPER CRETAUCEOUS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MUDSTONE: grayish red, moderately hard, partly silicified, blocky and non-calcareous. Rare angular quartz grains and rare, amorphous iron fragments.</td>
<td>Barren of microfauna.</td>
</tr>
<tr>
<td></td>
<td>CENA - CAMP.</td>
<td>UPPER PILLOW LAVA</td>
<td></td>
<td></td>
<td>10040</td>
<td>MUDSTONE: grayish red to moderate brown, hard, blocky and slightly silicified. Non-to slightly calcareous with rare angular quartz grains.</td>
<td>Rare indeterminate ?radiolaria.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Barren of microfauna.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MUDSTONE: grayish red, fine laminae, moderately hard, partly silicified, subfissile and non-calcareous.</td>
<td>Barren of microfauna.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10041</td>
<td>Barren of microfauna.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MUDSTONE: grayish brown, moderately hard, partly silicified and non-calcareous.</td>
<td>Rare, poorly-preserved indeterminate ?radiolaria.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10042</td>
<td>Barren of microfauna except for one poorly-preserved specimen of ?Stichomitra communis.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10042A</td>
<td>Barren of microfauna.</td>
<td></td>
</tr>
</tbody>
</table>

**SECTION 1 (12a)**

**SECTION 2 (12b)**

**SECTION 3 (12c)**

**SECTION 4 (12d)**

Figure 5.47 Generalised lithological and biostratigraphical summary of the Ayios Mamas sections (12a-d)

-148-
Aims: To recover a microfossil assemblage which could be used to date these inter-lava sediments and obtain a time scale for the lava phases and for the emplacement of the younger dykes.

Biostratigraphy: All samples are barren of microfauna and microflora with the exception of rare indeterminate ?radiolaria in samples 10038, 10039 and 10042 and one specimen of ?Stichomitra communis in sample 10042A.

Discussion: The recorded occurrences of radiolaria in samples 10038, 10039, 10042 and 10042A, although not abundant or well enough preserved to be useful for biostratigraphic interpretation in this instance, indicate that i. microfauna is present in these interlava sediments, and ii) further sampling and/or the use of improved processing techniques may potentially yield more productive microfaunal assemblages.

Age: Cenomanian - Campanian, based on regional evidence from publications.

5.2.13 Location 13 - Kapilio

Grid Ref.: 968547, 500m a.s.l.


Location: The section is located on a hill approximately 0.5 km NE of Kapilio village (Figure 5.48).

Description: This area exposes a thick volcanosedimentary sequence (Murton, 1986) with sediments exposed in contact with lavas. Two spot samples were collected from this area, Kapilio 1 was collected from a thin band of grayish red, hard, fissile and calcareous mudstones with fine laminae, lying above inverted pillow lavas. Kapilio-2 was collected from further uphill to the east from a thin band of grayish brown, hard, blocky and non-calcareous mudstones with fine laminae (Figure 5.49).
**Figure 5.48** Map showing the Location of the Kapilio Section (13)

Reproduced from D.O.S. (Geol.) 1103, Agros - Apsiou Area, (accompanies Memoir No. 7, Bear, L. M. and Morel, S. W., 1960). Geological Survey Department, Cyprus; Scale 2":1 mile. Relevant legend shown on page 182

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**Figure 5.49** Generalised lithological and biostratigraphical summary of the Kapilio section

<table>
<thead>
<tr>
<th>SEQUENCE</th>
<th>STAGE</th>
<th>Formation</th>
<th>Calc. Nannos.</th>
<th>Lithology</th>
<th>Sample Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-CRET.CEN. - CAMP.</td>
<td>U.P.L.</td>
<td>KAPILLO 1</td>
<td>INVERTED PILLLOW LAVA</td>
<td>BRECCIATED LAVA</td>
<td>not sampled</td>
</tr>
</tbody>
</table>

- **BRECCIATED LAVA**: not sampled.
- **KAPILLO 1**: light olive gray laminae, very hard, fissile and calcareous.
- **INVERTED PILLLOW LAVA**: barren of microfauna.
- **MUDSTONE**: grayish red with fine light olive gray laminae, very hard, fissile and calcareous.

Barren of microfauna.

**GENERALISED LITHOLOGY**

**BIOSTRATIGRAPHICAL ASSEMBLAGES**

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-150-
Aims: to assign an age to sediments deposited between lava flows.

Biostratigraphy: Both samples are barren of microfossils.

Calcareous nannofossils: One sample was analysed from this section, UCL Kapilio-2, which is barren of calcareous nannofossils.

Discussion: The two spot samples collected, although both geographically close to each other, and both deposited during interrupted periods in volcanic activity may represent two different times of deposition as they are lithologically dissimilar.

Age: Cenomanian - Campanian, based on regional evidence documented in the literature.

5.2.14 Location 14 - Mangaleni Mine

Grid Ref.: WD 125460, 200m a.s.l.


Location: Disused opencast mine, NW of Parekklisha village, and c. 0.75 km SE of church at Ayia Marina (Figure 5.50).

Description: Lithologies exposed at this locality include basal pillow lavas overlain by umber (sometimes-banded) or manganiferous shales. Towards the top of these sediments is a thin band (c.10cm) of salmon pink, silicified mudstone. The sequence is highly disturbed and folded. The section sampled at the eastern end of the mine (see Figure 5.51) consists of pillow lavas at the base overlain by bedded umber. Immediately above the umber is a thin (5cm) greenish sulphide bed, which in turn is overlain by a conglomerate. This conglomerate contains clasts of greenish gray mudstones in a whitish gray, marl-like matrix. Above the conglomerate are alternating beds of whitish gray limestone and marl. The conglomerates and the carbonate beds appear to be allochthonous and thrust over the umber.
In addition to the samples collected from the section shown in Figure 5.1 two spot samples, Man 1 and Man 2, were collected from an exposure c.100m to the west.

Aims: a) to duplicate the recovery of a Turonian radiolarian assemblage from the oldest sediments overlying the pillow lavas, the umber unit recorded by Irwin et al. (1980) and Blome and Irwin (1985); and, b) to determine the age and characteristics of the overlying calcareous sediments.

Biostratigraphy: Only one sample from the umber yielded radiolaria but the specimens are extremely poorly-preserved and could not be identified. The allochthonous carbonate conglomerate above the umbers yielded a radiolaria fauna of Cenomanian age.
<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>FORMATION</th>
<th>CAL. NUMBERS</th>
<th>SAMPLE POINTS</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.P. - U.P. CRE.</td>
<td></td>
<td></td>
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<tr>
<td>U.P. ALB. - CRE.</td>
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<tr>
<td>CRE.</td>
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<tr>
<td>U.C.</td>
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<tr>
<td>U.P.</td>
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</tbody>
</table>

**CHALK**: yellowish gray, moderately soft, moderately blocky with rare manganese.

**CONGLOMERATE**: matrix of mudstone - yellowish gray, moderately hard, blocky and non-calcareous. Common amorphous iron fragments; clasts of yellowish gray calcareous mudstone (1-4mm.)

**umber**: moderate yellowish brown to dark yellowish brown, moderately soft, moderately fissile and slightly calcareous. Locally common, poorly-sorted, angular quartz grains and rare chert fragments.

Abundant and diverse, well-preserved radiolaria. Common calcareous nannofossils.

Abundant and diverse, moderately well-preserved radiolaria. Rare agglutinated foraminifers. Barren of calcareous nannofossils.

Rare fish teeth and rare, indeterminate radiolaria. Barren of calcareous nannofossils.

Rare fish teeth. Barren of radiolaria and calcareous nannofossils.

Rare calcareous and agglutinated benthic foraminifers.

Figure 5.51 Generalised lithological and biostratigraphical summary of the Mangaleni Mine section

-153-
Calcareous nannofossils: One sample, Man 2, was analysed from the umbers of this section and is barren of calcareous nannofossils. Two samples, Man 8 and Man 9, yielded an assemblage characteristic of NF (sub) Zones CC9 - CC10A (Cenomanian) of Sissingh (1977).

Radiolaria: Indeterminate species recovered from the in-situ sediments, i.e. umbers, were very rare and very poorly-preserved. A moderately diverse, moderately well-preserved Cenomanian radiolarian assemblage has been recorded from the Cenomanian allochthonous unit, exposed overthrust onto the umber at the eastern end of the mine. This assemblage has, as yet, not been examined in detail.

Palaeoenvironment: The sparse faunas recovered from the umbers are consistent with rapid sedimentation in a deep marine, well-oxygenated environment as suggested by Robertson and Hudson (1973, 1974). Initial deposition of the overlying calcareous lithologies is considered to have occurred in deep marine conditions subject to normal circulatory conditions as suggested by the rich and diverse radiolarian faunas and calcareous nannofossil floras. These sediments have not been analysed in detail as they are interpreted here as allochthonous and therefore the environment of initial deposition is not directly relevant to this present study.
Discussion: This study failed to duplicate the results recorded by Irwin et al. (1980) and Blome and Irwin (1985) in recovering a Turonian radiolarian assemblage from the umbers at this locality. Their radiolarian-rich sample was collected in 1979 and the position of the sample collection as shown in a photograph in their paper is now obscured by scree. The analyses of several spot samples from the umbers of this mine, together with the analyses of the umbers from the section documented here in Figure 5.51 have yielded only rare, very poorly-preserved, indeterminate radiolarian specimens. This is attributed to the patchy distribution of radiolaria in the sediments. It is in instances such as these where determination of occurrence of faunas in the field, as documented by Baumgartner et al., 1981 and Cordey and Krauss (1990) can prove invaluable.

Many of the species recorded by Blome and Irwin (1985) have been recovered from other sections (Campanian) analysed during this study but their marker species, e.g. Pseudodictyomitra pseudomacrocephala (Range: Albian - Turonian, Schaaf (1984)) which indicates an age no younger than Turonian, has not been recorded in any of the samples analysed during this study. Interestingly, P. pseudomacrocephala has not been recorded in the Cenomanian assemblage recovered from the allochthonous unit overlying the umber at this locality. Although the age assignment of Turonian, based on the radiolarian assemblage of Blome and Irwin (1985) cannot be disputed on biostratigraphical evidence, as conclusive evidence for timing of the deposition of the umbers, their case rests on few specimens from one small sample and it was not found possible to substantiate their result.

5.2.15 Location 15 - Moni

Grid Ref.: WD 184444, 80m a.s.l.

Samples: Moni-1. Total 1.

Location: c.1km E of Moni village, adjacent to sewage tank, Site 15a.

Description: The section shows a small exposure of pillow lavas overlain by approximately 1m of umbers. Approximately 0.75m of mudstone is exposed above the umbers. A spot sample, Moni-1, was collected from this mudstone (Figure 5.54).

An additional spot sample (Moni-2) was also collected from an exposure of pale olive gray, bentonitic mudstone on the north side of the Limassol
road near milepost 42 (Site 15b). This latter exposure showed no contact with other lithological units.

<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>FORMATION</th>
<th>Calc. Nannox.</th>
<th>Lithology</th>
<th>Sample</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cen. - CAMP.</td>
<td>CAMP.</td>
<td>PERAFELIDH.</td>
<td>Nannox.</td>
<td>Lithology</td>
<td>Sample</td>
<td>MONI 1</td>
<td>Barren of microfauna.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MUDSTONE: light olive gray, soft, blocky and slightly calcareous.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Common poorly-sorted, angular quartz grains and common, poorly-sorted, subangular varicoloured lithic fragments.</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UMBER: not sampled.</td>
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<td></td>
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<td></td>
<td></td>
<td>PILLOW LAVA: not sampled.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.54 Generalised lithological and biostratigraphical summary of the Moni section

**Aims:** To record the comparative calcareous and siliceous microfossil content of the matrix of the Moni Mélange (= Moni Formation) in the type area and to confirm, by the use of biostratigraphy, the coeval deposition of this mélange with the Kannaviou Formation in S.W. Cyprus as suggested by Robertson (1977c).

**Biostratigraphy:** Sample Moni-1 is barren of microfossils. Sample Moni-2 yielded a low-diversity assemblage of radiolaria but is barren of all other microfossils.

**Calcareous nannofossils:** One sample, Moni-1, was analysed and is barren of calcareous nannofossils.

**Radiolaria:** Sample Moni-1 is barren of radiolaria. Sample Moni-2 yielded a low-diversity radiolarian assemblage dominated by elongate nassellarians. The co-occurrence of *Amphipyndax pseudoconulus* and *Amphipyndax tylotus* suggests deposition during late Campanian times in the lower part of the Amphipyndax tylotus Zone of Foreman (1977). Other species recorded in this sample have previously published ranges which include the Late Campanian.
Palaeoenvironment: The hemipelagic nature of the lithologies and the presence of radiolaria in sample Moni-2, suggests deposition in a deep marine, offshore environment subject to normal open marine circulation. The absence of calcareous planktic microfossils may be due to deposition below the CCD.

Discussion: No comparison of calcareous and siliceous microfossil content is possible due to the absence of the former. The lithologies, i.e. pale olive gray, silty to sandy, slightly calcareous, bentonitic mudstones, are similar to some of the lithologies found in the type section of the Kannaviou Formation in the Paleomylon Valley. The Moni lithologies however have a waxy appearance which may have been produced by shearing during mass flow movement or tectonic stress. The dominance of the radiolarian fauna by elongate forms suggests sorting or winnowing which is consistent with rapid deposition. All radiolarian forms recorded from this sample also occur in the Paleomylon Valley section. The findings of the analyses of these samples therefore is consistent with the suggestion by Robertson (1977c) that the matrix of the Moni Mélange consists of Kannaviou sediments, the deposition of which was coeval with the deposition of the Kannaviou Formation located to the present day west.
of the Moni Mélange type area. The sorting of the radiolarian fauna and the absence of benthos and calcareous planktic microfossils may, however, indicate that the Kannaviou sediments were not in-situ but reworked and redeposited, during late Campanian times, into deeper water shortly after initial deposition.

**Age:** Late Campanian, based on lithological characteristics and radiolarian assemblage recorded from sample Moni-2.

### 5.2.16 Location 16 - Kalavasos

**Grid Ref.:** WD 248510, 140m a.s.l.

**Samples:** UCL10184 - UCL10187; Kalavasos-1. Total 5.

**Location:** Lava sequence on E side of road, leading from E end of dam c. 200m S of the dam.

![Figure 5.56 Map Showing the Location of the Kalavasos Section (16)](image-url)
Description: The exposure shows a sequence of brecciated lava flows with thin (4cm) sedimentary bands occasionally exposed. Five spot samples were collected from these sedimentary bands.

Aims: To record comparative calcareous and siliceous microfossil content and to assign an age to these inter-lava sediments.
Biostratigraphy: All samples are barren of microfossils.

Calcareous nannofossils: One sample, Kalavassos-1, was analysed from this section and is barren of calcareous nannofossils.


Discussion: Although microfaunas have been recovered from interlava sediments in other areas, e.g. from the Kambia area by Mantis (1971a), and in this study from the Kambia and Ayios Mamas areas, however, the Kalavasos samples were barren. Further sampling from this area may prove productive.

Age: Cenomanian - Campanian, based on regional evidence documented in the literature.

5.2.17 Location 17 - Dhrapia

Grid Ref.: WD 256512, 180m a.s.l.

Samples: Dhrapia-1 - Dhrapia-2. Total 2.

Location: W side of road in small disused quarry c.200m S of Dhrapia village (Figure 5.58).

Description: The exposure shows pillow lavas at the base overlain by a sequence of umbers approximately 7m thick. Sample Dhrapia-1 was collected from the umber, 2.5m above the contact with the pillow lavas, and sample Dhrapia-2 was collected 5m above the contact (Figure 5.59).

Aims: To record comparative calcareous and siliceous microfossils recovered and to suggest an age and environment of deposition for these sediments.
Biostratigraphy: Microfossils recovered from these sediments include locally common, indeterminate radiolaria, common agglutinated foraminifera, rare calcareous benthic foraminifera, rare planktic foraminifera and rare shell debris.

![Figure 5.58 Dhrapia - distribution chart showing miscellaneous fossils](image)

Calcareous nannofossils: One sample, Dhrapia-2, was analysed from this section and is barren of calcareous nannofossils.

Radiolaria: Forms recovered are poorly-preserved and indeterminate making an age assignment impossible.

Palaeoenvironment: The presence of benthic foraminifera and shell debris together with planktic foraminifera and radiolaria suggests that conditions during deposition of these sediments were hospitable to both bottom dwellers and to pelagic faunas. The poor preservation of the radiolaria, the paucity of planktic foraminifera and the absence of calcareous nannofossils together with the presence of calcareous benthic foraminifera and shell debris favours an interpretation of post-burial dissolution rather than one of deposition below the CCD.

Discussion: A longer section c.1km to the west (see Robertson and Hudson, 1974 for description) has been sampled by Thurow (pers.)
Figure 5.59 Map showing the location of the base of the Dhrapia Section (17)
Reproduced from G.S.D. (Ged.) 8, Pharmakas - Kalavasos Area, (accompanies Memoir No. 8, Pantazis, Th., 1966). Geological Survey Department, Cyprus; Scale 1" = 1 mile. Relevant legend shown on page 184

<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>Formation</th>
<th>Calc.- Nann.</th>
<th>Lithology</th>
<th>Sample Points</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.P.L.</td>
<td>CENOMANIAN - CAMPAIGNIAN</td>
<td></td>
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</tbody>
</table>

Figure 5.60 Generalised lithological and biostratigraphical summary of the Dhrapia Section
comm., 1991) who recovered moderately well-preserved, moderately diverse, radiolarian faunas. Robertson and Hudson (1974) also report radiolarian-rich, pale grey, weakly silicified chert in the upper part of this latter umber section.

Age: Cenomanian - Campanian, based on regional evidence documented in the literature.

5.2.18 Location 18 - Layia

Grid Ref.: 229559, 400m a.s.l.

Samples: Layia-1, Layia-2. Total 2.

Location: c.100m to N of road between Layia and Vavla, c. 1 km to W of Vavla (Figure 5.61).

Description: The section shows pillow lavas overlain by brecciated lava flows. The lava flows are interrupted by two bands of red mudstone (Haematitic Shale), each varying in thickness from 5cm to 1m. Sample Layia-1 was collected from the lower band and Layia-2 was collected from the upper band (Figure 5.62).

Aims: To determine the age of interlava sediments in this section.

Biostratigraphy: Barren of microfauna and calcareous nanofossils.

Age: Cenomanian - Campanian, based on regional evidence documented in the literature.
Figure 5.61 Map showing the Location of the Base of the Layia Section (18)

Reproduced from G.S.D. (Geol.) 8, Pharmakas - Kalavasos Area, (accompanying Memoir No. 8, Pantazis, Th., 1966). Geological Survey Department, Cyprus; Scale 2":1 mile. Relevant legend shown on page 184.

Figure 5.62 Generalised lithological and biostratigraphical summary of the Layia section

<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>FORMATION</th>
<th>Calc. Nannoz</th>
<th>Lithology</th>
<th>Sample Points</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPPER CRETACEOUS</td>
<td>CAMP</td>
<td>UPPER PILLOW LAVA</td>
<td>☑️</td>
<td>☑️</td>
<td>LAYIA-2, LAYIA-1</td>
<td>LAVA: not sampled.</td>
<td>Barren of microfauna.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☑️</td>
<td>☑️</td>
<td>MUDSTONE: dark reddish brown, moderately hard, blocky and slightly calcareous. Common, poorly-sorted, angular quartz grains.</td>
<td>PILLOW LAVA: not sampled.</td>
</tr>
</tbody>
</table>
5.2.19 Location 19 - Kambia

Position: Latitude 35°N; Longitude 33° 16′E, 500m a.s.l.

Samples: Kambia 1 - 3; Kambia 4a - b; Kambia 5. Total 6.

Location: Three sections were sampled in this area. Sections 19a and 19b are to the W of Kambia village on either side of a small track. Section 19c is to the E of Kambia village on the N side of a small track.

Description: Section 19a, in a steep gully, exposes a thin horizon (c. 1m) of umberiferous sediments between pillow lavas below and c. 6m of brecciated lava above. Section 19b, c.50m to the south of this gully, exposes umbers overlying pillow lavas. Section 19c consists of pillow lavas overlain by c.3m of bedded umber, in turn overlain by chalks intercalated with only moderately calcareous mudstones (Figures 5.64 and 5.65).

Aims: To determine the conditions of depositional environments and the age and age relations between the umber and chalk formations.

Biostratigraphy: The umber samples yielded rare agglutinated foraminifera, rare calcareous benthic foraminifera, rare shell debris, rare to common fish teeth and rare indeterminate radiolaria but are barren of calcareous nanofossils and planktic foraminifera. The mudstones intercalated with the chalk horizons of the overlying Lefkara Formation yielded abundant, poorly-preserved, moderately diverse radiolaria.

Calcareous nanofossils: Two samples, Kambia-1 and Kambia-5 were analysed from this locality and both are barren of calcareous nanofossils.

Radiolaria: Samples Kambia-1, Kambia-2 and Kambia-3, from the umbers of all three sections, yielded rare indeterminate radiolaria. Samples Kambia-4a, Kambia-4b and Kambia-5 (location 19c) were all collected from the mudstone horizons of the Lower Lefkara and yielded abundant, poorly-preserved, moderately diverse radiolaria. The presence of *Amphipyndax tylotus* in these mudstone horizons suggests an Late
Campanian - Maastrichtian age (Amphipyndax tylotus Zone of Foreman (1977)) for this part of the section. Radiolarian species recorded here which have been elsewhere reported as being restricted to the Campanian include *Diacanthocapsa acanthica*, *Eostichomitra warzigita*, *Novixitus* sp.A, *Novixitus* sp.B, *Patellula verteroensis*, and *Pyramispongia*? sp.A. Species recovered from this section which have not previously been recorded from Campanian sediments are as follows:

*Amphipyndax conicus* Cenomanian - Santonian

**Palaeoenvironment:** The umber in section 19a was either deposited during a pause in volcanic activity or was later covered by a post-volcanic debris flow of brecciated lava. The pillow lavas were not examined in detail here and therefore they cannot be assigned either to the Upper or
### Generalised Lithology

<table>
<thead>
<tr>
<th>Stage</th>
<th>formation</th>
<th>Calc. Name</th>
<th>Lithology</th>
<th>Sample Notes</th>
<th>Generalised Lithology</th>
<th>Biostratigraphical Assemblages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Cretaceous</td>
<td>Kambian -</td>
<td></td>
<td>UMBER: dark yellowish brown,</td>
<td></td>
<td></td>
<td>Barren of calcareous nannofossils.</td>
</tr>
<tr>
<td></td>
<td>Pillow Lava</td>
<td></td>
<td>moderately hard, moderately fissile, very slightly calcareous.</td>
<td></td>
<td></td>
<td>Rare indeterminate radiolaria, rare agglutinated foraminifera, rare calcareous benthic foraminifera and common fish teeth.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PILLOW LAVA: not sampled.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SECTION 1 Location 19a</td>
<td></td>
<td></td>
<td></td>
<td>1m</td>
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</table>

### Brecciated Lava

<table>
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<th>Lithology</th>
<th>Sample Notes</th>
<th>Generalised Lithology</th>
<th>Biostratigraphical Assemblages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Cretaceous</td>
<td>Kambian -</td>
<td></td>
<td>UMBER: dark yellowish brown,</td>
<td></td>
<td></td>
<td>Rare calcareous benthic foraminifera, rare fish teeth and rare indeterminate radiolaria</td>
</tr>
<tr>
<td></td>
<td>Pillow Lava</td>
<td></td>
<td>moderately hard, slightly fissile, moderately calcareous.</td>
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<tr>
<td>SECTION 2 Location 19b</td>
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<td>1m</td>
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**Figure 5.64 Generalised lithological and biostratigraphical summary of Kambia Sections 1 and 2**

Lower Pillow lava group from field evidence. The umber in section 19b, which is at the top of the section, is presumed from its close geographical proximity and similar lithological and micropalaeontological characteristics to be a lateral equivalent of the umber in section 19a. The microfauna recovered from these lithologies, i.e. calcareous and agglutinated benthic foraminifera together with fish teeth and radiolaria, suggests an environment of deposition, above the CCD, hospitable to both bottom dwellers and to pelagic faunas. The absence of planktic foraminifera and calcareous nannofossils may have been due to a high sediment content in the water column (cf. the rapid sedimentation theory of Robertson and Hudson (1973)), but is more likely to be the result of
post-burial dissolution of less resistant calcium carbonate skeletons. The umber in section 19c contains only rare fish teeth, rare radiolaria and rare shell debris. However, despite the absence of bottom-dwelling foraminifera the same conclusions as above are reached, with the shell debris providing evidence of benthic activity.

The chalks and intercalated moderately calcareous mudstones of the overlying Lefkara Formation at location 19c suggest deposition under conditions of a fluctuating CCD. The sediments were deposited in deep water pelagic conditions as suggested by the chalk lithologies and the diversity of the radiolarian assemblages recovered from the mudstones. The absence of both calcareous nannofossils and planktic foraminifera suggests dissolution of calcium carbonate during or shortly after deposition. The chalk beds were not sampled but further investigation of these latter beds may be useful.
<table>
<thead>
<tr>
<th>Radiolaria</th>
<th>Miscellaneous Fossils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indeterminate radiolaria</td>
<td>Agglutinated foraminifera</td>
</tr>
<tr>
<td>Alievium gallovenz</td>
<td>Calcareous benthic foraminifera</td>
</tr>
<tr>
<td>Amphipondax conicus</td>
<td>Fish teeth</td>
</tr>
<tr>
<td>Amphipondax tyloths</td>
<td>Shell debris</td>
</tr>
<tr>
<td>Archaeodictyomitra spp.</td>
<td></td>
</tr>
<tr>
<td>Clathropysgus titthium</td>
<td></td>
</tr>
<tr>
<td>Crucella espartoensis</td>
<td></td>
</tr>
<tr>
<td>Crucella sp.</td>
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</tr>
<tr>
<td>Cryptophorella cona</td>
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<tr>
<td>Diacanthocapsa acanthica</td>
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</tr>
<tr>
<td>Dictyomitra andersoni</td>
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</tr>
<tr>
<td>Dictyomitra formosa</td>
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<tr>
<td>Eucurtis sp.f</td>
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</tr>
<tr>
<td>Novixitus spp.</td>
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</tr>
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<td>Orbiculiformis aff. O. quadrata</td>
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<td>Praeconocarquoma aff. univera</td>
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<tr>
<td>Pseudoaulophacus aff. floresenss</td>
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<tr>
<td>Pseudoaulophacus aff. floresenss</td>
<td></td>
</tr>
<tr>
<td>Pseudoaulophacus lenticulatus</td>
<td></td>
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<tr>
<td>Pseudoaulophacus spp.</td>
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<tr>
<td>Pyramispongia aff. sp.f</td>
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</tr>
<tr>
<td>Stichomitra communis</td>
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</tr>
<tr>
<td>Theocampe sp.f aff. T. salillum</td>
<td></td>
</tr>
<tr>
<td>Theocampe tina</td>
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<tr>
<td>Xitus sp.f</td>
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<tr>
<td>Orbiculiformis aff. O. railensis</td>
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<tr>
<td>Patellula verterpensis</td>
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<td>Stichomitra asymbatos</td>
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<tr>
<td>Amphipondax stocki</td>
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<tr>
<td>Curtocalpis compacta</td>
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<tr>
<td>Dictyomitra koslovae</td>
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<tr>
<td>Dictyomitra multicostata</td>
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<tr>
<td>Eostichomitra wargziga</td>
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<tr>
<td>Eucurtidium aff. sp.f</td>
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<tr>
<td>Gonglothorax aff. sp.f</td>
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<tr>
<td>Novixitus sp.f</td>
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</tbody>
</table>

Figure 5.66 Kambia - distribution chart showing radiolaria and miscellaneous fossils
Discussion: This section of umbers of the Perapedhi Formation and chalks and marls of the Lefkara Formation is located on the northern side of the Troodos mountains. Robertson (1976) suggests that the chalks and marls of the Lefkara Formation located on the northern side of the Troodos Massif differ from the lithologies on the southern side in that they are not influenced by turbiditic flows. One of the criteria he uses is the presence of benthic foraminifera in these northern sediments. The results from the samples analysed here agree with his findings.

The non-calcareous mudstones of the Perapedhi Formation and the bentonitic mudstones and volcanioclastic sandstones of the Kannaviou Formation found between the umbers and the basal Lefkara in regions south of the Troodos Massif are absent in this northern locality. The lower sediments of the Lefkara Formation, i.e. chalks intercalated with mudstones, differ from the basal chalks and marls found in exposures to the south of the Troodos Massif (e.g. at Kuoka and Arkhimandrita) in that these former mudstones are only moderately calcareous.

Age: Umber - Campanian or older, based on stratigraphical relations to the overlying chalk unit; Chalks and Marls - Late Campanian - Maastrichtian, based on radiolarian assemblages.

5.2.20 Location 20 - Paralimni

Location of Paralimni Village: Latitude 35° 02' N.; Longitude 33° 58' E., c. 50m a.s.l.

Samples: Paralimni A - F. Total 6.

Locations: Section 1 in disused quarry on W side of the road from Ayia Napa to Paralimni, c. 0.5 miles south of Paralimni centre (Samples Paralimni E and F). Section 2, a quarry adjacent to the Paralimni Shooting Club on the north side of the road between Paralimni and Sotira, approximately 0.8 miles east of Paralimni village (Samples Paralimni A, B and C). Section 3, a building excavation on the east side of the road
between Ayia Napa and Paralimni, approximately 0.7 miles south of Paralimni centre (Sample Paralimni D).

Figure 5.67 Map showing the Sample Locations in the Paralimni Area (201,3)
Reproduced from Geological Map of Cyprus, Geological Survey Department, Cyprus, 1979; Scale 1:250,000. Relevant legend shown on page 189

Descriptions: Location 1 is in a disused quarry where an exposure of light olive gray mudstones is unconformably overlain by conglomerate, possibly from the Mamonha Complex. Spot samples, Paralimni E, from the mudstone, and Paralimni F, from the overlying conglomerate, were collected. At location 2, yellowish gray to light olive gray mudstones are exposed in a quarry on the south margin of Paralimni lake. Samples Paralimni A - C were collected from here. Paralimni D is a spot sample of light olive gray bentonitic mudstone, collected from a building excavation.

Aims: To record comparative calcareous and siliceous microfossil assemblages and to compare the microfaunal and -floral content of these sediments with assemblages from the Kannaviou Formation and the matrix of the Moni Mélange.

-172-
**Figure 5.68 Generalised lithological and biostratigraphical summary of Paralimni Sections 1 and 2**

**Biostratigraphy:** Samples from locations 1 and 3 are barren of microfossils. The section at location 2 (samples PARA-A, PARA-B and PARA-C) yielded abundant, moderately diverse, moderately well-preserved radiolaria together with abundant calcareous nannofossils and rare planktic foraminifera in sample PARA-B.

**Calcareous nannofossils:** One sample was analysed from this locality (Figure 5.69). Sample Paralimni B - early Early Campanian to late Late Campanian, CC18 (FO Broinsonia parca) to CC22B?/22C (see discussion of sample 10158 (Phiti) above).

**Radiolaria:** The common occurrence of *Amphipynax tylotus* in sample PARA-C at the base of Section 2 and the consistent occurrence of this species throughout the section places these sediments in the Amphipynax tylotus Zone of Foreman (1977). (Figure 5.70) A number of Campanian restricted forms are also recorded from these samples including *Amphipynax (?) pyrgodes*, *Bisphaerocephalina (?)*
**Figure 5.69 Paralimni - distribution chart showing calcareous nannofossils**

<table>
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<tr>
<th>Species</th>
<th>Paleocene</th>
<th>Eocene</th>
<th>Oligocene</th>
<th>Miocene</th>
<th>Pliocene</th>
<th>Pleistocene</th>
<th>Holocene</th>
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<td>Chiastozugus bifarius</td>
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<td>Corollithion signum</td>
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<tr>
<td>Cribrosparedella ehrenbergi</td>
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<td>Eproolithus floralis</td>
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<td>Gartenago obliquum</td>
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<td>Kamptnerius magnificus</td>
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<td>Lithraphidites carniolensis</td>
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<td>Micula concava</td>
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<td>Micula cubiformis</td>
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*amazon, Diacanthocapsa acuminata, Novixius sp.B, Patellula verteroensis, Pseudoaulophacus vielseitigus, Rhopalosyringium kleinum, Cornutella californica, Diacanthocapsa acanthica, Orbiculiforma sacramentoensis, Praestyl ospaera hastata and Eostichomitra warzigita.* Species recorded here which have not previously been reported from Campanian sediments are as follows:

- **Actinomma(?) davisensis** Turonian
- **Amphipyndax conicus** Cenomanian - Santonian
- **Crucella irwini** Turonian - Coniacian

**Palaeoenvironment:** Microfossil assemblages recovered from section 2 consist entirely of planktic forms. These planktic forms, in particular the diverse nature of the radiolarian and calcareous nannofossil assemblages, suggest deposition in normal marine, open circulation conditions above the CCD. The lack of benthos may suggest rapid deposition by mass
### RADIOLARIA

| XX | Actinomma (?) daviesensi |
| X  | Spongostaurus (?) hokaidoensis |
| X  | Actinomma sp. A |
| X  | Amphipandax conicus |
| X  | Amphipandax stocki |
| O O X | Amphipandax tylotus |
| X  | Archaeospongoprunum huequi |
| X  | Bispherocephalina (?) amazon |
| O  | Bispherocephalina (?) heros |
| X  | Crucella espartoensis |
| X  | Crucella irwinii |
| X  | Cryptamphorella conara |
| X  | Cystocalpis compacta |
| O  | Diacanthocapsa acuminata |
| O O O | Dictyumitra andersoni |
| O O O | Dictyumitra multicostata |
| X  | Novixitus sp. B |
| O X | Novodiacanthocapsa (?) manifesta |
| X X O | Orbiculiforma aff. O raileiensi |
| X  | Patellula sp. A |
| X  | Patellula verteroensis |
| X  | Praestylosphaera pruvus |
| X O O | Pseudoaulophacus floresensis |
| X  | Pseudoaulophacus aff. floresensis |
| O  | Pseudoaulophacus lenticulatus |
| O  | Pseudoaulophacus vielseitigus |
| X  | Rhopalsomyringium kleiniae |
| O  | Stylodictya sp. A |
| X  | Stylodictya sp. B |
| X  | Thecampe spp. |
| X  | Triactoma spp. |
| X  | Kitus sp. B |
| X  | Cornutella californica |
| O  | Crucella sp. |
| X  | Diacanthocapsa acaanthica |
| O O | Eucyrtis sp. A |
| O  | Indeterminate radiolaria |
| X  | Orbiculiforma sacramentoensis |
| X  | Orbiculiforma (?) aff. O. quadrata |
| X  | Paronaella sp. C |
| X O | Patulibrachium sp. A |
| X X | Praestylosphaera hastata |
| X  | Archaeospongoprunum andersoni |
| O  | Dictyumitra formosa |
| X  | Eostichomitra warzigita |
| X  | Hexinastrum sp. |
| O  | Patulibrachium sp. C |
| X  | Pseudoaulophacid sp. B |
| X  | Pseudoaulophacus paragruenensis |

### MISCELLANEOUS FOSSILS

| O  | Sponge spicules |
| X  | Planktic foraminifera |

Figure 5.70 Paralimi - distribution chart showing radiolaria and miscellaneous fossils

-175-
flow/turbiditic processes from a previous site inhospitable to bottom dwellers.

**Discussion:** The lithological characteristics of the light olive gray and yellowish gray, bentonitic mudstones are similar to non-arenaceous mudstones of the Kannaviou Formation exposed to the south-west of the Troodos Massif. No olistoliths were recorded in detail in the field sections examined but blocks of serpentine and other lithologies were noted at Section 1. These olistoliths, together with the waxy nature of the mudstone in sample PARA-E (possibly indicative of shearing during mass flow movement), and the geographical location in the extreme east of the island may suggest that these sediments form part of the Moni Mélange (although samples from the Moni Mélange in the type area analysed in this study are only slightly calcareous) and are a lateral equivalent of the type Kannaviou Formation. The biostratigraphical contents of samples in this area are very different from the assemblage recovered from the mudstone in the Moni area. Calcareous nannofossils and planktic foraminifera are present in Paralimni samples and absent in the Moni sample. The radiolarian assemblage at Moni (Sample Moni-2) is of low diversity and is strongly dominated by elongate nassellarians. The three radiolarian assemblages recovered from Paralimni (section 2) are rich and diverse (49 species) and are not significantly dominated either by nassellarian forms (22 species) or by spumellarian forms (27 species), in species diversity or absolute numbers of specimens. The biostratigraphical evidence therefore suggests that these sediments are comparable with those of the Kannaviou Formation rather than the Moni Mélange. The lack of benthos and the fine grained pelagic nature of the lithologies can be explained by deposition in a deep water environment, but above the CCD.

**Age:**

Section 1 - Conglomerate - Indeterminate; Mudstone - ?Campanian, based only on lithological similarity to Kannaviou/Moni Formations.

Section 2 - Mudstone - Late Campanian, Amphipyndax tyloitus Zone (Foreman, 1977), based on radiolarian and calcareous nannofossil assemblages.

Section 3 - Mudstone - ?Campanian, based on lithological similarity to Kannaviou/Moni Formations.
Figure 5.71 Legend for Generalised lithological and biostratigraphical summaries
EXPLANATION OF GEOLOGICAL SIGNS AND COLOURS

LEGENDE

Sedimentary Rocks
Marine Terrace Deposits
Terrasses Marines
PEISTOCENE
PEISTOCENE

Recent
Recent
NILOGENE NILOGENE

Nicosia Formation (Myrtou Marl)
Formation de Nicosie
(Marnes de Myrtou)
PLIOGENE
PLIOGENE

Pakhna Formation (Lefkara Group)
Formation de Pakhna (Marnes de Lefkara)
MIocene-Upper Cretaceous
MIocene Cretaceous Sup

Grouse de Moni "Mélange"
(Pre-Lefkara)
PRE-EOCENE
ANTE-MAESTRICHTIEN

Kannaviou Formation (Moni clays & Parekklisha Sandstone)
Formation de Kannaviou
MAESTRICHTIAN-CAMPANIEN

Petra tou Romiou Formation
Formation de Petra tou Romiou
UPPER TRIASSIC (Carnian-Norian)
TRIAS SUP (Carnien-Norien)

Mamonia Formation Cherts Unit
Unit "Cherts"
JURASSIC - TRIASSIC

"Halobia Limestone" Unit
Unit "Calcera à Halobies"
JURASSIQUE - TRIASSIQUE

"Sandstone with fossil plant remains" Unit
Unit 'Gres à vegetaux"
UPPER TRIASSIC (Carnian-Norian)
TRIAS SUP (Carnien-Norien)

Igneous Rocks

Serpentinites
Serpentinites

Basaltic and andesitic Pillow Lavas
"Pillow Lava" (Troodos)
"Pillow Lava" (Troodos)
JURASSIC - TRIASSIC

Basaltic Dikes
"Diabase"
Complex Filonien

Micro-gabbro Andesitic Dikes
Filles de Microgabbro andesitiques

Gabbros (aphitiques)
Gabbros
TRIAS SUP (Carnien-Norien)

Gabbros (aphitiques)
Gabbros
TRIAS SUP (Carnien-Norien)

Basaltic Andesitic Pillow Lavas
Trachyandesites - Trachites

Pillow Lavas basaltiques andesitiques
Trachyandesites - Trachites

Metamorphic Rocks
Metamorphites

Figure 5.72 Legend for Geological Map of the Polis - Paphos Area (reproduced with permission from G.S.D. Cyprus)
CONVENTIONAL SIGNS
SIGNES CONVENTIONNELS

Strike and dip
Orientation et pendage

Inverted beds
Signe d’ inversion

Fold structures
Terminaison périclinale

Formation boundary
Limite

Inferred formation boundary
Limite supposée

Fault
Faille

Inferred fault
Faille supposée

Thrust
Contact anormai

Inferred thrust
Contacts anormai supposé

Landslide - slumping
Glissement de terrain

Tectonic Breccias
Breches tectoniques

Fossil
Gisement fossile

Gossan
Mineralisation

REFERENCE

Asphalted road
Route asphaltees

Non asphalted road
Route non asphaltees

Track and path
Piste

Contours in metres
Courbes de niveau en metres

Figure 5.72 continued
### SEDIMENTARY FORMATIONS

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<thead>
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<th>Formation</th>
<th>( \text{PLEISTOCENE} )</th>
<th>( \text{UPPER PLIOCENE} (?) )</th>
<th>( \text{LOWER PLIOCENE} )</th>
<th>( \text{UPPER MIocene} (?) )</th>
<th>( \text{MIDDLE MIocene} )</th>
<th>( \text{LOWER MIocene} )</th>
<th>( \text{EOCENE} ) or ( \text{UPPER CRETACEOUS} )</th>
<th>( \text{JURASSIC} )</th>
<th>( \text{TRIAS} ) or ( \text{OLDER} )</th>
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<td>Mesoaria Group</td>
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### VOLCANIC ROCKS

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<th>( \text{THE BASAL GROUP} )</th>
<th>( \text{THE DIABASE} )</th>
<th>( \text{THE DiABASE WITH MICROGABBRO SHEETS DOMINANT} )</th>
<th>( \text{MAJOR BASALTIC OR ANDESITIC DYKES &amp; SILLS} )</th>
<th>( \text{THE BASALTIC AGGLOMERATE} )</th>
<th>( \text{THE PITCHSTONE AGGLOMERATE} )</th>
<th>( \text{THE MASSIVE FAULT BRECCIA COMPOSED OF DIABASE &amp; GABBRO FRAGMENTS} )</th>
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<td>Lower Pillow Lava</td>
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<tr>
<td>Altered Basaltic, Andesitic &amp; Diabasic dykes with pillowed screens</td>
<td>Basal Group</td>
<td></td>
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<td></td>
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<tr>
<td>Sheeted Diabase</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Diabase with Microgabbro sheets dominant</td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Major Basaltic or Andesitic dykes &amp; Sills</td>
<td></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Basaltic Agglomerate</td>
<td></td>
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<td></td>
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<tr>
<td>Pitchstone Agglomerate</td>
<td></td>
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</tr>
<tr>
<td>Massive Fault Breccia composed of Diabase &amp; Gabbro fragments</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

### PLUTONIC ROCKS

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>( \text{THE GRANOPHYRIC GROUP} )</th>
<th>( \text{THE GABBRO} )</th>
<th>( \text{THE PERIDOTITE} )</th>
<th>( \text{THE HARZBURGITE-WEHRLITE GROUP} )</th>
<th>( \text{THE ENSTATITE-OLIVINITE} )</th>
<th>( \text{THE DUNITE} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granophyric Trondhjemite, Microgabbro</td>
<td>The Granophyric Group</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Epidotite &amp; Quartz-granulite</td>
<td></td>
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</tr>
<tr>
<td>Uralite-Gabbro</td>
<td>The Gabbro</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gabbro with subordinate hypersthene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olivine-Gabbro</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diopside-rich Peridotite with subordinate Pyroxenite</td>
<td>The Peridotite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ophitic Harzburgite &amp; Wehrlite, subordinate Lherzolite</td>
<td>The Harzburgite-Wehrlite Group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enstatite-olivinite</td>
<td>The Enstatite-Olivinite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basalt-serpentine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dunite</td>
<td>The Dunite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gabbro Pegmatite</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Figure 5.73 Legend for Geological Map of the Xeros - Troodos Area (reproduced with permission from G.S.D. Cyprus)**
**Conventional Signs**

- Horizontal
- Inclined, amount in degrees
- Dip of pillow flows, amount in degrees
- Strike & dip of multiple dykes or sheeted structures, amount in degrees
- Vertical multiple dykes or sheeted structures
- Pillow lava screens in Basal Group
- Dyke showing direction of inclination, amount in degrees
- Dip of mineral banding, amount in degrees
- Vertical mineral banding
- Joints, showing direction & degree of dip
- Vertical joint
- Formation boundaries
- Inferred formation boundaries
- Transitional boundaries
- Shear & brecciation in Bastite-serpentine
- Fault
- Inferred fault
- Shear plane showing degree of inclination
- Gossan
- Fossil Locality

**Mines & Quarries**

- **Cupreous Pyrites, Mine**
- **Cupreous Pyrites, Prospect**
- **Cupreous Pyrites, Old Working**
- **Pyrites Prospect**
- **Chromite, Mine**
- **Chromite, Prospect**
- **Chromite, Old Working**
- **Asbestos Mine**
- **Gold, Old Working**
- **Cupreous Pyrites Mine & old Gold Working**
- **Quarry**
- **Old Quarry**
- **Brick earths**

**Reference**

- Asphalated road, two lanes
- Asphalated road, one lane
- Non asphalated road
- Track and path
- Railway line (for carrying ore)
- River, Dam
- Contour in feet
- Triangulation point, (heights in feet)

**Figure 5.73 continued**

-181-
SEDIMENTARY ROCKS

**Chalk & Limestone Tlus**

- Limestone, Chalk & Marl
- Pakhna Formation, Dhali Group

**Lapithos Group**

- Grey Marl with subordinate Chert

**Lime stone, Chalk fr Marl**

- Marl & Limestone

**Mamonia Formation**

- Umbon, Manganiferous Shales, Radiolarites & Bentonitic Clays

**Trypa Group**

**VOLCANIC ROCKS**

- Basalts, Augitites, Limburgites with interlava Agglomerates & Tuffs
- Upper Pillow Lava
- Lower Pillow Lava
- The Troodos Pillow Lavas

- Pyroxene-, Albite-, & Quartz-diabase intrusives with screens of Keratophyric Pillow Lava
- Basal Group
- Diabase
- The Sheeted Intrusive Complex

**PLUTONIC & INTRUSIVE ROCKS**

- Microdiorites (Post-gabbro-granophyre)
- Screens of Quartz-porphyry
- Granophyric rocks undifferentiated including Tonalites, Trondjemites & Tonalite-aplites
- Olivine-gabbro
- Gabbro undifferentiated: Ecrite-Olivine-gabbro, Uraltite-gabbro, Hypersthene-gabbro, Quartz & Granophyric gabbro
- Anorthositic rocks
- Pyroxenite
- Peridotites mainly Harzburgites & Wehlrites
- Serpentine & Bastite-serpentine

*Figure 5.74 Legend for Geological Map of the Agros - Apsiou Area (reproduced with permission from G.S.D. Cyprus)*

-182-
CONVENTIONAL SIGNS

- + Horizontal Beds
- Dip of beds, amount in degrees
- Vertical Beds
- Overturned Strata
- Anticlinal Axis
- Synclinal Axis
- Dip observed on aerial photographs
- Strike & dip of multiple dykes
- Vertical multiple dykes
- Pillowed screens in Basal Group
- Dykes & relics of host rock
- Formation boundaries
- Inferred formation boundaries
- Shear & breccia zones
- Fault
- Inferred fault
- Gossans

Sediments

Sheeted Intrusive Complex

MINES & QUARRIES

- Quarry
- Copper, Nickel & Pyrites Prospect
- Chromite Prospect
- Chromite, Old Working

Figure 5.74 continued
<table>
<thead>
<tr>
<th>Sedimentary Formations</th>
<th>Superficial Deposits</th>
<th>Recent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium Sands, Silts, Clays and Pebbles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beach Sand and Gravel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blown Sands</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Talus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sands &amp; Calcareous Silts with angular Rock Fragments and Havara</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well-rounded Pebbles and Sands mostly of igneous origin, include usually secondary Limestone (Havara)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well-rounded, badly sorted Fossiliferous Pebbles and Sands mostly of igneous origin, Impure Bioclastic Calcarenites, Include Microliths and Megafossils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well-rounded, badly sorted Pebbles with Sands mostly of igneous origin, include minor amounts of Fossils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellowish-green to pale brown, Fossiliferous Sands, Marl, Impure Sands and Pebble Beds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gypsum including &quot;Marmarina&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bostron and Bohemian Reef Limestone.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thin-bedded Marl Limestones, medium to coarse grained, interbedded with Flaggy Limestones and Marl, Massive-bedded, yellowish, Bioclastic Limestones &amp; Calcarenites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discorprine Bond</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flaggy yellowish Marl Chalks interbedded with Marl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaved Chalks and occasionally flaggy Chalks almost devoid of Chert bands</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thick-bedded Chalks and Marl Chalks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>almost devoid of Chert bands</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalks (usually flaggy), interbedded with Chert</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pink and grey Marls intercalated with thin-bedded Chalks (h1) and Marl Chalks (h2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuffaceous Limestone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melange including Clays and Blocks of older Rocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grey-greenish and reddish-brown Clay, usually strongly sheared, with lenses of Gypsum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Umbros, Umbeliferous and Manganiiferous Shales.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiolarian Siltsiones and Mudstones</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poorly cemented yellowish-brown Sandstone, reddish-brown Hematitic in places, Occasionally Silicified, forming lens-like bodies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard, cream or pink Reef Limestone Radiolarian hard, Crystalline Pelagic Limestone, Ammonite-bearing brownish Pelagic Limestone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensely folded brown Shales and Tuffaceous Sediments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River Terrace Deposits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kyrenia Formation (Lower Marine Terrace)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher Marine Terrace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Athalassa Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kalavasos Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Koronia Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dhali Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paphna Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Upper Chalks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Lefkara Formation (ex-Lapithos)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Chalk with Chert</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Lower Marl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moni Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perapedhi Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pareklisha Sandstone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petra tou Romiou Formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mamonia Formation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.75 Legend for Geological Map of the Pharmakas - Kalavos Area (reproduced with permission from G.S.D. Cyprus)
### VOLCANIC ROCKS

- Tuffaceous Agglomerates
- Brecciated Tuffaceous Agglomerates, Tuffs and Hematitic Shales
- Mamon Pillow Laves
- Upper Pillow Laves
- Basaltic Pillow Laves with Dykes, Sills and Augites
- Lower Pillow Laves
- Andesitic Laves with Dykes and Sills
- Basaltic Pillow Laves with Dykes, Silis and Augites
- Altered Basaltic, Andesitic and Diabasic dykes with minor Pillowed Screens
- Di tribe dyke, swarms and multiple dykes
- Epidosites dominant
- The Troodos Pillow Lava Series
- The Basal Group
- The Diabase

### PLUTONIC ROCKS

- Quartz-felspar Porphyries
- Trondhjemites, Granophyres & Microgranodiorites
- Ultrabasic gabbro
- Pyroxene-gabbro, Gabbro with subordinate Hypersthene, Norite
- Olivine-gabbro with subordinate Olivite-Norites
- Pyroxene-gABBro
- Peridotites (Pyroxene-Peridotites, Orthopyroxene-Peridotites and Clinopyroxene Peridotites)
- Pyroxenite dominant
- Brecciated and Silicified Mamon Serpentinite associated with Fault Zones
- Serpentinite
- Shatterer Serpentinite
- Basalt Serpentinite

**Figure 5.75 continued**
CONVENTIONAL SIGNS

Vertical beds
Inclined, amount in degrees
Horizontal
Synclinal axis
Anticlinal axis
Inclined, amount in degrees
Vertical
Dyke showing direction of inclination, amount in degrees
Pillow Lava screens in Basal Group
Dip of mineral banding, amount in degrees
Vertical mineral banding
Joints, showing direction and dip
Formation boundaries
Inferred formation boundaries
Transitional boundaries
Shear and brecciation zones in Sediments and Igneous Rocks
Fault
Inferred Fault
Gossans and oxidised zones
Fossil locality

MINES AND QUARRIES

Cupreous Pyrites, Mine
Pyrites and Cupreous Pyrites, Old Working and Prospecting pits
Pyrites and Cupreous Pyrites, Prospect
Chromite, Prospect
Chromite, Old Working
Nickeliferous Pyrrhotite, Old Working and Prospect
Gold, Old Working
Gypsum Quarry
Bentonitic-clay Quarry
Other Quarries
Slag

Figure 5.75 continued
**SEDIMENTARY FORMATIONS**

<table>
<thead>
<tr>
<th>Sedimentary Formations</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>RECENT</td>
</tr>
<tr>
<td>Chalk &amp; Limestone Talus</td>
<td></td>
</tr>
<tr>
<td>Boulder beds &amp; secondary Limestone (Karkala)</td>
<td>Fanglomerate Series</td>
</tr>
<tr>
<td>Sandy Marls Secondary Limestone (Havara) &amp; Silty Limestone with Pebble beds</td>
<td></td>
</tr>
<tr>
<td>Fragmental Limestone with Marls</td>
<td></td>
</tr>
<tr>
<td>Buff &amp; Grey Marl, Sands &amp; Calcareous Siltstones</td>
<td></td>
</tr>
<tr>
<td>Conglomerates &amp; Sandstones</td>
<td></td>
</tr>
<tr>
<td>Reef Limestone</td>
<td>Koronia Limestone</td>
</tr>
<tr>
<td>Gypsum</td>
<td>Pakhna Formation</td>
</tr>
<tr>
<td>Chalks, Marls &amp; Limestones</td>
<td></td>
</tr>
<tr>
<td>White flaggy &amp; cleaved chalk</td>
<td></td>
</tr>
<tr>
<td>Chalk with chert bands &amp; pink Marls</td>
<td></td>
</tr>
<tr>
<td>Umberous Shales Radiolarian Shales &amp; Radiolitites</td>
<td>Perapedhi Formation</td>
</tr>
<tr>
<td>Manganiferous Shales &amp; Cherts</td>
<td></td>
</tr>
</tbody>
</table>

**VOLCANIC ROCKS**

<table>
<thead>
<tr>
<th>Volcanic Rocks</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillow Lavas, Olivine-basalt, glassy basalt &amp; Mugetanes</td>
<td></td>
</tr>
<tr>
<td>Olivine-basalt</td>
<td>Upper Pillow Lava</td>
</tr>
<tr>
<td>Altered Picrite-basalt &amp; Limurgite</td>
<td></td>
</tr>
<tr>
<td>Contemporaneous intrusives Dolente &amp; Olivine-dolerite</td>
<td></td>
</tr>
<tr>
<td>Pillow Lavas &amp; contemporaneous intrusives</td>
<td>The Troodos Pillow Lava Series</td>
</tr>
<tr>
<td>Andesites, Dacites &amp; Keratophyres</td>
<td></td>
</tr>
<tr>
<td>Silicified Pillow Lavas &amp; Intrusives</td>
<td></td>
</tr>
<tr>
<td>Volcanic Breccia</td>
<td>Lower Pillow Lava</td>
</tr>
<tr>
<td>Volcanic glasses-Augites</td>
<td></td>
</tr>
<tr>
<td>Hyalo-andesites &amp; dacites</td>
<td></td>
</tr>
<tr>
<td>Contemporaneous intrusives</td>
<td></td>
</tr>
<tr>
<td>Andesites</td>
<td></td>
</tr>
<tr>
<td>Dacites &amp; Keratophyres</td>
<td></td>
</tr>
<tr>
<td>Diabasic intrusives with Screens of Pillow Lava</td>
<td>Basal Group</td>
</tr>
<tr>
<td>Pyroxene &amp; Albite-diabase</td>
<td></td>
</tr>
<tr>
<td>Diabase, Microdiorite &amp; Microgabbro dykes locally epidotised</td>
<td></td>
</tr>
<tr>
<td>Epidostes dominant</td>
<td>Diabase</td>
</tr>
</tbody>
</table>

**Figure 5.76 Legend for Geological Map of the Akaki-Lythrodonda Area (reproduced with permission from G.S.D. Cyprus)**
CONVENTIONAL SIGNS

- Horizontal
- Inclined, amount in degrees
- Dip observed on aerial photographs
- Strike & dip of multiple dykes
- Vertical multiple dykes
- Pillowed screens in Basal group. Keratophyres
- Flow Agglomerates in Basal group. Keratophyres
- Lava Breccia

- Formation boundaries
- Inferred formation boundaries
- Transitional boundaries
- Fault
- Inferred fault
- Shear & breccia zone

- Gossan
- Macrofossils
- Foraminifera

- Sediments
- Basal group & Diabase

MINES & QUARRIES

- Pyrites mine
- Pyrites prospect
- Gold, old Working
- Bentonite, old Working
- Celadonite (Terre Verte), old Working
- Slag dumps

Figure 5.76 continued
## Legend

**Circum Troodos Sedimentary Succession**

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Formations</th>
<th>Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2</td>
<td>Silt, sand, gravel</td>
<td>Alluvium</td>
</tr>
<tr>
<td>Qb</td>
<td>Calcarenite, sand, gravel</td>
<td>Terrace deposits</td>
</tr>
<tr>
<td>T</td>
<td>Gravels, sands, silts, undifferentiated</td>
<td>Fanglomerate</td>
</tr>
<tr>
<td>Gb</td>
<td>Biocalcaremte, sand, sandy marl</td>
<td>Athalassa</td>
</tr>
<tr>
<td>N2</td>
<td>Biocalcaremte, sand, gravel, sandy marl, marl, marly limestone</td>
<td>Nicosia</td>
</tr>
<tr>
<td>N1</td>
<td>Alternating gypsum with chalky marl and marly chalk</td>
<td>Kalavasos</td>
</tr>
<tr>
<td>5</td>
<td>Reefs, biherms and biostroms</td>
<td>Koronia</td>
</tr>
<tr>
<td>1</td>
<td>Alternating chalks, marls, marly chalks, chalky marls and arenites</td>
<td>Pakhna</td>
</tr>
<tr>
<td>1</td>
<td>Reefs, biherms and biostroms</td>
<td>Terra</td>
</tr>
<tr>
<td>2</td>
<td>Chalk, marly chalk, chalky marl, marl with cherts in places as bands or nodules</td>
<td>Lefkara</td>
</tr>
<tr>
<td>3</td>
<td>Rock fragments mostly of Mamonia origin in clayey matrix</td>
<td>Moni</td>
</tr>
<tr>
<td>5</td>
<td>Bentonic clay interstratified with tuffaceous sandstone</td>
<td>Kannaviou</td>
</tr>
<tr>
<td>6</td>
<td>Umber; radiolarian chert</td>
<td>Perapedhi</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Figure 5.77 Legend for Geological Map of Cyprus (1979)**

(reproduced with permission from G.S.D. Cyprus)
CONVENTIONAL SIGNS

- Geological boundary
- Fault, definite and inferred
- Thrust, (saw teeth on upper plate)
- Unconformity
- Asphaltered road, two lanes
- Asphaltered road, one lane
- Non asphaltered road
- River, perennial and seasonal
- Heights of principal mountains and hills, in metres
- Contours in metres

Figure 5.77 continued
5.3 Conclusions

5.3.1 Introduction
This concluding part seeks to link evidence presented by other workers, outlined in Chapter 5.1, with the findings of this study in 5.2. The definitions of stratigraphical units generally follow those of Swarbrick and Robertson (1980).

In this project the analyses have been primarily concerned with samples from the autochthonous sedimentary cover. Further studies of the allochthonous sediments will contribute to the understanding of their provenance, timing of emplacement, and their relationships and sediment contributions to the autochthonous formations.

5.3.2 Conclusions from the interlava sediments:
These sediments are defined on stratigraphical position within the upper ophiolite complex. Samples have been analysed here from Perapedhi (locality 10), Ayios Mamas (locality 12), Kapilio (locality 13), Kalavasos (locality 16), Layia (locality 18) and Kambia (locality 19).

Lithologies vary from red baked mudstone, haematitic shales, sandy, yellowish brown mudstones and umber.

Biostratigraphy - Microfauna was recovered from three of these localities, i.e. Perapedhi, Ayios Mamas and Kambia. The assemblage recorded from Perapedhi is interpreted as a fissure deposit; the assemblage from Ayios Mamas contains non age-diagnostic radiolarians; the assemblages from the umberiferous sediments at Kambia are included below in the discussion of the Perapedhi Formation.

Palaeoenvironment - Boyle and Robertson (1984) interpret the lithologies analysed from the Mathiati-Margi area (to the north of the Troodos Massif) as "hydrothermally oxidised sediments deposited during a break in volcanic extrusion". They record the occurrence of radiolarians and coccoliths in their samples, the presence of the latter suggests deposition above the CCD.
In samples analysed from this project the stratigraphical position of the sediments, i.e. intercalated with pillowed and brecciated lavas, also indicates deposition between volcanic episodes. The presence of radiolarians and coccoliths in samples analysed by Boyle and Robertson (1984) and the presence of radiolarians in samples analysed here from Ayios Mamas suggest that the depositional environment was not inimical to pelagic faunas and that they were preserved during post-depositional events.

Interpretation - Microfauna have been recovered from interlava sediments by Mantis (1971a) from an area north of Troodos, by Boyle and Robertson (1984) from the same area and from Ayios Mamas to the south of the Troodos Massif. This confirms the potential for biostratigraphical dating of the interlava sediments and therefore for contributing to the understanding of the geological evolution of the area.

The biostratigraphical evidence currently available is not conclusive, i.e. Mantis (1971a) suggests a Cenomanian age for these sediments but bases this interpretation on only one, rarely-documented, species of agglutinated foraminifer recovered from one section in Cyprus. Although a Cenomanian age-assignment is not unreasonable, the supporting evidence is not strong enough to reach a conclusion of this importance.

5.3.3 Conclusions from the Perapedhi Formation:
The Perapedhi Formation can be divided into two distinct lithological units, basal umbers and conformably overlying, non-calcareous, non-arenaceous, varicoloured, radiolarian mudstones. The uppermost sediments of the mudstones probably represent a transitional zone between the Perapedhi Formation and the stratigraphically higher Kannaviou Formation.

a) Umbers - Defined as yellowish brown to brownish black metalliferous mudstones, conformably overlying the Upper Pillow Lavas.

Biostratigraphy - Moderately well-preserved radiolarian specimens can be recovered from these sediments as discovered by Blome and Irwin (1985).
They record a Turonian radiolarian assemblage from a sample collected from near the base of the umber section at the Mangaleni mine.

During this project umbers were analysed from Akamas (locality 1), Kuoka (locality 9), Perapedhi (locality 10), Trimiklini (locality 11), Mangaleni (locality 14), Dhrapia (locality 17) and Kambia (locality 19). Identifiable radiolaria were recovered from Akamas (Campanian) and Trimiklini (Cenomanian/Campanian). Specimens recovered from Mangaleni mine are very poorly-preserved and indeterminate. Samples from other locations are barren of radiolaria.

Thurow (*pers. comm.*, 1991) has recovered a moderately well-preserved, moderately diverse radiolarian assemblage from another section of umbers in the Dhrapia area, c. 2km to the west of the section described in this report. This latter fauna initially appears to be characteristic of Campanian age sediments but contains some forms for which an age range has not yet been established and further investigation of this material by Thurow is in progress.

Palaeoenvironment - Miscellaneous microfossils recovered from umber samples include agglutinated benthic foraminifera, sponge spicules and fish teeth at Akamas, agglutinated benthic foraminifera at Mangaleni and agglutinated benthic foraminifera, calcareous benthic foraminifera and fish teeth at Kambia. These assemblages suggest that environmental conditions were hospitable to both pelagic and benthic faunas during deposition of the umbers and the paucity of the faunas may suggest either rapid sedimentation or diagenetic destruction.

Interpretation - a) If, as suggested by Robertson and Hudson (1973, 1974), the umbers were deposited relatively rapidly then the Turonian age suggested by Blome and Irwin (1985) and the Campanian age (suggested here) are not consistent. Both age determinations are based on radiolarian biostratigraphy (although the two assemblages are markedly different and from different geographical locations, see Figure 5.2) and it may be that i) radiolarian ranges are not yet well enough established to be able to assign accurate dates; or ii) the sediments at the different locations may represent
two different episodes of umber deposition; or iii) one or both of the samples may have been subject to contamination or reworking.

The biostratigraphical evidence available, i.e. faunas from only two samples, is not conclusive but the successful recovery of radiolarian specimens from umber lithologies by Blome and Irwin (1985) (which is shown here, and by Thurow (pers. comm., 1991) to be repeatable) is encouraging for further sampling.

The samples analysed in this project which are barren show that radiolarian distribution within the sediments is inhomogeneous. This distribution pattern may be due to deposition at different times, e.g. when surface productivity fluctuated or when chemical stages in the associated volcanism varied (i.e. the chemical environment of deposition may have inhibited preservation of faunas at the time of deposition or during post-burial history). Initial coeval deposition of radiolaria may have been inhomogeneous due to localised transport by winnowing currents. Different diagenetic histories due to tectonic disturbance or subaerial exposure and groundwater leaching may also account for patchy distribution of solution-susceptible microfossils.

b) radiolarian mudstones - Defined as varicoloured, non-calcareous, locally manganiferous mudstones.

Biostratigraphy - Radiolarian assemblages recovered from these lithologies are generally rich and diverse with well-preserved to moderately well-preserved specimens. Three of the sections analysed here, Akamas (locality 1), Paleomylon Valley (locality 5) and Perapedhi (locality 10) contain this upper part of the Perapedhi Formation. All are dated as Campanian based on radiolarian faunas and identified in the parts of the sections defined by the following samples:
Akamas, samples 10106A - 10130 inclusive
Paleomylon Valley, samples 9838 - PV6
Perapedhi, samples 10179 - 10176 [- 10163 amalgamated samples]
Palaeoenvironment - The miscellaneous microfossils recovered from these non-calcareous mudstones in all three sections include fish teeth and agglutinated benthic foraminifera which suggests depositional environments of normal salinity and oxygenation suitable for both pelagic and benthic faunas. The absence of calcareous microfossils and the non-calcareous nature of the lithologies may be due to deposition below the CCD. Alternatively it is suggested that a correlation between abundant botryoidal manganese and absence or paucity of calcareous microfossils in these sediments indicates subsequent diagenetic removal of calcareous components initially deposited above the CCD.

Interpretation - Towards the top of these mudstones a transitional zone with the overlying Kannaviou Formation is proposed. Sediments become more calcareous, with rare occurrences of calcareous benthic foraminifera and rare planktic foraminifera, although samples are still barren of calcareous nannofossils. The sediments also show a slight increase in arenaceous content. A transitional zone is proposed in all three sections: Akamas between samples 10128 (FO rare planktic foraminifera together with minor silt component) and 10130; Paleomylon Valley between 9833 (FO of calcareous benthic foraminifera together with silt component) and sample 10087 (major sandstone unit); Perapedhi 10176/10163 [amalgamated samples] (FO rare calcareous benthic foraminifera and rare planktic foraminifera, barren of calcareous nannofossils, together with increased silt component).

This transitional unit is arbitrarily included within the Perapedhi Formation (rather than the Kannaviou Formation) because the definitions used here are too dependent on subjective characteristics for it to be redefined as a separate member of either formation. This is consistent with the view of Hedberg (1976, p. 32) who states that "the degree of change in lithology required to justify the establishment of distinctive formations (or other lithostratigraphic units) is not amenable to strict and uniform rules". Variation in lithological characteristics seems to be subjective. Is it, for example, feasible to differentiate lithologies merely on calcareous content which may be the result of local changes in basin topography or may even be the result of post-burial diagenetic change? Whittaker et al. (1991) suggest that a formation has lithological characteristics that
distinguish it from adjacent formations and that a member is a subdivision of a formation.

5.3.4 Conclusions from the Kannaviou Formation:
Kannaviou sediments are here defined as light olive gray to yellowish gray, calcareous, often silty to sandy bentonitic mudstones, siltstones and tuffaceous sandstones of volcanic origin. Samples from this formation were analysed from sections at Akamas (locality 1), Phiti (locality 2), Kritou Marottou (locality 3), Anadhiou-Sarama (locality 4), Paleomylon Valley (locality 5), Kithasi (locality 6), Arkhimandrita (locality 7), Petrou Romiou (locality 8), and Paralimni (locality 20).

Biostratigraphy - No evidence of Maastrichtian-restricted microfossils has been recorded in this study and it is suggested that despite the rare occurrences of poorly preserved specimens of the calcareous nannofossils *Quadrum trifidum* and *Broinsonia parca* (in Akamas samples EAK-2 and EAK-5) that the Kannaviou Formation was deposited entirely within the Campanian.

Palaeoenvironment - The occasional non-calcareous horizons in the higher parts of the Paleomylon section suggest either a lowering of the CCD through time, with intermittent fluctuations or post-burial destruction of calcareous components. The abundance and diversity of pelagic faunas and planktic faunas and floras together with rich and diverse benthic faunas suggests deposition in a deep-marine environment subject to well-oxygenated conditions of normal salinity conducive to both surface and bottom-dwelling organisms.

Interpretation - Late Cretaceous calcareous nannofossils co-occur with radiolaria in Kannaviou sediments in 10 samples in six of the nine sections analysed. These are: Akamas - EAK-2, EAK-5; Phiti - 10059, 10058; Kritou Marottou - BH03; Anadhiou-Sarama - 9812; Paleomylon Valley - 10098, 10112, 10113; Paralimni - PARA-B.

The parts of the section dated by calcareous nannofossils and by integrated nannofossil and radiolarian data are shown in Figure 5.78. Based on
integrated data, where available, and elsewhere on radiolarian data alone it is suggested that sediments of the Kannaviou Formation analysed in this study were deposited entirely within the Campanian.

Figure 5.78 Showing the possible biostratigraphical ranges of 6 Cyprus sections (defined by the respective sample numbers)
5.3.5 Conclusions from the Lefkara Formation:
Sediments from the Lefkara Formation are defined as pinkish to grayish white, sometimes silicified, marls and chalks. The basal sediments are sometimes, not always, pink and sometimes silicified.

Samples were collected from the lowermost exposed Lefkara lithologies at Phiti (locality 4), Arkhimandrita (locality 7), Petra tou Romiou (locality 8), Kuoka (locality 9) and Kambia (locality 19).

Biostratigraphy - Late Cretaceous radiolarian assemblages (interpreted as in-situ) characteristic of a Campanian age were recovered from Lefkara marls at Kambia (Samples Kambia-4a, 4b and 5). One sample, Kambia 5, was also analysed for calcareous nannofossils but was found to be barren. It is possible that these radiolaria are reworked but unlikely as the assemblages are moderately diverse (14 - 24 species); each assemblage contains forms coincident with forms occurring in the other two samples; the assemblages contain a wide range of sizes and shapes of morphotypes; and Robertson (1976) considers that the Lefkara Formation is relatively undisturbed on the north side of Troodos, as compared with the calciturbidites on the south side of the massif.

Late Cretaceous radiolaria were not recovered from Lefkara lithologies analysed from the other four localities.

Palaeoenvironment - The alternating chalks and non- to slightly calcareous intercalated mudstones together with moderately diverse radiolarian assemblages recovered from the Kambia section suggest an offshore depositional environment with a fluctuating CCD.

Interpretation - Deposition of the autochthonous sediments of the Lefkara Formation began in the Late Campanian during a period of tectonic disruption caused by the emplacement of the Mamonia allochthonous complex.

The presence of Campanian radiolarian faunas in the lowermost sediments of the Lefkara Formation suggests that they are Campanian in age and not Maastrichtian as previously suggested, and that the K/T boundary may be
present within this formation. No Maastrichtian or Early Palaeocene restricted microfaunas or -floras have been recovered during this study and it is therefore not possible to predict the presence of conformable K/T boundary sections in Cyprus. However, unconformable boundaries between the Kannaviou and Lefkara Formations have been identified here in sections at Phiti, Petra tou Romiou and (?)Arkhimandrita.

5.3.6 Conclusions from the Moni Formation:
Sediments of the matrix of the Moni Mélange are defined as green, bentonitic mudstones associated with exotic blocks in the type area as defined by Robertson (1977c).

Biostratigraphy - Two spot samples were collected from the matrix of the Moni mélange, one of which is barren, while the other yielded a low to moderately diverse assemblage of Campanian radiolaria. The specimens recovered are all of a similar size and shape (dominated by elongate forms) and other faunas or floras are absent.

Palaeoenvironment - The sorted and moderately low diversity characteristics of the radiolarian assemblage recovered together with the absence of other groups of microfossils, including calcareous forms, is consistent with the interpretation of rapid, downslope mass movement into a deep water setting.

Interpretation - Sediments of the Moni mélange are coeval with sediments of the Kannaviou Formation but differ in sand content and in containing olistoliths (some of very great size). The matrix is Campanian, Kannaviou-derived, an interpretation based on the colour, mineral content and bentonitic characteristics of the lithologies and on the microfossil content. All of the radiolarian species recovered from the fossiliferous Moni (15b) sample are also present in the type Kannaviou in the Paleomylon Valley section.

Additionally, the field evidence (olistoliths) and the location in the Moni mélange type area suggests that the sediment is Campanian and reworked/redeposited as a Campanian mélange matrix, consistent with the interpretation by Robertson (1977c) as a para-autochthonous sequence.
5.3.7 Discussion

The original reason for the micropalaeontological analyses of Cyprus sediments was that they were known to contain co-occurring calcareous and siliceous microfossils. From these assemblages it was hoped that an integrated zonation scheme could be constructed, i.e. the main aim of the exercise was to use the microfossil assemblages as a tool to contribute to the refining of Late Cretaceous biostratigraphical zonation schemes on a global scale.

It is now apparent, at this stage in the investigations, that the sedimentary rocks of Cyprus are not ideal for this purpose. This is because the extremely complicated tectonic and sedimentary history of the island (as summarised by Robertson, 1990) make straightforward micropalaeontological comparisons between sections difficult for the following reasons:

a) the number of lithologies and their complex association with each other focuses disproportionate attention on the geology rather than the micropalaeontology, i.e. a basic understanding of the geology is essential to micropalaeontological interpretation;

b) siliceous microfossils are very susceptible to dissolution resulting in patchy occurrences. In sediments with a wide variation of lithological characteristics the effects of diagenetic change cannot be uniformly monitored; and

c) the proximity to basaltic rocks and volcaniclastic sediments which may influence ocean water chemistry thereby promoting production and preservation of siliceous microfossils in ocean water and preservation due to the chemistry of the pore waters during initial burial also is responsible for the selective destruction of both calcareous and siliceous microfossils during post-burial history of the sediments, for example through leaching by hydrothermal circulation.

To make more efficient use of micropalaeontology as a tool for unravelling the geological history of Cyprus, sampling in conjunction with detailed field mapping or in collaboration with other workers is essential. This study however gives a general indication of the potential uses for the correlation of members or units of lithologically similar sections and for
the identification of unconformities and hiatuses/periods of non-
deposition.

The work here constitutes a preliminary study indicating areas to
concentrate on for future work. This is the result of not enough
fossiliferous samples being incorporated into the study to allow significant
interpretations to be made. More sampling of strategic horizons such as
interlava sediments, lithological boundaries and chronostratigraphical
boundaries is required.

Summary of main conclusions
Interlava sediments and umbers potentially yield radiolaria, agglutinated
foraminifera and calcareous benthic foraminifera. A more comprehensive
sampling strategy and better established radiolarian ranges will facilitate
future determination of the biostratigraphical positions of these sediments.

The Perapedhi Formation radiolarian mudstones have an abundant and
diverse fauna of radiolarians but lack calcareous microfossils. There is
potential here for a more refined zonation of these sediments if radiolarian
ranges were better established and more samples from long coherent
sections were analysed.

The Kannaviou Formation contains co-occurring calcareous and siliceous
microfossils but integrated correlations are limited by the highly disturbed
nature of the sediments (i.e. slumps, faults and repeated sequences);
deposition within a geologically relatively short time interval; a high
incidence of selective dissolution of both calcareous nannofossils and
radiolarians; and the fragmented nature of exposures.

The Kannaviou/Lefkara boundary is difficult to study in places due to
Mamonia emplacement and probable local erosion of the uppermost
Kannaviou and/or lowermost Lefkara induced by the disruptive phase. It
is possible that there are localities where the Kannaviou Formation passes
conformably into the Lefkara Formation but these were not located in this
project.
On the northern side of the Troodos Massif (at least), the K/T boundary is within the Lefkara Formation.

The time scale of deposition of these sediments has proven to be too short for developing a biostratigraphical framework, and the distribution of radiolaria and calcareous nannofossils subject to extensive dissolution. However, contributions are made with regard to radiolarian ranges and associations which will significantly refine, confirm or revise existing zonation schemes. These findings are discussed in detail in Chapter 7.

The radiolarian faunas from Cyprus are compared with coeval faunas from the Atlantic Sites in Chapter 7.
CHAPTER 6

ATLANTIC

6.1 Introduction

6.1.1 Brief Evolutionary History of the North Atlantic Ocean
Late Triassic shallow-marine, basinal evaporites were precipitated on continental crust on the eastern Canadian margin and off Morocco (DSDP Site 546), between palaeolatitudes 10° to 25°N (Jansa, 1986). Marine sedimentation after the evaporite deposition marks the origin of the North Atlantic Ocean. During the Jurassic, the evaporites were successively overlain by continentally-derived red shales, followed by shallow-water carbonates around the margins and dark calcareous muds in the deeper parts of the developing basin (Jansa, 1986). Marine faunas increased as a result of the expanding habitat whilst the arid conditions which had prevailed in the Triassic gave way to an increasingly humid, temperate climate (Jansa, 1986). Magnetic anomaly patterns show that North America and Eurasia split at c.180Ma (Early Jurassic) (Pitman and Talwani, 1972).

Data used by Barron (1987) and Tyson and Funnell (1987) were gathered from numerous DSDP/ODP sites and used to produce palaeogeographical reconstruction maps for stages through the Cretaceous. They illustrate that spreading was active between eastern North America/Newfoundland and NW Africa/Spain c.120Ma (Barremian) until c.75Ma (Campanian), when the location of spreading moved to an axis between Biscay and the Labrador Sea (Laughton, 1975). Rifting between Greenland and North America began in the Turonian (Barron, 1987).

In the Early Cretaceous, pelagic carbonates were common, whilst the Late Cretaceous was characterised by interbedded red/green/black claystones and shales and pale chalks, with an extensive black shale facies occurring in the Middle Cretaceous (the result of a rise in the CCD and a decrease in bottom-water circulation together with high organic productivity) (Arthur and Dean, 1986). Marine productivity and biotic variety was high during the Middle/Late Cretaceous, when sea-levels were high giving rise to
large expanses of warm, shallow seas. The climate had become warm, equable and humid (Arthur and Dean, 1986).

Sheridan (1986) relates major transgressive episodes in the Middle to Late Jurassic and Middle to Late Cretaceous to rapid plate-spreading.

6.1.2 Aims of Present Study
The aims are to compare results between three sites studied in the central Atlantic, and in future incorporate data from initially five other sites (see Figure 6.1) with regard to provincial similarities and differences within siliceous microfossil assemblages and comparison with associated calcareous microfossils. Initial sites chosen are between Lat. 15° and 39°N and provide an opportunity for comparison of N-S and E-W patterns and an estimate as to the influence of prevailing water masses with regard to hypotheses on palaeogeography and palaeoceanography.

An additional aim is to expand the existing databases provided by previous workers by using different processing techniques for extraction and concentration of the microfossils.

6.1.3 Samples Selected for the Present Study
The three DSDP sites described below were selected for examination because they all lie at in approximately equivalent latitudinal band to that of Cyprus, i.e. within 15° - 39°N of the equator. Samples were selected from sections of cores from sites 152, 369A and 612 which have been dated as between Santonian and Maastrichtian in age in initial reports of the DSDP. These three sites are the first of a proposed study of eight Atlantic sites (see Figure 6.1) at which calcareous and siliceous microfossils occur within related sections of Campanian sediments (derived from survey of sites described in Chapter 4). The position of the sites are as follows:

DSDP Site 13 Latitude 6°02.4'N; Longitude 18°13.71'W
DSDP Site 95 Latitude 24°09'N; Longitude 86°23.85'W
DSDP Site 144 Latitude 09°27.23'N; Longitude 54°20.52'W
*DSDP Site 152 Latitude 15°52.72'N; Longitude 74°36.47'W
DSDP Site 363 Latitude 19°45.45'S; Longitude 10°31.95'E
*DSDP Site 369A Latitude 26°35.05'N; Longitude 14°59'W
DSDP Site 511 Latitude 51°28'S; Longitude 46°58.30'W
*DSDP Site 612 Latitude 38°49.21'N; Longitude 72°46.43'W
* = sites studied here

Records of occurrences within the initial reports are either presented in the core barrel sheets or in individual papers within the reports.

Each site is discussed in turn below, giving details of the geological setting, lithological characteristics of the section, previous micropalaeontological analyses, reasons for sample selection for further analyses, biostratigraphical analyses from this study and discussion of results.

Samples were selected at approximately 1m (or less) intervals. 15cc of each sample was processed. After processing with H₂O₂ (as described in Chapter 3) approximately half of each sample was then treated with HCl. Lithological characteristics and microfaunal content of samples are recorded and shown in the respective charts and figures in this chapter. N.B. much smaller quantities of material were processed for these sites than for the onshore Cyprus samples.
Figure 6.1 Present day locations of DSDP/IPOD Sites Studied
6.2 Analyses of DSDP/IPOD Sections

6.2.1 DSDP Site 152 (Leg 15)

Location: Latitude 15° 52.72′N.; Longitude 74° 36.47′W.
Water Depth 3899m.
Depth of base of section below sea level 4376m.

Introduction: This site was drilled in 1971 during DSDP Leg 15 and the initial report published in 1973. The site is located on the lower SE flank of the Nicaragua Rise, close to the northern end of the Columbian Basin in the Caribbean Sea (Figures 6.2, 6.3). The aim of Leg 15 was to determine the origin and history of the Caribbean Sea. Leg 15 was considered supplementary to Leg 4 which was the original leg designed for this purpose and which, due to bit failure, had left various problems unresolved. However, it was established that there were 2 major seismic
reflectors, Horizon A", represented by an Eocene chert and Horizon B", representing the top of the basalt. Site 152 was drilled, with improved bits, in order to locate these two seismic reflectors previously identified in the Venezuelan Basin, and to allow comparison between the bio- and lithostratigraphies between the Venezuelan and Columbian Basins.

Figure 6.3 Cross-section showing the location of DSDP Site 152 (after Edgar et al., 1973)

Coring was intermittent in the Late Cretaceous sequence because of slow penetration rates and poor recovery. 477m of sediment were penetrated with 28% overall core recovery. Eocene to Campanian sediment cores, with basalt at the base, were recovered. Horizon A", represented by Eocene chert in chalk was penetrated and Horizon B", the basalt-limestone contact was not recovered, but large recrystallized limestone fragments containing Campanian foraminifera and radiolaria were found as inclusions in the basalt (Saunders et al., 1973).

Samples for this study were selected from 61 metres of section (with c.10m recovery) from cores 19 through 24 (Figure 6.4). This interval was dated as Campanian by Edgar et al. (1973), based on the planktic foraminiferal Globotruncanina elevata and Globotruncanina calcarata Zones. The section is located between 4315m and 4376m below present sea level.
<table>
<thead>
<tr>
<th></th>
<th>AGE</th>
<th>Formations</th>
<th>Core Number</th>
<th>Core Section</th>
<th>Lithology</th>
<th>Sample Depth</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core 19</td>
<td>Cored Interval 416-425m.</td>
<td>U. CR.</td>
<td>1</td>
<td></td>
<td>48.5-100</td>
<td>CHALK: white, moderately hard and blocky.</td>
<td>Rare, poorly-preserved radiolaria. Common, poorly-preserved planktonic foraminifers and common calcareous benthic foraminifers. Common inoceramids.*</td>
<td></td>
</tr>
<tr>
<td>Core 20</td>
<td>Cored Interval 425-434m.</td>
<td>U. CR.</td>
<td>1</td>
<td>VOID</td>
<td>117-123</td>
<td>CHALK: drilling breccia, soft, friable with common whitish chert fragments.</td>
<td>Mixed assemblage of Tertiary and Cretaceous radiolaria and planktonic foraminifers.</td>
<td></td>
</tr>
<tr>
<td>Core 21</td>
<td>Cored Interval 435-442m.</td>
<td>U. CR.</td>
<td>1</td>
<td>VOID</td>
<td>75-78</td>
<td>CHALK: white, moderately hard with rare, whitish chert fragments.</td>
<td>Abundant Cretaceous planktonic foraminifers and very rare radiolaria</td>
<td></td>
</tr>
<tr>
<td>Core 22</td>
<td>Cored Interval 462-471m.</td>
<td>U. CR.</td>
<td>1</td>
<td>VOID</td>
<td>96-100</td>
<td>LIMESTONE: light greenish gray with slightly darker, fine laminae, very hard and burrowed.</td>
<td>Rare to common radiolaria. Rare to abundant planktonic foraminifers and common benthic foraminifers. All microfauna is poorly-preserved.</td>
<td></td>
</tr>
<tr>
<td>Core 23</td>
<td>Cored Interval 471-474m.</td>
<td>U. CR.</td>
<td>1</td>
<td>CHALK</td>
<td>30-35</td>
<td>CHALK: yellowish grey, hard and blocky. BASALT</td>
<td>Common to abundant poorly-preserved planktonic foraminifers, benthic foraminifers, radiolaria and calcareous nannofossils.</td>
<td></td>
</tr>
<tr>
<td>Core 24</td>
<td>Cored Interval 474-477m.</td>
<td>U. CR.</td>
<td>1</td>
<td>LIMESTONE</td>
<td>142-148</td>
<td>LIMESTONE: greyish red, very hard with large, green mineral crystals.</td>
<td>Abundant, moderately diverse, moderately well-preserved radiolaria. Abundant and diverse calcareous nannofossils.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.4 Generalised lithological and biostratigraphical summary of cores analysed from DSDP Site 152
Previous work: The Initial Report contains two papers on Mesozoic foraminifera, one by Pessagno and Longoria (1973) and one by Premoli-Silva and Bolli (1973). Calcareous nannofossils are discussed by Hay and Beaudry (1973). There are no detailed accounts of Pre-Tertiary siliceous microfaunas or flora within the report (i.e. silicoflagellates, diatoms or radiolaria) although rare occurrences are recorded on the core barrel sheets. In a paper on Cenozoic Radiolaria in the same volume, Riedel and Sanfilippo (1973) record radiolarians in the Cretaceous cores of site 152 as "generally absent, or present as rare to few, poorly preserved (silicified) specimens.

Description: Sediments in the studied section are calcareous (chalks, limestones) which have been compacted and silicified to varying degrees, with interspersed volcanic constituents (ash). Near the base of the recovered section the sediments are associated with basalt (i.e. large recrystallized limestone fragments were found as inclusions in the basalt, see above) although no distinct contact (Horizon B") is evident from the cores.

Biostratigraphy: Planktic foraminifera and calcareous benthic foraminifera occur rarely to abundantly throughout the section. *Inoceramus* prisms and sponge spicules show rare, sporadic occurrences. Foraminifera and miscellaneous fossils are shown on Figure 6.5. One sample (20-1/117-123) contains abundant and diverse, well-preserved Tertiary radiolaria and Tertiary planktic foraminifera together with rare, poorly-preserved Cretaceous radiolaria and rare poorly-preserved Cretaceous planktic foraminifera. The Tertiary microfossils in this sample are interpreted here as downhole contamination. Although Maastrichtian sediments are identified higher in the hole by shipboard scientists no Maastrichtian-restricted radiolaria were identified from this contaminated sample, probably due to the sparse, poorly-preserved nature of the Cretaceous forms.

Planktic foraminifera are wholly or partially silicified near the base of the section.
Figure 6.5 DSDP Site 152 - distribution chart showing radiolaria and miscellaneous fossils

Figure 6.6 DSDP Site 152 - distribution chart of calcareous nannofossils
Radiolaria: Twenty one samples were analysed from this site. 8 are barren, 9 contain sparse assemblages of radiolarians while 4 contain abundant and moderately diverse forms. Cretaceous specimens recovered throughout the section were generally very poorly preserved, etched and partly dissolved. The radiolarian assemblages throughout the section are usually dominated by spumellarians. Figure 6.5 shows the distribution and abundance of radiolarians recovered.

The co-occurrence of *Amphipyndax tylotus* and *Amphipyndax pseudoconulus* in the lowermost sample analysed (24CC) suggests that this limestone was deposited during late Campanian times and is placed in the lower part of the Amphipyndax tylotus Zone (Late Campanian - Maastrichtian) of Foreman (1977). The Campanian restricted species *Patellula verteroensis* is also commonly recorded in sample 24CC. In sample 22-2/145-150 the presence of the Campanian restricted species *Rhopalosyringium kleinum* suggests a Campanian age at this level. Samples above this horizon in the section contain sparse assemblages of radiolaria, interpreted as Mesozoic, but cannot be refined further than a Campanian-Maastrichtian age range.

Radiolarian species not consistent with previously published ranges which include the Campanian are:

*Crucella irwini* Turonian-Coniacian  
*Paronaella venadoensis* Turonian-Coniacian

Calciteous Nannofossils: Two samples were analysed from this section (Figure 6.6).

Sample 23-1/142-148cm: Late Late Campanian, CC22B/C (approximate FO *Prediscosphaera stoveri*) to CC22C (approximate LO *Eiffellithus eximius*).

Sample 24CC: Late Santonian to early Early Maastrichtian, c.CC16 (approximate FO *Placozygus fibuliformis*) to CC23B (LO *Tranolithus orionatus*).

Palaeoenvironment: The sediments, faunas and floras recorded from these samples suggest deposition in an outer shelf environment, above the CCD, subject to normal marine conditions suitable for both planktic and benthic biota.
Discussion: The stratigraphically highest sample analysed in this study is 19-1/48-51 which is dated as late Campanian in the Initial Report. The recovery of Tertiary radiolaria from sample 20-1/117-123 is interesting because in Site 146 Riedel and Sanfilippo (1973) record Cretaceous radiolaria from a ?Palaeogene sample. These occurrences in Site 146 are interpreted by Riedel and Sanfilippo (1973, p.705) as allochthonous. In Site 152, however, the source cannot be attributed to reworking but the lithological nature and microfossil assemblages suggest downhole contamination. Another interesting feature is that the Cretaceous assemblage from Site 146 contains forms not found in Site 152. Intercalated radiolarian sands at Site 146/149 indicate rapidly transported material from topographic highs within the basin. Lithologies from Site 152 represented by pelagic and sometimes hemipelagic sediments. There is no evidence of terrestrial/littoral siliclastics.

Age: Campanian - based on integrated data from radiolaria and calcareous nannofossils recorded here together with the planktic foraminifera recorded by Premoli-Silva and Bolli (1973).

6.2.2 DSDP/IPOD Site 369A (Leg 41)

Location: Latitude 26° 35.5’N; Longitude 14° 59’W.
Water Depth 1752 metres.
Depth of base of section below sea level 2264.5m.

Introduction: This site was drilled in 1975 through the continental slope (between the shelf and the continental rise) off Cape Bojador, Spanish Sahara (Figures 6.7, 6.8) and the initial report was published in 1978. The primary objective of drilling in this locality was to compare results with those from adjacent onshore wells. However, care had to be taken not to drill through the top of an anticlinal structure because of the possibility of disturbing hydrocarbon accumulations, and to drill through
Figure 6.7 Location Map of DSDP Site 369A  
(after Lancelot et al., 1978)

Figure 6.8 Cross-section showing the location of DSDP Site 369A  
(after Lancelot et al., 1978)
<table>
<thead>
<tr>
<th>AGE</th>
<th>Calc. Nanofossils</th>
<th>Core Section</th>
<th>Lithology</th>
<th>Sample Depth</th>
<th>GENERALISED LITHOLOGY</th>
<th>BIOSTRATIGRAPHICAL ASSEMBLAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

### Core 37: Cored Interval 384.3-393.5m

1. VOID
2. 89-91
3. 60-69
4. 74-10
5. 108-111
6. 57-60
7. 10-13
8. 57-60
9. CC

- **CHALK**: yellowish grey, moderately hard, blocky with rare chert. Common light grey burrow infilling.
- Abundant, moderately diverse, moderately well-preserved radiolaria. Abundant and diverse calcareous nanofossils.

### Core 38: Cored Interval 393.5-403m

1. VOID
2. 92-96
3. 39-42
4. 138-141
5. 91-94
6. 44-47
7. 126-129
8. 94-97
9. CC

- **CHALK**: yellowish grey, moderately hard and blocky. Locally common fine laminae. Common light olive grey burrow infilling.
- Abundant, moderately diverse, moderately well-preserved radiolaria. Abundant and diverse calcareous nanofossils.

### Core 39: Cored Interval 403.4-412.5m

1. CC32A
2. 78-81
3. 78-82
4. 78-81
5. 29-32
6. 129-132
7. CC
8. 78-82
9. CC

- **CHALK**: white to yellowish grey, locally soft and subfissile with fine, light olive grey laminae and burrows.
- Abundant, moderately diverse, poorly-preserved planktic foraminifers and radiolaria. Common, low-diversity, calcareous nanofossils.

**Figure 6.9** Generalised lithological and biostratigraphical summary of cores analysed from DSDP Site 369A

A thin sediment cover for additional safety. 512.5m were drilled with a 79% recovery (Lancelot *et al*., 1978).

The Aptian to Quaternary lithologies comprise predominantly pelagic, calcareous marls with varying amounts of siliceous components, and argillaceous to silty chalks and limestones, interbedded with cherts and porcellanites (including volcanic ash components).
Samples were selected from 28.5 metres of section (with c.20m recovery) from cores 37 through 39. This interval was dated as Campanian - Maastrichtian by Lancelot et al. (1978), based on the planktic foraminiferal, Globotruncana elevata Zone (Campanian) and calcareous nannofossil Eiffellithus eximius Zone (Campanian) of Thierstein (1971, 1973) in core 39; calcareous nannofossil Tetralithus trifidus Zone (Late Campanian - early Maastrichtian) in core 38; calcareous nannofossil Lithraphidites quadratus Zone (Maastrichtian) in core 37. The section studied is located between 2154 m and 2182.5 m below present sea level.

**Previous work:** Planktic foraminifera are discussed in this volume only in the site reports by Lancelot et al. (1978); Radiolarian results are presented in a paper by Foreman (1978b); calcareous nannofossils are presented in a paper by Cepek (1978). Some of the samples have also been analysed by Schaaf (1985).

This hole was specifically chosen for examination because Foreman (1977) integrated data from this site (with additional data from other Atlantic sites) for the compilation of her Campanian - Maastrichtian Amphipyndax tylotus Zone. This zonation is discussed in more detail in Chapter 7.

**Description:** The core samples analysed (Figure 6.9) are white to yellowish gray chalks which are moderately hard and blocky in cores 37 and 38 and locally soft and subfissile in core 39. Fine, light olive gray laminae are common throughout the section. Macrofossils recovered are locally abundant shell debris and locally rare Inoceramus prisms, sponge spicules, fish teeth and bryozoans. Evidence of macro benthos, i.e. in the form of light olive gray burrows, was noted throughout the section.

**Biostratigraphy:** In addition to macrofossils mentioned above, calcareous benthic foraminifera and planktic foraminifera are rare to abundant in samples throughout the section analysed. Radiolaria are rare to common in all samples except 37-1/89-91, 37CC and 39CC. Samples
Figure 6.10 DSDP Site 369A - distribution chart of radiolaria and miscellaneous fossils
<table>
<thead>
<tr>
<th>Nannofossil Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ancyaliellina regularia</td>
</tr>
<tr>
<td>Amphiporella brodiei</td>
</tr>
<tr>
<td>Anthhegasteria cyathiformis</td>
</tr>
<tr>
<td>Bicuculina elliptica</td>
</tr>
<tr>
<td>Ctenocyclus parca</td>
</tr>
<tr>
<td>Calcareites obscurus</td>
</tr>
<tr>
<td>Ceratolithoides aculeus</td>
</tr>
<tr>
<td>Ceratolithoides arcuatula</td>
</tr>
<tr>
<td>Chiasmoclypeus amphipone</td>
</tr>
<tr>
<td>Ctenarhabdus conicus</td>
</tr>
<tr>
<td>Cribrocorona gallica</td>
</tr>
<tr>
<td>Cribrospirella enebergii</td>
</tr>
<tr>
<td>Culinoidithus bicaris</td>
</tr>
<tr>
<td>Eiffellithus eximus</td>
</tr>
<tr>
<td>Eiffellithus turriselliferi</td>
</tr>
<tr>
<td>Gartnerago obliquum</td>
</tr>
<tr>
<td>Gephyrocapsa coronadavantii</td>
</tr>
<tr>
<td>Kaspriella magnifica</td>
</tr>
<tr>
<td>Lithraphites carniolensis</td>
</tr>
<tr>
<td>Manivitella psmatoidea</td>
</tr>
<tr>
<td>Micrhrhabdus decoratus</td>
</tr>
<tr>
<td>Nicula concava</td>
</tr>
<tr>
<td>Nicula cubiformis</td>
</tr>
<tr>
<td>Nicula staurophora</td>
</tr>
<tr>
<td>Nicula swastica</td>
</tr>
<tr>
<td>Placezogus fimbiformis</td>
</tr>
<tr>
<td>Prediscoscapha cretesa</td>
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<tr>
<td>Prediscoscapha micrhrhabdulina</td>
</tr>
<tr>
<td>Prediscoscapha ponticula</td>
</tr>
<tr>
<td>Prediscoscapha etoveri</td>
</tr>
<tr>
<td>Quadrum gartneri</td>
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<tr>
<td>Quadrum gothicus</td>
</tr>
<tr>
<td>Quadrum eisenghii</td>
</tr>
<tr>
<td>Reinhardtites anthophorus</td>
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<tr>
<td>Retecapsa angustiforata</td>
</tr>
<tr>
<td>Retecapsa conula</td>
</tr>
<tr>
<td>Tranolithus miniatus</td>
</tr>
<tr>
<td>Tranolithus orionatus</td>
</tr>
<tr>
<td>Watsonaueria barnesae</td>
</tr>
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<td>Watsonaueria biporta</td>
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<td>Watsonaueria fossaepecta</td>
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<td>Watsonaueria ovata</td>
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<td>Zeughrhabdus compactus</td>
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<td>Zeughrhabdus esbergeri</td>
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<td>Anthhegasteria speciella</td>
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<td>Microhrhabdus undosus</td>
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<td>Neocrepidolithus cohani</td>
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<td>Prediscoscapha grandis</td>
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<tr>
<td>Reinhardtites levis</td>
</tr>
<tr>
<td>Retecapsa echinusobrachiate</td>
</tr>
<tr>
<td>Staurolithites compacta integra</td>
</tr>
<tr>
<td>Staurolithites laffitiae</td>
</tr>
<tr>
<td>Ctenarhabdus striatus</td>
</tr>
<tr>
<td>Cyclospirella margeelli</td>
</tr>
<tr>
<td>Eiffellithus goritae</td>
</tr>
<tr>
<td>Rhegodicus plebei</td>
</tr>
<tr>
<td>Rhegodicus splendens</td>
</tr>
</tbody>
</table>

Figure 6.11 DSDP Site 369A - distribution chart of calcareous nannofossils
also yielded locally rare to common ostracods and agglutinated foraminifera. Figure 6.10 shows the abundance and distribution of miscellaneous fossils recovered.

**Radiolaria:** Twenty two samples were analysed, three of which are barren. The nineteen fossiliferous samples contain assemblages of low to moderate diversity with moderately well-preserved radiolarians (Figure 6.12). The size range of radiolarian forms recovered is relatively wide, the smallest forms being represented by nassellarians and the largest by spumellarians. The assemblages are not, however, dominated by either order and distribution of genera and species is further discussed in Chapter 6.3.3.

The presence of species such as *Amphipyndax(?) pyrgodes*, *Praestylsphaera pusilla* and *Diacanthocapsa acuminata* in the lowermost samples of this section suggest that these sediments are no older than Campanian in age. Throughout the remainder of the section, radiolarian species thought to have last occurrences within the Campanian are recorded near the top of the section in (37-3/108-111). No evidence of Maastrichtian-restricted forms has been discovered from this section.

Radiolarian species recorded from this section which have previously been considered to have Last Occurrences in sediments older than Campanian are as follows:

*Amphipyndax conicus* Cenomanian-Santonian

*Orbiculiforma maxima* Cenomanian

**Calcereous Nannofossils:** Three samples were analysed, all of which yielded abundant and diverse calcereous nannofossils (Figure 6.11). Sample 369A 37-4/57-60; Late Maastrichtian (CC25A) based on the absence of *Reinhardtites levis* and the absence of *Lithraphidites quadratus.*

Sample 369A 38-4/126-129; Earliest Maastrichtian (CC23B) based on the co-occurrence of *Reinhardtites levis* with *Tranolithus orionatus* and the absence of *Reinhardtites anthophorous* and the absence of *Broinsonia parca.*
Sample 369A 39CC; Latest Campanian (CC22B) based on the presence of *Reinhardtites anthophorus* and the absence of *Reinhardtites levis*. Cepek (1978) data were reinterpreted.

**Palaeoenvironment:** Sediments in this section are represented by pelagic chalks. The abundant and diverse planktic and benthic forms recovered suggest deposition in normal salinity, well-oxygenated open marine conditions suitable both for surface and bottom water dwelling taxa.

The presence of keeled planktic foraminifera and the often moderately diverse nature of radiolarian assemblages indicate a deep, probably outer shelf environment of deposition. Locally intense bioturbation is evidence of burrowing organisms.

**Discussion:** During the initial analyses no radiolaria were recovered from these samples. Foreman (1978b) had recovered > 47 species from these same samples although the abundances were rare to very rare. A search was made of published papers by this author from 1966 to 1978b for reference to processing and viewing methods used but no records were found. It was assumed therefore that it was possible that not enough material had been examined to reveal the occurrences that she has recorded. The material in this present study was then re-examined and radiolaria were recovered. The rate of recovery was approximately two specimens per hour, picking from dry residue using reflected light.

**Age:** Campanian - ?Maastrichtian, based on integrated data from radiolaria and calcareous nanofossils. This age assignment is questionable: the calcareous nanofossil ages (summarised in Figure 6.9), the ages of samples discussed earlier in this section, and the reinterpretation of data presented by Cepek (1978) are not consistent with currently accepted ranges of some of the radiolarian species recorded. These species, which are thought to last occur within the Campanian but which have here been recorded in samples dated as Maastrichtian by calcareous nanofossils are as follows: *Amphipyndax(?) pyrgodes*, *Amphipyndax mediocris*, *Bisphaerocephalina(?) heros*, *Eostichomitra warzigita*, *Amphipyndax pseudoconulus*,

-220-
Orbiculiforma sacramentoensis, Praestylosphaera hastata, Cryptamphorella macropora and Protoxiphotractus kirbyi. The ranges of the age-diagnostic calcareous nannofossils are better established than the ranges of these radiolarians and it is possible that the radiolarian ranges should be extended into the Maastrichtian. Alternatively, due to the intense bioturbation also recorded, it may be that the radiolarians have been reworked upwards or the calcareous nannofossils reworked downwards by burrowing sediment feeders.

6.2.3 DSDP/IPOD Site 612 (Leg 95)

Location: Latitude 38° 49.21'N; Longitude 72° 46.43'W
Water Depth 1404m.
Depth of base of section below sea level 2079.3m.

Figure 6.12 Location Map of DSDP/IPOD Site 612
(after Poag and Watts, 1987)

Introduction: This site was drilled in 1983 and the initial report published in 1987. The site was located on top of an anticline in a small SE trending channel cutting downslope through the New Jersey continental slope off Eastern North America (see Figures 6.12, 6.13).

-221-
675.3m. of Campanian to Pleistocene sediments were drilled at 86% overall core recovery.

The drilling objective was to link the COST B-3 well and DSDP Site 605 across the continental slope and to allow comparison between this site and DSDP Sites 548 (Goban Spur Continental Slope, SW of Ireland) and Site 369A (see previous section) on the eastern side of the Atlantic as part of a programme to construct a margin-wide stratigraphic transect extending along 700km (see Figure 6.12). During Leg 93 holes were drilled at Site 603 on the lower continental rise and at sites 604 and 605 on the upper continental rise. "Leg 95 was principally intended to provide a crucial link between shelf and lower rise sites" (Poag and Watts, 1987).

Samples were selected from 34.56 metres of section (with almost complete recovery) from cores 69X through 72X (Figure 6.14). This interval was dated as Campanian by Hart (1987), based on planktic foraminifera and located between 640.24m and 674.8m below the sediment surface.

Previous work: The Initial Report includes brief discussions on the occurrence of radiolarians and calcareous nannofossils by Poag et al. in the site reports and a paper by Hart (1987) which records in detail the occurrence of foraminifera. Rutledge (in preparation) has analysed alternate samples from this study for calcareous nannofossils.
<table>
<thead>
<tr>
<th>AGE</th>
<th>Interval</th>
<th>Lithology</th>
<th>Biostratigraphical Assemblages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core 69X</td>
<td>636.5-646.2m</td>
<td>MUDSTONE: light gray, olive gray and brownish gray, soft, blocky to subfissile and highly calcareous. Locally common glauconite, pyrite and mica. Sometimes silty.</td>
<td>Rare to abundant planktic foraminifera, common calcareous benthic foraminifera and rare agglutinated foraminifera. Very rare indet. radiolaria. Abundant well-preserved calcareous nannofossils.</td>
</tr>
<tr>
<td>Core 70X</td>
<td>646.2-655.9m</td>
<td>MUDSTONE: medium dark gray to brownish black, moderately soft, blocky to subfissile and highly calcareous. Locally common glauconite and mica.</td>
<td>Common burrows. Abundant planktic foraminifera, common calcareous benthic foraminifera and rare agglutinated foraminifera. Abundant well-preserved calcareous nannofossils.</td>
</tr>
<tr>
<td>Core 71X</td>
<td>655.9-665.6m</td>
<td>MUDSTONE: medium dark gray to brownish black, moderately soft, blocky and highly calcareous. Common mica, common glauconite and rare pyrite.</td>
<td>Common to abundant planktic foraminifera, common calcareous benthic foraminifera, rare agglutinated foraminifera. Abundant and diverse well-preserved calcareous nannofossils and locally common Inoceramus prisms. Barren of siliceous microfossils.</td>
</tr>
<tr>
<td>Core 72X</td>
<td>665.6-675.3m</td>
<td>MUDSTONE: light gray to dark brownish gray, moderately hard, blocky to subfissile and highly calcareous. Common mica, rare glauconite and rare sub-spherical, rounded quartz grains.</td>
<td>Locally common burrows. Abundant planktic foraminifera and calcareous nannofossils. Common calcareous and agglutinated benthic foraminifera. Very rare, poorly-preserved, occasionally pyritized, indet. radiolaria.</td>
</tr>
</tbody>
</table>

Figure 6.14 Generalised lithological and biostratigraphical summary of cores analysed from DSDP/IPOD Site 612
Description: The core samples analysed are light gray, medium dark gray and brownish black mudstones which are moderately soft, blocky to subfissile and highly calcareous. Lithologies are sometimes silty with sub-spherical, rounded quartz grains, and locally common mica, glauconite, zeolites and pyrite are present. The only macrofossils recovered were locally common *Inoceramus* prisms, sponge spicules and bryozoans although evidence of burrowing organisms was noted throughout the section, particularly in core 72X.

Biostratigraphy: Apart from a few unidentifiable ?Cretaceous pyritized radiolarian fragments in sample 72CC all the samples are barren of radiolaria. Very rare specimens representing Tertiary diatom contaminants were observed during the examination of the transmitted light preparations but otherwise there is no evidence of any siliceous microfossils in any of the samples analysed. The calcareous groups, planktic and benthic foraminifera and calcareous nannofossils are well represented throughout the section. The planktic foraminifera are abundant, diverse and well-preserved whilst the calcareous nannofossil assemblages are remarkable for the excellent preservation of individuals.

Radiolaria: Barren of identifiable radiolaria.

Calcareous Nannofossils: Six samples were analysed all of which yielded abundant and diverse well-preserved calcareous nannofossils.
Sample 612 69-4/69-72; Age late Late Campanian (CC22) based on FO *Reinhardtites levis*.
Sample 612 70-2/50-53; early Late Campanian (CC21c) based on LO *Ceratolithoides verbeeki*.
Sample 612 71-5/109-112; early Late Campanian (CC21b) based on the occurrence of *Ceratolithoides arcuatus*.
Sample 612 72-2/72-76; early Late Campanian (CC21a) based on FO *Quadrum sissinghii*.
Sample 612 72-3/139-142; late Early Campanian (CC20) based on FO *Ceratolithoides aculeus*.
Sample 612 72-6/88-91; late Early Campanian (boundary of CC19a - CC19b) based on LO *Bukryaster hayii*.
Discussion: The results from this section are disappointing because all criteria, such as presence of a potentially complete section, easily disseminated mudstones, long section, good core recovery rate and calcareous control are positive. Reasons for lack of siliceous microfossils may be a too high sediment content of water, or chemically or thermally unsuitable water mass characteristics inhibiting surface productivity. It is more likely, however, that specimens have been destroyed during diagenesis.

Age: Campanian - based on integrated data from calcareous nannofossils by Rutledge (in preparation) and on the planktic foraminiferal assemblages of Hart (1987).

6.3 Conclusions

6.3.1 Reinvestigation of material from previous publications: This study has been useful in gauging standards set by other workers with particular reference to:

a) the variation in amount of raw sediment needed to recover satisfactory microfossil assemblages;

b) the variation between different workers in the number of species used in a zonation proposal, and in the definition of a new species;

c) the degree of intra- and inter-species variation currently in use by experienced workers;

d) the amount of time needed to produce viable results;

e) variations in subjective concept, for example, the term "moderately well-preserved";

f) sample processing. During difficulties encountered in matching the recovery of radiolaria by Foreman (1978b) from site 369A, it was found that a significant difference was caused not by the sample preparation method, as first suspected, but by the means of visual analysis of the samples. All Foreman's (1978b) samples had been examined using transmitted light whilst this study also involved picking specimens from dried residues. Although a very slow process, as mentioned above, the species recovered from residues included some not recorded by Foreman.
(1978b), and therefore achieved one of the initial aims of this current study, i.e. that of expanding existing databases.

g) viewing methods - It was initially assumed that Foreman (1978b) used transmitted light preparations because of limited access to an S.E.M.. Investigation of strewn slides in this current study showed, however, that specimens not obvious in dried residues were seen much more easily using transmitted light. This is because each specimen is surrounded by a 'halo' of sediment that in a dried residue would appear to be a clump of disaggregated sediment. Viewing in transmitted light, therefore, is useful for determining whether a sample needs further washing and/or recording of specimens which might otherwise remain undiscovered. The disadvantage with this system is that, unless temporary mounts are prepared, no S.E.M. record can be produced. Additionally, as mentioned earlier in this report, the fact that radiolaria were present in samples which, on preliminary analysis had appeared barren and the fear that previous samples logged as barren were in fact sparsely fossiliferous can be to an extent dispelled by viewing these samples in transmitted light. If no radiolaria are then found and the other organic components, e.g. foraminifera, are not surrounded by a sediment halo then it can be more confidently assumed that the samples are, in fact, barren.

6.3.2 Proposals for analysis of further DSDP/IPOD/ODP Sites:
An important conclusion is that further useful data, concerning the geographical distribution and species association of the siliceous assemblages and the association of calcareous assemblages and siliceous assemblages, would be gained from a more geographically widespread selection of samples rather than detailed analysis of more samples from fewer sections. If the sampling intervals are stratigraphically too closely spaced, the assemblages recovered from the samples tend to become repetitive and therefore less useful for zonation purposes, i.e. it is necessary to have a sampling strategy which could provide samples to define zonal boundaries but samples within zones would not necessarily all be analysed.
As a more widespread geographical distribution of data is desirable, it is intended, initially, to analyse the five DSDP/IPD/ODP Sites listed in Chapter 6.1.3.

6.3.3 Biostratigraphical results from sites analysed

a) Radiolaria - distribution, diversity and preservation:
DSDP/IPOD Site 612 is barren of identifiable siliceous microfossils; DSDP Site 152 yielded 8 (out of 21) productive samples, with a maximum species diversity in any one sample of 13; DSDP Site 369A yielded 19 (out of 22) productive samples, with a maximum species diversity in any one sample of 25.

In Site 152, 16 genera (6 nassellarian genera and 10 spumellarian genera) and 17 (7 nassellarians and 10 spumellarians) forms were identified to species level. In comparison with Site 369A, one genus and five species are exclusive to Site 152.

In Site 369A 30 genera (13 nassellarians, 16 spumellarians and 1 incertae sedis) and 52 forms were identified to species level (28 nassellarians, 23 spumellarians and 1 incertae sedis). In comparison with Site 152, 14 genera and 40 species are exclusive to Site 369A.

The distribution of genera and species are illustrated in Chapter 7, Figure 7.11.

A comparison was made with material recorded by Foreman (1978b). She recorded 48 species (35 nassellarians, 12 spumellarians and 1 incertae sedis) only 15 of which are also recorded in this study, from seven samples, with a maximum diversity in any one sample of 35 species (Foreman 1978b, table 2, p. 741), although she analysed more samples not shown on her range chart. Of the 15 common species, 9 are nassellarians.

Schaff (1985) also analysed five samples from this section, with a maximum diversity in any one sample of 16 species. He recorded 14 genera (11 nassellarian, 2 spumellarian and 1 incertae sedis) and 18
species (15 nassellarian, 2 spumellarian and 1 incertae sedis), of which 5 (all nassellarian) are also recorded from this study.

A comparison of these Atlantic assemblages with the total radiolarian faunas recovered from Cyprus (110 productive samples out of 180), yielding 46 genera (24 nassellarian and 1 incertae sedis) and 141 species (59 nassellarian, 81 spumellarian and 1 incertae sedis), is not significant in that more and larger samples were processed from Cyprus, from a greater variety of lithologies. Additionally, more time pro rata was devoted to these latter analyses. All genera and species recorded from Atlantic sites are also present in samples analysed from Cyprus. Some species, e.g. *Arens liriodes* (Plate 2, figs. 4/5 from Cyprus and fig. 6 from the Atlantic) show intra-specific morphological variation but insufficient data have been collected during this project to be able to estimate whether this is due to evolutionary or provincial factors.

b) Comparative distribution of radiolaria in sites analysed:
The lack of radiolarians in Site 612 could be directly connected to the type of minerals deposited at this site. The surface nutrient conditions were sufficient to support abundant and diverse assemblages of calcareous nannofossils and planktic foraminifera. The water depth is likely to have been sufficiently deep to accommodate radiolarians and keeled planktic foraminifera. The presence of high amounts of calcareous material alone cannot account for the absence of radiolarias as shown in other sites. Remaining hypotheses include unknown factors inhibiting surface production, unknown factors inhibiting preservation, undersaturation of silica in surface waters preventing test building, or undersaturation and low pH values in local water mass(es) induced by dissolution of alkaline minerals in the depositing sediment or temperature conditions combined with dissolution (i.e. if radiolarias were rare to start with).

As suggested above, and by results recorded from Cyprus the absence of radiolarias cannot be attributed solely to the highly calcareous nature of the sediment, or the grain size of the sediment, or the mode or rate of deposition (e.g. pelagic, hemipelagic, turbiditic), or competition from other groups of microfossils. The most likely causes for poor recovery of microfossils are considered to be low surface productivity, depositional
environment not chemically conducive to the preservation of these forms, and processing and viewing methods used.

c) **Co-occurrence of calcareous and siliceous microfossils:**
Calcareous plankton (calcareous nannofossils and planktic foraminifera) have been recovered with poor to moderately-good preservation at all three sites analysed, and exceptionally well-preserved calcareous nannofossils are recorded from Site 612. Radiolaria have been recovered with poor to moderately good preservation only at Sites 152 and 369A. This indicates that the presence of calcareous faunas and floras does not alone exclude the presence of siliceous faunas, either in the zone of productivity or from preservation within the same sediments.

d) **Depth of burial:** The depth of the base of each section below present sea level has been calculated by adding water depth and approximate drilling depth for each of the sites analysed. This exercise was carried out to establish the presence/absence of any correlation between radiolarian preservation and overburden. Radiolarians are preserved near the base of Site 152 at a total depth of 4376m (3899m water + 477m lithology); radiolarians are preserved near the base of Site 369A at a total depth of 2264.5m (1752m water + 412.5m lithology); radiolarians are not preserved near the base of Site 612 at a total depth of 2079.3m (1404 water + 675.3m lithology). The data from these three sites indicate that the depth of burial alone does not contribute to poor recovery of radiolaria from sediments.

e) **Host sediment:** Data collected here are not sufficient to correlate the sediment thickness within a time framework or to construct geohistory diagrams but the depth of sections representing penetration of Campanian(?) age sediments are comparable in all three sections.

Two of the three sections analysed are predominantly of carbonate facies, the partly silicified pelagic chalks of Site 152 and largely unsilicified pelagic chalks of Site 369A. The third section, Site 612 consists entirely of highly calcareous, hemipelagic mudstones. A detailed mineralogical analysis of sediments sampled is beyond the scope of this project, although the smear slide analyses recorded on core-barrel sheets by
shipboard scientists have been consulted. By 1978, the format of these records had changed to a more specific presentation of percentage of components such as sand, silt and accessory minerals but unfortunately this is not readily available for the earlier sites. If, for example, dissolution of siliceous microfossils is promoted or inhibited by the presence of an accessory mineral, it may show up by comparing these results.

f) Analytical methods: Analyses by Foreman (1978b) were biased towards viewing with transmitted light and her processing methods were not published. Analysis in this study was biased towards viewing in reflected light, although transmitted light was also used. This bias is considered to account mainly for the differences in genera/species recorded.
CHAPTER 7

THE BIOSTRATIGRAPHICAL USE OF SILICEOUS MICROFOSSILS

7.1 Introduction

Biostratigraphy is a science which places sedimentary rocks in relative positions within the geological record based on the occurrence of fossilized organisms. These positions which are superimposed on one another correspond to the time (both relative and absolute) of deposition of the sediments. Biostratigraphy helps to correlate geographically widespread, and often lithologically diverse, sediments within a relative time scale by using as reference points the evolutionary history of a variety of organisms of diverse lifestyle and habitat which are preserved in these sediments. Absolute (= radiometric) dating of sediments is generally not possible except where tie-points, i.e. a lava flow can be calibrated against a framework established by biostratigraphy. Recent work on elements found in sea water and preserved in fossil or sediment material, e.g. Strontium, offer good prospects of new comparative stratigraphies for correlation with biostratigraphy.

The biostratigraphical studies discussed here deal with micro-organisms and how their evolutionary histories can be used as a tool for relative dating of sediments. Also considered are factors which influence the reconstruction of the evidence of evolutionary patterns of groups and individuals. These factors include palaeoenvironmental interpretations and diagenetic history, together with methods of analysis.

7.1.1. The use of biostratigraphy

The primary function of biostratigraphy is to provide relative dating of sediments, as stated above, and by means of correlatable fossil assemblages provide relative time planes for lithostratigraphical sequences. Moreover, apart from purely relative dating of sediments the nature of biostratigraphical assemblages can contribute to an understanding of events involving depositional history, post-burial diagenesis and tectonism events within an area. Differing areas can then be correlated and global patterns, processes and influences interpreted.
7.1.2 The use of microfossils in biostratigraphy

Both academically and industrially microfossils play an important rôle in the interpretation of the earth's geological history. Until comparatively recently the most important group, with regard to stratigraphical and palaeoenvironmental interpretations, has been the planktic foraminifera. The increasingly intensified study, since the late 1960's, of another calcareous fossil group, the calcareous nannofossils, has provided a useful supplement, and frequently a more refined zonation scheme to the already existing biostratigraphical framework. The successful recovery of these two groups of microfossils, however, depends substantially on both suitable palaeoenvironmental conditions at the time of deposition and favourable post-depositional diagenesis.

Although traditionally palynology has also contributed significantly to biostratigraphy, a rapid growth in importance of organic-walled microfossils has become apparent within the last two decades. This is largely due to increased amounts of data, generated by the petroleum industry, facilitating a higher resolution of biozonation schemes. This discipline too, however, has its limitations. Pollen and spores can be valuable age markers in non-marine as well as marine sequences but although their differential deposition may be useful in an areal context for palaeogeographical interpretation, this characteristic reduces the diversity of the assemblage in distal, offshore locations so reducing stratigraphical usefulness.

Dinocysts, produced by rapidly evolving, marine, planktic dinoflagellates are also extremely valuable in biostratigraphy but can be limited in palaeoenvironmental interpretations as dinoflagellates are restricted to the upper layers of the water column and also the abundance and diversity of assemblages decreases progressively towards fully open marine conditions.

Micro-biostratigraphical determinations of pre-Upper Jurassic sections rely heavily on palynology, although published biozonation schemes for a large proportion of the Palaeozoic era are generally inadequate.
7.1.3 Characteristics of biostratigraphically useful microfossils

The basic characteristics of microfossils in general, which are useful in biostratigraphical analyses, and the specific ways in which radiolarians meet these requirements are discussed below.

**Geological Range** - For microfossils to be used to date sediments at least part the evolutionary history of the group must be coincident with the time of sediment deposition. Some groups of microfossils are useful only in parts of the geological column, e.g. calpionellids have a short evolutionary history in the Late Jurassic/Early Cretaceous, calcareous nannofossils range from Triassic - Recent, planktic foraminifera from ?Late Jurassic - Recent, whilst radiolarians are recorded from sediments throughout most of the geological record, at least from Ordovician - Recent.

**Global distribution** - The group of fossils used must have a widespread biogeographical distribution, usually associated with planktic organisms. In the case of planktic foraminifera it is sometimes difficult to correlate Boreal (cold water) assemblages with Tethyan (warmer water) assemblages because no common species are present. Climatically controlled provincialism can also influence calcareous nannofossil assemblage distribution patterns.

Until comparatively recently it was widely believed that radiolarians only occur provincially and are not globally widespread enough to be useful. Some workers consider that radiolarians did/do not occur in waters where the silica budget was/is low, whilst others consider that the building of skeletons from silica requires a large energy input and therefore significant numbers of these organisms only occur where the nutrient supply was/is high. Baumgartner (*pers. comm.*, 1990) suggests that when the nutrient supply is low it can be compensated for by interaction between the host radiolaria and its symbionts. This hypothesis then adds a new consideration, i.e. the adequate occurrence of symbionts in a given regime - particularly photosynthesising symbionts in relation to seasonality and depth of the photic zone.
Although radiolarians as a group do display provincialism the effects are not as pronounced as in other groups, (particularly when dealing with Mesozoic radiolaria) and some recognisable elements are normally present in any assemblage. This feature is probably due to the high diversity of radiolarian species present at any one time in geological history.

**Rates of Evolution** - In order to refine the ages of sediments into as many distinct stratigraphical horizons as possible the characteristics of each horizon must be identifiable. These identities are manifested by the fossil assemblages and become more numerous during time periods when the rate of evolution of the fossil group increases. The most reliable indicators are the evolutionary appearance and disappearance of species end-members. Other useful indicators include transitional forms between end-members (if recognisable), abundance, and radiation and extinction events although local influence (environmental or diagenetic) may distort this evidence. The above indicators may be confined to one group of microfossils or may affect more than one group, e.g. a response to sea-level change is manifest in both radiolarian and calcareous nannofossil assemblages within the Cretaceous and in the Eocene (Bown *et al.*, 1991). Since radiolarian assemblages are usually more diverse than other groups there are more specific appearance and disappearance events to identify and calibrate and therefore more potential for refined zonation schemes. During any one geological stage radiolarian populations show a relatively high species diversity, e.g. it is not uncommon for over 200 species to be present in a well-preserved assemblage which is approximately ten times the number of planktic foraminiferal species which could be expected in a diverse assemblage.

This generally high species diversity displayed by radiolarians as a group means that they have more potential as biostratigraphical markers in terms of absolute number of evolutionary events, i.e. each species has both a first appearance and a last appearance datum. It must also be considered that although there may be a large number of species they are not all ubiquitous in fossil assemblages (partly because of dissolution susceptibility and partly due to provincialism), e.g. Baumgartner (1984b) analysed 226 samples from 43 localities involving a database of 110 species. The cumulative number of species recorded at each section ranges
from 5 to 92 but only six of the sections yielded a cumulative diversity of more than 55 species.

Size range of individuals - Microfaunal assemblages may display a restricted size range, which may mean that a potential index species may be either missing due for example to current sorting, provincialism, or dissolution or is represented by unidentifiable juvenile forms. The cause of these size-biased populations may be due to factors such as decreased nutrients although some studies have shown that increased nutrients lead to a smaller size of individuals because they reproduce more rapidly in favourable conditions. Populations of adult radiolarians have a wide size range (c.40 microns or less to 400 microns or more) and they therefore have more potential to appear as useful index markers in any size-restricted population.

This potentially wide size-range makes processing difficult and may account for the perception that radiolarians have a more sporadic occurrence than is actually the case. For example, they are difficult to recognise systematically in preparations made for other fossil groups such as calcareous nannofossils because they are larger, or in foraminifera samples because they are commonly smaller, i.e. radiolarians are usually most abundant in the 63 - 125 |\(\mu\)m fraction. This fraction is often only given a brief examination by foraminifera workers because specimens of planktic foraminifera present are likely to be juvenile forms.

Host sediment - Planktic organisms whose distributions are not facies controlled such as planktic foraminifera, calcareous nannofossils, dinocysts and radiolaria are the most useful for a) a more complete record of deposition of a sequence and b) correlation of coeval, but differing lithological formations.

Chemical composition of fossil remains - Differences in chemical composition of fossil representatives of each group give them advantages or disadvantages in comparison with other groups with respect to post-
mortem preservation in the fossil record. Chemical composition also plays a rôle in recovery rate during processing. Radiolarian skeletons are potentially recoverable from all types of lithologies including chert, limestone, silicified limestone and sometimes dolomite but also have an original limitation in availability of materials for skeletogenesis.

Since 1966 Dumitrica (pers. comm., 1991) has been able to recover radiolarians from chert samples by processing with Hydrofluoric acid. Pessagno and Newport published details of this method in 1972 and it has subsequently become a widely used preparation technique. Pessagno (1976, 1977b, 1977c) demonstrated the contribution of radiolarians in the understanding of geologically complex terrains such as the Great Valley Sequence of California, in sediment horizons where other microfossils are lacking. Holdsworth (1967) demonstrated the recovery of radiolarians from dolomites.

Radiolaria, because of their chemical composition, have a disadvantage in that the world's oceans are, and have been in the past, periodically, undersaturated in silica and the susceptibility of opaline silica to dissolution, and therefore to differential preservation, means that siliceous microfossils may not have occurred or be recoverable consistently. In any comparative assessment of the effects this susceptibility to dissolution may have on the usefulness of siliceous microfossils, the similar susceptibility to dissolution of calcareous microfossils in ocean waters undersaturated in calcium carbonate must be considered. Additionally, although it would appear that deficits in the calcium carbonate saturation of the ocean waters are regarded as less common than deficits in the silica budget, it is in these instances that the low CaCO3 content of the water may coincide with a relatively high SiO2 content facilitating an abundant population of siliceous forms. This demonstrates that over-reliance on calcareous forms or on any one group of microfossils is undesirable.

**Palaeoenvironmental Interpretations** - Both because of the chemical nature of their tests and because of their environmental sensitivity (e.g. preference for open marine blue water conditions in areas of relatively high nutrient levels and species-restricted temperature sensitivity) Recent radiolarians are extremely useful environmental indicators (see Lozano &
Hays (1976); Casey (1971, 1972); Casey et al. (1971); Anderson (1983). Very little material concerning palaeoenvironmental studies of Mesozoic forms has been published to date. Empson-Morin (1984) is one of the most comprehensive studies, detailing latitudinal differences in assemblages and potential depth indicator species.

Radiolarians, as a group are thought to live at different depths in the water column (Casey, 1971a, Petrushevskaya, 1971) and could therefore be used as indicators of differential movements of stratified layers in the water masses.

Blueford (1989) demonstrated how the use of "radiolarian assemblages, in Late Cretaceous through Eocene biosiliceous sediments, can help trace major paleocirculation patterns". She compares present day radiolarian distribution patterns and assemblage characteristics with those of fossil records from Late Mesozoic - Palaeogene sediments.

**Basinal History Analyses** - Radiolarian tests can contribute to interpretations of the diagenetic history of sediments. The initially opal-A tests are found in a variety of secondary recrystallisation states, i.e. opal-A, opal-CT, quartz, the transitional phases between these states, and can also be replaced by other minerals such as calcite and pyrite. The crystalline state of the fossil radiolarian tests together with the state of preservation of surface ornamentation gives an indication of the history and the rate of diagenetic change of the host sediment.

**7.1.4 Summary**
Siliceous planktic microfossils as a group display a number of advantages in common with the calcareous and organic-walled microfossils in that they are biogeographically widespread, can show relatively rapid evolutionary progression and have a long geological history. The group also has a number of complementary advantages, in relation to other microfossil groups mentioned, including the fact that they can live and/or be deposited below the carbonate compensation depth and that their skeletons can survive otherwise destructive diagenetic processes such as dolomitization. Additionally, radiolaria can be useful in palaeoenvironmental interpretations as their habitat is not confined to the
upper layers of the water column, whilst diatoms can be used to supplement biostratigraphical interpretations of non-marine sequences.

7.2 Zonation schemes

7.2.1 Constructing and refining zonation schemes

For the construction of a zonation scheme which will be valid on a global scale the collation of schemes from smaller geographical areas is required. Only when satisfactory regional schemes have been erected can they be compared and evaluated on a global basis. It would be expected that although the schemes do not involve the same marker species for each region, and that FO's and LO's\(^1\) may not always be synchronous (e.g. evolutionary as opposed to migration first appearances), that the global scheme can be adjusted to justify the differences by consideration of variables such as palaeotemperatures, seaways, localized influences, currents, etc..

Individual zonations must be based on adequate sample numbers from an adequate number of sections, preferably both onshore and offshore. In recent publications a good example is given by Jakubowski (1987) who constructed a zonation scheme for the Moray Firth using nannofossils. Samples from regular intervals (c.10m) in over 30 wells (Jakubowski, pers. comm., 1992), complemented with data from an onshore section were used to test and revise existing zonation schemes from this area.

In refining existing zonations it is sometimes possible to make significant contributions from the study of a smaller number of sections particularly when using the occurrence of new species or by integrating provincially controlled or endemic forms. For example, Burnett (1990) uses two Campanian sections, one from NW Germany and one from eastern England to refine the primarily Tethyan zonation of Sissingh (1977) by the use of a number of Boreal restricted species.

\(^1\) In this work the stratigraphically lowest and stratigraphically highest occurrence of taxa are referred to as FO's and LO's respectively because insufficient data is available to determine the full evolutionary range of these forms. In Chapter 7.3.2 the terms FA and LA (first and last appearance) are used when quoting events described by other authors as such.
There are a number of ways to improve existing zonation schemes (and to enhance palaeoenvironmental interpretations):
i). extending and refining the database via publications and other available research results,
ii). improving processing techniques as better recovery of microfossils provides more and better quality data (as discussed in Chapter 3),
iii). better management of available data (electronic storage, etc.), and
iv). integration of data from different groups e.g. palynomorphs, foraminifera, calcareous nanofossils and siliceous microfossils. The different environmental requirements of these groups and their differing chemical compositions in the fossil state mean that they can be useful in both complementary and supplementary roles.

Any zonation is more accurate/refined in a local or regional context than in a global one and the above methods do not distort this relationship, only increase the relative effectiveness in each instance.

7.2.2 Factors to consider when integrating one group from different areas, or one or more groups from the same area
One of the disadvantages of integrated biostratigraphy is the difficulty in integrating data recovered from sediments in a non-standard way. Such difficulties can be overcome to a certain extent by relying only on positive evidence, e.g. the occurrence of a species is important while the absence cannot be attributed to environmental factors when the real reason may be the processing involved. Conclusions that radiolarians are never preserved in host lithology 'A' may be inaccurate and their absence due not to burial history but to loss during processing. Variables of this kind together with natural species exclusiveness, due to different depth habitats, etc. should be kept in mind.

Different biological (=fossil) groups will have had different genetic characteristics reflected by different environmental tolerances, morphological variability, etc. and problems of integration are likely to be manifest in a number of ways:
a) The groups are to a greater or lesser extent environmentally influenced but the same environmental influences may promote different reactions in
different groups, e.g. manifest as differences in abundance, diversity, presence/absence and preservation.

b) The differing chemical compositions of the different (fossil) groups results in i) different productivity rates in different conditions, and ii) different post-mortem preservation.

c) The amount of work done on a particular group or the degree of sophistication of the database is never uniform.

d) Stratotypes do not necessarily contain all fossil groups so relative ages are by inference, often several times removed.

"Reliability" is also an inherent factor of a fossil group itself. For example, one group may have been more susceptible to environmental change than another and the rate of response may have been different. Variation of response also occurs within a group at species and generic level, etc.. To give a hypothetical example, if the mean sea temperature increased by 10 degrees between 83Ma. and 83.0001Ma. the calcareous nannofossil population in any one area may have completely changed but another group such as the foraminifera may have been more eurythermal and not show change until say, 85Ma., i.e. a different and slower response. One group of workers, i.e. nannofossil workers, may place the Santonian/Coniacian boundary slightly lower stratigraphically than the foraminiferal workers. This presents problems when trying to compare and integrate different fossil groups with the information currently available, on a relative time scale and with an absolute time scale. However, as knowledge increases it will be a distinct advantage in the construction of refined zonation schemes. No information is a disadvantage although the way it is used may make it such.

Response to temperature variation is only one of the factors influencing distribution and others such as salinity, light, currents, interrelationships with competitors and symbionts, water sediment content, etc. change at different rates at different times, i.e. are dynamic.

Summary
The combined use of at least two or more groups of microfossils throughout a sequence is very desirable. Over-reliance on one group alone should be avoided as local events can result in distortion of stratigraphical
interpretations. The limitations of the calcareous and organic-walled microfossils, and the risks of over-reliance on any one of these groups can be reduced by the incorporation of the siliceous microfossils, i.e. radiolaria, silicoflagellates and diatoms, into the zonation schemes already established for each area.

In the past biostratigraphical zonations primarily used foraminifera and ostracods. These were followed by the use of palynology and calcareous nannofossils. Intra-basinal zones are now quite refined but have potential for further improvement by the integration of another group of chemically different microfossils which react differently to diagenesis, and probably habitat, to complement existing interpretations.

7.2.3 Integrated zonation schemes and the application of the method applied to this material
The limitations of the use of integrated data in zonation schemes as discussed above apply to the samples examined in this project. Since considerable time was spent in experiments with processing and other techniques the samples were not all processed or examined in the same way, as would be the case where tried and tested methods could be chosen before the start of the project and retained as standard throughout.

Biostratigraphical occurrence of radiolarian species in Cyprus calibrated with calcareous nannofossil zones
The 73 radiolarian species shown on Figure 7.1 have all or part of their range within the zonal interval defined by co-occurring calcareous nannofossils. The radiolarian species either occur in the same samples as the calcareous nannofossils recorded or stratigraphically between these samples and have been included on this basis.

The samples used are from 6 sections in Cyprus as shown on Figure 5.78 in Chapter 5. All the occurrences are here assigned a Campanian age.
<table>
<thead>
<tr>
<th>RADIOLARIA</th>
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<tbody>
<tr>
<td><em>Pseudoaulophacus floresensis</em></td>
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<td><em>Arene liriodes</em></td>
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<td><em>Atriovum gallowayi</em></td>
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<td><em>Amphiphax xanthodes</em></td>
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<td><em>Amphiphax pseudocalculus</em></td>
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<td><em>Amphiphax tylotus</em></td>
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<td><em>Amphiphax purpureus</em></td>
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<td><em>Archaeodictyomitra lemmloticostata</em></td>
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<td><em>Archaeodictyomitra sp.A aff. D. striata</em></td>
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<td><em>Archaeodictyomitra sp.B</em></td>
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<td><em>Archaeodictyomitra moki</em></td>
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<td><em>Biapherocephalina iheros</em></td>
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<td><em>Clathropurgerus tititum</em></td>
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<td><em>Croziella californica</em></td>
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<td><em>Crucella aster</em></td>
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<td><em>Croziella cachemira</em></td>
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<td><em>Croziella exoptoena</em></td>
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<td><em>Croziella sp.A</em></td>
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<td><em>Croziella sp.C</em></td>
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<td><em>Cryptaephorilla conara</em></td>
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<td><em>Cryptaephorilla macropora</em></td>
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<td><em>Diacanthocepaea acuminata</em></td>
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<td><em>Diacanthocepaea sp. A</em></td>
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<td><em>Dictyomitra sagitifera</em></td>
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<td><em>Dictyomitra sp.A aff. D. sagitifera</em></td>
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<td><em>Dictyomitra sp.B aff. D. sagitifera</em></td>
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<td><em>Eostichoita variata</em></td>
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<td><em>Eucultia sp.A</em></td>
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<td><em>Foremanina schona</em></td>
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<td><em>Gonplathorax sp.A</em></td>
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<td><em>Hexapyramids pantanelli</em></td>
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<td><em>Hita sp.A</em></td>
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<td><em>Houkites sp.A</em></td>
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<td><em>Patellula vertebreens</em></td>
</tr>
<tr>
<td><em>Patellula sp.A</em></td>
</tr>
<tr>
<td><em>Patellibraccium sp.A</em></td>
</tr>
<tr>
<td><em>Phaeoforma lako</em></td>
</tr>
<tr>
<td><em>Praeconocaulus universae</em></td>
</tr>
<tr>
<td><em>Praetulostphaera hastata</em></td>
</tr>
<tr>
<td><em>Praetulostphaera priva</em></td>
</tr>
<tr>
<td><em>Praetulostphaera pusilla</em></td>
</tr>
<tr>
<td><em>Protunus sp.A</em></td>
</tr>
<tr>
<td><em>Pseudoaulophacis sp.C</em></td>
</tr>
<tr>
<td><em>Pseudoaulophacis floresensis</em></td>
</tr>
<tr>
<td><em>Pseudoaulophacis lentuculatus</em></td>
</tr>
<tr>
<td><em>Pseudoaulophacis paragoreanus</em></td>
</tr>
<tr>
<td><em>Pseudoaulophacis velistetigius</em></td>
</tr>
<tr>
<td><em>Pseudodictyomitra ludogoensis</em></td>
</tr>
<tr>
<td><em>Pyreospongia sp.A</em></td>
</tr>
<tr>
<td><em>Rhopalosphaerium viltium</em></td>
</tr>
<tr>
<td><em>Rhopalosphaerium magnificum</em></td>
</tr>
<tr>
<td><em>Stichomitra asyntobas</em></td>
</tr>
<tr>
<td><em>Stichomitra comica</em></td>
</tr>
<tr>
<td><em>Theocarpus xalter</em></td>
</tr>
<tr>
<td><em>Trachoma sp.A</em></td>
</tr>
<tr>
<td><em>Trachoma sp.B</em></td>
</tr>
</tbody>
</table>

Figure 7.1 Chart showing 73 radiolarian species from Cyprus which have all or part of their ranges within the respective zonal intervals defined by co-occurring calcareous nannofossils
Biostratigraphical occurrence of radiolarian species in central Atlantic sites studied calibrated with calcareous nannofossil zones

Twelve radiolarian species shown on Figure 7.2 from the DSDP Sites 152 and 369A have all or part of their range within the interval dated by the co-occurring calcareous nannofossils as Santonian/Campanian (CC16/CC22). Twenty three radiolarian species are shown to have occurrences within the Maastrichtian as they are recorded in samples dated as CC23B and CC25A by calcareous nannofossils. Six of these radiolarian species are not previously recorded from sediments as young as Maastrichtian and have been interpreted in Chapter 6.2.2 as reworked.

This example emphasises the need to incorporate all available information in biostratigraphical interpretations.

Calcareous nannofossil data recorded by Cepek (1978, Table 8, pp. 676 - 677) from Site 369A has also been incorporated into the zonal interpretation.

Figure 7.2 Chart showing 31 radiolarian species recorded from Atlantic DSDP Site 152 and DSDP/IPOD Site 369A which have all or part of their range within the respective zonal intervals defined by co-occurring calcareous nannofossils
Co-occurring radiolarian species and calcareous nannofossil species and their relative distribution in Cyprus sections.

The chart (Figure 7.3) shows 90 calcareous nannofossil species and 43 co-occurring radiolarian species. The data have been compiled from 6 Cyprus sections which yielded co-occurring radiolarians and calcareous nannofossils: Akamas, Phiti, Kritou Marottou, Anadhiou, Paleomylon and Paralimni. The numbers in the matrix indicate the number of sections in which the two species co-occurred, e.g. *Afens liriodes* co-occurs with *Arkhangelskiella specillata* in one section; *Pseudoaulophacus floresensis* co-occurs with *Watznaueria barnesae* in all six sections.

The analysis, however, has limited use at the present time but indicates potential for future development. For example, it is suspected that species which have a high number of occurrences may be more solution resistant than those rarely recorded. This suspicion is supported by the occurrence pattern of *Watznaueria barnesae*, a calcareous nannofossil species known to be solution resistant. Additionally, species which co-occur in a high number of samples would be more likely to have at least partly co-incident age-ranges. These models cannot currently be tested as either biostratigraphical or dissolution indicators because of the insufficient size of the sample set and the lack of well-established age-range data for radiolarian species, which also inhibits identification of reworking or contamination.

**Summary**

In this study the limitations of using one group of fossils to provide a coarse biostratigraphical framework against which another group can be calibrated have been demonstrated. The calcareous nannofossil assemblages recovered from the samples analysed were not diverse enough to be able to mark exactly correlatable stratigraphical horizons. This is thought to be partly due to dissolution and preservation of the calcareous nannofossils and partly due to an environmentally patchy distribution of the marker species. As discussed above one of the most important features of a reliable index species is widespread distribution but this reliability remains relative. When, as in this study, only a few selected samples from each section are analysed it is highly unlikely that the complete
Co-occurring radiolarian species and calcareous nannofossil species and their relative distribution in Cyprus sections (the figures in the matrix are the percentages of occurrence of each species).

<table>
<thead>
<tr>
<th>Species</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biscutum ellipticum</td>
<td>3%</td>
</tr>
<tr>
<td>Arkhangelskiella cumiformis</td>
<td>4%</td>
</tr>
<tr>
<td>Amphizygus brooksii</td>
<td>5%</td>
</tr>
<tr>
<td>Stauroolithites mielnicensis</td>
<td>6%</td>
</tr>
<tr>
<td>Stauroolithites laffittei?</td>
<td>7%</td>
</tr>
<tr>
<td>Rotelapillus crenulatus</td>
<td>8%</td>
</tr>
<tr>
<td>Rhagodiscus reniformis</td>
<td>9%</td>
</tr>
<tr>
<td>Rhagodiscus angustus</td>
<td>10%</td>
</tr>
<tr>
<td>Placozygus fibuli formis</td>
<td>11%</td>
</tr>
<tr>
<td>Broinsonia enormis</td>
<td>12%</td>
</tr>
<tr>
<td>Tranolithus minimus</td>
<td>13%</td>
</tr>
<tr>
<td>Octolithus multiplus</td>
<td>14%</td>
</tr>
<tr>
<td>Calculites dualis</td>
<td>15%</td>
</tr>
<tr>
<td>Calculites pbscurus</td>
<td>16%</td>
</tr>
<tr>
<td>Microrhabdulus undosus</td>
<td>17%</td>
</tr>
<tr>
<td>Microrhabdulus decoratus</td>
<td>18%</td>
</tr>
<tr>
<td>Manuitella pemmatoida</td>
<td>19%</td>
</tr>
<tr>
<td>Lucianorhabdus caqexii</td>
<td>20%</td>
</tr>
<tr>
<td>Chiastozygus platqrhethus</td>
<td>21%</td>
</tr>
<tr>
<td>Lithraphidites carniolensis</td>
<td>22%</td>
</tr>
<tr>
<td>Kamptnerius magnificus</td>
<td>23%</td>
</tr>
<tr>
<td>Corollithion signum</td>
<td>24%</td>
</tr>
<tr>
<td>Cretarhabdus striatus</td>
<td>25%</td>
</tr>
<tr>
<td>Cretarhabdus conicus</td>
<td>26%</td>
</tr>
<tr>
<td>Clindralithus biarcus</td>
<td>27%</td>
</tr>
<tr>
<td>Cribrocorona gallica</td>
<td>28%</td>
</tr>
<tr>
<td>Discorhabdus ignotus</td>
<td>29%</td>
</tr>
<tr>
<td>Clindralithus nudus</td>
<td>30%</td>
</tr>
<tr>
<td>Euogrhabdotus erectus</td>
<td>31%</td>
</tr>
<tr>
<td>Euogrhabdotus elegans</td>
<td>32%</td>
</tr>
<tr>
<td>Watznaueria manuitae</td>
<td>33%</td>
</tr>
<tr>
<td>Watznaueria fossacincta</td>
<td>34%</td>
</tr>
<tr>
<td>Uekshinella angusta</td>
<td>35%</td>
</tr>
</tbody>
</table>
assemblage for any one particular zone will be recovered from every sample. A succession or suite of samples usually yields a better recovery rate of index and associated species.

7.3 Comparison of published Upper Cretaceous siliceous microfossil zonation schemes

7.3.1 Introduction

Figure 7.4 shows radiolarian schemes for the Upper Cretaceous which have been erected since 1973. Of these only Pessagno (1976) has based divisions largely on spumellarian data. Zonations are limited when based on only one section or when used with no other group control. Moore (1973) used 6 sections from the North Pacific, Dumitrica (1975) used only one onshore section from Romania, whereas Riedel and Sanfilippo (1974) used several sections with calcareous control and later Sanfilippo and Riedel (1985) used probabilistic ranges.

Although index marker species and characteristic assemblages have been described here, there is not enough established information on a global scale to reliably date partial assemblages, e.g. if there are no zonal index markers present then dating the sample on the appearance of one or two characteristic forms is dangerous because they may have longer, or regionally different ranges than reported.

The most established and satisfactorily tested zonations to date are illustrated. However, limitations exist in that not enough index markers have been identified (and published) and therefore the existing schemes are difficult to apply in some provinces e.g. the Austral province, the Indian Ocean and the North European Boreal.

7.3.2 Summary of Zonation Schemes

Described below are brief accounts of zonation schemes published to date which have used Upper Cretaceous material. Each section gives the locality of the material, the methods of calibration used by each author, the zones assigned and a discussion of the application of the zonation scheme to material analysed in this study. Only taxa in common with
material from this study are included and in the text and in Figures 7.4 - 7.8 the synonymous names of morphotypes have been standardized in accordance with Appendix 2. The species concepts of all morphotypes used in the analyses below have been interpreted from a combination of both descriptions and figures provided by the respective authors of the zonations. Other species recorded by respective authors but which were not found in this study have been omitted.

Moore (1973)
Moore described his zones as tentative due partly to poorly preserved material, partly because of sparse assemblages and to poor core recovery. He erected 7 zones (RK1 - RK7) from Tithonian to Maastrichtian based on first occurrences of easily identifiable radiolarian species from six sites drilled on DSDP Leg 17 in the North Pacific. He bases the age of his zones on analyses of calcareous fossils from the same cores by Douglas (1973) and Roth (1973) and does not use radiolarian age data in isolation.

Application - Comparison of the material used in this study with that of Moore (1973) shows that 14 species are recorded in both reports. Three of these 14 species are used by Moore to define zones. The FA of *Alievium superbum* defines the base of Zone RK5 (c. Cenomanian - Turonian); FA *Clathropyrgus titthin* defines the base of Zone RK6 (c. Coniacian - Santonian); FA *Afens liriodes* defines the base of Zone RK7 (c. Campanian - Maastrichtian).

The species found in this study in common with Moore (1973), which according to his interpretation have LO's before the Campanian are as follows:

*Dictyomitra sagitafera* Cenomanian-Turonian

*Pseudoaulophacus pargueraensis* and *Amphipyndax conicus* have a range restricted to the Coniacian and Santonian. One species, *Afens liriodes* is restricted to the Campanian.

Riedel and Sanfilippo (1974)
Riedel and Sanfilippo erected a composite zonation scheme from Tithonian to Maastrichtian with 7 zones, in which the Upper Cretaceous
Figure 7.4 Correlation of Upper Cretaceous radiolarian zonation schemes

<table>
<thead>
<tr>
<th>Upper Cretaceous Radiolarian Zones</th>
<th>Correlation Scheme 1</th>
<th>Correlation Scheme 2</th>
<th>Correlation Scheme 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone B</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Zone C</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Zone D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone F</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Note: The correlation schemes are based on specific radiolarian assemblages and their distribution across different geological strata.
has 4 zones. Material used in the Upper Cretaceous part of the scheme is mostly from DSDP Leg 17 in the northwest Pacific (as was that of Moore 1973) but also includes data from the Caribbean DSDP Leg 15, the Indian Ocean DSDP Leg 27 together with material from localities in Bavaria, Spain, Caribbean islands and Australia. They base the age of the zones on "broadly defined species or groups of species which are recognisable in poorly preserved assemblages by normal transmitted-light microscopy" (Riedel & Sanfilippo, 1974, p. 773). Riedel & Sanfilippo base the ages of their zones on analyses of the co-occurring calcareous material, (Bolli, 1957; McWhae et al., 1958; Herm, 1962; Douglas 1973; Roth 1973; Premoli-Silva & Bolli 1973) and also on comparison of radiolarian assemblages.

Application - Comparison of the material used in this study with that of Riedel and Sanfilippo shows that 10 morphotypes are recorded in both reports. Four of these 10 morphotypes are used by Riedel and Sanfilippo to define zones. FA of Amphipyndax pseudoeonulus defines the base of the Amphipyndax enesseffi zone (c. Campanian), LA of Pseudoaulophacus pargueraensis and Dictyomitra koslovae, Dictyomitra formosa approximate the base of the Theocapsomma comys Zone (c. Maastrichtian). All 4 of these species therefore co-occur within the Campanian, and reference to Riedel & Sanfilippo (1974, Figure 1) shows that all of the 10 common morphotypes co-occur within the Campanian in the lower part of the Amphipyndax enesseffi Zone.

Pessagno (1976)

Pessagno analysed material from numerous localities in the Great Valley Sequence in California and divided the Upper Cretaceous into 8 Zones which are further sub-divided by 9 sub-zones. He calibrated his scheme with planktic foraminifera, ammonites and inoceramids.

Application - Twenty seven morphotypes recorded by Pessagno (1976) also occur in the material studied for this project. Of those morphotypes which are common to both reports the following 21 species and 1 genus
are considered diagnostic by Pessagno in the definition of zones and subzones:

the LA of *Orbiculiforma maxima* defines the top of the Rotaforma hessi Zone (Early to Late Cenomanian); the FA of *Alievium superbum* and the FA of *Crucella cachensis* define the base of the Alievium superbum Zone (Turonian); the base of the Archaeospongoprunum *venadoensis* Subzone is defined by the FA of *Crucella irwini* and *Crucella cachensis* and the top of this Subzone and the top of the Alievium superbum Zone are defined by the LA of *Actinomma(?) daviesensis*; the base of the Alievium praegallowayi Zone (Coniacian) is defined by the first occurrences of *Pseudoaulophacus lenticulatus*, *Paronaella venadoensis*, *Archeospongoprunum bipartitum*, *Orbiculiforma quadrata*, *Praeconocaryomma universa* and *Dictyomitra formosa*; the first occurrence of *Orbiculiforma personex* defines the base of the Orbiculiforma vacaensis subzone (late Coniacian); the last occurrences of *Paronaella venadoensis*, *Crucella irwini* and *Orbiculiforma personex* defines the top of the Orbiculiforma vacaensis subzone and the top of the Alievium praegallowayi zone; the first occurrence of *Alievium gallowayi* marks the base of the Alievium gallowayi zone (Santonian); the last occurrences of *Archeospongoprunum bipartitum* and *Orbiculiforma quadrata* define the top of the Alievium gallowayi Zone (Santonian); the first occurrences of *Patulibracchium californiаensis*, *Archeospongoprunum andersoni* and *Protoxiphotractus kirbyi* define the base of the Crucella espartoensis Zone (Early - early Late Campanian) and the base of the Protoxiphotractus perplexus Subzone (Early Campanian); the first occurrence of *Pseudoaulophacus riedeli*, *Archeospongoprunum hueyi* and *Bisphaerocephalina(?)* amazon define the base of the Phaseliforma carinata Subzone (early Late Campanian); the last occurrences of *Pseudoaulophacus floresensis* and *Pseudoaulophacus lenticulatus* and the genus *Pseudoaulophacus* define the top of the Phaseliforma carinata Subzone (early Late Campanian) and the top of the Crucella espartoensis Zone (Early to early Late Campanian).
The distribution of species in material studied in this project is not consistent with Pessagno's zonation scheme with regard to super-positional patterns, although there is a relatively high number of common species. Pessagno (pers. comm, 1991) has since extended the ranges of many of the species although they have not been published.

Of the 27 morphotypes common to this study and the work of Pessagno (1976) 23 are spumellarians and 4 are nassellarians. This strong relative bias towards spumellarians, in contrast with other workers, is because Pessagno prefers to use, as index species, forms which are easily identifiable on external features. Nassellarians (probably including Amphipyndax pseudoconulus and Amphipyndax tylotus) are present in the samples used for the Upper Cretaceous zonation scheme of Pessagno but only a small percentage of species from the total assemblage were recorded (Pessagno, pers. comm, 1991).

Foreman (1977)
In 1977 Foreman emended her 1975 zonation scheme (originally based largely on Pacific material) and proposed two new zones for the Campanian - Maastrichtian interval. Four zones divide the Upper Cretaceous. The material used is from central Atlantic DSDP sites 13A, 138, 144, and 369A and from DSDP site 95 in the Gulf of Mexico; from 2 wells in the southwestern Atlantic and one well in Trinidad; from onshore sections in Cuba and Italy. This zonation is calibrated with calcareous plankton, mostly provided in site 369A and analysed in the Initial Reports by Cepek (1978) and Lancelot et al. (1978). Foreman states the use of supplementary calcareous control in other samples but does not give details.

Application - Comparison with the material used in this study (N.B. similar material in DSDP Site 369A to that used by Foreman, 1978b)) with that of Foreman (1977) shows that 16 morphotypes are common to both reports. Of these 16 forms 2 are used by Foreman to define zones, the FA of Amphipyndax pseudoconulus defines the base of the Amphipyndax enesseffi zone and the FA of Amphipyndax tylotus defines the base of the Amphipyndax tylotus Zone. Both these species
co-occur within the Campanian. Reference to Foreman (1977, Figure 6) shows that 15 co-occur within the Lower Campanian. *Alievium superbum* is recorded as having a LA during the Turonian.

**Taketani (1982)**

Taketani analysed material from 12 sections from the Urakawa and Obira areas, onshore Japan. The sampled sections consistently yielded diverse assemblages of reasonably well-preserved radiolarians and were calibrated with planktic and benthic foraminiferal zones of Maiya and Takayanagi (1977) and the inoceramid zones of Matsumoto (1977). However, Taketani correlated the sections using radiolarian data in isolation.

The zonation scheme is generally comparable to the scheme proposed by Pessagno (1976) except that the basal Campanian Spongostaurus (?) hokkaidoensis Zone of Taketani and the Crucella espartoensis Zone of Pessagno differ considerably, although they do have common elements of *Crucella espartoensis* and *Pseudoaulophacus lenticulatus*.

Taketani erected 8 zones from (probably) upper Albian to lowermost Campanian, and used 4 first occurrences and three last occurrences to define the zones. Of these 7 zone fossils the stratigraphically lowest 5 are nassellarians.

Application - Taketani only has one zone which correlates with the present material i.e. the Spongostaurus (?) hokkaidoensis Zone although 16 species have been recovered in this study which have also been recorded by Taketani. The index fossils are recorded on Figure 7.4. and of these 16 species Taketani records 11 as ranging into the Campanian. The remaining 5 are as follows: *Archaeospungoprunum bipartitum* with a last occurrence in the Santonian; *Alievium superbum*, *Stichomitra communis* and *Pseudodictyomitra lodogaensis* with last occurrences in the Coniacian; *Diacanthocapsa euganea* with a last occurrence in the Turonian.
Sanfilippo and Riedel (1985)

Sanfilippo and Riedel (1985) erected a composite zonation scheme using probabilistic techniques. The scheme ranges from Tithonian to Maastrichtian, the Upper Cretaceous is divided into 4 zones and is calibrated by the use of calcareous nanofossils and planktic foraminifera. Material used for the scheme is from published sources from the Atlantic and Pacific DSDP sites (Foreman, 1973b, 1975, 1977, 1978b; Petrushevskaya & Kozlova, 1972; Moore, 1973; Riedel & Sanfilippo, 1974; Schaaf), 1981, from onshore Japan (Taketani, 1982) and from an unpublished section from northern Italy. Although the basic scheme is valid it must be noted that the individual ranges of species presented are the result of probabilistic analysis and also that some of these reported ranges have been extended since the publication of the scheme on the basis of new data (Riedel, pers. comm., 1988).

Application - Morphotypes used by Sanfilippo & Riedel (1985) and also recorded in this study number 14. Of these 14, 5 are spumellarians, 8 are nassellarians and 1 is incertae sedis. Of the 14 morphotypes common to both studies 6 are used as zonal index markers by Sanfilippo & Riedel and are as follows: - the first occurrence of *Theocampe salillum* defines the base of the *Theocampe urna* Zone (mid Coniacian - Santonian); *Amhippyndax pseudoconulus* defines the base of the *Amphipyndax pseudoconulus* Zone (Campanian); the last occurrence of *Alievium superbnum* defines the top of the *Amphipyndax pseudoconulus* Zone (Campanian); *Pseudoaulophacus lenticulatus* is restricted to this zone; the first occurrence of *Amphipyndax tylotus* defines the base of the *Amphipyndax tylotus* Zone (late Campanian - Maastrichtian); the last occurrences of *Archaeodictyomitra lamellicostata* and *Amphipyndax tylotus* define the top of the *Amphipyndax Zone* (Late Campanian - Maastrichtian).

Reference to the range chart of Sanfilippo & Riedel (1985, Text-figure 3) shows that 11 of the species co-occur in the late Campanian but that *Alievium superbnum* does not co-occur with *Dictyomitra koslova* or with *Amphipyndax tylotus*, and that
Pseudoaulophacus lenticulatus does not co-occur with Amphipyndax tylotus.

Thurow (1988a)
Thurow uses a slightly modified compilation of the zonal schemes presented by Schaaf, (1985), and Sanfilippo & Riedel (1985) for his analyses of samples from north Atlantic ODP sites 638, 640, 641 and DSDP Sites 398, 603. This material was correlated with calcareous plankton where present. The Tithonian to Maastrichtian is divided into 15 zones with the Turonian - Santonian unzoned. He introduces one new zone, the Crucella cachensis zone (latest Cenomanian/earliest Turonian) based on the first occurrence of Crucella cachensis. Of the morphotypes Thurow (1988a) presents in his range chart of index and associated species (1988a, Figure 5) in the text, and in his occurrence charts (Tables 1, 2), 23 species occur in his work which also occur in this study. These include 13 spumellarians, 9 nassellarians and 1 incertae sedis. Of these forms Thurow identifies 4 as zonal index species. These are as follows:- FA Mita gracilis defines the base of the Mita gracilis Zone (late Albian); FA Crucella cachensis defines the base of the Crucella cachensis Zone (latest Cenomanian/earliest Turonian); FA Amphipyndax pseudoconulus defines the base of the Amphipyndax pseudoconulus Zone (Santonian - Campanian); FA Amphipyndax tylotus defines the base of the Amphipyndax tylotus Zone (Campanian - Maastrichtian). In his range chart (Thurow 1988a, Figure 5) he shows that 15 of the 23 species co-occur in the Amphipyndax pseudoconulus Zone of the Campanian. Those species are shown as not occurring are as follows:-

Crucella cachensis LA in early Coniacian. However, Thurow now believes (pers. comm., 1990) that the upper limit of the range of this species should be extended, possibly as high as the Campanian.

Amphipyndax tylotus - FA in late Campanian. This species does co-occur with 9 of the 23 species but appears after the last occurrence of Aliievium superbum, Praeconocaryomma universa, Dictymitra formosa, Pseudoaulophacus lenticulatus, Patulibracchium californiensis, Heliocryptocapsa sp.A.
7.3.3 Discussion
Many Upper Cretaceous species are first recorded around the Albian/Cenomanian boundary where a radiation of new species is pronounced. Many Lower Cretaceous species do not survive beyond the Cenomanian/Turonian Boundary. This could be related to global events or could be due to better preservation related to palaeoceanographical conditions.

Integration of zonation schemes constructed by using fossil evolutionary ranges becomes more difficult and less accurate the greater the geographical separation. Therefore, it is important to rely only on positive evidence and not the absence of forms - "Absence of evidence is not evidence of absence" (Anonymous). Assemblages in different areas are distorted by a number of factors such as provincialism, evolutionary migration patterns, preservation differential in a variety of host lithology types and by different post-burial histories.

In a local area or hydrocarbon field it is sometimes more feasible to use absences of forms to provide a more accurate interpretation of events. For example in a well-known field a stratigraphic horizon may be marked by an abundance of species Y. If horizon "Y" is not encountered it may be feasible, taking into account experience, lithological type and supplementary data from, for example, wireline logs to interpret the section as incomplete. Alternatively if horizon "Y" is encountered more than once an interpretation of repeated sequence due to tectonic disruption may be applied.

Sediments dated in this study are all Campanian in age, that is they were deposited during the same time period that is assigned the name Campanian based on ammonites in the stratotype and extrapolated by the use of calcareous fossils. This age has been shown by comparison with co-occurring calcareous fossils (where present) in this study and the calcareous fossils used by other authors to calibrate their radiolarian assemblages, and by comparison of the relative age ranges of radiolaria within assemblages as reported by other authors.
Records of the ranges of species (recorded by the authors of the seven zonation scheme discussed above) which are synonymous with 50 of the species recognised in this study (see also Figure 7.6) were plotted on a chart (Figure 7.5) to compare the variation in published ranges. The aim of this analysis is to assess how the perception of ranges of these species has changed from 1973 - 1988. There are limitations in that not all authors examined the whole Upper Cretaceous interval, e.g. Taketani (1982) only analysed sediments older than mid lower Campanian, and that complete sections were not available to some authors, e.g. Thurow (1988a) has no Coniacian - Santonian data. Zonation schemes examined here are also selected because they include analyses of Campanian sediments, thus schemes such as Dumitrica (1975) and Schaaf (1985) primarily concerned with analyses of older Upper Cretaceous assemblages are omitted.

A table was constructed (Figure 7.6) using the species recorded in each of the seven authors zonation schemes (see Figure 7.4) which are considered to be identifiable with 50 of the species recovered during this study. This was to attempt to establish the validity of each form as an index species, i.e. the more times a species is recorded then the more reliable and useful as a correlatable index it is likely to be because it is easily recognisable and has a widespread occurrence; it is also likely to be a relatively solution-resistant species.

There are discrepancies in ranges as shown in Figure 7.5. These are accounted for in part by mis-identification and changes in species concepts (longer or shorter ranges recorded), poor preservation (shorter ranges recorded), insufficient data, (shorter ranges recorded), unrecognised reworking (longer ranges), provincialism, migration patterns and environmental conditions (longer or shorter ranges recorded) and also methodological artefacts.

In addition, the sections are dated by the various authors using a variety of methods (see Chapter 7.3.2). Many different, unsubstantiated and probably insignificant interpretations can be made from Figure 7.5 but possibly the most interesting is that the most commonly recorded species i.e. 5 or more records on Figure 7.6, are dominantly nassellarians.

-258-
Additionally, each species range (when shown twice or more on Figure 7.5) given by each author is the same, or overlaps with that of the other authors.

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Figure 7.6 Publications recording synonymous forms with selected species from this study
7.4 Biostratigraphical Analysis
Described below is a summary of attempts to determine biostratigraphical and palaeogeographical occurrence patterns of radiolarian species recorded during this study.

7.4.1 Composite ranges of synonymous forms from publications listed in Chapter 1, Figure 1
The range charts Figures 7.7, 7.8 have been constructed from the data provided by the authors cited in Chapter 1, Figure 1.2, from which are taken the synonymy lists in Appendix 2 of this work. Each authors concept of the species has been considered, using the illustrations and descriptive text provided by them. The ranges shown here are the longest ranges reported by a combination of authors, e.g. one author may report a Santonian - Campanian range for a species whilst another may report the species only from the Turonian so here the species is shown as ranging from the Turonian to the Campanian. This method is open to the following errors:

a) the sediment may not have been the age the author thought it was - the control used should be evaluated;

b) species concept may differ between authors (no original material has been examined, only illustrated specimens have been compared); and,

c) samples may vary in spacing, quality, lithology, and quantity processed and it is therefore important to use only positive evidence.

An alternative method would have been to use the minimum range, i.e. the overlap interval agreed by all authors. This method is open to the errors described above and also:

1. the species ranges would be restricted by the age of the stratigraphically shortest sections investigated;

2. inhibits progress towards establishing the true range of the species;

3. does not allow for provincial differences in assemblages, i.e. global, or evolutionary species history;

4. does not allow for the localised range reductions due to dissolution of species.

The ranges are plotted by stage, actual ranges within a stage may well be shorter. Only Upper Cretaceous ranges are shown - some species range further into the Albian and/or Palaeocene.
Figure 7.8 Upper Cretaceous radiolarian ranges compiled from publications and plotted in order of highest occurrence plus new data from this thesis added by thin dashed lines.
The results of analyses carried out during this work suggest that the ranges of 15 of the species identified should be extended into the Campanian stage. Of these taxa 3 have previously recorded extinction datums within the Santonian, 5 within the Coniacian, 2 within the Turonian and 5 within the Cenomanian. However, the identifications in this work of 4 of these taxa are questionable and therefore the extensions of their respective ranges are also questionable. These species are as follows:

Orbiculiforma (?) aff. O. quadrata,
Archaeodictyomitra ?sliteri, Orbiculiforma aff. O. railensis
and Pseudodictyomitra ?lodogaensis.

7.4.2 Tie-Line Correlation diagram
Six Cyprus sections were chosen which had calcareous nannofossil control in part or all of the section. These are Akamas, Phiti, Kritou Marottou, Anadhiou-Sarama, Paleomylon Valley and Paralimni, from W to E. Taxa which occurred in two or more of the sections were selected, arranged in alphabetical order and assigned a number from 1 - 108. Using these code numbers the species were arranged in vertical columns in order of stratigraphical occurrence within each section with the oldest or FO at the base of the column (Figure 7.9). Where two or more species occur at the same level within a section (i.e. the data is taken from the same sample on the distribution charts) then they are arranged in alphabetical order from base to top of the column. This situation is also indicated by a box around these numbers. The species in each column/section are then correlated with the nearest section to the east.

The diagram was extended to correlate each section with each section (i.e. a permutation of 36 correlations) by placing successive layers of tracing paper over the first diagram, but this is not shown here. The results of the diagram shown here and the one mentioned above (not shown), were similar in that many of the lines crossed.

The results from this exercise indicate that no distinctive correlation pattern can be established on this data which is probably due to the following factors:
a) the samples are from sections which are all of a very similar age range;  
b) the high dissolution factor of radiolaria influences the occurrence patterns; and  
c) because the samples have been collected from sections with a high incidence of tectonic disruption there is a strong probability that unidentifiable reworking is complicating the FO/LO occurrence patterns.

7.4.3 Unitary Associations
Introduction
Unitary Associations is a method of automated correlation which can compare the occurrence of each species with every other species in the assemblage(s) in which it is recorded: a) to determine the stratigraphical interval over which a pair or a set of species coexist; b) to determine the superpositional relationships of pairs or sets of species; and, c) to determine the position of virtually associated species i.e. those not observed but whose positions can be inferred.

Detailed accounts of this method are given by the authors of the program Guex and Davaud (1984) and a critical assessment is provided by Baumgartner (1984a). Baumgartner (1984b) demonstrates the use of the method in constructing a zonation scheme.

For this current study data were compiled in ASCII format for 14 sections, 2 from the Atlantic (DSDP Site 152, DSDP Site 369A) and 12 from Cyprus (Akamas, Phiti, Kritou Marottou, Anadhiou-Sarama, Paleomylon, Kithasi, Arkhimandrita, Petra tou Romiou, Kouka, Perapedhi, Trimiklini, Moni, Kambia and Paralimni).

The data input consisted of 100 radiolarian species and 90 calcareous nannofossil species. Data were run in 9 different combinations by Dr. Guex in 1990:

1. Radiolarian species from 12 Cyprus sections.
2. Radiolarian species from 2 Atlantic sections.
3. Radiolarian species from 12 Cyprus sections and 2 Atlantic sections.
Figure 7.9: Tie-Line correlation diagram showing the stratigraphic distribution of 108 radiolarian species in 6 Cyprus sections.
4. Calcareous nannofossil species from 6 Cyprus sections.
5. Calcareous nannofossil species from 2 Atlantic sections.
6. Calcareous nannofossil species from 6 Cyprus sections and 2 Atlantic sections combined.
7. Radiolarian species from 12 Cyprus sections and calcareous nannofossil data from 6 of these sections combined.
8. Radiolarian species and calcareous nannofossil species from 2 Atlantic Sections.
9. Radiolarian species from 12 Cyprus sections and 2 Atlantic sections and calcareous nannofossil species from 6 Cyprus sections and 2 Atlantic sections.

No associations were repeatably established, which may be due to:

a. errors in identification of radiolarian species;
b. extensive dissolution of radiolarians because as a group they have a higher inherent susceptibility to dissolution than other groups of microfossils such as calcareous nannofossils;
c. samples compromised by reworking/contamination;
d. age range represented by sections is too short, i.e. the relative age range of each species is too long in relation to the time interval examined to be able to subdivide the interval;
e. interactive factors, e.g. dissolution in conjunction with short time interval

Conclusion
It is considered that the primary cause of the failure of this method to identify repeated associations in this instance is due to the short and similar age-ranges of the compared sections, a situation which is further complicated by the other factors listed above.

7.4.4 Geographical Distribution of Radiolarian Genera and Species

Figure 7.10 shows the species diversity at each site, the number of sections in which a species occurs, species exclusive to the Atlantic (0) and species exclusive to the respective Cyprus sections. Surface productivity is
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Figure 7.10 Chart showing radiolarian species diversity and distribution in relation to calcareous lithologies in 13 Cyprus sections and 2 Atlantic sections
Figure 7.11 Chart showing the distribution of radionuclides in 13 Cyprian sections.
assumed to be constant for the Cyprus samples as the time span analysed is interpreted as being relatively short. From this assumption the species diversity can be compared with variables such as the calcareous values of the host sediment, the proximity to an unconformity, the number of samples analysed and the number of productive samples. The sections with the greatest diversity were those where the greatest number of samples was analysed. This is because more time was spent on processing the Paleomylon samples, and more time was spent analysing the Akamas and Perapedhi samples, as they are longer sections and were expected to be more valuable stratigraphically, and also because the faunal assemblages were well-preserved. The higher the diversity the more chance of exclusive species. Calcareous lithologies do not seem to have a negative correlation with species diversity.

Figure 7.11 shows the areal distribution of radiolarian species occurrence in 13 Cyprus sections and 2 central Atlantic DSDP sections.

One genus and species is found in DSDP Site 152 on the western side of the central Atlantic and not in DSDP Site 369A on the eastern side of the central Atlantic. Fourteen genera and forty species are found in DSDP Site 369A which are not found in DSDP Site 152. All genera (47) and species (141) recorded in this study are present in Cyprus.

Taxa recorded during this study have been recovered from a relatively narrow palaeolatitudinal belt between 0° - 30°N (see Figure 8.1). Of the 141 forms documented in this work (Appendix 2) 49 have no identified synonymous forms in the literature; 9 have been recorded only from the Atlantic and/or from U.S.S.R.; 79 are also recorded from the Pacific region (includes onshore California and Japan); 12 from the Indian Ocean and 4 from the Tasman Sea. Taking into account the distribution of sites published (see Chapter 1, Figure 1) and allowing for the paucity of publications on the Austral province it would seem that many, if not most of the species recorded here are cosmopolitan.

Empson-Morin (1984) found that 11 species, representing only 7% of the total Campanian species she recorded, were globally cosmopolitan. Although her data are apparently not consistent with the results obtained
here it must be noted that she compared assemblages from more extreme latitudes, i.e. her samples and selected species were intentionally biased.

7.4.5. Comparisons with other biostratigraphically useful microfossil groups

Figure 7.12 shows a chart of the ranges of Upper Cretaceous calcareous nannofossils (adapted from Sissingh, 1977, Perch-Nielsen, 1985 and Burnett, 1990) and Figure 7.13 shows a chart of the ranges of Upper Cretaceous planktic foraminifera (from Caron, 1985). The ranges of species have here been artificially "smoothed out" into classes delimited by stage boundaries, i.e. if a species last occurs at or near the base of the Campanian, the fact that it occurs at all in the Campanian means that it is plotted throughout the whole stage range. This artificial "smoothing" has been adopted here for the following reasons:

a) the uncertainty of detailed correlation of datums defined by the integration of different groups of microfossils, especially from different regions, e.g. even correlation of stage boundaries to absolute time scales may be inconsistent when different fossil groups are used;
b) the current state of zonation schemes for Mesozoic radiolarian ranges cannot be refined to a greater degree on a global scale at the present time and if the three groups are to be compared the data must be standardized in this way; and,
c) due to practical limitations of the software used for plotting occurrence.

The aim was to compare patterns in the three groups to determine the potential of radiolarians as biostratigraphical indicators, and in particular to identify the stratigraphical distribution of first and last occurrences. Interpretation of the data is subject to limitations of method of collation, for example, the foraminiferal chart is compiled from global occurrences of species which have been established as index marker species.

The numbers of species plotted are approximately equal, 89 foraminifera, 90 calcareous nannofossils, 82 radiolarians, but the foraminifera represent the entire Upper Cretaceous.

Results show that the planktic foraminifera, the most intensively studied group, show potentially the highest number of definable biostratigraphical horizons. The chart is biased in that all species
Figure 7.13: Upper Cretaceous ranges of selected planktic foraminifera. Recorded in the study area from Ishihara, 1985 (not compiled from species recovered during this study).

- **Papueoidea vulgaris**
- **Praegloboasmaniidae**
- **Globotruncana elongata**
- **Globorotalia menardii**
- **Globigerina bulloides**
- **Globorotalia troughtonii**
- **Globigerina rubescens**
- **Globigerinoides antiquus**
- **Globigerinoides ruber**
- **Globigerinoides neurosphericus**

- **Chiasmolithus praehelveticus**
- **Chiasmolithus praecox**
- **Chiasmolithus carinatus**
- **Chiasmolithus pennatus**
- **Chiasmolithus quadrangularis**
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used are selected global index species and because of this are likely to have shorter ranges. If data were taken from a more geographically restricted area or occurrences of all species were plotted then the pattern may be different, e.g. more locally applicable FO's and LO's would be expected.

The calcareous nannofossil chart is composed entirely from species found in this study, many of which are not stratigraphically useful, e.g. range throughout the Upper Cretaceous. Fourteen have last occurrences within the Tethyan Campanian, 17 have first occurrences within the Campanian.

The radiolarian charts (Figures 7.7, 7.8) are composed entirely of species found in this study, of which 41 have last appearances within the Campanian and 40 have first appearances within the Campanian. These ranges are currently not reliably established, however, (see discussion in Chapter 7.4.1) and these comparisons can only be regarded as an interim assessment of biostratigraphic potential of radiolarians from Campanian sediments.

7.4.6 Discussion
Data collection has barely started and each time a new publication is released then the chances are that the range of a particular species will have been extended. Radiolarian biostratigraphy still has to go through first this lengthening of ranges stage followed by re-evaluation of data and subsequent shortening of ranges due to misidentification and reworking, refinement of taxonomy, etc. before a settled phase, or plateau of acceptable data is reached. This lack of data also affects phylogenetic studies in that it is possible to assume that species or genera are related but often not possible to say which way the evolution progressed, e.g. did it grow more spines or did the spines become vestigial in the descendants. This is because the samples with the ultimate end members have yet to be discovered. This also complicates the use of transitional members of a group which otherwise, as in the case of foraminifera, can be very useful in refining zonation schemes.
From the analyses in this chapter of both published material and sample material examined during the course of this work several conclusions are reached which are summarised as:

a. The potentially high diversity of radiolarian assemblages together with the fact that they are recoverable from lithologies hostile to other microfossil groups (in particular calcareous forms) confirms their role as at least complementary, in biostratigraphic zonation schemes.

b. Difficulties in integration of range data are enhanced by non-standard processing, viewing and illustrative methods of various workers.

c. Despite the high diversity of Upper Cretaceous radiolarian faunas there is a paucity of universally established/agreed index marker species, e.g. the Campanian stage (which is relevant to material studied in this work) is divided only into two generally accepted biozones, the Amphipyndax pseudoconulus Zone of Foreman and the Amphipyndax tylotus Zone of Foreman. The identification of these zones relies on two species Amphipyndax pseudoconulus and Amphipyndax tylotus, the identifications of which are inhibited by: i) the fact that the internal structure of the cephalis must be examined for positive identifications; and ii) that both species are very similar to each other, morphological variation being difficult to establish in poorly-preserved material.

d. The methods used to determine the super-positions of recorded taxa were largely unsuccessful due to the short time scale of deposition of sediments analysed combined with the high susceptibility of radiolarians to dissolution.

e. Of the 82 taxa recovered in this study which have published ranges, 67 have been previously recovered from Campanian age sediments. Of the remaining 15 species 4 are only questionably identified. The ranges of the remaining 11 species are here extended into the (stratigraphically higher) Campanian stage.
8.1 Introduction
In Chapter 2 some of the main controls on the production and preservation of siliceous organisms as microfossils were discussed. This chapter considers how the evidence from modern seas, combined with the Campanian radiolarian distribution patterns, can be used to interpret the Late Cretaceous marine silica budget.

Discussed below are the main factors considered to affect radiolarian production and preservation and the extent to which these factors were applicable in the Late Cretaceous.

Significant influential factors which are taken into account are:

a) Physical palaeoceanography - including continental positions, bathymetry, sea level, water mass and current patterns;
b) Chemical palaeoceanography - including water chemistry and biogeochemical cycles/budgets; and
c) Palaeoclimatology - including weather patterns, climate, polar ice, atmospheric composition and wind patterns together with the effects of the latter on upwelling systems. Climate also controls weathering, erosion and run-off from continents, which together with physical palaeoceanographic and chemical palaeoceanographic influences control global sediment budgets.

8.2 Interpretation of conditions in the Late Cretaceous
Evidence from a variety of disciplines has been combined to reconstruct conditions during the Late Cretaceous, e.g. palaeontological, geochemical, geophysical, etc. The resulting models can be tested by comparison with evidence from radiolaria and other siliceous faunas. The prediction of siliceous microfossil occurrences in unexplored areas should be more accurate if the knowledge of controls is increased, and an understanding of radiolarians in general will be enhanced by correlation of faunal response to conditions during this time period. Local and regional
events which may differ from general global trends during any period of
time further complicate interpretations.

8.3 Continental Land Masses

Sea covered more of the earth's surface during the Cretaceous than during
the Triassic or Jurassic, so there is more marine sediment of this age than
for the rest of the Mesozoic (Frakes, 1979) and, therefore, more potential
evidence for reconstruction of events. The fossil and sediment records are,
however, always uneven and/or modified.

Fragmentation of continents accelerated during Late Mesozoic times,
leading to extensive Cretaceous sea floor, which is still present in large
areas of modern oceans (Frakes, 1979). The general distribution of
continents in the Mesozoic is similar to the present day in that the majority
of land mass is located in the northern hemisphere, leaving large areas of
uninterrupted ocean in the southern hemisphere. Figure 8.1 shows a
palaeogeographical reconstruction (c.80Ma) and the reconstructed
locations of the sites studied in this work. The latitudinal position of
Cyprus, for example, is interpreted as c.5° south of its present day
position.

Continental positions also affect atmospheric circulation patterns and the
climate, the position of the seaways (the main difference between the
present day geography and that of the Late Cretaceous is the existence
then of a global equatorial seaway), and the current routes. The oceanic
circulation patterns of Late Cretaceous oceans and the influence of
continental configuration are discussed by Blueford (1989, Figure 2.2).

Configuration of the continents (formerly the Gondwana supercontinent)
affects heat radiation and the retention of energy, thereby affecting both
oceanic and atmospheric circulation, together with land climate, which
drives circulation. Barron and Washington (1985) suggest that the degree
of high latitude continentality is of major importance, as high latitude land
serves as a surface for the accumulation of high albedo snow and also
limits poleward heat transport by the ocean.
8.4 Tectonic activity and associated volcanics

Accelerated fragmentation of continents in the Late Cretaceous was associated with an increased rate of uplift and erosion and of submergence of land areas. These conditions increased available silica for dissolution in marine water and facilitated an increase in radiolarian production.

Associated volcanic activity may have also been responsible for release of silica into sea water directly from active submarine volcanicity or from weathering of volcanic rocks or volcanic ash. There are many examples in the literature documenting the recovery of Mesozoic radiolarians from sediments associated with extrusive volcanic rocks, e.g. Farinacci (1989) records a great proliferation of Late Jurassic siliceous organisms associated with submarine volcanism in Tethys, and Nachev et al. (1989) document occurrences of Cretaceous siliceous microfaunas from Bulgaria, with associated volcanic sediments. In this work, abundant and diverse radiolarian assemblages have been recovered from sediments containing volcanic constituents in Cyprus and in Atlantic DSDP/IPOD Sites 152 and 369A.

Whether or not volcanism enhances surface production of siliceous microfossils, burial in proximity to basaltic rocks is thought to have a destructive effect on siliceous tests during diagenesis. Baumgartner (pers. comm., 1990) suggests that the weathering of basalt produces a silica-poor clay which then acts as a silica sink. He reports that well-preserved radiolarians are never found in the 10 - 12m of sediments overlying basement and also that well-preserved specimens are never recovered from sediments between pillow lavas. Cann (pers. comm., 1990) agrees with this view and acknowledges the possibility that "the alteration of basalt material to various clay minerals depletes circulation solutions in silica and so acts as a drain on silica and therefore must be replaced by a further solution of silica in the sediment". Karl (1989) documents radiolarians from Cretaceous cherts overlying basalts in the Kelp Bay group of S.E. Alaska but these may be preserved due to the highly siliceous nature of the host sediment.

The destructive influence of proximity to ocean floor basalt can be illustrated by material from this study as shown by the etched nature of
radiolarians (and foraminifera) from the lower sediments of DSDP Site 152 and the paucity of radiolarians in the umber sections of Cyprus, possibly due to hydrothermal leaching.

8.5 Sea Level
Siliceous peaks are recorded by numerous authors as coeval with times of high sea levels. Comparison of published accounts of rich and diverse radiolarian assemblages in the Cenomanian/Turonian and the Campanian correspond with the rise of global sea levels as illustrated by Haq et al. (1988). Reported occurrences of high radiolarian productivity and diversity in Tethyan Albian sediments by Jud (pers. comm., 1988) and high productivity of siliceous microfossils in the Upper Palaeocene-Lower Eocene sediments of the North Sea and the Lower Eocene sediments of the South Atlantic also correspond with these predicted relatively high, global sea levels. Associated transgressive phases, i.e. flooding of continental margins, are a source of input of nutrients as well as a source of silica into the marine realm. The flooding of continental margins produced shallow epicontinental seas.

Peaks of diversity correlating with higher sea levels also apply to calcareous nannofossils (Bown et al., 1991).

Late Cretaceous transgressions culminated in the Santonian and were exceeded in extent only by those of the Palaeozoic (Frakes, 1979). Sea level rise may have accelerated because of an increased rate in sea floor spreading and an increase in mid-ocean ridge length and volume.

Intensified radiolarian production is recorded in Late Cretaceous through Eocene transgressive seas by Blueford (1989). She suggests that a shallow sea extended down the west side of the present Atlantic from the Arctic sea to the Gulf of Mexico during late Albian to Maastrichtian times therefore inhibiting radiolarian productivity. This may explain the paucity of radiolarian faunas recovered in this study from DSDP/IPOD Site 612. However, moderately rich and diverse radiolarian assemblages were recovered from Albian - Campanian sediments by Thurow (1988a) from nearby Sites 603 and 605. Additionally, Site 612 yielded abundant and
diverse assemblages of calcareous nannofossils which indicate open marine, high nutrient conditions.

8.6 Climate

Increasing attention is being paid to palaeoclimatic modelling and techniques for interpreting Cretaceous climates are being improved. There is general agreement that there was a warming to a mid-Cretaceous peak and then a cooling trend until the end of the Maastrichtian. One of the techniques used is oxygen isotope analysis. Spaeth et al. (1971) used this method to record a warming towards the mid Cretaceous and then a cooling, based on belemnites. Results of studies by Douglas and Savin (1975) from the central and northwest Pacific show a slight warming from the Valanginian to Albian and then a marked cooling from Campanian to Maastrichtian. They also suggest that vertical temperature gradients in the oceans were less than 50% of present day temperature gradients. Savin (1977) records warming from mid-Cenomanian to late Coniacian and then cooling until the Maastrichtian in the Pacific and the South Atlantic. Data processed in this way is however subject to error as different workers have used different faunas (e.g. planktic foraminifera and belemnites) and collected material from different depths.

Barron and Washington (1985) estimate that temperatures in the Late Cretaceous were 4 - 8°C warmer than the present day and examine whether a higher atmospheric content of CO₂ may be the cause of this warming rather than geographical configuration of the land masses of the period. It is also coincident with a period of high CO₃ productivity and deposition in the oceans at that time.

The climatic influences also have a direct influence on run-off and sedimentation rates into the oceans.

Less intensive radiation impact on surface waters at high latitudes and a higher penetration by radiation of the water column at low latitudes may have affected symbionts and therefore promoted provincialism in radiolarian faunas. In addition provincialism may have been promoted by the use of certain groups of symbionts as an adaptation to low fertility
(Baumgartner, *pers. comm.*, 1990), i.e. symbionts could change or be changed depending on the radiolarian host or on the situation.

8.7 Upwelling

Upwelling systems are important sites of biogenic silica secretion and deposition in modern seas, primarily diatoms with subordinate radiolarians. In the Late Cretaceous the role of the diatom was probably less important than now but availability of nutrients would have had a similar effect on food chains and similar results for radiolarians.

It is generally accepted that upwelling areas which bring nutrient rich waters to the surface are the sites of high plankton productivity. Many workers believe that it is only or mainly in these areas in which high productivity is sustained that the productivity of siliceous microfossils is high enough for a fraction of the initial population to be preserved in the sediment record. This theory is based, in part, on the fact that the uptake of silica from sea water for test building is a process requiring high energy levels and therefore high nutrient levels, and partly because of the fact that opal A (i.e. amorphous silica of organic tests) has a high susceptibility to dissolution, both in the water column during settling and during the post-depositional/pre-burial stage, and therefore the survival potential of fossil remains is so small that significant fossil assemblages will only be found in high productivity areas.

Barron (1985) demonstrates that the location of upwelling regions is sensitive to geography. He found that model predictions of Cretaceous ocean and coastal upwellings compared favourably with present day observations and with estimates of primary productivity.

Although it is agreed that these observations may be true up to a point, it does not mean that siliceous microfossils can only be recovered from areas of predicted palaeo-upwelling. Other variables must be considered, such as the silica budget of the water mass at a particular time or in a particular area, biogenic competition both in the surface layers and at the site of deposition (i.e. carbonate deposition negligible below the CCD), pH and temperature of the water, anoxicity, etc., e.g. Kuhnt *et al.* (1986) record
blooms and diversification in radiolarian populations as coeval with the onset or intensification of anoxic conditions.

Kuhnt et al. (1986) suggest upwellings play a role in temperature control, i.e. that colder water promotes optimum conditions for biomineralization of skeletons and that upwelling brings this colder water together with nutrients into the surface water layers, therefore providing an environment favourable to high productivity. Baumgartner (pers. comm., 1990) suggests that dissolved silica is also brought into the zone of productivity by upwelling, i.e. bottom water with dissolved Si from diagenetic pore waters. Comparison of interpreted sites of palaeo-upwelling (as given by Parrish and Curtis (1982) for example) and the recorded occurrences of Late Cretaceous radiolarians (Figure 1.2 and Figures 4.3, 4.4), however, point out the disparity between radiolarian occurrence and upwelling zones, i.e. that while radiolarians are found in upwelling areas they are also found commonly in other locations.

Drewry et al. (1974) record the deposition of Cretaceous cherts as almost entirely confined to an area then between the 30°N and S lines of palaeolatitude. They suggest that these areas of deposition represent local upwellings associated with the Trade Winds. Modern polar extremes of temperature lead to shallower CCD at poles, a situation which probably was not true during the Cretaceous when there was perhaps a more uniform CCD depth in tandem with low equatorial to pole temperature gradients.

Although fossil radiolarians or siliceous oozes are considered to play a major part in the origin of certain chert formations and radiolaria can be recovered in abundance from cherts, they are also recovered, both as SiO₂ and replacement minerals, from chert-free lithologies such as chalks, limestones and mudstones, e.g. in this study from Cyprus and DSDP/IPOD Site 369A, demonstrating that oceanic conditions, high productivity and favourable preservation conditions are the key aspect of fossilization potential. It is probable that favourable conditions fluctuated during the Cretaceous, i.e. the silica concentration of the water may have been high at different times in different places and at different water depths and that preservation potential varied geographically through time.
8.8 Relationships with other microfaunal groups
It is possible that in certain conditions the presence of radiolaria in zones of productivity may have been adversely affected by population explosions or unusually high productivity by other groups, e.g. diatom blooms. Local conditions (including upwelling zones), such as unusually high nutrient supplies, may have promoted dominance by one species or group. It is unlikely however that the duration of these conditions was sustained over relatively long periods of time. Sufficient numbers of available symbionts may also have been a factor in inter-group competition.

A high incidence of bioturbation due to favourable, oxygenated bottom conditions may destroy radiolarian tests after only shallow burial, either by re-exposure to sea water, or by dissolution by the organic acid secretions of burrowing organisms. In the material analysed for this project, communities of radiolarians have been recovered from the same samples as planktic foraminifera and calcareous nannofossils, suggesting that cohabitation of the same life environment was likely in the Late Cretaceous as it is at the present day.

8.9 Rates and patterns of evolution
General trends in skeletal evolution of radiolarians, at least from the Triassic to Recent, apparently show a thinning of the test and development of more delicate structures, e.g. Triassic forms appear sturdy with thick, often twisted spines whilst Cenozoic and Recent forms are thinner and more delicate. It may be that more delicate forms existed in the early Mesozoic but have not survived diagenesis or it may be a function of the evolution of the silica budget through time, together with later competition for skeletal materials from increased production of other siliceous organisms such as diatoms and silicoflagellates. Species living at greater depths may have stronger or thicker skeletons to withstand the greater hydrostatic pressure and therefore may be more resistant to dissolution. Additionally, they have less distance to travel downwards through the water column and may be buried sooner (Casey, 1977). It is possible that thicker tests during the Mesozoic may reflect greater availability of silica or may have been necessary to be more resistant to dissolution.
Thurow (1988a) suggests siliceous peaks (manifested in widespread and abundant fossil radiolarian assemblages) in Cenomanian/Turonian and Campanian times. It is however difficult to identify Coniacian and Santonian sediment intervals using microfossils, particularly in non-calcareous sediments, and these apparent peaks may just be in relation to lack of events in Santonian/Coniacian. Sissingh (1977) records only 4 first occurrences of calcareous nannofossils in these latter stages and no last occurrences. Caron (1985) records 23 last occurrences of planktic foraminifera. However, this method of assessment has limitations in that species are not all globally widespread.

8.10 Host sediment
From the calculated rate of sedimentation, it is possible to indirectly calculate the average sediment content of the water column over a period of time. Radiolarians, particularly those forms living at greater depths (for example, below the photic zone) may find a high sediment content of the water mass inhibiting (i.e. turbid water). In this context, explanations are sought for the absence of radiolarians in IPOD/DSDP Site 612.

The nannofloras in Site 612 are exceptionally well-preserved, the host sediment being highly calcareous, which supports a theory that radiolarians are not well-preserved in calcareous sediments unless the sediments are silicified, i.e. dissolution of a fraction of the siliceous faunas has been inhibited by silification of host sediments during diagenesis. Conversely, however, there are many exceptions to this model, as illustrated by Baumgartner and others who have recovered good radiolarian faunas from Tethyan limestones of southern Europe. In DSDP Site 152 radiolarian faunas coexist with calcareous faunas in silicified limestone. In DSDP/IPOD Site 369A and in Cyprus sections, radiolarians have been recovered from unsilicified chalks.

Westberg-Smith et al. (1987) in a study of radiolaria from DSDP/IPOD Site 609 in the North Atlantic record "a strong tendency for the radiolarians to be better and more abundant where mineral grains are fewer and vice versa". They further suggest that this is evidence for dissolution of siliceous microfossils in the presence of high concentrations of terrigenous silt and sand size components. Johnson (1976) also found
an inverse correlation between siliceous microfossil preservation and input of terrigenous silicates in sediments of the eastern tropical Pacific. However, in DSDP/IPOD Site 607, also in the North Atlantic, Westberg-Smith and Riedel found that low abundances of poorly preserved radiolarians are not associated with high concentrations of mineral grains. These observations suggest that it may not be the presence/absence or abundance of mineral grains which influence the presence of radiolaria in the life environment (discussed above) but that the preservational potential after deposition may be (at least partly) governed by the characteristics of the mineral grains, e.g. volume, shape or mineralogy. The absence or the poor preservation of radiolarians in sediment with abundant mineral grains may be the physical influence of the grain size, shape and distribution of the minerals directly influencing porosity and, more importantly, the permeability of the sediment. A high permeability value would allow a greater rate of pore water movement and produce greater potential for chemical dissolution and subsequent removal of susceptible material, i.e. an open system would maximise potential loss during diagenesis of SiO₂, CaCO₃ etc. In this work it was observed that in some sediments with an abundance of quartz grains >63μm, (e.g. as in the Anadhiou-Sarama section, Cyprus), that although radiolarian preservation is moderately good the preservation of calcareous components such as nannofossils and foraminifera is poor with most specimens being highly etched. This preferential dissolution suggests the presence and movement of acid pore waters.

It has been shown that radiolarians prefer an oceanic or deeper water (i.e. live at depth) offshore environment (Anderson, 1983), which is also an environment likely to have little suspended sediment in near surface water layers, however, it has not been shown that there is a casual link with a preference for offshore habitats.

In this study, radiolarians have been found in similar abundances and preservational conditions in samples with no silicate mineral grains above 63μm in size (e.g. DSDP/IPOD Site 369A and Perapedhi (location 10) where specimens were rare to common and moderately well-preserved, and in the Paleomylon (location 5) and Akamas (location 1) sections where specimens are abundant and well-preserved). Conversely, in
samples with common mineral grains above 63 μm, (e.g. certain samples from Paleomylon and Akamas) radiolarians have been recovered with varying abundances and preservation. It seems that it is not the particle load in the water column or type of sediment (e.g. mudstone, limestone or sandstone) which governs the radiolarian environment of preservation but the chemical composition and chemical - physical association of the mineral grains present during diagenesis which determine the solubility of the skeletons.

8.11 Diagenesis
Diagenetic history, including temperature and pressure effects and the rate at which they were exerted, is responsible for both local and regional variation in the preservation of siliceous microfossils in sediment. Lithology, bottom water chemistry and pore water chemistry, tectonic activity, time, rate of sedimentation and burial, subsidence rate (and any inversion history) are all fundamental in determining the post depositional history of a sediment and its contained microfossils. Although radiolarians are marine planktic organisms and are therefore not facies controlled in their living environment, the sediment and conditions in which they are buried play a part in their preservational history as they effectively become sediment particles during diagenesis.

As discussed above, in Chapter 8.4, proximity to igneous rocks may have an adverse preservational effect on radiolarian skeletons; it may also effect calcareous tests. In DSDP Site 152 both the radiolarians and the planktic foraminifera are etched and planktic foraminifera are silicified in proximity to ocean floor basalt.

It is likely that diagenetic effects unfavourable to the preservation of radiolarians are promoted by input of certain terrestrially derived sediments, i.e. chemical characteristics of the sediment as discussed in Chapter 8.10.

Time may also be an important factor in diagenesis, one which cannot be easily simulated in laboratory experiments. It is, however, not merely the ageing factor which should be considered but also the fact that the
sediments have been available longer for other processes to act on them. Cretaceous faunas have had a longer time to be buried deeper than faunas in younger rocks and are more susceptible in this way.

8.12 Discussion
In the DSDP/IPOD reports in which radiolaria were actively sought a reasonably accurate picture of their occurrence is assumed. In the 140 DSDP/IPOD sites (Figure 4.5) which penetrated Cretaceous lithologies in Legs 1-96, 76 of these sites contain Cretaceous radiolaria, whilst 124 record calcareous nannofossils and 122 record planktic foraminifera. This should not be viewed in terms of relative occurrence patterns but in terms of relative perception of occurrences. The fact that positive occurrences have been recorded at c. 55% of sites analysed shows that radiolaria are a significant component in microfaunal assemblages. The pattern of occurrence (cf. Figures 1.2, 4.3, 4.4) is more difficult to interpret and when plotted on a map there seems to be no latitudinal or geographical rationale behind the pattern of radiolarian records. It is unlikely that water mass distributions can be a significant factor as sites of the same age in close proximity to each other may or may not yield radiolaria (cf. Figures 1.2, 4.5).

It seems an improbable assumption that a successful group such as radiolarians, which are geologically long-ranging, locally abundant and diverse, and geographically widespread, would not have had a cosmopolitan occurrence throughout Late Cretaceous times. They may have suffered temporary local competition from other groups, such as diatoms, but although diatoms are now volumetrically the dominant phytoplankton group, during the Late Cretaceous they were not as well established. The fact that radiolarians have survived at least another 100 million years in association (or competition) with diatoms makes it unlikely that they were a serious displacement factor for radiolaria. Late Cretaceous diatom occurrences recorded in the literature are sparse and it seems unlikely that diatoms were serious competition to radiolarians in the Late Mesozoic.

Evidence of radiolarian occurrence documented to date appears to indicate correlations with areas of concentration of nutrients and...
with offshore (>200m water depth) marine habitats. The main controlling influence on occurrence seems to have been, as now, the configuration of the continents. This configuration provides the physical constraint on oceanic movements, controls the volume of water in relation to climatic belts, and thus influences all biogeochemical cycles. The stratigraphical distribution of radiolaria compared with sea level change shows a positive correlation. The abundance of living radiolaria correlates with the distribution of upwelling zones.
CHAPTER 9

CONCLUSIONS

Chapters 1 - 8 each contain concluding points and discussion. This chapter provides a summary of the main conclusions discussed in the previous text.

9.1 History of research
Investigation into the history and rate of research into siliceous microfossils indicates a growing interest in radiolarians since the early 19th Century. However, even though research into these forms has been going on for nearly 200 years, only recently (within the last 20 years, and probably as recognition of their potential for addressing geological problems) has communication and co-operation between international workers significantly improved. The large number of synonyms which was previously rife is being overcome, mainly with the establishment and dissemination of computerised databases. Siliceous microfossils represent a significant potential resource for both a) refining existing biostratigraphical zonation schemes, b) in dating cherts and c) interpretation of palaeoenvironments/palaeoceanography.

9.2 Production and Preservation of siliceous microfossils
Distribution patterns of siliceous microfossils are a function of both sufficient biogenic production (i.e. areas of high productivity such as upwelling zones, where post-mortem deposition is most likely to exceed dissolution) and favourable preservational conditions (i.e. low pH values, lack of bottom-water turbulence, etc.) at the site of deposition. Regional conditions affecting the post-burial history (e.g. depth-controlled temperature and pressure conditions) could be expected to have only a localised influence on global distribution patterns. Probably the most important influencing factor, however, is the state, during any one period in time, of the silica budget and the distribution of $\text{H}_4\text{SiO}_4$ during that period. The interaction of major global conditions such as continental position, climate and sea-level change, etc., and the rate of change in these conditions will undoubtedly have had significant effect on the evolution of the silica cycle.
9.3 Preparation techniques and methods
During these investigations an appreciation has been acquired of how slight differences in sample preparation, viewing, data recording and data presentation techniques can result in exaggerated differences in results and hence of interpretation. This experience has produced a greater understanding of possible causes of discrepancies among published reports by different authors. Any interpretations made from collated information must take into account possible assemblage distortion caused by the analytical techniques used.

From the wide range in size and type of skeletal materials found in radiolarians no single universal preparation and concentration method can be applied.

9.4 The selection of studied sections
An extensive literature review shows that the geographical and stratigraphical distribution of radiolaria and other siliceous microfossils is widespread, often co-occurring with calcareous microfossils. A paucity of documented occurrences is considered due more to lack of investigation than to the absence of siliceous organisms. It is also apparent from this literature survey that there are no unusual global or stratigraphical parameters controlling the occurrence of siliceous microfossils and that their presence in sediments examined is governed by the same factors as for other groups of microfossils, i.e. primarily palaeoenvironmental conditions and diagenetic history. In any attempt to demonstrate the potential biostratigraphical and palaeoenvironmental use of siliceous microfossils it is therefore necessary to be critical about the identification of sections which will provide a variety of data for comparative investigations.

9.5 Cyprus
The geological history of Cyprus is extremely complicated and agreement on the age of genesis and emplacement of the Troodos Complex and associated sedimentary cover is far from settled. The twenty sections analysed from Cyprus, representing a variety of lithological formations and sediment types, have yielded micropalaeontological evidence which contributes to a further understanding of past events in this area.
1. Radiolaria, agglutinated foraminifera and calcareous benthic foraminifera have been recovered from interlava sediments and umbers. Although the faunas examined to date are sparse, poorly-preserved and lack age-marker species a greater potential is indicated for future investigations. A more comprehensive sampling strategy and better established radiolarian ranges will facilitate future determination of the biostratigraphical positions of these sediments.

2. The Perapedhi Formation radiolarian mudstones have an abundant and diverse fauna of radiolarians which confirm a Campanian age interpretation for these sediments in the absence of calcareous microfossils. There is potential for a more refined radiolarian zonation of coherent and stratigraphically longer sections.

3. The Kannaviou Formation contains co-occurring calcareous and siliceous microfossils of Campanian age but integrated correlations between sections are limited by: i) the highly disturbed nature of the sediments (i.e. slumps, faults and repeated sequences); ii) deposition within a geologically relatively short time interval; iii) a high incidence of selective dissolution of both calcareous nannofossils and radiolaria; and, iv) the fragmented nature of exposures.

4. The Kannaviou/Lefkara boundary is difficult to study in places due to the effects of the emplacement of the Mamonia Complex and probable local erosion of the uppermost Kannaviou and/or lowermost Lefkara induced by this disruptive phase. It is possible that there are localities where the Kannaviou Formation passes conformably into the Lefkara Formation but these were not located in this project. On the northern side of the Troodos Massif (at least), the Cretaceous/Tertiary boundary is within the Lefkara Formation.

Development of a biostratigraphical zonation scheme for sediments examined during the course of this work, both from Cyprus and from the Atlantic, has been inhibited by combined factors of too short a time scale of deposition of the sediments selected (Campanian - Campanian/Maastrichtian) and by the fact that the distribution of radiolaria and calcareous nannofossils have been subject to extensive
dissolution. However, contributions are made with regard to radiolarian ranges and associations which significantly refine, confirm or revise existing zonation schemes.

9.6 Atlantic
Radiolaria from 2 sites (DSDP Site 152 and DSDP/IPOD Site 369A) were analysed and dated as Campanian and Campanian - Campanian/Maastrichtian respectively), one other site (DSDP/IPOD Site 612) lacked identifiable radiolaria. Examination of samples from DSDP/IPOD sections which have previously been analysed by other workers has been useful in gauging standards of approach and result. These standards particularly apply to: a) the variation between samples in amount of raw sediment needed to recover satisfactory microfossil assemblages; b) the variation between different workers in the number of species used in establishing biozones, and in the definition of a new species; c) the degree of intra- and inter-specific variation currently in use by experienced workers; d) the amount of time needed to produce viable results; e) variations in subjective concept, for example, the term "moderately well-preserved"; and, f) the influence of viewing methods on results obtained.

9.7 Biostratigraphical use of siliceous microfossils
From the analyses of both published material and sample material examined during the course of this work several conclusions are reached which are summarised as:

a) the potentially high diversity of radiolarian assemblages together with the fact that they are recoverable from lithologies unfavourable to other microfossil groups (in particular calcareous taxa) confirms their role as at least complementary in importance in biostratigraphic zonation schemes;

b) difficulties in integration of range data are enhanced by non-standard processing, viewing and illustrative methods of various workers;

c) despite the high diversity of Upper Cretaceous radiolarian faunas there is a paucity of universally established/agreed index markers species, e.g. the Campanian stage (which is relevant to material studied in this work) is divided only into two generally accepted biozones, the Amphipyndax pseudoconulus Zone of Foreman and the Amphipyndax tylotus Zone of Foreman. The identification of these zones relies on two species
Amphipyndax pseudoconulus and Amphipyndax tylotus the identifications of which are inhibited by: i) the fact that the internal structure of the cephalis must be examined in positive identifications; and ii) that both species are very similar to each other, morphological variation being difficult to establish in poorly-preserved material; d) of the 82 taxa recovered in this study which have published ranges, 67 have been previously recovered from Campanian age sediments - of the remaining 15 species 4 are only questionably identified, and the ranges of the other 11 species positively identified are here extended into the (stratigraphically higher) Campanian stage. There is clearly considerable scope for developing and refining radiolarian-based biozonation.

9.8 Controls on occurrence and preservation of siliceous microfossils in the Late Cretaceous
The main controlling influence on radiolarian occurrence seems to have been, as now, the configuration of the continents combined with the topography of the ocean basins. This configuration provides the physical constraint on oceanic movements, controls the volume of water in relation to climatic belts, and thus influences all biogeochemical cycles. Strong correlations with interpreted areas of palaeo-upwelling and high recovery rates of Mesozoic radiolarians are not at present convincing. The stratigraphical distribution and abundances of radiolaria appears to correlate most closely with eustatic sea-level change. In general periods of high sea-level stand appear to correlate with high diversity and abundance of radiolaria.

9.9 Lithological analyses
The storage of lithological and microfaunal analyses of samples on a machine database allowed rapid search facilities for correlative or inversely correlative characteristics. Similarly, the system allows for future rapid sample selection for specific purposes: e.g. refining a biostratigraphical zonation scheme, or with well-preserved radiolaria for a taxonomic atlas.

9.10 Systematic Palaeontology
The compilation of a taxonomic atlas with synonyms, geographical and stratigraphical occurrence patterns, descriptions and comprehensive
illustrations forms the basis of sound biostratigraphical interpretations. In Appendix 2 forty seven genera and one hundred and forty one species are identified. Of these taxa, fifty nine are left in open nomenclature, many of which represent new and undescribed species to be formally described when their occurrence patterns are more fully researched.

9.11 Future Work

9.11.1 Preparation techniques and Methodology
Data analysis and storage are still not far enough advanced or agreed upon to have become standard practice among the international community. A quantitative approach to preparation techniques may help to define an optimum potential recovery. The cataloguing of taxa should become more computer-orientated in the future, perhaps with individual workers standardizing descriptions into a form which is easy to enter onto a computer-generated database which is then relatively easy to disseminate to interested parties. There are a number of projects underway at present involving radiolaria, palynomorphs and foraminifera in particular whereby digitised images can be stored on compact disc. This pictorial information is also far easier to disseminate than the actual fossil type specimens.

9.11.2 Project direction
The field of research into siliceous microfossils is quite open at present. There is scope for extended research into the complex stratigraphy of Cyprus: when a biostratigraphy is established (using siliceous and calcareous micro/nannofossils), the tectonic evolution of the island can be unravelled. A greater number of more stratigraphically-extensive sections would have to be studied for an effective integrated biostratigraphy to be established for Cyprus. This could be checked against a biostratigraphy derived from more stratigraphically extensive, and carefully sampled DSDP/IPOD/ODP material.

Radiolarian work is in many respects still in a data gathering phase, a necessary precursor to better understanding of evolutionary and distributional patterns. A particular need at present is for information about biogeographical patterns in relation to the environment of living radiolaria.
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APPENDIX 1

LITHOLOGICAL DESCRIPTIONS

Introduction.
The following descriptions are records of the main characteristics of the samples studied and are not full sedimentological analyses. The data are stored on disc to facilitate machine recognition of positive and negative character correlations.

The aims of the exercise are:
1. to store basic sample information so as to allow computer searches for directly or inversely correlative characters, e.g. botryoidal manganese was found never to co-occur with calcareous foraminifera or nannofossils in the dataset; and
2. to permit recognition of individual samples for re-examination of a specific feature, e.g. those with well-sorted minerals may also contain well-sorted fossil material which may indicate reworking or transport.

Similarly, the system allows rapid selection of samples for specific purposes: e.g. refining a biostratigraphical zonal scheme, or with well-preserved radiolaria for a taxonomic atlas.

Each original sample was examined when dry for sedimentological structures, hardness, fissility, colour [using the Geological Society of America Rock Color Chart, 1979] and reactivity to HCl. Simple smear slide preparations of the raw samples were also examined. Following processing with \( \text{H}_2\text{O}_2 \) and HCl, smear slides of the sediment were prepared for transmitted light study. Dried residues retained after washing on a 63 \( \mu \text{m} \) sieve were inspected for their fossil and mineral content.

Samples are listed in numerical order, which is not necessarily stratigraphical order (see locality information in Chapters 5 and 6). Due to the word constraint placed on this work the sample data is not included here but is deposited in the Department of Geological Sciences, University College London.

Discussion
The recording of the lithological characteristics of a sediment sample (including faunal, floral and sedimentological content) is important for interpretation of the history of the sediment. Evidence which can suggest environmental conditions at the time of deposition and the subsequent diagenetic history can be collated in this way. Usually this
information is recorded on paper but in this study the potential for electronic storage and handling has been superficially explored by the input of data collected into a machine database.

With regard to the machine handling of data several conclusions were reached:

1. Adequate software for rapid analyses is required.

2. The design of data input and quality of data are major factors in the quality and quantity of data output. Categories and standards of the data to be collected must be defined and recorded in a consistent manner. Inconsistencies which would normally be compensated for when reading a report are not automatically be compensated for by machine analyses.

3. Interrogation design is a major factor in the quality and quantity of data output. For example, during the construction of the chart shown in Figure A1 no preservational or abundance characteristics were considered. The chart therefore gives no indication of the probable preservation or abundance of microfossils recovered from, say, chalk, but merely indicates that some of the chalk samples yielded microfossils in an unknown state of preservation.

4. The facility for improved interpretation can be significantly accelerated. On a small scale the database could be asked to list all samples which contain calcareous nanofossils and radiolaria but exclude planktic foraminifera. On a broader scale the samples containing reworked lithic fragments from older formations can be identified whilst in the same operation determining whether there is biostratigraphical potential for dating the time of erosion of these older formations.

5. Theories which might otherwise be disregarded can be immediately and effortlessly tested and areas for further research identified, e.g. why do fish teeth co-occur in samples with quartz grains but not in samples with lithic grains?

6. Confirmation of expectation can be established, for example calcareous nanofossils would not be expected to occur in non-calcareous sediments. Also, the non-confirmation of expectation can be an extremely valuable indicator of the need for further investigation, e.g. the occurrence of extremely well-preserved and abundant microfossils in sandstones.
7. The potential number of questions which can be rapidly answered by this method is enormous. Examination of the experimental matrix in Figure A1 reveals 812 examples of co-occurrence or non co-occurrence but because state of preservation (for example) was not included in the 29 characteristics it gives no indication of the likely preservation of microfossils recovered from chalk. If 812 questions can be answered from the plotting of 29 variables against each other showing the co-occurrence of only two of these 29 variables then the potential number of questions using more variables and the co-occurrence of three or more of these variables is enormous.

Preliminary conclusions from both the manual and machine analyses of data collected here are as follows:-

1. The presence of botryoidal manganese was not found to co-occur with calcareous microfossils, suggesting replacement or uptake of the calcite during manganese formation. The presence of larger, possibly more robust calcareous microfossils such as calcareous benthic foraminifera, planktic foraminifera and ostracods, but not calcareous nannofossils, in the same samples as angular manganese suggests either a tolerance by these larger forms to certain processes of manganese formation or a tolerance to co-existence with certain manganese compositions. Alternatively it may suggest that the manganese fragments have been re-worked into these particular samples.

2. Particular attention was given to the size range and size/shape diversity of radiolarian faunas recovered from samples with well-sorted mineral grains to determine the probability of reworking of the fossils. No samples with significant amounts of size- or shape-sorted fossils were recorded and although minor reworking is present in some samples no assemblages are interpreted as predominantly reworked.

3. Calcareous nannofossils and planktic foraminifera can be preserved in the same host sediment as siliceous microfossils.

4. Planktic foraminifera recovered from samples with abundant quartz grains and well-preserved radiolarians are poorly-preserved, being etched rather than abraded, broken or overgrown.

Specific conclusions reached from the collation of these data are discussed under the respective section headings both for the Cyprus and the Atlantic Sites analysed.
Figure A1 Correlation chart of fossil and mineral components compiled from 255 sediment samples analysed during this project.
APPENDIX 2

SYSTEMATIC PALAEONTOLOGY

Appendix 2.1 - Introduction

More time has been devoted to taxonomy in this project than was intended but the exercise provided significant reinforcement to the accepted rule that careful taxonomy is essential, in every application, for advancing biostratigraphical precision. The study of radiolarian taxonomy presents a special problem because of the high diversity of populations and the wide size range of radiolaria (c.30 - c.500 microns) presents a special challenge in terms of preparational and observational techniques.

A2.1.2 Historical Perspective

Radiolarians were first identified from marine sediments by Meyen (1834) when he described two new species from Mediterranean sediments. Following this initial report workers during the latter part of the 19th Century such as Ehrenberg, Rust, Parona and Haeckel also published accounts of radiolarian occurrences. The largest monograph of these organisms was produced by Haeckel (1887) and while he states (1887, p. ci) that "the natural system must be regarded as the goal of systematic classification" he admits that his ideals had to be compromised, in many cases, for a less desirable artificial system. The problems he identifies are the great diversity of forms present in this group and the fragmentary knowledge of radiolarians at the time of his investigations. Over a hundred years later and after the publication of more than 2500 studies, including major taxonomic revisions by Riedel (1967, 1971) and numerous modifications by other workers, these problems of classification have still not been satisfactorily resolved. Improved microscopy and photographic techniques together with electronic data storage and handling facilities, expert systems and increased scientific interest may now accelerate progress. However, large numbers of new forms are still being identified and the extent of the task has not yet been fully assessed.

A2.1.3 Classification schemes

Although, as explained below, grouping of forms into a classification scheme higher than generic level has been largely avoided in this work, the influence of higher schemes is still present. The scheme followed here is partly after Haeckel (1887) and Riedel (1967, 1971), with subsequent modifications at all levels below Suborder. Emendations relevant to forms discussed in the following text include the work of Baumgartner (1980), Dumitrca (1970),

A2.1.4 Presentation of Data

The format of the systematic section follows that of authors such as Schaaf (1981), Baumgartner (1984b) and Thurow (1988a) because of the extremely complex, and as yet poorly understood, nature of phylogenetic (and possibly polyphyletic) relationships within this group. This format lists genera, and their included species in alphabetical order and does not normally discuss higher taxonomic relationships. Importance is placed on recording and illustrating forms recovered, rather than attempting classificatory revision based on the present stratigraphically restricted assemblages. Morphotypes identified only to generic level have been left in open nomenclature and assigned codes such as sp.A, sp.B, etc. The naming of these forms awaits further detailed investigation.

As can be seen from papers published in the last twenty years, many of the names given to genera have changed rapidly and groups redistributed systematically. However, by giving the fullest text and figure documentation here it will be possible to easily revise and reorganise the data. This philosophy follows that of Haeckel (1887) who emphasised the hypothetical and provisional character of his classification.

Abbreviations - "aff." - specimens showing affinities with named species but not morphologically the same in some minor way; a major morphological difference would have resulted in a new name or code sp.A, etc. - "cf." - specimens compared with a named species but some evidence is missing, usually due to preservational factors such as breakage, overgrowth, dissolution or replacement minerals.

Synonymy - Synonymy lists have been compiled for each species. They are relatively comprehensive but omit clearly erroneous or ambiguous published records to achieve taxonomic consistency. Included in synonymies are forms which agree well with the species concept defined by the original illustrations and description/remarks. Comparative and type material from published collections has not yet been examined but material from samples used by Foreman (1978b) from DSDP Site 369A (the assemblages which contribute significantly to her 1977 zonation scheme) have been processed and examined.

Publications relating to the original description of a species have been marked with an asterisk (*).
Dimensions - ten specimens (when available) of each species were selected, including specimens from extremes of the size range.

Many species were represented by forms larger than the holotype, a pattern which may be due to either environmental or evolutionary factors but which has not been analysed in detail.

Remarks on genera - largely confined to observations on variable morphological features at generic level gained from the original description, subsequent observations by other workers, or from personal observations. These variable morphological features are discussed further, when relevant, in the species remarks and illustrated in the respective plates.

Occurrence [publications]: entries refer to positive occurrences in the region stated and are not meant to delimit the range of the species. Some records are clearly reworking and others poorly delimited stratigraphically. Occurrences cited (e.g.) as "Cenomanian - Maastrichtian" indicate that the relevant author considers the species to range from the first cited stage through to the second, whilst "Cenomanian/Maastrichtian" indicate that the age of sediments from which the species has been reported is somewhere within the Cenomanian to Maastrichtian interval. The abbreviation "N/G" indicates that a suggested age for deposition of the host sediment is not given by the author.

Occurrence [this work]: the format used above is followed and where possible a positive age based on calcareous nannofossil ranges (using the zonation scheme of Sissingh, 1977), is given.

A detailed discussion of species range concept is included in Chapter 7.

A2.1.5 Discussion

Morphological variation - it is important for reliable taxonomic and evolutionary studies to consider morphological variation however slight, but it was not considered practical in this study to oversplit similar forms into different species because:- a) at this stage in the development of a radiolarian classification scheme better understanding via more data collection and publication is first needed to sort out the relationships at a higher family level, and b) a broader approach is biostratigraphically more useful at the moment pending the establishment of reliable species ranges.

Once the taxonomical features of a group of forms are understood subsequent adoption of methods recording slight morphological variation of form may prove valuable. This is
particularly relevant in the collection and interpretation of data concerning palaeoenvironmental conditions, more refined biostratigraphical zonation schemes and the correlation of global events. These methods are demonstrated by Pokorny (1970) and Sanfilippo (1990).

Hierarchical Ranking of Morphological Features - difficulties have been encountered in the ranking of morphological features for taxonomy during assignment of forms to genera when, for example, they have the overall shape or general architecture of one genus and the internal or wall structures of another. A possible solution is to consider the stratigraphical range of these forms together with geographical pattern of occurrence to determine whether features are more likely to be attributable to homeomorphy, phyletic gradualism or temporary adaptation to environmental influence. Homeomorphy, for example in foraminifera, tends to be recognised by many authors when a substantial time interval occurs between the forms in question. When similar morphologies occur within the same time interval the animals are usually interpreted as being either genetically related or responding to environmental adaptation. This can apply to such features as general shape, presence of spines, etc. Another approach is to abandon preconceived classification schemes and interpret forms using "artificial intelligence" approaches.

Relevance of Taxonomical Studies in Routine Biostratigraphy - the ultimate requirement of radiolarian study for use as a biostratigraphical tool in routine analyses is to be able to identify specimens in both transmitted and reflected light. The more comprehensive the preliminary S.E.M. studies are the better the understanding of the morphology (e.g. key features) and accurate identification at lower magnification. In the classification of this particular group of organisms, both fossil and Recent, the study of both internal and external morphology is necessary. Only in this way by establishing seemingly insignificant, or easily overlooked features (e.g. presence/absence of descending thoracic spines in the cryptocephalic genera) can the problems of homeomorphy be tackled and confident identifications be made using less demanding observational methods.

Standards of Publication - the guidelines for publication by Dumitrica & De Wever (in De Wever et al. 1979) have been followed as far as possible. Difficulties have been encountered in extracting and comparing data of variable quality from published records. Different authors, methods of sample preparation and analysis have a significant effect on results recorded, especially in relation to taxonomy and assemblage composition. Some publications report only subsequent interpretations without original data. Ranges and occurrences are often given from a composite of isolated spot samples (a situation sometimes
not revealed without careful analysis of the text). Such ranges are clearly of limited reliability as they are a result of interpretation by the author. This is a major source of error which will only be resolved by more careful research.

The material illustrated here is deposited in the collection of University College London. The catalogue numbers refer to one of the film negatives used for each specimen.
APPENDIX 2.2
Index of Generic and Specific Names.

This index has been compiled following the format used by Pessagno (1976). The page numbers refer to Appendix 2 Taxonomic Atlas. Species are indexed both by their generic and specific names.

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<thead>
<tr>
<th>Species</th>
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<tr>
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<td>Alievium aff. A. zartum Empson Morin</td>
<td>A31</td>
</tr>
<tr>
<td>altamontensis (Campbell &amp; Clark), Theocampe</td>
<td>A122</td>
</tr>
<tr>
<td>amazon (Foreman), Bisphaeroccephalin(?</td>
<td>A43</td>
</tr>
<tr>
<td>Amphipyndax conicus Nakaseko &amp; Nishimura</td>
<td>A32</td>
</tr>
<tr>
<td>Amphipyndax mediocris (Tan Sin Hok)</td>
<td>A33</td>
</tr>
<tr>
<td>Amphipyndax pseudoconulus (Pessagno)</td>
<td>A34</td>
</tr>
<tr>
<td>Amphipyndax (?) pyrgodes Renz</td>
<td>A35</td>
</tr>
<tr>
<td>Amphipyndax stocki (Campbell &amp; Clark)</td>
<td>A36</td>
</tr>
<tr>
<td>Amphipyndax tylotus Foreman</td>
<td>A37</td>
</tr>
<tr>
<td>ancus (Foreman), Diacanthocapsa</td>
<td>A57</td>
</tr>
<tr>
<td>andersoni Pessagno, Archaeospongoprunum</td>
<td>A41</td>
</tr>
<tr>
<td>andersoni (Campbell &amp; Clark), Dictyomitria</td>
<td>A59</td>
</tr>
<tr>
<td>Archaeodictyomitria lamellicostata (Foreman)</td>
<td>A38</td>
</tr>
<tr>
<td>Archaeodictyomitria ?sliteri Pessagno</td>
<td>A38</td>
</tr>
<tr>
<td>Archaeodictyomitria sp. A aff. Dictymitria striata Lipman</td>
<td>A39</td>
</tr>
<tr>
<td>Archaeodictyomitria sp. B</td>
<td>A40</td>
</tr>
<tr>
<td>Archaeospongoprunum andersoni Pessagno</td>
<td>A41</td>
</tr>
<tr>
<td>Archaeospongoprunum cf. A. bipartitum Pessagno</td>
<td>A41</td>
</tr>
</tbody>
</table>
Archaeospongoprunum hueyi Pessagno ......................................................... A42

aster (Lipman), Crucella ........................................................................... A48

asymbatos Foreman, Stichomitra ............................................................ A118

australis Pessagno, Orbiculiforma .......................................................... A77

bipartitum Pessagno, Archaeospongoprunum cf. A ................................... A41

Bisphaerocephalina(?) amazon (Foreman) .............................................. A43

Bisphaerocephalina(?) heros (Campbell & Clark) ................................ A44

californiaensis Pessagno, Patulibracchium ........................................... A85

californica Campbell & Clark, Cornutella ............................................. A46

cachensis Pessagno, Crucella ................................................................. A48

Clathropyrgus titthium Riedel & Sanfilippo ........................................ A45

Clathropyrgus aff. C. titthium Riedel & Sanfilippo .............................. A46

communis Squinabol, Stichomitra ......................................................... A119

compacta Haeckel, Cyrtocalpis .............................................................. A55

conara (Foreman), Cryptamphorella ................................................... A52

conicus Nakaseko & Nishimura, Amphipyndax ................................... A32

Cornutella californica Campbell & Clark ............................................. A46

Crucella aster (Lipman) ........................................................................ A48

Crucella cachensis Pessagno ............................................................... A48

Crucella espartoensis Pessagno ............................................................ A49

Crucella irwini Pessagno ................................................................. A49

Crucella (?) sp.A .................................................................................. A50

Crucella (?) sp.B .................................................................................. A51

Crucella (?) sp.C .................................................................................. A51

Cryptamphorella conara (Foreman) ................................................... A52

Cryptamphorella macropora Dumitrica ............................................. A53

Cryptamphorella sp.A ......................................................................... A54

Cryptamphorella sp.B ......................................................................... A54

Cyrtocalpis compacta Haeckel ............................................................ A55

daseia (Foreman), Siphocampe ............................................................. A114

dauerhafta Empson Morin, Praeconocaryomma(?) .............................. A92

Diacanthocapsa acanthica Dumitrica .................................................. A56

Diacanthocapsa acuminata Dumitrica ................................................ A56

Diacanthocapsa cf. ancus (Foreman) ................................................... A57

Diacanthocapsa euganea Squinabol ..................................................... A57

Diacanthocapsa (?) sp.A ......................................................................... A58

Dictyomitra andersoni (Campbell & Clark) ......................................... A59
<table>
<thead>
<tr>
<th>Species Name</th>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Dictyomitra formosa</em></td>
<td>Squinabol</td>
<td>A60</td>
</tr>
<tr>
<td><em>Dictyomitra koslovae</em></td>
<td>Foreman</td>
<td>A61</td>
</tr>
<tr>
<td><em>Dictyomitra multicostata</em> (Zittel)</td>
<td></td>
<td>A62</td>
</tr>
<tr>
<td><em>Dictyomitra sagafera</em> Kh. Aliev</td>
<td></td>
<td>A63</td>
</tr>
<tr>
<td><em>Dictyomitra sp. A aff. D. sagafera</em> Kh. Aliev</td>
<td></td>
<td>A63</td>
</tr>
<tr>
<td><em>Dictyomitra sp. B aff. D. sagafera</em> Kh. Aliev</td>
<td></td>
<td>A64</td>
</tr>
<tr>
<td><em>dogeli</em> Gorbovets, <em>Septinastrum douglasi</em> Pessagno, <em>Actinomma(l)</em></td>
<td></td>
<td>A112</td>
</tr>
<tr>
<td><em>Eostichomitra warzigita</em> Empson Morin</td>
<td></td>
<td>A65</td>
</tr>
<tr>
<td><em>Eucyrtidium (?) sp. A</em></td>
<td></td>
<td>A66</td>
</tr>
<tr>
<td><em>Eucyrtidium (?) sp. B</em></td>
<td></td>
<td>A66</td>
</tr>
<tr>
<td><em>Eucyrtis sp. A</em></td>
<td></td>
<td>A67</td>
</tr>
<tr>
<td><em>eucesscei</em> Empson Morin, <em>Patellula</em></td>
<td></td>
<td>A83</td>
</tr>
<tr>
<td><em>euganea</em> Squinabol, <em>Diaconthocapsa</em></td>
<td></td>
<td>A57</td>
</tr>
<tr>
<td><em>floresensis</em> Pessagno, <em>Pseudoaulophacus?</em></td>
<td></td>
<td>A98</td>
</tr>
<tr>
<td><em>Foremanina schona</em> Empson Morin</td>
<td></td>
<td>A68</td>
</tr>
<tr>
<td><em>formosa</em> Squinabol, <em>Dictyomitra</em></td>
<td></td>
<td>A60</td>
</tr>
<tr>
<td><em>gallowayi</em> (White), <em>Alievium</em></td>
<td></td>
<td>A27</td>
</tr>
<tr>
<td><em>Gongylothorax (?) sp. A</em></td>
<td></td>
<td>A69</td>
</tr>
<tr>
<td><em>gracilis</em> (Squinabol), <em>Mita</em></td>
<td></td>
<td>A71</td>
</tr>
<tr>
<td><em>hastata</em> (Campbell &amp; Clark), <em>Praestlyosphaera</em></td>
<td></td>
<td>A93</td>
</tr>
<tr>
<td><em>Heliocryptocapsa sp. A</em></td>
<td></td>
<td>A69</td>
</tr>
<tr>
<td><em>heros</em> (Campbell &amp; Clark), <em>Bisphaerocephalina (?)</em></td>
<td></td>
<td>A44</td>
</tr>
<tr>
<td><em>Hexapyramis pantanellii</em> Squinabol</td>
<td></td>
<td>A70</td>
</tr>
<tr>
<td><em>?hokkaidoensis</em> Taketani, <em>Spongostaurus?</em></td>
<td></td>
<td>A115</td>
</tr>
<tr>
<td><em>irwini</em> Pessagno, <em>Crucella</em></td>
<td></td>
<td>A49</td>
</tr>
<tr>
<td><em>kleinum</em> Empson Morin, <em>Rhopalosyringium</em></td>
<td></td>
<td>A110</td>
</tr>
<tr>
<td><em>kirbyi</em> Pessagno, <em>Protoxiphotractus</em></td>
<td></td>
<td>A96</td>
</tr>
<tr>
<td><em>koslovae</em> Foreman, <em>Dictyomitra</em></td>
<td></td>
<td>A61</td>
</tr>
<tr>
<td><em>lamellicostata</em> (Foreman), <em>Archaeodictyomitra</em></td>
<td></td>
<td>A38</td>
</tr>
<tr>
<td><em>laxa</em> Pessagno, <em>Phaseliforma</em></td>
<td></td>
<td>A89</td>
</tr>
<tr>
<td><em>lenticulatus</em> (White), <em>Pseudoaulophacus</em></td>
<td></td>
<td>A101</td>
</tr>
<tr>
<td><em>liriodes</em> Riedel &amp; Sanfilippo, <em>Afens</em></td>
<td></td>
<td>A26</td>
</tr>
<tr>
<td><em>lodogaensis (?)</em> Pessagno, <em>Pseudodictyomitra</em></td>
<td></td>
<td>A108</td>
</tr>
<tr>
<td><em>macropora</em> Dumitrica, <em>Cryptamphorella</em></td>
<td></td>
<td>A53</td>
</tr>
<tr>
<td><em>magnificum</em> Campbell &amp; Clark, <em>Rhopalosyringium</em></td>
<td></td>
<td>A111</td>
</tr>
</tbody>
</table>
maxima Pessagno, *Orbiculiforma* .................................................. A77
mediocris (Tan Sin Hok), *Amphipyndax* ......................................... A33
*Mita gracilis* (Squinabol) .............................................................. A71
*Mita* sp.A ...................................................................................... A72
*Mita* sp.B ...................................................................................... A73
multicostata (Zittel), *Dictyomitra* .................................................. A62
*Novixitus* sp.A .............................................................................. A73
*Novixitus* sp.B .............................................................................. A74
*Novodiacanthocapsa (?) manifesta* (Foreman) ................................. A75
*Orbiculiforma australis* Pessagno .................................................. A77
*Orbiculiforma maxima* Pessagno .................................................. A77
*Orbiculiforma persenex* Pessagno .................................................. A77
*Orbiculiforma (?) aff. O. quadrata* Pessagno .................................... A78
*Orbiculiforma aff. O. railensis* Pessagno .......................................... A78
*Orbiculiforma sacramentoensis* Pessagno ....................................... A79
*Orbiculiforma* sp.A ......................................................................... A79
*Orbiculiforma* sp.B ......................................................................... A80
*pantanelli* Squinabol, *Hexapyramis* ............................................ A70
*pargueraensis* Pessagno, *Pseudoaulophacus* .................................. A102
*Paronaella venadoensis* Pessagno .................................................. A80
*Paronaella* sp.A .............................................................................. A81
*Paronaella* sp.B .............................................................................. A81
*Paronaella* sp.C .............................................................................. A82
*Patellula euesseei* Empson Morin ................................................... A83
*Patellula verteroensis* (Pessagno) .................................................... A84
*Patellula* sp.A ................................................................................ A84
*Patulibrachium californiensis* Pessagno .......................................... A85
*Patulibrachium* sp.A ....................................................................... A86
*Patulibrachium* sp.B ....................................................................... A87
*Patulibrachium* sp.C ....................................................................... A87
*Patulibrachium* sp.D ....................................................................... A88
*Patulibrachium* sp.E ....................................................................... A88
*persenex* Pessagno, *Orbiculiforma* ................................................. A77
*Phaseliforma laxa* Pessagno ............................................................ A89
*Phaseliforma aff. P. laxa* Pessagno ................................................... A90
*Phaseliforma* sp.A ........................................................................... A90
*Phaseliforma* sp.B ........................................................................... A90
Praeconocaryomma (?) dauerhafta (Empson Morin) .................. A92
Praeconocaryomma (?) universa Pessagno .................. A92
praegallowayi Pessagno, Alievium .................. A29
Praestylosphaera hastata (Campbell & Clark) ................. A93
Praestylosphaera privus (Foreman) .................. A94
Praestylosphaera pusilla (Campbell & Clark) ................. A95
Praestylosphaera sp.A ........................................ A95
Protoxiphotractus kirbyi Pessagno .................. A96
Protunum (?) sp.A ........................................ A97
?Pseudoaulophacus floresensis Pessagno ................. A98
Pseudoaulophacus aff. P. floresensis Pessagno ................. A99
Pseudoaulophacus sp.A ........................................ A99
Pseudoaulophacus sp.B ....................................... A100
Pseudoaulophacus lenticulatus (White) .................. A101
Pseudoaulophacus paragueraensis Pessagno ............... A102
Pseudoaulophacus vielseitigus Empson Morin .............. A103
Pseudoaulophacid sp.C ....................................... A104
Pseudoaulophacid sp.D ....................................... A105
Pseudoaulophacid sp.E ....................................... A106
Pseudoaulophacus riedeli Pessagno .................. A106
Pseudoaulophacid sp.F ....................................... A107
Pseudoaulophacid sp.G ....................................... A107
pseudoconulus (Pessagno), Amphipyndax .................. A34
Pseudodictyomitra ?iodogaensis Pessagno ............... A108
Pyramispongia (?) sp.A ...................................... A109
pyrgodes Renz, Amphipyndax (?) .................. A35
Rhopalosyringium kleinum Empson Morin .................. A110
Rhopalosyringium magnificum Campbell & Clark .......... A111
riedeli Pessagno, Pseudoaulophacus .................. A106
sacramentoensis Pessagno, Orbiculiforma .................. A79
sagitafera Kh. Aliev, Dictyomitra .................. A63
salillum Foreman, Theocampe .................. A122
schona Empson Morin, Foremanina .................. A68
Septinastrum dogeli Gorbovets .................. A112
Septinastrum cf. S dogeli Gorbovets .................. A112
Septinastrum sp.A ........................................ A113
Septinastrum sp.B ........................................ A113
Siphocampe daseia (Foreman) .......................................................... A114
?sliteri Pessagno, Archaeodictyomitria........................................ A38
Spongodiscid sp.A ........................................................................ A115
?Spongostaurus(?) hokkaidoensis Taketani................................. A115
starka Empson Morin, Acaeniotyle.......................................... A23
Staurodictya sp.A ........................................................................ A116
Staurodictya sp.B ........................................................................ A117
Staurodictya sp.C ........................................................................ A117
Staurodictya sp.D ........................................................................ A118
Stichomitra asymbatos Foreman .............................................. A118
Stichomitra communis Squinabol ............................................. A119
stocki (Campbell & Clark), Amphipyndax ................................ A36
Stylodictya sp.A ........................................................................... A120
Stylodictya sp.B ........................................................................... A120
Stylodictya (?) sp.C ..................................................................... A121
superbum (Squinabol), Aliievium ............................................. A30
Theocampe altamontensis (Campbell & Clark)............................ A122
Theocampe salillum Foreman .................................................... A122
Theocampe sp.A aff. T. salillum Foreman ................................ A123
Theocampe sp.B aff. T. salillum Foreman ................................ A124
tithium Riedel & Sanfilippo, Clathropyrgus .............................. A45
Triactoma sp.A ........................................................................... A124
Triactoma sp.B ........................................................................... A125
tylotus Foreman, Amphipyndax ................................................ A37
universa Pessagno, Praeonacaryomma(?) .................................. A92
venadoensis Pessagno, Paronaella ............................................ A80
verteroensis (Pessagno), Patellula .............................................. A84
vielseitigus Empson Morin, Pseudoaulophacus ....................... A103
warzigita Empson Morin, Eostichomitra ................................ A65
Xitus sp.A .................................................................................. A125
Xitus sp.B .................................................................................. A126
zartum Empson Morin, Alievium .............................................. A31
APPENDIX 2.3

Glossary of Morphological Terms Used in the Text

**ABDOMEN** - "Third chamber or segment of nassellariinid test", Pessagno (1976).

**APICAL HORN** - "Spine at apex of cephalis: connects internally to apical bar of cephalic skeletal elements; same as horn", Pessagno (1976).

**APICAL PORES** - "Variable number of large pores situated near apical horn in nassellarians", Pessagno (1976).

**BAR** - "Rod-like structure forming component part of polygonal pore frame", Pessagno (1971).

**BRACCHIOPYLE** - "Cylindrical, porous tube extending in a distal direction from the centre of the tip of the primary ray. Only known to date in *Halesium*, and *Patulibracchium*, Pessagno (1971).

**CAMPANULATE** - Bell-shaped.

**CENTRAL AREA** - "Area situated at juncture of rays", Pessagno (1971), describing *Patulibracchium*.

**CENTRAL DEPRESSION** - "Prominent depression on either side of disc-shaped test of members of *Orciculiforma*, Pessagno (1972).

**CEPHALIC SKELETAL ELEMENTS** (Nassellarians) - "Basic skeletal framework of cephalis: considered to be important in interpretation of the phylogeny of the Nassellariina", Pessagno (1976).

**CEPHALIS** - "First chamber or segment of nassellariinid test", Pessagno (1976).

**CORTICAL SHELL** (Spumellaria) - "Outermost of concentrically arranged shells of the Spumellariina; may be latticed or spongy", Pessagno (1976).

**COSTA (AE)** (Nassellaria) - "Linear to sublinear, continuous to discontinuous ridges on surface of nassellariinid test", Pessagno (1976).

**CRYPTOCEPHALIC** - Nassellarian test with cephalis depressed into the thorax or abdomen.

**CRYPTOTHORACIC** - Nassellarian test with thorax depressed into the abdomen.

**DISCOIDAL** - Test disc shaped e.g. *Pseudoaulophacus*, Phacodiscids, Coccodiscids and Spongodiscids.

**JOINT** (Nassellaria) - Refers to juncture between two chambers or segments.

**LACUNA** - "Cavity occurring in central area of some species of *Crucella*, sometimes covered by thin veneer of spongy meshwork", Pessagno (1971).
LOBES - Thickened, petal-shaped areas of the test in some Pseudoaulophacids, can be expressed at the equatorial margin producing a crenulated margin.

LUMBAR STRICTURE - Stricture between thorax and abdomen.

MAMMA (AE) (Spumellaria) - "Term describing cone-like tubercules characteristic of the cortical shells of the Praeconocaryommidae", Pessagno (1976).

MARGIN (LOBATE) - As in Pseudoaulophacus pargueraensis; should be closely inspected to make sure that lobed appearance is not produced by differential solution of broken spine bases, as in Pseudoaulophacus lenticulatus.

MEDULLARY SHELL(S) (Spumellaria) - "One or more concentrically arranged inner shells beneath cortical shell of certain Spumellariina", Pessagno (1976).

MOUTH (Nassellaria) - "Primary aperture of nassellariinid test", Pessagno (1976).

ONTOGENY - "The process of growth and development of an organism from inception of growth to maturity", Anderson (1983).

PATAGIUM - "Delicate spongy meshwork surrounding rays; comprised of polygonal pore frames consisting of bars lacking nodes at pore frame vertices", Pessagno (1971), describing Halesium. A patagium is also often present in some members of the genera Patulibracchium, Crucella, Septinastrum and ?Paronaella.

POLYPHYLETIC - "As a result of convergent evolution, a group of organisms may consist of members which have evolved from different series of ancestral forms", Whitten and Brooks (1972).

PORE FRAME - "Polygonal structure formed of bars or tabulae and bars usually connected (except with patagium) by nodes at vertices", Pessagno (1971).

PORES (PRIMARY) (Nassellaria) - "Pores of certain of the Archaeodictyomitridae. Distinguished from relict pores by remaining open and functional during ontogeny", Pessagno (1976).

PORES (RElict) (Nassellaria) - "Pores that become buried by accretion of later shell material during ontogeny and cease to be functional; visible only on eroded specimens. Characteristic of Dictyomitra sensu stricto", Pessagno (1976).

POST-ABDOMINAL CHAMBER(S), (Nassellaria) - "One or more chambers or segments following abdomen in a multichambered nassellariinid test", Pessagno (1976).

QUINCUNICALLY - arrangement of five pores in a set so that four are at corners of square or rectangle and the other at its centre (e.g. resembles the arrangement of the five on dice or cards).

RAY (PRIMARY) - "In Halesium, and Patulibracchium, ray possessing bracchiopyle", Pessagno (1971).
RAY (SECONDARY) - "In Halesium, and Patulibracchium, ray to left of primary ray", Pessagno (1971).

RAY (TERTIARY) - "In Halesium and Patulibracchium, ray to right of primary ray", Pessagno (1971).

SPINES (POLAR) (Spumellaria) - "Massive spines on diametrically opposed ends of elongate tests of some Spumellariina", Pessagno (1976).

SPINES (PRIMARY) (Spumellaria) - "Massive spines of cortical shell of certain Spumellariina; connect beneath and are aligned with radial beams of medullary shells", Pessagno (1977c).

STRUCTURE(S) (Nassellaria) - "Contraction of test of Nassellariina at position of joint between two successive chambers (segments)", Pessagno (1976).

SUTURAL PORE - A differentiated large pore located at a junction between two segments, usually between the thorax and abdomen.

THOLUS(I) (Spumellariina) - "Dome-like structures on opposite sides of test in members of Pseudoaulophacus: characterised by possessing markedly larger pore frames", Pessagno (1976). The term is also used to describe raised central areas in other Pseudoaulophacids and in the genus Patellula.

THORAX (Nassellaria) - "Second chamber (segment) of nassellariinid test; follows cephalis", Pessagno (1976).
APPENDIX 2.4

Generic and Specific Descriptions

Genus ACAENIOTYLE Foreman

Acaeniotyle FOREMAN 1973b, p. 258.
Type Species Xiphosphaera umbilicata Rust, 1898, p. 7, pl. 1, fig. 9.

Remarks: Acaeniotyle differs from the genera Praestylosphaera, Protoxiphotractus and Archaeospongoprurnum by the nodose wall structure of the cortical shell.

Acaeniotyle starka Empson Morin
Plate 1, Figures 1-3

1970 Actinommid gen. et sp. indet. Riedel & Sanfilippo, p. 504, pl. 1, fig. 1.
1971 Actinommid gen. et sp. indet. Kling, pl. 6, fig. 5.
*1981 Acaeniotyle starka Empson Morin, p. 260, pl. 4, figs 1 - 3B.
1988 Acaeniotyle starka Empson Morin; Abin, p. 54, pl. 5, fig. 6.

Remarks: Apparently closely related to Acaeniotyle umbilicata (Rust) but differs in lacking the pronounced nodes on the outer wall of the test. All specimens recovered are infilled and examination of internal structures was not possible. Size range: 180 - 330| µm (measured along the greatest axis and including the spines, 10 specimens).
Specimens frequently have one of the spines (usually assumed to have been the longer spine) missing through breakage and none of the specimens recovered have a third primary spine or spine base.

Occurrence [publications]: ?Campanian, Central Atlantic; Campanian, North Pacific, Campanian, North Pacific; Campanian, Cuba.
Occurrence [this work]: Campanian, Cyprus.
Genus *ACTINOMMA* Haeckel

*Actinomma* HAECKEL 1862, p. 440.

Type Species: *Haliomma trinacrium* Haeckel 1860, p. 815.

Remarks: Surface ornamentation and character and number of primary and secondary spines used to distinguish species. When studied with the S.E.M. members of this genus were frequently found to possess at least one unusually large circular pore frame in the wall of the cortical shell (see Plate 1, figs. 7, 8, 10). Infilling usually prevented examination of internal structures.

*Actinomma(?) douglasi* Pessagno

Plate 1, Figures 4 - 6

*1976* *Actinomma(?) douglasi* Pessagno, p. 43, pl. 12, figs. 6 - 8.

Remarks: The diameter of the cortical shell, excluding spines, of ten specimens ranges from 100 - 130 μm. Forms recovered here appear to have slightly more substantial spines than the holotype figured by Pessagno (1976, pl. 12, figs. 6 - 7).

Occurrence [publications]: Campanian, California.

Occurrence [this work]: Campanian, Cyprus.

*Actinomma(?) aff. A. douglasi* Pessagno

Plate 1, Figures 7 - 9

aff. *1976* *Actinomma(?) douglasi* Pessagno, p. 43, pl. 12, figs. 6 - 8.

Remarks: Pessagno records the presence of 'thinner subsidiary spines, circular in axial section' on the holotype but these features have not been observed in the present material because of poor preservation. The diameter of the cortical shell of ten specimens, excluding spines, ranges from 180 - 230 μm. Forms recovered in Cyprus are much larger (x2) than the type-series recorded by Pessagno (1976).
Occurrence [publications]: Campanian, California.
Occurrence [this work]: Campanian, Cyprus.

Actinomma sp.A
Plate 1, Figures 10 - 12

1982 Actinommid gen. et sp. indet. Kling, p. 545, pl. 1, fig. 4.

Description: Spherical to ellipsoidal test with six primary triradiate spines; two polar spines and four equatorial spines arranged at approximately 90 degrees. At least one medullary shell is present. Cortical shell consists of raised hexagonal pore frames surrounding round pores. Specimens observed showed little size variation. Size range: 140 - 160 \( \mu \text{m} \) (measured along the greatest length of the cortical shell excluding spines, 10 specimens).

Remarks: All specimens were wholly or partially infilled making examination of internal structures difficult. Specimens observed in transmitted light appear to show at least one medullary shell. No specimens were recovered with unbroken primary spines intact so it is not possible to document either the absolute or relative lengths of these features.

Occurrence [publications]: Campanian, North Pacific.
Occurrence [this work]: Campanian, Cyprus.

Actinomma sp.B
Plate 2, Figures 1 - 3

Description: Cortical shell spherical to sub-spherical with at least five, massive, triradiate spines. All specimens recovered are damaged and none has well-preserved spines. Pores are round to oval, irregular in size and surrounded by polygonal pore frames which have minute spines at junctions. At least one medullary shell with much finer meshwork is present located in a slightly off-centre position. Size range: 100 - 110 \( \mu \text{m} \) (diameter of the cortical shell, excluding spines, 5 specimens).
Remarks: This form resembles *Hexalonche senta* Kozlova (*in* Kozlova and Gorbovets, 1966, p. 58, pl. 8, figs. 8 - 11) from the Eocene of Western Siberia. As it is recorded rarely from Cyprus samples it may therefore be due to contamination although the source is unknown. The preservation of the silica of the tests of these forms is not significantly different from the Campanian radiolarian assemblage recovered from the same sample although the former are rarely infilled.

Occurrence [publications]: Eocene, Western Siberia.
Occurrence [this work]: ?Campanian, Cyprus.

Genus *AFENS* Riedel & Sanfilippo

*Afens* RIEDEL & SANFILIPPO 1974, p. 775
Type Species: *Afens liriodes* Riedel & Sanfilippo 1974, p. 775, pl. 11, fig. 11, pl. 13, figs. 14 - 16.

*Afens liriodes* Riedel & Sanfilippo
Plate 2, Figures 4 - 6

1973 Incertae sedis sp. A Moore, p. 830, pl. 13, figs. 1-3.
*1974* *Afens liriodes* Riedel & Sanfilippo, p. 775, pl. 11, fig. 11, pl. 13, figs. 14 - 16.
1978b *Afens liriodes* Riedel & Sanfilippo; Foreman, p. 750, pl. 5, fig. 24.
1981 Unnamed Nassellaria Nakaseko & Nishimura, pl. 13, fig. 6.
1982 *Afens liriodes* Riedel & Sanfilippo; Kling p. 548, pl. 1, figs. 23, 24; pl. 3, figs. 5, 6.
1985 *Afens liriodes* Riedel & Sanfilippo; Sanfilippo & Riedel, p. 624, text fig. 13, 3a-3c.
1988a *Afens liriodes* Riedel & Sanfilippo; Thurow, pl. 2, fig. 1.

Remarks: The siliceous skeleton and the occurrence in association with radiolarian assemblages seem to be the justification for classifying this form as a radiolarian. Size range: 200 - 500 µm (max. length, 10 specimens), usually c.300 µm and commonly recovered in radiolarian samples. It does not seem to have complex internal skeletal structures although Plate 2, fig. 5 shows two chambers just above the stalk. A specimen...
figured by Sanfilippo & Riedel (1985, text-fig. 13.3c) also shows an internal chamber in this same region. *A. liriodes* occurs, usually, in association with sponge spicules and may in fact be a sponge and has possibly also been recorded in non-radiolarian papers under another name. Radiolarian or not, it is a useful biostratigraphical marker as, because of its size and shape, it is easily distinguished and appears to have a relatively short range within the Senonian. The orientation of figures 4 - 6 follows that of the authors (Riedel & Sanfilippo) and of Foreman (1978b), although most workers favour the reversed orientation of Moore (1973) who first illustrated this form. Morphological variation can be relatively diverse, e.g. compare the two morphotypes illustrated in this report with Riedel & Sanfilippo (1974, pl. 13, fig. 14) and Kling (1982, pl. 1, fig. 24).

**Occurrence [publications]:** Campanian, Central Pacific; Coniacian - Maastrichtian, Indian Ocean; Campanian - Maastrichtian, Central Atlantic; N/G, Japan; Campanian, North Pacific; Campanian - Maastrichtian, Caribbean; Campanian, Caribbean; Campanian, North Atlantic; Campanian, Cuba.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22). Campanian/Maastrichtian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC23B).

**Genus ALIEVIUM** Pessagno


Type Species *Theodiscus superbus* Squinabol, 1914, p. 271, pl. 20, fig. 4.

**Remarks:** Differs from *Pseudoaulophacus* Pessagno (to which it may be ancestral) in lacking tholi and possessing meshwork of relatively uniform size throughout. Species are differentiated by a combination of size range, inflation of test and shape of primary spines in axial section.

*Alievi um gallowayi* (White)

Plate 2, Figures 7 - 9

*1928 Baculogypsina (?) gallowayi* White, p. 305, pl. 4, figs. 9, 10.

1962 *Aulophacus gallowayi* (White); Pessagno, p. 364, pl. 3, figs. 5, 6.

1963 *Pseudoaulophacus gallowayi* (White); Pessagno, p. 202, pl. 2,
\[ \text{figs. 1, 3, 6, pl. 4, figs. 2, 5, 7, pl. 7, figs. 2, 4.} \]

1970 \textit{?Pseudoaulophacus gallowayi} (White); Riedel & Sanfilippo, p. 505, pl. 2, fig. 5.

1972 \textit{Pseudoaulophacus gallowayi} (White); Petrushevskaya & Kozlova, p. 527, pl. 6, fig. 1.

1972 \textit{Alievium gallowayi} (White); Pessagno, p. 299, pl. 25, figs. 4-6, pl. 26, fig. 5, pl. 31, figs. 2, 3.

1973a \textit{Alievium gallowayi} (White); Foreman, p. 429, pl. 13, fig. 9.

1975 \textit{Alievium gallowayi} (White); Foreman, p. 613, pl. 1D, figs. 2, 3, pl. 5, fig. 11.

1976 \textit{Alievium gallowayi} (White); Pessagno, p. 27, pl. 8, figs. 13, 14, pl. 9, fig. 1.

1977c \textit{Alievium gallowayi} (White); Pessagno, pl. 6, figs. 5, 6.

1978a \textit{Alievium gallowayi} (White); Foreman, p. 840.

1981 \textit{Alievium gallowayi} (White); Nakaseko & Nishimura, p. 142 pl. 2, fig. 3.

1982 \textit{Alievium gallowayi} (White); Kling, p. 548, pl. 1, fig. 16.

1982 \textit{Alievium gallowayi} (White); Taketani, p. 50, pl. 10, fig. 7.

1985 \textit{Alievium gallowayi} (White); Sanfilippo & Riedel, p. 594, text fig. 6.1.

1988a \textit{Alievium gallowayi} (White); Thurow, p. 396, pl. 2, fig. 3.

\textbf{Remarks:} \textit{A. gallowayi} can be difficult to distinguish from \textit{A. superbum} and \textit{A. praegallowayi} as differentiation depends on spines being circular in axial section throughout their length in \textit{A. gallowayi} and these spines are commonly broken off. There is also moderate intra-specific variation in the inflation of the test and the coarseness of the surface meshwork - Pl. 2, fig. 7 shows a moderately inflated specimen with coarse meshwork and relatively large nodes, whilst Plate 2, fig. 9 shows a specimen with finer meshwork. \textit{A. gallowayi} is the only species in this genus in which some individuals show an extremely coarse meshwork. Plate 2, fig. 8, a light micrograph, shows internal thickening midway along the length of each edge of the test. This is only seen in some specimens but supports an affinity with the genus \textit{Pseudoaulophacus}, possibly they are part of a transition between \textit{A. gallowayi} and \textit{Pseudoaulophacus riedeli} Pessagno (Pl. 27, figs. 7-9).

Pessagno (1972) suggests that \textit{A. praegallowayi} gave rise to \textit{A. gallowayi} in latest Coniacian or earliest Santonian times.

\textbf{Size range:} 150 - 220 \(\mu\text{m}\) (maximum width of test in lateral view, 10 specimens).
Alievium praegallowayi Pessagno
Plate 2, Figures 10 - 12

1972 Alievium praegallowayi Pessagno, p. 301, pl. 25, figs. 2 - 3.
1973b Alievium cf. praegallowayi Pessagno; Foreman, p. 262, pl. 14, figs. 12, 15.
1975 Alievium praegallowayi Pessagno; Foreman, p. 613, pl. 1D, figs. 4, 5, pl. 5, fig. 9.

Remarks: This species is distinguished from A. superbum and A. gallowayi by the shape of its primary spines in axial section, which are triradiate at their proximal ends. This configuration continues for varying lengths until the spines become fully circular in axial section distally. It has been suggested (Pessagno 1972, 1976) that A. praegallowayi is a transitional form first occurring in late Turonian or early Coniacian times (A. superbum → A. praegallowayi → A. gallowayi). This model appears to be likely, although no evidence was found in this work. The shape of the spines is critical for species identification and these spines are commonly missing or truncated due to breakage.

Sizes range: 110 - 160 \( \mu \text{m} \) (maximum width of test, 10 specimens).

Occurrence [publications]: Turonian/Coniacian - Santonian, California; ?Cenomanian, North Pacific; Turonian - Santonian, North Pacific.

Occurrence [this work]: Campanian, Cyprus.
Alievium superbum (Squinabol)
Plate 3, Figures 1 - 3

*1914 Theodiscus superbus Squinabol, p. 271, pl. 20, fig. 4.
1917 ?Pseudoaulophacus superbus (Squinabol); Kling, pl. 6, figs. 13, 14.
1917 Pseudoaulophacus superbus (Squinabol); Foreman, p. 1675, pl. 2, fig. 5.
1972 Alievium superbus (Squinabol); Pessagno, p. 302, pl. 24, figs. 5, 6, pl. 25, fig. 1.
1972 ?Pseudoaulophacus superbus (Squinabol); Petrushevskaya & Kozlova, p. 527, pl. 3, figs. 1 - 3.
1973 Pseudoaulophacus superbus (Squinabol); Dinkleman, p. 790, pl. 1, fig. 9.
1973 ?Pseudoaulophacus superbus (Squinabol); Moore, p. 825, pl. 12, figs 4, 5.
1974 ?Pseudoaulophacus superbus (Squinabol); Riedel & Sanfilippo, p. 780, pl. 3, figs. 1-3.
1975 Alievium superbum (Squinabol); Dumitrica, p. 88, fig. 2.42
1976 Alievium superbum (Squinabol); Pessagno, p. 27, pl. 3, fig. 12.
1980 Alievium superbum (Squinabol); Schmidt-Effing, p. 245, fig. 14.
1981 Alievium superbum (Squinabol); Nakaseko & Nishimura, p. 142, pl. 2, fig.2.
1982 Alievium superbum (Squinabol); Taketani, p. 51, pl. 10, fig. 8.
1985 Alievium superbum (Squinabol); Sanfilippo & Riedel, p. 594, text fig. 6.2.
1986 Alievium superbum (Squinabol); Schaaf, pl.2, fig. 1.
1988a Alievium superbum (Squinabol); Thurow, p. 397, pl. 2, fig. 2.
1988 Alievium superbum (Squinabol); De Wever et al., p. 167, pl. 1, fig. 4.

Remarks: Distinguished from A. gallowayi and A. praegallowayi by the degree of inflation of the test and by the shape of the spines. Alievium superbum is thought to be the first member of this lineage, and its earliest reported occurrence is from the Cenomanian of Romania (Dumitrica 1975). This latter report has been used by many authors, however, Dumitrica (pers. comm. 1991) now considers the form he recorded to be closer to Alievium murphyi Pessagno than Alievium superbum, and to probably be a new species.

Ten specimens were measured across the maximum width of the test and these measurements range from 155 - 195 μm.
Occurrence [publications]: Upper Cretaceous, Italy; Campanian, North Pacific; Albion - Maastrichtian, Central Atlantic; Santonian - Campanian, Central Pacific; ?Campanian, Central Pacific; Cenomanian - Maastrichtian, Central Pacific; Coniacian - Maastrichtian, Indian Ocean; Turonian/Coniacian, California; Cenomanian, Romania; Turonian - Campanian, California; N/G, Japan; Cenomanian, Costa Rica; N/G, Japan; Turonian - Coniacian, Japan; Turonian - Campanian, Composite; Campanian, Oman; Cenomanian - Maastrichtian, North Atlantic; Turonian - Campanian, Oman.

Occurrence [this work]: Campanian, Central Atlantic, Cyprus.

Allevium zartum Empson Morin
Plate 3, Figures 4 - 6

1978b Allevium sp. A Foreman, p. 744, pl. 3, figs. (7)4, 6.
*1981 Allevium zartum Empson Morin, p. 257, pl. 1, figs. 1A-D, 2A-C.

Remarks: Size range: 90 - 120|/-tm (measured across the broadest part of the test, 6 specimens). This species is much smaller than other members of the genus, (usually in the range 110 - 195|/-tm), the triangular pore frames are more delicate and the size ratio of spine length to test width is much greater. Two morphotypes are illustrated in Plate 3, figs. 5/6 showing a specimen with relatively coarse meshwork and fig. 4 with much finer meshwork, produced into a delicate spinose surface. No specimens were observed with any of the three primary spines preserved and so no comment can be made on the length or shape of these features.

Occurrence [publications]: Campanian - Maastrichtian, Central Atlantic; Campanian, North Pacific, Venezuela, Mexico.

Occurrence [this work]: Campanian (or older), Cyprus.

Allevium aff. A. zartum Empson Morin
Plate 3, Figures 7 - 9

Description: Test discoidal with sub-rounded to sub-triangular outline in lateral view. Three triradiate spines located on the equatorial margin of the test forming angles at c.120° to each other. These spines are long in relation to the test although no specimens have been recovered with complete spines. The spines, which usually show a slight
curvature distally, appear to consist of three hollow tubes. The meshwork on the upper and lower test surfaces is in the form of coarse equilateral triangles with nodes at junctions. No examination of internal structures of this material was possible. Size range: 100 - 130 µm (measured across maximum width of test excluding spines, 10 specimens).

Remarks: These morphotypes are not included in A. zartum because it is not certain whether A. zartum possesses hollow spines formed from three tubes and because the meshwork of the forms found here is much coarser than that of Empson Morin's (1981) figured material.

Occurrence [this work]: Campanian, Cyprus.

Genus AMPHIPYNDAX Foreman

Amphipyndax FOREMAN 1966, p. 356, text figs. 10, 11.

Type species: Lithostrobus pseudoconulus Pessagno, 1963, p. 210, pl. 1, fig 8, pl. 5, figs. 6, 8.

Remarks: As members of this genus are defined on the internal structure of the cephalis (i.e. the division of the latter into an upper and [smaller] lower chamber by a shelf-like structure) it is necessary to use transmitted light to positively identify specimens

Amphipyndax conicus Nakaseko & Nishimura

Plate 3, Figures 10 - 12

1973 Lithocampe pseudochrysalis var. [alpha] Tan Sin Hok; Moore, p. 828, pl. 8, fig. 4.

*1981 Amphipyndax conicus Nakaseko & Nishimura, p. 143, pl. 12, figs. 1 - 2, pl. 17, fig. 8.

Non 1927 Lithocampe pseudochrysalis var. [alpha] Tan Sin Hok, p. 64, pl. 13, fig. 108.
Remarks: Nakaseko & Nishimura describe and illustrate an irregular dent in the middle of the shell which was not observed on specimens studied herein, possibly due to preservation.

*A. conicus* differs externally from *Stichomitra communis* Squinabol (Pl. 32, figs. 1 - 3) by the thickening of the shell wall in the cephalo-thoracic region.

Size range: 195 - 220 μm (measured along greatest length of test, 10 specimens, all with nine segments).

**Occurrence [publications]:** Coniacian - Santonian, Central Pacific; Albian/Cenomanian, Japan.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nanofossil assemblage dated as CC20/CC22C). Campanian/Maastrichtian, Central Atlantic.

*Amphipyndax mediocris* (Tan Sin Hok)

Plate 4, Figures 1 - 3

*1927* *Dictyomitra mediocris* Tan Sin Hok, p. 55, pl. 10, fig. 82.

1971 *Amphipyndax* cf. *A. stocki* (Campbell & Clark); Kling, pl. 8, fig. 10.

1974 *Amphipyndax mediocris* (Tan Sin Hok); Renz, p. 788, pl. 5, figs. 7 - 9.

1981 *Amphipyndax mediocris* (Tan Sin Hok); Nakaseko & Nishimura, p. 144, pl. 12, fig. 6.

Remarks: *A. mediocris* is distinguished from *A. stocki* by the lack of externally expressed segmental strictures. *A. mediocris* is probably shorter, having fewer post-abdominal segments than *A. stocki* but it is not certain if specimens of *A. mediocris* recovered in this work are complete.

Present specimens have either three or four post-abdominal segments. Size range: 120 - 150 μm (measured along greatest length of test, 10 specimens).

**Occurrence [publications]:** Cretaceous, Rotti; Campanian, North Pacific; Aptian/Maastrichtian, Indian Ocean; Albian/Campanian, Japan.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nanofossil assemblages dated as CC20/CC22C; CC22). Campanian/Maastrichtian - Maastrichtian, Central Atlantic (co-occurs with calcareous nanofossil assemblage dated as CC25A).
Amphipyndax pseudoconulus (Pessagno)
Plate 4, Figures 4 - 6

*1963 Lithostrobus pseudoconulus Pessagno, p. 210, pl. 5, figs. 6, 8.
1963 Lithostrobus punctulatus Pessagno, p. 210, pl. 5, figs. 4, 5.
1966 Amphipyndax enesseffi Foreman, p. 356, text figs. 10, 11a - b.
1972 Amphipyndax sp. A, Petrushevskaya & Kozlova, p. 545, pl. 8, fig. 18.
1973b Amphipyndax enesseffi Foreman; Foreman, pl. 15, fig. 19.
1973 Amphipyndax enesseffi Foreman; Dinkleman, p. 790, pl. 1, fig. 10.
1973 Amphipyndax enesseffi Foreman; Moore, p. 827, pl. 11, fig. 5.
1974 Amphipyndax enesseffi Foreman; Riedel & Sanfilippo, p. 755, pl. 10, figs. 12, 13.
1977 Amphipyndax enesseffi Foreman; Foreman, p. 313, pl. 1, fig. 2.
1978b Amphipyndax enesseffi Foreman; Foreman, p. 745, pl. 4, fig. 3.
1981 Amphipyndax enesseffi Foreman; Nakaseko & Nishimura, pl. 17, fig. 14.
1982 Amphipyndax enesseffi Foreman; Kling, p. 548, pl. 2, fig. 12, pl. 4, figs. 2, 3.
1982 Amphipyndax pseudoconulus (Pessagno); Empson Morin, p. 510, pl. 1, fig. 5, pl. 2, figs. 2-4, 5, 9, 10, 12.
1985 Amphipyndax pseudoconulus (Pessagno); Sanfilippo & Riedel, p. 596, text fig. 7, 1a-1c.
1988 Amphipyndax enesseffi Foreman; Abin, p. 63, pl. 7, fig. 5.

Remarks: Sanfilippo & Riedel (1985) distinguish A. pseudoconulus and A. tylotus by the surface tubercles in A. pseudoconulus being present only at segmental divisions. In SEM photographs this is sometimes difficult to identify, e.g. Sanfilippo & Riedel reject the identification of Empson Morin (1982, pl. 2, figures 6, 7, 8, & 11) and consider them to be A. tylotus; this is particularly confusing with regards to their assessment of one of the illustrations of Empson Morin (1982, fig. 11). Sanfilippo and Riedel consider that only pl. 17, fig. 14, in Nakaseko & Nishimura (1981) is A. pseudoconulus and that pl. 12, figs. 9 & 10 are not, a case which seems correct. Sanfilippo & Riedel confuse matters, however, by using an ambiguous form for their illustration of A. tylotus in text fig. 7.2b. (taken from Empson Morin 1982, Pl. 3, fig 5, and identified by her as A. tylotus) which they do not list in their synonymy for A. tylotus. Pending further investigation forms recorded here are placed in A. pseudoconulus when nodes or thickening of the test wall occur only at segmental
divisions. Forms with irregular wall-thickening at and between segmental divisions are placed in *A. tylotus*.

Size range: 140 - 250 \( \mu \text{m} \) (measured along greatest length of test, 10 specimens with between four and six post-abdominal segments).

**Occurrence [publications]:** Campanian - ?Maastrichtian, Puerto Rico; Santonian - Campanian, Composite; Maastrichtian, Central Atlantic; Campanian, North Pacific; ?Campanian, Central Pacific; Campanian - Maastrichtian, Indian Ocean; Campanian, Composite; Campanian, Central Atlantic; Campanian, Japan; Campanian, North Pacific; Campanian, Puerto Rico, North Pacific; Campanian, Cuba.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22C; CC22). Campanian - Maastrichtian, Central Atlantic.

*Amphipyndax* (?)*pyrgodes* Renz

|Plate 4, Figures 7 - 9|

*1974* *Amphipyndax* (?)*pyrgodes* Renz, p. 788, pl. 5, fig. 4.

*1984* *Novixitus* sp. A Empson Morin, pl. 2, fig. 11.

**Remarks:** The material is similar to *A. (?) pyrgodes* Renz but has fewer post-abdominal chambers and is therefore smaller. The exterior of the cephalis with small papillae and the antapical view is similar to members of the genus *Amphipyndax*. The internal cephalic structure of specimens recovered here is difficult to determine due to recrystallisation. Renz (1974) was also unable to examine the internal cephalic structure and the species was therefore only tentatively assigned to *Amphipyndax*.

Size range: 95 - 150 \( \mu \text{m} \) (measured along greatest length of test, 10 specimens with two post-abdominal segments).

**Occurrence [publications]:** Aptian/Maastrichtian, Indian Ocean; Campanian, Austria, Cyprus.

**Occurrence [this work]:** Campanian, Cyprus; (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22C; CC22). Campanian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblages dated as CC16/CC22; CC25A).
Amphipyndax stocki (Campbell & Clark) emend. Foreman
Plate 4, Figures 10 - 12

*1944 Stichocapsa megalocephalia Campbell & Clark, p. 44, pl. 8, figs. 26, 34.
1944 Stichocapsa (?) stocki Campbell & Clark, p. 44, pl. 8, figs. 31 - 33.
1966 Dictyomitra uralica Gorbovets; Kozlova & Gorbovets, p. 116, pl. 6, figs. 6 - 7.
1968 Amphipyndax stocki (Campbell & Clark); emend. Foreman, p. 78, pl. 8, fig. 12a.
1972 Amphipyndax stocki (Campbell & Clark); Petrushevskaya & Kozlova, p. 545, pl. 8, figs. 16 - 17.
1974 Amphipyndax stocki (Campbell & Clark); Riedel & Sanfilippo, p. 775, pl. 11, figs. 1 - 3, pl. 15, fig. 11.
1975 Amphipyndax stocki (Campbell & Clark); Pessagno, p. 1016, pl. 4, figs. 4 - 8.
1978b Amphipyndax stocki (Campbell & Clark); Foreman, p. 745, pl. 4, fig. 4.
1982 Amphipyndax stocki (Campbell & Clark); Taketani, p. 52, pl. 2, figs. 9a - b, pl. 10, fig. 14.
1982 Protostichocapsa stocki (Campbell & Clark); Empson Morin, p. 516, pl. 4, figs. 1 - 4.

Remarks: A. stocki is similar to A. mediocris but differs in possessing externally expressed strictures between segments. Pessagno (1975) differentiates between forms of A. stocki with or without cephalic papillae. Papillae are present, and are more-or-less pronounced depending on preservation, on all Amphipyndax spp. observed during this work.
Size range: 140 - 220 μm (measured along greatest length of test, 10 specimens with between five and seven post-abdominal segments).

Occurrence [publications]: ?Campanian, California; ?Campanian, California; Campanian, Western Siberia; Campanian - Maastrichtian, California, South Atlantic; Santonian - Coniacian, Cuba; Santonian, Trinidad; Maastrichtian, Central Atlantic; Campanian, Caribbean; Campanian, Tasman Sea; Campanian - Maastrichtian, Central Atlantic; Cenomanian - Campanian, Japan; Campanian, North Pacific, California.
Amphipyndax tylotus Foreman
Plate 5, Figures 1 - 3

1972 *Amphipyndax* sp. aff. *A. enesseffi* Foreman; Petrushevskaya & Kozlova, pl. 8, fig. 14.
1972 *Amphipyndax enesseffi* Foreman; Petrushevskaya & Kozlova, p. 545, pl. 8, fig. 15.
1977 *Amphipyndax tylotus* Foreman, pl. 1, fig. 1.

*1978b* *Amphipyndax tylotus* Foreman; Foreman, p. 745, pl. 4, figs. 1, 2.
1981 *?Amphipyndax tylotus*, Nakaseko & Nishimura, p. 145, pl. 12, figs. 11a-b, pl. 17, fig. 3.
1982 *Amphipyndax pseudoconulus* (Pessagno); Empson Morin, pl. 2, figs. 6-8, 11.

Remarks: For remarks on identification see *A. pseudoconulus*.
Size range: 150 - 220 \( \mu m \) (measured along greatest length of test, 10 specimens with between two and four post-abdominal segments).

Occurrence [publications]: Maastrichtian, Central Atlantic; Campanian - Maastrichtian, Central Atlantic; Campanian - Maastrichtian, Composite; Campanian - Maastrichtian, Central Atlantic; Campanian, Japan; Campanian, North Pacific.

Occurrence [this work]: Campanian Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22; CC22). Campanian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC25A).

Genus *ARCHAEODICTYOMITRA* Pessagno

*Archaeodictyomitra* PESSAGO 1976, p. 49.
Type species: *Archaeodictyomitra squinaboli* Pessagno, 1976, p. 50, pl. 5, figs. 2-8.

- A37 -
Remarks: This genus is distinguished from *Pseudodictyomitra* because the costae in *Archaeodictyomitra* are continuous down the length of the test but are interrupted in *Pseudodictyomitra*. The genus is distinguished from *Dictyomitra* by the absence of primary pores at strictures and by possessing a less lobate outline on post-abdominal chambers. In the distinction between species of *Archaeodictyomitra* the shape of the costae in cross-section may be important.

*Archaeodictyomitra lamellicostata* (Foreman)

Plate 5, Figures 4 - 6

1968  *Dictyomitra lamellicostata* Foreman, p. 65, pl. 7, figs. 8a,b.

1972  *Dictyomitra aff. regina* (Campbell & Clark); Petrushevskaya & Kozlova, p. 550, pl. 8, fig. 11.

1978b  *Dictyomitra lamellicostata* Foreman; Foreman, p. 747, pl. 4, figs. 13, 14.

1985  *Archaeodictyomitra lamellicostata* (Foreman); Sanfilippo & Riedel, p. 599, text figs. 7.5 a-d.

Remarks: *A. lamellicostata* is distinctive because of its bullet-like shape and costae which are thickened and merge at the proximal end of the test.

Size range: 200 - 250 μm (measured along greatest length of test, 10 specimens with between seven and nine segments).

Occurrence [publications]: Upper Campanian - Maastrichtian, California; Coniacian - Maastrichtian, Central & South Atlantic; Campanian - Maastrichtian, Central Atlantic; Campanian - Maastrichtian, Central Atlantic; Campanian, W. Pacific; Campanian, N. Atlantic.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22; CC22; CC22/CC23A). Campanian - Maastrichtian, Central Atlantic.

*Archaeodictyomitra ?sriteri* Pessagno

Plate 5, Figures 7 - 9

1972  *Dictyomitra costata* (Squinabol); Petrushevskaya & Kozlova, p. 550, pl. 2, fig. 3.

- A 38 -
1975 *Dictyomitra* sp.A Foreman, p. 615, pl. 2G, fig.18.

?*1977c* *Archaeodictyomitra sliteri* Pessagno, p. 43, pl. 6, figs. 3, 4, 22, 23, 27.

?1981 *Archaeodictyomitra sliteri* Pessagno; Nakaseko & Nishimura, p. 146, pl. 15, fig. 4.

**Remarks:** This form is easily distinguished by the general test shape, i.e. only a very gradual increase in width of successive post-abdominal chambers, and by the relatively small numbers of massive costae in lateral view, usually 8 - 10. Pessagno (1977c) records length range of 130 - 310 \(\mu m\) for specimens with between nine and eleven segments, recovered from Cenomanian sediments. The size range of Campanian specimens with between seven and nine segments studied here is narrower i.e. 250 - 300 \(\mu m\).

**Occurrence [publications]:** Albian - Cenomanian, Central Atlantic; Aptian-Albian, North Pacific; Cenomanian, California; Cretaceous, Japan.

**Occurrence [this work]:** Campanian, Cyprus.

*Archaeodictyomitra sp.A, aff. Dictyomitra striata* Lipman

Plate 5, Figures 10 - 12


**Remarks:** *Archaeodictyomitra* sp.A is similar to *Dictyomitra striata* in the shape of the proximal segments, the rate of increase of post-abdominal segments and the number of costae in lateral view. Specimens recorded here, however, have costae which display a clockwise torque on the proximal segments and therefore differ slightly from those specimens illustrated by Lipman (1952). The present specimens also have a less lobate outline than those illustrated by Lipman and by Petrushevskaya & Kozlova (1972), and have therefore been placed in *Archaeodictyomitra*.

Size range: 220 - 245 \(\mu m\) (measured along greatest length of test, 10 specimens with between eight and ten segments).

**Occurrence [publications]:** Santonian - Maastrichtian, Western Siberia; Campanian - Maastrichtian, Central Atlantic.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22). Campanian/Maastrichtian, Central Atlantic.

*Archeodictyomitra* sp.B
Plate 6, Figures 1 - 3

**Description:** Test sub-conical with between seven and eleven segments. The first three chambers increase gradually in width whilst a few of the post-abdominal chambers are inflated. The distalmost chambers decrease very slightly in width, giving the test an irregular lobate appearance. Approximately eleven, bladed costae are present in lateral view, merging at the proximal end of the test.

Size range: 250 - 310 μm (measured along greatest length of test, 10 specimens with nine segments).

**Remarks:** Occurrence restricted in this work to the lower samples of the Paleomylon Valley section and, although occurring commonly, *Archeodictyomitra* sp.B may be an aberrant endemic form influenced by local environmental conditions.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22).

**Genus ARCHAEOSPONGOPRUNUM** Pessagno

*Archaeospongoprunum* PESSAGNO 1973a, p. 57.

Type Species: *Archaeospongoprunum venadoensis* Pessagno, 1973a, p. 68, pl. 10, figs. 2-3.

**Remarks:** Species are differentiated on the general shape of the test and also on the design of the polar spines in both axial and longitudinal section. The polar spines are usually of unequal length and may also be dissimilar in design.
Archaeospongoprunum andersoni Pessagno
Plate 6, Figures 4 - 6

*1973a Archaeospongoprunum andersoni Pessagno, p. 57, pl. 14, figs. 1-2.
1976 Archaeospongoprunum andersoni Pessagno; Pessagno, p. 33, pl. 11, fig. 4.
1988 Archaeospongoprunum andersoni Pessagno; Abin, p. 47, pl. 3, fig. 11.

Remarks: The specimens found in the Cyprus samples are not exactly the same regular shape as the holotype (Pessagno 1973a, 1976), as the external wall structure of specimens observed is uniform and lacks the two bands of slightly enlarged surface structure which encircle the test near to the polar spines. The specimens included here, however, are similar in general test shape and possess two straight, tetraradiate polar spines. Viewed in transmitted light some specimens show a denser test area near to the polar spines but can be distinguished from A. bipartitum on the basis of these tetraradiate polar spines.

Size range: 150 - 200μm (body of the test [Measurement AA' of Pessagno, 1973a], 10 specimens).

Occurrence [publications]: Campanian, California; Campanian, Cuba.

Occurrence [this work]: Campanian, Cyprus.

Archaeospongoprunum cf. A. bipartitum Pessagno
Plate 6, Figures 7 - 9

cf. *1973a Archaeospongoprunum bipartitum Pessagno, p. 59, pl. 11, figs. 4 - 6.
cf. 1976 Archaeospongoprunum bipartitum Pessagno; Pessagno, p. 33, pl. 6, fig. 3.
cf. 1982 Archaeospongoprunum bipartitum Pessagno; Taketani, p. 48, pl. 2, figs. 1a - b; pl. 9, fig. 8.
cf. 1988 Archaeospongoprunum bipartitum Pessagno; Abin, p. 47, pl. 3, fig. 9.

Remarks: This species is distinguished by the overall test shape, by possession of a median sulcus separating two denser polar regions and by having polar spines which are straight and triradiate. Although the specimen illustrated here has both spines broken and

- A41 -
is therefore recorded as *A. cf. A. bipartitum* attention has been given to these morphological features during sample analyses, i.e. specimens recorded as *A. bipartitum* have been observed with two complete spines. Size range: 140 - 190 μm
(body of the test [measurement AA' of Pessagno, 1973a], 10 specimens).

**Occurrence [publications]:** Coniacian - Santonian, California; Turonian - Santonian, Japan; Campanian, Cuba.

**Occurrence [this work]:** Campanian, Cyprus.

*Archaeospongoprunum hueyi* Pessagno

Plate 6, Figures 10 - 12

1972 *Spongoprunum (?) sp. aff. Cyphants probus* Rust; Petrushevskaya & Kozlova, p. 529, pl. 4, fig. 6.

*1973a Archaeospongoprunum hueyi* Pessagno, p. 61, pl. 13, fig. 1.

1976 *Archaeospongoprunum hueyi* Pessagno; Pessagno, p. 33, pl. 11, fig. 5.

1978b *Archaeospongoprunum hueyi* Pessagno; Foreman, p. 745, pl. 2, fig. 12.

**Remarks:** The longitudinal ridges on the spines are not always perfectly straight, sometimes showing a very slight torque at the proximal end. This feature is illustrated on the holotype (Pessagno, 1973a, pl. 13, fig. 1). Also, in some specimens observed during this work the longitudinal ridges of one of the spines may show small secondary grooves (see Plate 6, fig. 10). Size range: 105 - 120 μm (body of the test [measurement AA' of Pessagno, 1973a], 30 specimens, sample 9827 Paleomylon Valley section).

*A. hueyi* can be distinguished from *A. tehamaensis* Pessagno (1973a, from Cenomanian of California) by its more elongate test body.

**Occurrence [publications]:** Maastrichtian, Central Atlantic; Campanian, California; Campanian - Maastrichtian, Central Atlantic.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22; CC22/CC23A). Campanian/Maastrichtian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblages dated as CC23B; CC25A).

- A 42 -
Genus *BISPHAEROCEPHALINA* Petrushevskaya

*Bisphaerocephalina* PETRUSEVSKAYA 1965, p. 91.

**Type Species:** *Bisphaerocephalina armata* Petrushevskaya, 1965, p. 91, text-fig. 8.2.

**Remarks:** Foreman (1968) separates *Bisphaerocephalina* from *Lithomelissa* on the organisation of cephalic structure but includes under the former genus a species with more than two segments. Foreman (1968) and Pessagno (1976) question the cephalic structure of *Bisphaerocephalina* as described by Petrushevskaya and, because these problems have not been resolved here, the species below are only questionably assigned to this genus.

*Bisphaerocephalina(?) amazon* (Foreman)

Plate 7, Figures 1 - 3

1968 *?Lithomelissa amazon* Foreman, p. 26, pl. 4, figs. 1a - b.
1976 *Bisphaerocephalina(?) amazon* (Foreman); Pessagno, p. 54, pl. 13, figs. 12 - 16.

**Remarks:** Size range: 120 - 170 µm (measured along greatest length of cephalis and thorax excluding apical horn, 10 specimens). This species differs from *B. (?) heros* (below) in possessing a sparsely perforated, terminal tube-like structure; a smoother cephalis externally; a longer, more slender apical horn; and is generally slightly smaller.

**Occurrence [publications]:** Maastrichtian, California; Campanian - Maastrichtian, California.

**Occurrence [this work]:** Campanian, Cyprus. Campanian/Maastrichtian - Maastrichtian, Central Atlantic (co-occurs with calcareous nanofossil assemblage dated as CC25A).

- A 43 -
Bisphaerocephalina(?) heros (Campbell & Clark)
emend. Foreman
Plate 7, Figures 4 - 6

1944 Lithomelissa heros Campbell & Clark, p. 25, pl. 7, fig. 23.
1968 Lithomelissa? heros Campbell & Clark; emend. Foreman, p. 25, pl. 3,
figs. 5a - b; text-fig. 1.7.
1976 Bisphaerocephalina(?) heros (Campbell and Clark), emend. Foreman,
1968; Pessagno, p. 54, pl 13, fig. 11.

Remarks: Size range: 140 - 200 μm (measured along length of cephalis and thorax, excluding the apical horn, 10 specimens). The distinction between B.(?) heros and B.(?) amazon is given under the latter species above.

Occurrence [publications]: Campanian, California; Campanian - Maastrichtian, California; Maastrichtian, California.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nanofossil assemblage dated as CC20/CC22C). Campanian/Maastrichtian - Maastrichtian, Central Atlantic (co-occurs with calcareous nanofossil assemblages dated as CC23B; CC25A).

Genus CLATHROPYRGUS Haeckel

Clathropyrgus HAECKEL 1881, p. 439.
Type Species: None designated. [Haeckel (1887, p. 1441) describes the genus Clathropyrgus and the species Clathropyrgus trifenestra and illustrates C. trifenestra on Pl. 75, fig. 7].

Remarks: Although quite frequently recorded this genus requires further cataloguing for consistent species recognition. Its unusual shape, morphological variation, apparent resistance to dissolution and restricted stratigraphical range make it a useful biostratigraphical index fossil.
Clathropyrgus titthium Riedel & Sanfilippo

Plate 7, Figures 7 - 9

1971 Theoperids gen. et sp. indet., Kling, pl. 8, figs. 7, 8.
1971 Theoperid gen. et sp. indet., Foreman, p. 1676, pl. 3, fig. 3.
1973a Theoperid gen. et sp. indet., Foreman, p. 430, pl. 13, fig. 1.
1973 *Artopilium* sp. A, Moore, p. 830, pl. 11, fig. 7.
1973 Gen. et sp. indet., Riedel & Sanfilippo, pl. 4, fig. 15.
*1974 Clathropyrgus titthium* Riedel & Sanfilippo, p. 775, pl. 3, fig. 12, pl. 12, figs. 10 - 12.
1975 *Clathropyrgus titthium* Riedel & Sanfilippo; Foreman, p. 613, pl. 6, fig. 10.
1978b *Clathropyrgus titthium* Riedel & Sanfilippo; Foreman, p. 746, pl. 5, fig. 19.
1982 *Clathropyrgus titthium* Riedel & Sanfilippo; Kling, p. 548, pl. 1, fig. 21(?), pl. 3, fig. 7.
1985 *Clathropyrgus titthium* Riedel & Sanfilippo; Sanfilippo & Riedel, p. 616, text fig. 13.2 a-e.
1988a *Clathropyrgus titthium* Riedel & Sanfilippo; Thurow, p. 398, pl. 2, fig. 24.
1988 *Clathropyrgus titthium* Riedel & Sanfilippo; Abin, p. 57, pl. 8, fig. 13.

**Remarks:** Size range: 145 - 250 µm (measured along greatest length of test, 10 specimens).

**Occurrence [publications]:** Campanian, North Pacific; ?Campanian, Central Pacific; Campanian, Gulf of Mexico; Coniacian - Campanian, Central Pacific; Cretaceous, Caribbean; Coniacian - Campanian, Indian Ocean; Tertiary, North Pacific; Campanian, Central Atlantic; Campanian, North Pacific; Campanian, Central Pacific, California; Campanian, North Atlantic; Campanian, Cuba.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22).
Clathropyrgus aff. C. titthium Riedel & Sanfilippo
Plate 7, Figures 10-11

Remarks: This form differs from C. titthium in the proportional size of the lateral wings. The size range of these specimens is similar to that of C. titthium as recorded above.

Occurrence [this work]: Campanian, Cyprus.

Clathropyrgus aff. C. titthium Riedel & Sanfilippo
Plate 7, Figure 12

Remarks: This form differs from C. titthium by possessing a more elongate abdomen and smaller, downward projecting lateral wings. The size range of these specimens is similar to that of C. titthium as recorded above.

Occurrence [this work]: Campanian, Cyprus.

Genus CORNUTELLA Ehrenberg, emend. Nigrini

Cornutella EHRENBerg 1838, p. 128.

Type Species: Cornutella clathrata Ehrenberg, 1856, pl.35B, fig. 21.

Cornutella californica Campbell & Clark
emend. Foreman
Plate 8, Figures 1 - 3

*1944 Cornutella californica Campbell & Clark, p. 22, pl. 7, figs. 33, 34, 42, 43.
1968 Cornutella californica Campbell & Clark, emend. Foreman, p. 21, pl. 3, fig. 1b.
1974 ?Cornutella californica Campbell & Clark; Renz, p. 790, pl. 4, fig. 11;
pl. 12, fig. 7.

1975 *Cornutella californica* Campbell & Clark; Pessagno, p. 1017, pl. 5, fig. 13.

1982 *Cornutella californica* Campbell & Clark; Taketani, p. 65, pl. 6, figs. 6a-b, 7, pl. 13, fig. 7.

**Remarks:** This species was rare and never found with the apical horn complete. Size range 130 - 180 μm (measured along greatest length of test excluding apical horn, 10 specimens).

*Cornutella californica* Campbell & Clark differs from *C. cretacea* Taketani by possessing a pronounced cephalis and thinner test.

**Occurrence [publications]:** ?Campanian, California; Campanian - Maastrichtian, California, South Atlantic; Santonian, Trinidad; Aptian/ Maastrichtian, Indian Ocean; Campanian, Tasman Sea; Coniacian - Campanian, Japan.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC18/CC22C).

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**Genus CRUCELLA Pessagno**

emend. Baumgartner

*Crucella* PESSAGNO 1971, p. 52,


**Type species:** *Crucella messinae* Pessagno, 1971, p. 56, pl. 6, figs. 1 - 3.

**Remarks:** Criteria used in species differentiation include the longitudinal and axial shape of the rays, the ratios of ray length to width and to the size of the central area, the character of the terminal spines at the ray tips, the surface texture on the central area and on the rays, and the character of the central area of the test surface. It is important to view both sides as some specimens have been found by other workers (De Wever, *pers. comm.* 1990) to have a lacuna on only one side of the central area. All forms studied here, however, have similar structures on opposing sides of the test.
Crucella aster (Lipman)
Plate 8, Figures 4 - 6

*1952 Histiastrum aster Lipman, p. 35, pl. 2, figs. 6, 7.
1962 Histiastrum aster Lipman; Lipman, p. 300, pl. 2, fig. 5.
1966 Histiastrum aster Lipman; Kozlova, p. 84, pl. 3, fig. 9.
1979 Crucella spp., Nakaseko et al., p. 21, pl. 8, figs. 3, 4.
1981 Crucella cf. cachensis Pessagno; Schaaf, p. 433, pl. 8, fig. 3.
1981 Crucella aster (Lipman); Nakaseko & Nishimura, p. 148, pl. 2, figs. 9, 10.
1984 Crucella? sp. A., Empson Morin, pl. 1, figs. 4-5.
1988a Crucella (?) sp. A., Thurow, pl. 2, figs. 12, 16.
1988 Crucella (?) sp. A. Empson Morin; Abin, p. 46, pl. 3, fig. 5.

Remarks: Specimens show some morphological variation (Plate 8, figs. 5 - 6), but they are all regarded here as members of the same species. No specimens with complete spines preserved at the ray tips were recovered. Size range: 240 - 310 μm (measured at maximum width in parallel to two of the rays excluding spines, 10 specimens).

Occurrence [publications]: Santonian - Campanian, U.S.S.R.; Santonian - Campanian, U.S.S.R.; Coniacian - Campanian, Western Siberia; Cretaceous, Japan; Barremian, North Pacific; Upper Jurassic/Cretaceous, Japan; Campanian, Caribbean; Campanian, North Atlantic; Campanian, Cuba.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22C). Campanian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC16/CC22).

Crucella cachensis Pessagno
Plate 8, Figures 7 - 9

*1971 Crucella cachensis Pessagno, p. 53, pl. 9, figs. 1-3.
1976 Crucella cachensis Pessagno; Pessagno, p. 31, pl. 3, figs. 14, 15.
1982 Crucella cachensis Pessagno; Taketani, p. 50, pl.9, fig. 16.
1986 Crucella cachensis Pessagno; Kuhnt et al., pl. 7.J.
1986 Crucella cachensis Pessagno; Thurow & Kuhnt, text figs. 9.5, 6.
1988a Crucella cachensis Pessagno; Thurow, p.399, pl.2, fig. 13.
Remarks: A similar species was found by Dumitrica (1973) in the Albian of the Northeast Atlantic but not figured.
Size range: 320 - 370μm (measured at maximum width in parallel to two of the rays excluding spines at ray tips, 5 specimens).

Occurrence [publications]: Turonian, California; Turonian, California; Coniacian/Campanian, Japan; Turonian, North Atlantic.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22C).

**Crucella espartoensis** Pessagno  
Plate 8, Figures 10 - 12

1971 *Crucella espartoensis* Pessagno, p. 54, pl.18, figs. 1-4.
1976 *Crucella espartoensis* Pessagno; Pessagno, p. 32, pl. 8, fig. 16.
1982 *Crucella espartoensis* Pessagno; Taketani, p. 50, pl. 9, fig. 15.
1988a *Crucella espartoensis* Pessagno; Thurow, p. 399, pl. 2, fig. 14.
1988 *Crucella espartoensis* Pessagno; Abin, p. 46, pl. 3, fig. 4.

Remarks: Size range 270 - 320μm (measured across greatest width of test parallel to two of the rays and excluding spines at ray tips, 10 specimens). Remnants of a patagium are present on some, but not all, of the specimens.

Occurrence [publications]: Santonian - Campanian, California; Coniacian - Campanian, Japan; Campanian, North Atlantic; Campanian, Cuba.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22; CC22/CC23A). Campanian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC16/CC22).

**Crucella irwini** Pessagno  
Plate 9, Figures 1 - 3

*1971* *Crucella irwini* Pessagno, p. 55, pl. 9, figs. 4 - 6.
1976 *Crucella irwini* Pessagno; Pessagno, p. 32, pl. 3, fig. 16.
1985  *Crucella irwini* Pessagno; Blome & Irwin, Fig. 4.1.

1986  *Crucella* cf. *irwini* Pessagno; Kuhnt et al., pl. 8, fig. P.

**Remarks:** This form is distinctive because of the relatively long, slender rays. Size range: 240 - 280 μm (measured across greatest width of test parallel to two of the rays but excluding spines at ray tips, 6 specimens).

**Occurrence [publications]:** Turonian, California; Turonian - Coniacian, California; Turonian, Cyprus; Turonian, Morocco.

**Occurrence [this work]:** Campanian, Cyprus. Campanian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC16/CC22).

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*Cruella* (?) sp.A

Plate 9, Figures 4 - 6

**Description:** Test consists of four rays or arms at right angles to each other forming a cross. All rays are normally of a similar length. Ray tips are slightly expanded laterally with a triradiate spine base at the tip. Specimens with complete spines have not been recovered. At the proximal ends the rays converge on a central area with a lacuna which is a circular to subcircular depression present on both sides of the test. The surface of the test consists of polygonal pore frames with nodes at the junctions of these frames. Size range: 300 - 350 μm (measured across greatest width of test parallel to two of the rays excluding spines at ray tips, 10 specimens).

**Remarks:** This form is tentatively assigned to the genus *Crucella* because the internal structure has not been examined in section and cannot be reliably determined from the exterior surface of the test. Plate 9, fig. 4, illustrates an aberrant form which shows a slight degree of asymmetry.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22/CC23A).
**Crucella(?). sp.B**

Plate 9, Figures 7 - 9

**Description:** Test consists of four arms or rays at right angles to each other forming a cross. Two opposed rays are equal but smaller than the other two equally-sized rays. Rays are petal-shaped, inflated and remnants of a patagium are always present. No spine bases were observed at ray tips. The rays converge at their proximal ends on a rectangular central area. The test surface is difficult to examine due to poor preservation but seems to consist of polygonal pore frames. Size range: 180 - 250 μm (measured across greatest width of test parallel to the two longest rays, 10 specimens).

**Remarks:** This form is tentatively assigned to the genus *Crucella* because the internal structure has not been examined in section and cannot be reliably determined from the exterior surface of the test. Additionally, the rays are of unequal length and no spines have been observed at ray tips.

**Occurrence [this work]:** Campanian, Cyprus.

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**Crucella(?). sp.C**

Plate 9, Figures 10 - 12

**Description:** Test consists of four arms or rays at right angles forming a cross. One pair of opposed rays is slightly shorter than the other pair. Rays are flattened in cross section at the extreme proximal ends, becoming inflated towards the distal ends. No spines are present at the ray tips. The rays converge at a central circular area which is in the form of a raised disc or tholus. The test is similar on both sides. All specimens recovered are poorly preserved but the test surface appears to be entirely covered with polygonal pore frames. Size range: 180 - 220 μm (measured across greatest width of test parallel to the two longest rays, 6 specimens).

**Remarks:** This form is tentatively assigned to the genus *Crucella* because the internal structure has not been examined in section and cannot be reliably determined from the exterior surface of the test. Additionally, the rays are of unequal length and no spines have been observed at the ray tips.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC22; CC22/CC23A).

Genus CRYPTAMPHORELLA Dumitraca

Cryptamphorella DUMITRICA 1970

Type Species: Hemicryptocapsa conara Foreman, 1968, p. 35, pl. 4, figs. 11a, b.

Remarks: Species are distinguished primarily on the character of the sutural pore and on the nature and degree of depression of the cephalo-thoracic segments.

Cryptamphorella conara (Foreman)
Plate 10, Figures 1 - 3

*1968 Hemicryptocapsa conara Foreman, p. 35, pl. 4, figs. 11a, b.
1970 Cryptamphorella conara (Foreman); Dumitraca, p. 80, pl. 11, figs. 66a-c.
1973 Cryptamphorella conara (Foreman); Moore, p. 827, pl. 7, figs. 4, 5(?).
1975 Cryptamphorella conara (Foreman); Dumitraca, fig. 2.28
1979 Cryptamphorella conara (Foreman); Nakaseko et al., p. 21, pl. 6, fig. 1.
1981 Cryptamphorella conara (Foreman); Nakaseko & Nishimura, p. 148, pl.5, figs. 11a, b.
1982 Cryptamphorella conara (Foreman); Kling, p. 549, pl. 5, figs. 10, 11.
1982 Cryptamphorella conara (Foreman); Taketani, p. 67, pl. 7, figs. 6a, b, 7a, b.
1985 Cryptamphorella conara (Foreman); Sanfilippo & Riedel, p. 613, text fig. 12.1 a-c.
1988a Cryptamphorella conara (Foreman); Thurow, p. 399, pl. 1, fig. 2, pl. 5, fig. 1.

Remarks: The fact that this form is commonly recorded in the literature with a relatively long stratigraphical range is probably due in part, to the resistant, spherical test structure. Spherical tests of foraminifera (e.g. Orbulina spp.) have been found to be more resistant than other test architectures to dissolution or breakage during post-mortem transport and burial (Banner, pers. comm., 1984). The species may also be easily
reworked, although this would not account fully for the relative length of the stratigraphic range (i.e. it is unlikely to have been consistently reworked from Cenomanian sediments into Maastrichtian sediments.

Size range: 90 - 150 \( \mu m \) (measured along greatest length of test, 10 specimens).

**Occurrence [publications]:** Maastrichtian, California; Cenomanian - Turonian, Romania; Cenomanian - Campanian, Central Pacific; Cretaceous, Japan; Albian - Cenomanian, Japan; Cretaceous, North Pacific; Cenomanian - Maastrichtian, Composite; Barremian - Maastrichtian, North Atlantic.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22C; CC22; CC22/CC23A). Campanian - Campanian/Maastrichtian, Central Atlantic.

*Cryptamphorella macropora* Dumitrica

Plate 10, Figures 4 - 6

*1970* *Cryptamphorella macropora* Dumitrica, p. 81, pl. 10, figs. 64a - b, 65.

*1981* *Cryptamphorella macropora* Dumitrica; Nakaseko & Nishimura, p. 149, pl. 4, figs. 6, 7, pl. 14, fig. 6

*1988a* *Cryptamphorella macropora* Dumitrica; Thurow, p. 400, pl. 1, fig. 3.

**Remarks:** This form is similar to *C. conara* except that it possesses a large sutural pore. Specimens recovered here usually have a more elongate and asymmetrical abdomen and possess an apical horn. Size range: 150 - 200 \( \mu m \) (measured along greatest length of test, 10 specimens). The size of specimens is generally larger than those reported from Romania (110 - 165 \( \mu m \), Dumitrica 1970).

**Occurrence [publications]:** Campanian, Romania; Albian - Cenomanian, Japan; Campanian, North Atlantic.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22). Maastrichtian, Central Atlantic.
Cryptamphorella sp.A
Plate 10, Figures 7 - 9

Description: Cryptothoracic test with three segments or chambers. The cephalis is partially buried in the test wall. The abdomen is an elongate, oval shape with sub-rounded to polygonal pore frames. The specimen illustrated in Plate 10, fig. 9 has a surface texture which suggests that the pore frames may once have been polygonal, have been subsequently abraded and now appear rounded. Size range: 140 - 180 µm (measured along greatest length of test, 10 specimens).

Remarks: No sutural pore has been observed on these forms.

Occurrence [this work]: Cyprus, Campanian.

Cryptamphorella sp.B
Plate 10, Figures 10 - 12

Description: Cryptothoracic test with three chambers or segments. The cephalis is free with a poreless wall ornamented with strong longitudinal ridges. The abdomen is elongate and sub-ovoid with relatively robust, generally hexagonal pore frames. Size range: 150 - 180 µm (measured along greatest length of test, 10 specimens).

Remarks: No sutural pore has been observed on these forms. Cryptamphorella sp.B differs from Cryptamphorella sp.A by having a free cephalis and larger pore frames.

Occurrence [this work]: Cyprus, Campanian.

Genus CYRTOCALPIS Haeckel

Cyrto calpis HAECKEL 1860, p. 835.
Type Species: Cyrto calpis amphora Haeckel, 1862, p.286, pl. 5, fig. 2.
(Subsequent designation Campbell, 1954, p. D121).
**Remarks:** Species are distinguished on overall shape of test, distribution pattern and density of pore spacing, shape of pores, and the width of the aperture. The genus is defined as lacking an apical horn.

*Cyrtocalpis compacta* Haeckel

Plate 11, Figures 1 - 3

*1887* *Cyrtocalpis compacta* Haeckel, p. 1187, pl. 52, figs. 7 - 8.

**Remarks:** Specimens recovered during this work differ from original figures of *C. compacta* Haeckel in that the mouth is wider than one-third the maximum width of the test, although this may be because only incomplete specimens have been recovered here. The pattern of distribution of pores also differs in that morphotypes examined here show a denser distribution towards the proximal end of the test. Specimens in this work also seem to have the base of an apical horn although no complete horns have been observed. This species differs significantly from *C. operosa* Tan Sin Hok in the distributional pattern and spacing of the pores. *Cyrtocalpis compacta* is also comparable with *C. oblonga* from Urschlau, illustrated by Rust (1885, pl. 10, fig. 5) and with *C. lepida* from West Switzerland, illustrated by Rust (1885, pl. 10, fig. 10).

Size range: 80 - 120μm (measured along maximum length of test, 10 specimens).

**Occurrence [publications]:** N/G, Central Pacific, Caribbean.

**Occurrence [this work]:** Campanian, Cyprus.

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**Genus Diacanthocapsa** Squinabol, emend. Dumitrica

*Diacanthocapsa* SQUINABOL 1903, p. 133.


Type Species: *Diacanthocapsa euganea* Squinabol, 1903, p. 133, pl. 8, fig. 26.

**Remarks:** Species have been differentiated by the variation in general test shape and the relative sizes of the thoracic and abdominal segments. The presence and position of the sutural pore and of the aperture are also taxonomically significant.
Diacanthocapsa acanthica Dumitrica
Plate 11, Figures 4 - 6

*1970 Diacanthocapsa acanthica Dumitrica, p. 66, pl. 8, figs. 48, 50; pl. 20, figs. 127a - b.
1981 Diacanthocapsa acanthica Dumitrica; Nakaseko & Nishimura, p. 149, pl. 5, fig. 9; pl. 14, fig. 13.
1982 Eucyrtidium (?) matsumotoi Taketani, p. 57, pl. 4, figs. 1a - 3b; pl. 11, figs. 11 - 12.

Remarks: The sutural pores marked by the arrow in Plate 11, fig. 4, vary slightly in configuration from those illustrated by Dumitrica (1970).
Size range: 140 - 160 μm (measured along greatest length of test, 10 specimens).

Occurrence [publications]: Campanian, Romania; Cretaceous, Japan; Coniacian - Santonian, Japan.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22; CC22/CC23A).

Diacanthocapsa acuminata Dumitrica
Plate 11, Figures 7 - 9

*1970 Diacanthocapsa acuminata Dumitrica, p. 65, pl. 7, figs. 38, 39a - b, 43.
1981 Diacanthocapsa acuminata Dumitrica; Nakaseko & Nishimura, p. 149, pl. 5, figs. 7 - 8.

Remarks: In forms examined in transmitted light the cephalis usually occupies a slightly off-centre position.
Size range: 110 - 130 μm (measured along greatest length of test, 10 specimens).

Occurrence [publications]: Campanian, Romania; Upper Jurassic/Cretaceous, Japan.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22/CC23A). Campanian/Maastrichtian, Central Atlantic.
Diacanthocapsa cf. D. ancus (Foreman)
Plate 11, Figures 10 - 12

cf. *1968 Theocapsoma ancus Foreman, p. 32, pl. 4, fig. 3.

1970 Diacanthocapsa cf. ancus (Foreman); Dumitrica, p. 64, pl. 6,
figs. 35a - b; pl. 7, fig. 40; pl. 20, fig. 125.

1981 Diacanthocapsa cf. ancus (Foreman); Nakaseko & Nishimura, p. 149,
pl. 5, fig. 5.

Remarks: Forms with a slightly greater degree of lateral abdominal inflation than the
specimen illustrated (Plate 11, figs. 10 - 12) have been here included in this species.
Size range: 140 - 170 μm (measured along greatest length of test, 10 specimens).

Occurrence [publications]: Maastrichtian, California; Cenomanian - Campanian,
Romania; Upper Jurassic/Cretaceous, Japan.

Occurrence [this work]: Cyprus, Campanian. Campanian/Maastrichtian -
Maastrichtian, Central Atlantic.

Diacanthocapsa euganea Squinabol
Plate 12, Figures 1 - 3

*1903 Diacanthocapsa euganea Squinabol, p. 133, pl. 8, fig. 26.

?1975 Diacanthocapsa? sp. Dumitrica, text fig. 2.38.

1982 Diacanthocapsa euganea Squinabol; Taketani, p. 68, pl. 8, figs. 2a - b,
3a - b; pl. 12, fig. 15.

Remarks: A slight variation in the degree of abdominal inflation in relation to length
was recorded between specimens. Size range: 150 - 180 μm (measured along greatest
length of test, 10 specimens).

Occurrence [publications]: Cretaceous, Italy; Cenomanian, Romania; Cenomanian -
Coniacian, Japan.

Occurrence [this work]: Campanian, Cyprus.
Diacanthocapsa (?) sp. A
Plate 12, Figures 4 - 6

Description: Test consists of three chambers although all specimens examined here may be incomplete. The cephalis is free, poreless with a ridged surface ornamentation. The thorax is hemispherical and increases in width gradually. In contrast the subspherical abdomen is greatly inflated in relation to the thorax. The thorax and abdomen have round pores surrounded by hexagonal pore frames. The pore frames are smaller on the thoracic portion of the test. Minute spines are produced at the junctions of the pore frames and are illustrated in profile on Plate 12, fig. 4.

Size range: 110 - 130 μm (measured from highest point of cephalis to base of thorax, 10 specimens).

Remarks: It is uncertain as to whether the present specimens have a complete test and they are therefore only tentatively assigned to the genus Diacanthocapsa on the basis of their cephalo-thoracic characteristics and external appearance of the wall structure. The shape of this morphotype made it extremely difficult to examine the cephalis in transmitted light.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22; CC22/CC23A). Maastrichtian, Central Atlantic.

Genus Dictyomitra Zittel

Dictyomitra ZITTEL 1876 p. 77.
Type Species: Dictyomitra multicostata Zittel, p. 81, pl. 2, figs. 2-4.

Remarks: Dictyomitra can be distinguished from Archaeodictyomitra by the presence of distinct primary pores at strictures and by the former possessing a more lobate outline.
**Dictyomitra andersoni** (Campbell & Clark)
emend. Foreman
Plate 12, Figures 7 - 9

1944 *Dictyomitra (Dictyomitroma) multicostata* Zittel; Campbell &
Clark, p. 39, pl. 8, figs. 23, 25, 28.

1944 *Dictyomitra (Dictyomitroma) tiara* Campbell & Clark, p. 40, pl. 8,
figs. 4, 12.

*1944* *Lithocampe (Lithocampanula) andersoni* Campbell & Clark, p. 42,
pl. 8, fig. 25.

1968 *Dictyomitra andersoni* (Campbell & Clark), emend. Foreman, p. 68, pl.
7, figs., 6a - d.

1971 *Dictyomitra andersoni* (Campbell & Clark); Foreman, p. 1677, pl. 3,
fig. 8.

1972 *Dictyomitra ornata* Aliev; Petrushevskaya & Kozlova, p. 550, pl. 8, fig. 8.

1988 *Dictyomitra multicostata* (l) Zittel; Abin, p. 60, pl. 6, fig. 9.

**Remarks:** This species resembles *Pseudodictyomitra iodogaensis* (Pl. 28,
figs. 4 - 6) in poorly preserved material but can be distinguished by the presence of
continuous costae and by the size and shape of the proximal segments. No specimens of
*D. andersoni* were recovered with an apical horn preserved. The specimen figured in
Plate 12, figs. 7 - 9, shows ornate, wavy costae. Foreman (1968) includes forms with
very variable surface ornamentation.

Size range: 180 - 220 \(\mu m\) (measured along greatest length of test, 10 specimens with
between eight and eleven segments).

**Occurrence** [publications]: ?Campanian, California; ?Campanian, California;
?Campanian, California; Santonian, Caribbean; Campanian/Maastrichtian, South
Atlantic; Campanian? - Maastrichtian, California; Santonian - Maastrichtian, Central
Pacific; Albion - Maastrichtian, Central Atlantic; Campanian, Cuba.

**Occurrence** [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil
assemblages dated as CC20/CC22; CC22; CC22/CC23A). Campanian/Maastrichtian -
Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblages dated
as CC23B; CC25A).


Dictyomitra formosa Squinabol
Plate 12, Figures 10 - 12

*1904 Dictyomitra formosa Squinabol, p. 232, pl. 10, fig. 4.
1971 "Dictyomitra" sp., Kling, p. 1089, pl. 9, fig. 2.
1972 Dictyomitra duodecimcostata grp., Petrushevskaya & Kozlova, p. 550, pl. 2, fig. 10.
1973 Dictyomitra formosa Squinabol; Moore, p. 829, pl. 1, figs. 1 - 3.
1973 Amphipyndax sp., Dinkleman, p. 790, pl. 1, fig. 11.
1973b Dictyomitra torquata Foreman; Foreman, p. 256, pl. 15, figs. 9 - 11.
1973b Dictyomitra sp., Foreman, p. 264, pl. 10, fig. 6.
1974 Dictyomitra torquata Foreman; Riedel & Sanfilippo, p. 778, pl. 5, figs. 1 - 2.
1975 Dictyomitra duodecimcostata (Squinabol); Foreman, p. 614, pl. 1G, figs. 5 - 6.
1978b Dictyomitra duodecimcostata duodecimcostata (Squinabol); Foreman, p. 746, pl. 4, figs. 8 - 9.
1981 Dictyomitra formosa formosa Squinabol; Nakaseko & Nishimura, p. 150, pl. 8, figs. 7 - 8; pl. 16, figs. 4, 11.
1982 Dictyomitra sp., Kling, p. 548, pl. 2, fig. 4.
1982 Dictyomitra duodecimcostata duodecimcostata (Squinabol); Kling, p. 548, pl. 2, figs. 8 - 9.
1985 Dictyomitra formosa Squinabol; Blome & Irwin, p. 402, fig. 4.6.
1988a Dictyomitra formosa Squinabol; Thurow, p. 400, pl. 1, fig. 25.
1988a Dictyomitra cf. formosa Squinabol; Thurow, p. 400, pl. 1, fig. 23.

Remarks: Previous authors have sub-divided this form into D. duodecimcostata (Squinabol), D. torquata Foreman and D. formosa Squinabol on the basis of differences in the expansion rates of post-abdominal segments. This slight differentiation is here regarded as intra-specific variation pending investigation of a broader stratigraphical range of samples. Size range: 240 - 280 μm (measured along the greatest length of test, 10 specimens with between eight and nine segments).

Occurrence [publications]: Senonian, Italy; Campanian, North Pacific; Maastrichtian, Central Atlantic; Albian - Campanian, Central Pacific; ?Campanian,
Central Pacific; Valanginian - Hau
terivian, North Pacific; Campanian, North Pacific; Cenomanian - Campanian, Indian Ocean; Cenomanian - Santonian, North Pacific; Albian, North Pacific; Campanian, Central Atlantic; Coniacian - Campanian, Japan; Campanian, North Pacific; Campanian, North Pacific; Turonian, Cyprus; Turonian - Campanian, North Atlantic; Turonian - Campanian, North Atlantic.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22; CC22; CC22/CC23A). Campanian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblages dated as CC16/CC22; CC25A).

*Dictyomitra koslovae* Foreman

Plate 13, Figures 1 - 3

1971 *Dictyomitra* sp., Foreman, p. 1677, pl. 3, fig. 5.

1972 *Dictyomitra duodecimcostata* grp., Petrushevskaya & Kozlova, p. 550, pl. 2, fig. 11.

1973 *Dictyomitra* cf. *torquata* Foreman; Moore, p. 829, pl. 9, fig. 1.

1974 *Dictyomitra torquata* Foreman; Riedel & Sanfilippo, p. 778, pl. 14, fig. 2.

*1975 Dictyomitra koslovae* Foreman, p. 614, pl. 7, fig. 4.

1978b *Dictyomitra koslovae* Foreman; Foreman, p. 746, pl. 4, fig. 10.

1981 *Dictyomitra koslovae* Foreman; Nakaseko & Nishimura, p. 151, pl. 8, fig. 2, pl. 16, fig. 3.

1982 *Dictyomitra koslovae* Foreman; Kling, p. 548, pl. 2, fig. 10.

1988a *Dictyomitra koslovae* Foreman; Thurow, p. 400, pl. 1, fig. 29.

Remarks: Forms with a more lobate outline than that of the holotype figured by Foreman (1971, pl. 3, fig. 5) are here included within this species. A significant distinguishing feature is that the widest proximal segment is always followed by a segment of similar or narrower width. Subsequent segments increase in width very gradually, if at all.

Size range: 210 - 230μm (measured along greatest length of test, 10 specimens with seven segments).

Occurrence [publications]: Santonian - Campanian, Central Pacific; Campanian, Central Atlantic; Cenomanian - Maastrichtian, Central Pacific; Aptian/Maastrichtian,
Indian Ocean; Santonian, North Pacific; Campanian, Central Atlantic; Coniacian - Campanian, Japan; Campanian, North Pacific; Campanian, North Atlantic.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22C).

*Dictyomitra multicostata* Zittel
emend. Pessagno
Plate 13, Figures 4 - 6

*1876* *Dictyomitra multicostata* Zittel, p. 81, pl. 2, figs. 2 - 4.

1944 *Dictyomitra multicostata* Zittel; Campbell & Clark, p. 39, pl. 8, fig. 42.

1944 *Lithocampe andersoni var. paucisepta* Campbell & Clark, p. 43, pl. 8, fig. 13.

1968 *Dictyomitra* cf. *multicostata* Zittel; Foreman, p. 63, pl. 7, figs. 9a - b.

1971 *Dictyomitra* sp. cf. *D. multicostata* Zittel; Foreman, pl. 5, fig. 16.

1972 *Dictyomitra multicostata* Zittel; Petrushevskaya & Kozlova, p. 550, pl. 8, figs. 9 - 10.

1975 *Dictyomitra* sp. A Foreman, p. 615, pl. 2G, fig. 19.

1976 *Dictyomitra multicostata* Zittel; emend. Pessagno, p. 52, pl. 14, figs. 4 - 9.

1981 *Dictyomitra multicostata* Zittel; Nakaseko & Nishimura, p. 151, pl. 8, fig. 1.

Remarks: This species has a distinctive lobate outline and two rows of inter-segmental pores that are almost always clearly visible. The thinner final segment is usually preserved.

Size range: 150 - 170 μm (measured along greatest length of test, 10 specimens with between eight and nine segments).

Occurrence [publications]: N/G, Germany; ?Campanian, California; ?Campanian, California; Campanian - Maastrichtian, California, South Atlantic; Cenomanian/Turonian, Central Pacific; Albian - Maastrichtian, Central Atlantic; Aptian - Albian, North Pacific; Campanian - Maastrichtian, California; Campanian, Japan.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22; CC22/CC23A). Campanian -
Maastrichtian, Central Atlantic (co-occurs with calcarceous nannofossil assemblages dated as CC23B; CC25A).

*Dictyomitra sagitafera* Kh. Aliev

Plate 13, Figures 7 - 9

1961 *Dictyomitra sagitafera* Kh. Aliev, p. 25, pl. 1, figs. 1 - 3.

1965 *Dictyomitra sagitafera* Kh. Aliev; Kh. Aliev, p. 55, pl. 10, figs. 2 - 4.

1973 *Dictyomitra sagitafera* Kh. Aliev; Moore, p. 829, pl. 8, fig. 9.

Remarks: Some specimens have costae which appear to be discontinuous over segmental divisions (see Plate 13, fig. 7) but as these features do seem continuous when viewed in transmitted light and because the costae remain aligned throughout the length of the post-abdominal chambers it is considered a preservational rather than a genetic feature. Two examples of morphological variation are shown in Plate 13 (figs. 7/8 and fig. 9) and three examples of intra-specific variation are shown by Kh. Aliev (1965). The specimens found here most closely resemble Kh. Aliev's (1965) pl. 10, fig. 4.

Size range: 200 - 290\(\mu\text{m}\) (measured along greatest length of test, 10 specimens with between nine and ten segments).

Occurrence [publications]: Albian - Cenomanian, Azerbaidzhan; Albian - Cenomanian, Azerbaidzhan; Cenomanian - Turonian, Central Pacific.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcarceous nannofossil assemblage dated as CC18/CC22).

*Dictyomitra* sp.A, aff. *D. sagitafera* Kh. Aliev

Plate 13, Figures 10 - 12

Remarks: The external shape of the proximal segments of this morphotype is produced by a thickening of the test wall on segments 2 - 4. This form differs from *D. sagitafera* sensu-stricto in having an almost free cephalis. Specimens of *D. aff. D. sagitafera* are better preserved than those of *D. sagitafera* and show a lateral rib pattern between costae which is similar to that observed on specimens of *D. formosa* and *D. koslovae*. Size range: 200 - 230\(\mu\text{m}\) (measured along greatest length of test, 10 specimens with between eight and ten segments).
**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22C): Campanian/Maastrichtian, Central Atlantic.

*Dictyomitra* sp.B, aff. *D. sagitafera* Kh. Aliev

Plate 14, Figures 1 - 3

**Remarks:** This form differs from *Dictyomitra* sp.A described above by having a less free cephalis and a less lobate outline. The external shape is produced, as in *Dictyomitra* sp.A, by thickening of the test wall of segments 2 - 4 but in *Dictyomitra* sp.B maximum thickness is present on the third segment. *Dictyomitra* sp.B also shows lateral ribs between costa, as in *D. formosa* and *D. koslovae*. Plate 14, fig. 2, an antapical view of this specimen, shows the relatively narrow mouth with reinforced margin which is a characteristic of the genus *Dictyomitra*. Size range: 190 - 210 μm (measured along greatest length of test, 10 specimens of eight segments).

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22C). Campanian/Maastrichtian, Central Atlantic.

**Genus EOSTICHOMITRA** Empson Morin


Type species: *Eostichomitra warzigita* Empson Morin, 1981, p. 280, pl. 13, figs. 1A - D.

**Remarks:** The terminology of Empson Morin is followed here although the justification for the distinction between *Eostichomitra* and *Stichomitra* appears to be based on the presence of an apical horn in *Eostichomitra* Empson Morin, whilst Cayeux (1897, p. 204) states that *Stichomitra* Cayeux has no apical spine.
*1981* *Eostichomitra warzigita* Empson Morin, p. 280, pl. 13, figs. 1A - D.

1982 *Stichomitra warzigita* (Empson Morin); Taketani, p. 56, pl. 11, fig. 9.

1988 *Eostichomitra* sp. cf. *E. warzigita* Empson Morin; Abin, p. 68, pl. 6, fig. 12.

**Remarks:** Taketani (1982) places this form in the genus *Stichomitra* Cayeux, thereby following the classification of Foreman (1968) although he states that his specimens agree well with *E. warzigita* Empson Morin apart from the nature of the apical horn. Since the specimens in this work also agree well with those of Empson Morin (1981), and because the genus *Stichomitra* Cayeux seems to be in need of revision, the classification of Empson Morin is followed here.

Size range 150 - 165 μm (measured along greatest length of test excluding apical horn, 10 specimens with between four and five segments).

**Occurrence [publications]:** Campanian, North Pacific; Cenomanian - Campanian, Japan; Campanian, Cuba.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22). Campanian/Maastrichtian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC25A).

**Genus EUCYRTIDIU M** Ehrenberg

*Eucyrtidium* EHRENBerg 1847b, p. 54.

Type Species: *Lithocampe acuminata* Ehrenberg, 1844, p. 84; *Eucyrtidium acuminata* (Ehrenberg), Ehrenberg, 1854a, pl. 22, fig. 27.

**Remarks:** Two species are tentatively included in *Eucyrtidium* based on the shape of the test, stout apical horn and number of chambers. It was not possible to make detailed investigations of internal structures due to preservational state of the specimens.
Eucrytidium(?) sp.A
Plate 14, Figures 7, 8, 12

Description: Test sub-ovoid with four segments and short, stout, bladed apical horn. The apical horn is usually located in an asymmetric position. The test wall has sub-rounded, regularly-spaced pores and the outer wall surface is covered by a generally irregular system of pore frames or bars. The distalmost segment is narrower than the abdomen, smoother and more sparsely perforate. Size range: 120 - 140 μm (measured along greatest length of test excluding apical horn, 10 specimens).

Remarks: This form is included in Eucrytidium but only tentatively because of the decrease in size of the distalmost segment. This form may belong in the genus Eusyringium Haeckel (1881, p. 437) but specimens of this latter genus figured by Haeckel (1887, Pl. 78, figs. 10, 11, 12) appear to have a final segment with a narrower, more distinctly tube-like structure.

Occurrence [this work]: Campanian, Cyprus.

Eucrytidium(?) sp.B
Plate 14, Figures 9-11

Description: Test sub-ovoid with four segments and short, stout, bladed apical horn. The apical horn is usually located in an asymmetric position. The test wall has sub-rounded, regularly-spaced pores and the outer wall surface is covered by a generally irregular system of pore frames or bars. The test wall is sometimes thickened into keel-like structures (marked by arrows on Plate 14, figs. 10 - 11), but this is not a consistent feature. The distalmost segment is very slightly narrower and externally smoother than the abdomen although the distribution of the pores is consistent. Size range: 140 - 155 μm (measured along greatest length of test excluding apical horn, 10 specimens).

Remarks: Eucrytidium(?) sp.B differs from Eucrytidium(?) sp.A in the characteristics of the fourth segment and in being generally slightly larger in size.

Occurrence [this work]: Campanian, Cyprus.
Genus *EUCYRTIS* Haeckel

*Eucyrtis* HAECKEL 1881, p. 438.

Type Species: *Eucyrtis conoidea* Rust, 1885, p. 316, pl. 40, fig. 10. (Subsequent designation by Foreman, 1973b, p. 264).

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*Eucyrtis sp.A*

Plate 15, Figures 1 - 3

**Description**: Test is elongate with no pronounced external strictures. Internally the test is divided into (usually) nine chambers (i.e. cephalis, thorax, abdomen and six post-abdominal chambers), although up to eleven have been observed. The chambers increase only slightly in width as added, reaching maximum width approximately midway down the length of the test and then gradually decreasing again. The proximal end of the test is non-porous, sometimes slightly papillose, pointed and may represent the base of a longer apical horn or projection although no specimens with such a horn have been recorded here. The distal end of the test is constricted and may produce a terminal tubular-like aperture although all specimens examined here appear to be incomplete. The surface of the test consists almost entirely (except for extreme distal and proximal ends as described above) of small sub-rounded pores. Pores are surrounded by a regular arrangement of approximately equally-sized angular pore frames. The junction between segments is sometimes marked by a very slight change in contour of the test outline and sometimes by a row of enlarged pore frames.

**Size range**: 320 - 350μm (measured along greatest length of test, 10 specimens with between nine and eleven segments).

**Remarks**: This form slightly resembles *Eucyrtis(?) zhamoidai* Foreman (1973b, p. 264, pl. 10, fig.10, U. Jurassic - L. Cretaceous)) but lacks any surface spines and has a less pronounced increase in chamber width. No specimens with apical horns preserved have been recovered.

**Occurrence [this work]**: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22; CC22). Campanian/Maastrichtian, Central Atlantic.
Genus *FOREMANINA* Empson Morin

*Foremanina* EMPSON MORIN 1981, p. 270
Type Species: *Foremanina schona* Empson Morin, 1981, p. 272, pl. 13, figs. 2 - 4.

*Foremanina schona* Empson Morin
Plate 15, Figures 4 - 6

\*1981 *Foremanina schona* Empson Morin, p. 272, pl. 13, figs. 2 - 4.
1988 *Foremanina schona* Empson Morin; Abin, p. 66, pl. 6, fig. 11.

Remarks: The forms here included in this species agree well with *Foremanina schona* Empson Morin in respect of general test shape and in possessing four quincunically arranged rows of pores per segment.
Size range: 200 - 270 μm (measured along greatest length of test, 10 specimens with between seven and nine segments).

Occurrence [publications]: Campanian, North Pacific; Campanian, Cuba.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages CC20/CC22; CC22/CC23A).

Genus *GONGYLOTORAX* Foreman

*Gongylothorax* FOREMAN 1968, p. 19.
Type Species: *Gongylothorax verheeki* (Tan Sin Hok), 1927, p. 44, pl. 8, figs. 40, 41.

Remarks: Distinguished from *Holocryptocanium* Dumitrica by the absence of descending spines on the thorax. This feature could not be examined in this material because of infilling and recrystallisation and specimens are therefore questionably assigned to this genus.
Gongylothorax (? ) sp. A
Plate 15, Figures 7 - 9

Description: Test sub-spherical with flattened area in the region of the cephalis (see plate 15, fig. 9). The cephalis is almost completely depressed and has a slightly papillose surface (plate 15, fig. 8). The surface of the test is formed of angular, usually hexagonal, pore frames arranged in slightly curved rows down the length of the test crossing in a diagonal pattern before converging on a small basal pore/aperture. This basal pore is surrounded by an imperforate rim. A row of pore frames encircles the cephalis. The pore frames are produced at junctions and may represent spine bases.

Size range: 150 - 170μm (measured along greatest length of test, 10 specimens).

Remarks: Internal examination of specimens was inhibited by infilling of the tests and because of the absence of a significantly larger pore or tube at the junction of the thorax and cephalis and the presence of a basal aperture these specimens are questionably assigned to Gongylothorax.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22; CC22). Campanian/Maastrichtian, Central Atlantic.

Genus HELIOCRYPTOCAPSA Dumitrica


Type Species: Heliocryptcapsa neagui Dumitrica, 1970, p. 59, pl. 3, figs. 14 - 19; pl. 4, figs. 20, 21a - c.

Heliocryptcapsa sp. A
Plate 15, Figures 10 - 12

1970 Heliocryptcapsa sp.2, Dumitrica, p. 60, pl. 4, fig. 22, pl. 5, figs. 24a - b.
1988a Heliocryptcapsa (?) sp. A, Thurow, p. 401, pl. 1, fig. 4.
1988 Heliocryptcapsa sp. 1 Dumitrica; Abin, p. 67, pl. 8, figs. 3 - 4.

Description: Test disc-shaped, inflated with two segments. The cephalis is depressed into the thorax and the position of the cephalis is indicated by an arrow on Plate 15, fig.
10. Seven spine bases are present around the equatorial margin. No specimens with spines intact have been recovered. The surface of the thorax consists of uniformly sized hexagonal pore frames which are always infilled masking the nature of the pores.

Size range: 150 - 170 μm (measured across maximum diameter of thorax excluding spines, 10 specimens).

**Remarks:** This morphotype differs from *H. neagui* Dumitrica (1970, Romania, Campanian) in lacking additional spines on the apical hemisphere.

**Occurrence [publications]:** Campanian, Romania; Campanian, Austria; Campanian, North Atlantic; Campanian, Cuba.

**Occurrence [this work]:** Campanian, Cyprus.

**Genus HEXAPYRAMIS** Squinabol

*Hexapyramis SQUINABOL* 1903, p. 113.

Type Species: *Hexapyramis pantanellii* Squinabol, 1903, p. 114, pl. 10, fig. 5.

**Remarks:** This morphology breaks in such a way that fragments recovered from the sediment sometimes resemble other species such as *Histiastrum* spp. (noted by Thurow, 1988a; see Schaaf, 1981, pl. 8, fig. 1, pl. 11, fig. 5). The size and shape of these forms, when relatively undamaged, make examination in transmitted light difficult. Only a low magnification objective (x20 or below) can be used at a relatively high focal plane to avoid crushing the specimen. Additionally, the probable infilling and recrystallisation of specimens studied here means that further investigation with transmitted light is impossible until the specimens have been sectioned.

*Hexapyramis pantanellii* Squinabol

Plate 16, Figures 1 - 3

*1903 Hexapyramis pantanellii* Squinabol, p. 114, pl. 10, fig. 5.

?1981 *Histiastrum aster* Lipman; Schaaf, p. 435, pl. 8, fig. 1; pl. 11, fig. 5.

1988a *Hexapyramis pantanellii* Squinabol; Thurow, p. 401, pl. 6, fig. 5.
Remarks: Thurow (1988a) suggests that the specimens figured by Schaaf (1981) more closely resemble *Hexapyramis pantanellii* Squinabol than *Histiastrum aster* Lipman, an opinion followed here. The specimens studied are difficult to examine in transmitted light partly because of their shape and size. It was not possible to focus on the wall structure or internal features because the depth of focus could not be achieved without breaking the specimen. Also, it was not possible to determine whether the internal structure may be dense or whether obscured as a result of preservational features, i.e. specimens may be infilled and/or recrystallised. Future investigations will involve sectioning of these specimens.

Size range: 200 - 240 μm (measured along greatest length of test excluding spines, 4 specimens).

Occurrence [publications]: Cretaceous, Italy; Albian - Cenomanian, North Pacific; Turonian, North Atlantic.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22).

Genus *Mita* Pessagno

*Mita* PESSAGNO 1977c, p. 44.

Type Species: *Mita magnifica* Pessagno, 1977c, p. 44, pl. 6, figs. 2, 5, 11, 13, 17,
pl. 7, fig. 24, pl. 12, fig. 11.

Remarks: *Mita* differs from *Archaeodictyomitra* by possessing primary pores on the post-abdominal chambers. Species may be distinguished on overall shape of complete specimens, by the size of the test, and by relative pore size and pore distribution.

*Mita gracilis* (Squinabol)

Plate 16, Figures 4 - 6

*1903 Sethoconus gracilis* Squinabol, p. 131, pl. 10, fig. 13.

1981 *Mita magnifica* Pessagno; Schaaf, p. 435, pl. 24, figs. 13a - b.

1981 *?Mita magnifica* Pessagno; Schaaf, p. 435, pl. 6, fig. 10.

1982 *Mita gracilis* (Squinabol); Taketani, p. 60, pl. 5, figs. 2a - b; pl. 12, fig. 3.

1984 *Mita gracilis* (Squinabol); Schaaf, p. 110, pl. G, figs. 2, 3, 4a - b.
Remarks: On well-preserved specimens the pores between the costae occur in double rows from approximately mid-way down the length of the test, reverting again to a single row at approximately the point where the segments become narrower at the antapical end of the test. The approximate positions of these changes are marked by arrows on Pl. 16, fig. 4.

Size range: 340 - 420 μm (measured along greatest length of test, 10 specimens with between nine and eleven segments).

Occurrence [publications]: Cretaceous, Italy; Albian - Cenomanian, North Pacific; Cenomanian, Japan; Albian - Turonian, North Atlantic; Albian - Turonian, North Pacific; Albian - Cenomanian, Yugoslavia; Albian, North Atlantic.

Occurrence [this work]: Campanian, Cyprus.

*Mita* sp.A
Plate 16, Figures 7 - 8

Description: Test conical, curved, usually with at least nine post-abdominal chambers. No complete specimens have been recovered. Costae robust with pores distributed in double rows throughout most of the length of the test. The position of change from a single row of pores to a double row is marked by the arrow on Plate 16, fig. 8.

Size range: 180 - 200 μm (measured along greatest length of test, 4 incomplete specimens).

Remarks: All forms recorded here have a curvature to the test which may be naturally present or may have occurred during diagenesis. All specimens were recovered from mudstones but it would be interesting to compare them with specimens of the same species which had been recovered from cherts. These latter specimens may not be found to be curved as they could be expected to have a different diagenetic history having been preserved in a more protective burial environment.

The wall structure of *Mita* sp.A shows a superficial resemblance to *Eucyrtid* gen. et sp. indet. Baumgartner (1984b, pl. 3, figs. 13 - 16), although there is a difference in the distribution of the longitudinal costae.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22/CC23A).

*Mita* sp.B
Plate 16, Figure 9

**Description:** Test conical, proximal segments usually bent at a slight angle to the remainder of the test. Usually with between eight and eleven segments and no external strictures between segments visible. Ten straight continuous costae are present in lateral view and separated by single rows of round pores. Size range: 185 - 250μm (measured along greatest length of test, 4 specimens with eight segments).

**Remarks:** Specimens of *Mita* sp.B are rare and the state of preservation makes it difficult to determine the distribution pattern of inter-costal pores. These forms resemble *Mita regina* (Campbell and Clark) figured by Taketani (1982, pi. 5, figs. 3a - b) from the Coniacian - Campanian of Japan, but differ in that they are generally much smaller.

Occurrence [this work]: Campanian, Cyprus.

Genus *NOVIXITUS* Pessagno

*Novixitus* PESSAGNO 1977c, p. 54

**Type Species:** *Novixitus mclaughlini* Pessagno, 1977c, p. 54, pl. 9, fig. 17.

**Remarks:** Pessagno differentiates *Novixitus* from *Xitus* on the basis of the presence of a single row of pores between the cephalis and the thorax and the absence of an apical horn. Species have been distinguished by previous workers on test outline; distribution, size and pattern of pore frames and tubercles; and the relative size of the cephalo-thoracic region to the remainder of the test.

*Novixitus* sp.A
Plate 16, Figures 10 - 12

1984 *Novixitus* sp.B Empson Morin, pl. 2, fig. 12.
**Description:** Test conical, usually of eight segments, and wide in relation to height. The first two post-abdominal chambers increase gradually in width. The third post-abdominal chamber abruptly decreases in width producing a "waisted" appearance to the test as the fourth and fifth post-abdominal chambers flare outwards. All specimens observed are poorly-preserved and the surface of the test has a roughened, uneven texture making determination of shape and arrangement of pores impossible.

*Size range:* 350 - 410 μm (measured along greatest length of test, 10 specimens).

**Remarks:** The internal structure of this form could not be examined as all specimens recovered were infilled.

**Occurrence [publications]:** Campanian, Austria, Cyprus.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22).

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**Novixitus** sp.B

Plate 17, Figures 1 - 3

1984 *Novixitus* sp.C Empson Morin, pl. 2, fig. 13.

**Description:** Test conical. Post-abdominal chambers increase rapidly producing a campanulate outline. The cephalis is imperforate or sparsely perforate and the thorax and abdomen have round pores arranged in a regular pattern. Post-abdominal segments show a variety of surface textures on the outer wall layer ranging from mostly regularly arranged hexagonal pore frames (Plate 17, fig. 1), to a highly irregular system of different-sized polygonal pore frames. Regular and irregular pore frames are often present on the same specimen (Plate 17, fig. 3).

*Size range:* 290 - 400 μm (measured along greatest length of test, 10 specimens).

**Remarks:** Forms recovered from Cyprus are similar to *Novixitus* sp.C Empson Morin which she recovered from the Campanian of SE Cyprus. Surface texture of anastomising ridges or bars varies between specimens but this variation is here admitted on forms with the same characteristic overall test shape. The general shape of the test resembles *Amphipyndax*? *epiplatys* Renz (1974, p. 788, pl. 5, fig. 1; pl. 12, fig. 2) from the 'Senonian to Aptian' of the Indian Ocean.
Occurrence [publications]: Campanian, Cyprus, Romania.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22; CC22).

Genus **Novodiacanthocapsa** Empson Morin


Type Species: *Diacanthocapsa ovoidea* Dumitrica, 1970, p. 63, pl. 5, figs. 25a-b, pl. 6, figs. 26 - 29b.

1944 *Dictyocephalus* Ehrenberg; Campbell & Clark, p. 28.
1968 *Theocapsomma* Haeckel; emend. Foreman, p. 29 (in part).
1974 *Theocapsomma* Haeckel; Riedel & Sanfilippo, p. 781.
1975 *Diacanthocapsa* Squinabol, emend. Dumitrica; Pessagno, p. 1017.
1978b *Stichomitra* Cayeux; Foreman, p. 728 (in part).

Remarks: Empson Morin (1981) divides many of the forms previously assigned to the genus *Diacanthocapsa* into two new genera, *Novodiacanthocapsa* and *Eastonerius*. Members of the former genus have a variable number of segments and a wide aperture. Members of the latter genus have usually two or three chambers, sutural pores and a constricted aperture. In this work the genus *Diacanthocapsa* Squinabol is still recognised but the value of a new genus for forms such as *Novodiacanthocapsa* (?) *manifesta* (Foreman) is acknowledged.

*Novodiacanthocapsa* (?) *manifesta* (Foreman)

Plate 17, Figures 4 - 6

1972 *Diacanthocapsa* sp.B Petrushevskaya & Kozlova, p. 536, pl. 7, fig. 5.
*1978b Stichomitra manifesta* Foreman, p. 748, pl. 5, fig. 4.
1981 *Novodiacanthocapsa manifesta* (Foreman); Empson Morin, p. 270, pl. 9, figs. 2A - 4D.
1982 *Stichomitra manifesta* Foreman; Taketani, p. 55, pl. 3, figs. 8a - b, pl. 11, figs. 7 - 8.

**Remarks:** This species is tentatively assigned to *Novodiacanthocapsa* Empson Morin, although this genus appears to be in need of revision due to the wide variety of forms included within it. Empson Morin herself questions this genus in a subsequent paper (1984). *Novodiacanthocapsa (?) manifesta* shares many common characteristics with species in the genus *Diacanthocapsa* Squinabol but differs in possessing a wide aperture and in lacking sutural pores. Specimens recovered during this work invariably consist of four chambers. Size range: 105 - 140 \(\mu m\) (measured along the greatest axis, 8 specimens).

**Occurrence [publications]:** Maastrichtian, Central Atlantic; Campanian - Maastrichtian, Central Atlantic; Campanian, North Pacific; Turonian - Campanian, Japan.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22/CC23A). Campanian/Maastrichtian - Maastrichtian, Central Atlantic.

Genus *ORBICULIFORMA* Pessagno, emend. Pessagno

*Orbiculiforma* PESSAGNO 1973a, p. 71

*Orbiculiforma* Pessagno, emend. Pessagno, 1976, p. 34.

Type Species: *Orbiculiforma quadrata* Pessagno 1973a, p. 71, pl. 16, figs. 1-4, pl. 18, fig. 3.

**Remarks:** Species in this genus are distinguished by 1) overall test size and shape, 2) the relative size, shape and depth of the central depression, 3) the characteristics of the peripheral spines, and 4) the nature of the meshwork of the test wall. Some forms are questionably assigned to this genus because they appear to lack peripheral spines. Pessagno (1977c, p. 27, pl. 1, fig. 14), reports some specimens of *Orbiculiforma* with "cylindrical, perforate tubes analogous to the brachioptyle of *Patulibracchium* Pessagno extending from the margin of the test". Although no tubes have been observed in material during this study the notches or indentations on the margin of some specimens may represent the sites of unpreserved tubes.
Orbiculiforma australis Pessagno
Plate 17, Figures 7 - 9

*1975 Orbiculiforma australis Pessagno, p. 1014, pl. 1, figs. 3 - 4.

Remarks: The small notch or indentation in the edge of the test may indicate the original site of a small tube-like projection as described under generic remarks above. Size range: 220 - 250 µm (measured across maximum width of test, 10 specimens).

Occurrence [publications]: Campanian, Tasman Sea.
Occurrence [this work]: Campanian, Cyprus.

Orbiculiforma maxima Pessagno
Plate 17, Figures 10 - 12

*1976 Orbiculiforma maxima Pessagno, p. 34, pl. 1, figs. 14, 16.

Remarks: Size range: 200 - 300 µm (measured across maximum width of test, 10 specimens). These are smaller than the holotype and paratypes (400 - 600 µm) described by Pessagno (1976) from the lower Cenomanian of California, but agree well with his specimens in all other respects including possession of an angled periphery.

Occurrence [publications]: Cenomanian, California.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC22; CC22/CC23A). Campanian/Maastrichtian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblages dated as CC23B; CC25A).

Orbiculiforma persenex Pessagno
Plate 18, Figures 1 - 3

*1976 Orbiculiforma persenex Pessagno, p. 35, pl. 6, figs. 12-13.

Remarks: Size range: 200 - 260 µm (measured across maximum width of test, 10 specimens).
Occurrence [publications]: Coniacian, California.

Occurrence [this work]: Campanian, Cyprus.

*Orbiculiforma* (?) aff. *O. quadrata* Pessagno

Plate 18, Figures 4 - 6

aff. "1973a *Orbiculiforma quadrata* Pessagno, p. 73, pl. 16, figs. 1-4, pl. 18, fig. 3.

aff. 1976 *Orbiculiforma quadrata* Pessagno; Pessagno, p. 35, pl. 6, figs. 10, 11.

aff. 1982 *Orbiculiforma quadrata* Pessagno; Taketani, p. 50, pl. 10, figs. 5 - 6.

Remarks: This form is questionably assigned to *Orbiculiforma* because of the relative depth of the test and the lack of a prominent rim around the central depression. Forms figured by Pessagno, including the holotype, appear to be thicker in relation to the overall test size. The illustration of a specimen in transmitted light (Plate 18, fig. 5) corresponds to *Staurodicya fresnoensis* Foreman (1968, Pl.2, figs. 1a-e) from the Upper Maastrichtian of California, in general shape and position of spines but here shows a different chamber arrangement.

Size range: 280 - 320 μm (measured across maximum width of test, 5 specimens).

Occurrence of *O. quadrata* Pessagno [publications]: Coniacian - Santonian, California; Turonian - Santonian, Japan.

Occurrence of *O. aff. quadrata* [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC18/CC22).

*Orbiculiforma* aff. *O. railensis* Pessagno

Plate 18, Figures 7 - 9

aff. "1977c *Orbiculiforma railensis* Pessagno, p. 28, pl. 1, figs. 14, 21; pl. 12, fig. 5.

aff. 1988a *Orbiculiforma railensis* Pessagno; Thurow, p. 403, pl. 5, fig. 18; pl. 9, fig. 20.
Remarks: The notch visible on the equatorial margin of the specimen figured in Plate 18, fig. 7 is possibly the site of a tube-like bracchiopyle structure. Size range: 170 - 210 μm (measured across maximum width of test, 10 specimens).

Occurrence O. railensis Pessagno [publications]: Albian, California; Albian, North Atlantic.
Occurrence O. aff. railensis [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC22).

O. sacramentoensis Pessagno
Plate 18, Figures 10 - 12

*1976 Orbiculiforma sacramentoensis Pessagno, p. 36, pl. 11, fig. 8.

Remarks: Pessagno did not show details of the spines due to poor preservation of his material, but specimens recovered during this work show spines which are circular in axial section at the distal ends and bladed at the extreme proximal ends. Although Pessagno described the overall shape of the test of the holotype as hexagonal his illustration (1976, Plate 11, fig. 8) shows that the shape is not as clearly defined as in the specimen figured here in Pl. 18, figs. 11 - 12.
Size range: 190 - 220 μm (measured across maximum width of test. 10 specimens).

Occurrence [publications]: Campanian, California; Campanian, Cyprus.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC18/CC22). Campanian/Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC23B).

O. sp.A
Plate 19, Figures 1 - 3

1982 Spongodiscid gen. et sp. indet. Kling, pl. 1, fig. 8.

Description: Test disc-shaped with a central depression on both sides, circular in outline with a crenulated margin. Meshwork spongy. Size range: 170 - 200 μm (measured across maximum width of test, 10 specimens).
Remarks: No specimens with peripheral spines preserved have been recorded from this material.

Occurrence [publications]: Campanian, North Pacific.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22; CC22; CC22/CC23A). Campanian, Central Atlantic.

*Orbiculiforma* sp. B
Plate 19, Figures 4 - 6

Description: Test disc-shaped, elliptical in outline with an indented margin towards one end. Test possesses a central depression on both sides. Meshwork spongy. Size range: 190 - 220 μm (measured along maximum length of test, 10 specimens).

Remarks: The indented margin is not thought to be due to damage as it is consistent on all specimens (c.10) and as close examination of the area reveals no irregularity in the pattern of the meshwork. It is not considered to be an aberrant form as it occurs commonly at several horizons and in different sections.

Occurrence [this work]: Campanian, Cyprus.

Genus *PARONAELLA* Pessagno
emend. Baumgartner

*Paronaella* PESSAGNO 1971, p. 46.
Type Species: *Paronaella solanoensis* Pessagno, 1971, p. 48, pl. 10, figs. 2, 3.

*Paronaella venadoensis* Pessagno
Plate 19, Figures 7 - 9

*1971  Paronaella venadoensis* Pessagno, p. 49, pl. 10, figs. 4 - 6; pl. 11, fig. 1.
1976  *Paronaella venadoensis* Pessagno; Pessagno, p. 31, pl. 5, fig. 16.

- A 80 -
Remarks: This species is distinguishable by the two characteristic, lateral, secondary spines on each side of the primary spine at ray tips. These spines are almost always preserved in material examined here.

Size range: 140 - 155μm (tertiary ray [measurement TX of Pessagno, 1971], 10 specimens).

Occurrence [publications]: Turonian/Coniacian - Coniacian, California; Coniacian, California.

Occurrence [this work]: Campanian, Cyprus. Campanian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC16/CC22).

Paronaella sp.A
Plate 19, Figures 10 - 12

Description: Test disc-shaped with three arms or rays in lateral view. Two of the rays are equal in length and the third is longer. Primary spines are present at ray tips and are circular in axial section. Reference to Plate 19, fig. 12 shows that spines appear to be constructed of six hollow tubes around a central shaft. Pore frames on the surface of the test are sub-rounded to subangular and arranged in parallel rows along the length of the rays. A patagium is usually present on material examined here.

Size range: 145 - 160μm (tertiary ray [measurement TX of Pessagno, 1971], 10 specimens).

Remarks: This form has been placed in the genus Paronaella because the pore frames along the rays are arranged in parallel rows and because no evidence of a bracchiopyle was found on any of the specimens examined.

Occurrence [this work]: Campanian, Cyprus. Campanian/Maastrichtian, Central Atlantic.

Paronaella sp.B
Plate 20, Figures 1 - 3

Description: Test disc-shaped with three arms or rays in lateral view. Two of the rays are equal in length and the third is longer. Spines are present at ray tips and are triradiate.
at extreme proximal ends becoming circular in axial section distally. The rays converge at a circular central area. The surface of the central area possesses pseudoaulophacid triangular meshwork and the surfaces of the rays show four to five rows of nodes and bars arranged in sub-rectangular patterns and centrally located down the length of each ray. The areas between the rays are infilled with spongy meshwork and although relatively substantially constructed this is regarded as the patagium.

Size range: 110 - 120 \( \mu m \) (tertiary ray [measurement TX of Pessagno, 1971], 10 specimens).

Remarks: This form has been placed in the genus *Paronaella* primarily because the meshwork of the test does not consist entirely of triangular bars with nodes at the junctions, which would make it *Pseudoaulophacus*, and because it has three rays with meshwork consisting of rectangular pore frames arranged in parallel rows, as opposed to the more irregular arrangement in the genus *Patulibracchium*. All specimens have spine bases at ray tips and none are recorded with a bracchiopyle.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nanofossil assemblage dated as CC22/CC23A). Campanian/Maastrichtian - Maastrichtian, Central Atlantic (co-occurs with calcareous nanofossil assemblage dated as CC25A).

*Paronaella* sp. C

Plate 20, Figures 4 - 6

Description: Test disc-shaped with three arms or rays in lateral view. Two arms are equal in length and the third arm is longer and more substantial. Spines are present at the ray tips and are circular in axial section. The patagium of this species is always well-developed giving an almost triangular outline to the test. The surface of the test is always poorly-preserved in this material but appears to consist of angular pore frames which are aligned in parallel rows of the arms or rays.

Size range: 170 - 180 \( \mu m \) (tertiary ray [measurement TX of Pessagno, 1971], 10 specimens).

Remarks: The specimen figured (Pl. 20, fig. 5), shows a pipe or tube projecting perpendicular to the surface of the test. Similar structures have been recorded adhering to the surfaces of spongodiscids and *Crucella* spp. It is probably a piece of debris,
although no microfossils have been recorded in this material which could have resulted in debris fragments such as this.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC18/CC22).

Genus *Patellula* Kozlova, emend. Empson Morin

*Patellula* KOZLOVA 1972, p. 527.
Type Species: *Stylospongia planoconvexa* Pessagno, 1963, p. 199, pl. 3, figs. 4-6, pl. 6, fig. 1

1963 *Stylospongia* Haeckel; Pessagno, p. 199.

Remarks: The extent of surface area of the test consisting of spongy meshwork versus angular pore frames on different specimens seems variable (as noted by Empson Morin, 1981) and may be at least partly due to preservational factors. Specimens assigned to this genus have equatorial spines which are hollow (at least at the distal ends).

*Patellula euessceei* Empson Morin

Plate 20, Figures 7 - 9

*1981 Patellula euessceei* Empson Morin, p. 257, pl. 1, figs. 4A-8C.
1988 *Patellula euessceei* Empson Morin; Abin, p. 42, pl. 1, figs. 3 - 4.

Remarks: *Patellula euessceei* differs from *P. planoconvexa* Pessagno (1963) from the Campanian of Puerto Rico, and from *P. verteroensis* (see below) because it is symmetrical on both sides of the test. Abin (1988) divides forms with relatively variable sizes of tholi into sub-species but these forms are here regarded as intra-specific variation.

Size range: 160 - 260 \( \mu \text{m} \) (measured across maximum width of test excluding spines, 10 specimens).
Occurrence [publications]: Campanian, North Pacific, Venezuelan Basin, Mexico, Puerto Rico, Cuba, Cyprus; Campanian, Cuba.

Occurrence [this work]: Campanian, Cyprus.

*Patellula verteroensis* (Pessagno)
Plate 20, Figures 10 - 12

*1963* Stylospongia verteroensis Pessagno, p. 199, pl. 3, figs. 1-3, pl. 6, figs. 2-3, pl. 7, figs. 3, 6.

1972 *Patellula verteroensis* (Pessagno); Petrushevskaya & Kozlova, p. 527, pl. 3, figs. 8, 9.

1981 *Patellula verteroensis* (Pessagno); Empson Morin, p. 257, pl. 2, figs. 1-5.

1988a *Patellula verteroensis* (Pessagno); Thurow, p. 403, pl. 2, figs. 19, 20.

1988 *Patellula verteroensis* (Pessagno); Abin, p. 43, pl. 1, figs. 1 - 2.

Remarks: Abin (1988) separates forms with a variably elevated tholus on the more convex side of the test into two sub-species. In this work forms showing variation in this way are grouped together as *P. verteroensis* and this feature is regarded as acceptable intra-specific variation. Pessagno (1963) separates *P. planoconvexa* and *P. verteroensis* using characteristics of the central tholus on both sides of the test.

Size range: 190 - 240 μm (measured across maximum width of test excluding spines, 10 specimens).

Occurrence [publications]: Campanian, Puerto Rico; Campanian, Central Atlantic; Campanian, North Pacific, Venezuelan Basin, Mexico, Cyprus; Campanian, North Atlantic; Campanian, Cuba.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nanofossil assemblages dated as CC18/CC22; CC20/CC22; CC22; CC22/CC23A). Campanian - Campanian/Maastrichtian, Central Atlantic (co-occurs with calcareous nanofossil assemblage dated as CC16/CC22).

*Patellula* sp.A
Plate 21, Figures 1 - 3

Description: Test disc-shaped, lenticular in peripheral view. In lateral view the test is sub-circular to angular with between 9 and 11 equatorial spine bases. These spine bases are
triradiate in axial section and no specimens with spines preserved have been recorded in this material. Tholi of equal diameter and equal elevation are present on both sides of the test and are encircled by shallow, moat-like depressions. The surface of the test is covered with sub-circular to sub-angular pore frames. No examination of internal structures has been attempted on this material. Size range 200 - 230\(\mu\)m (measured across maximum width of test excluding spines, 10 specimens).

**Remarks:** This form shows affinities with the pseudoaulophacid lineage with regard to general morphology but differs in lacking characteristic pseudoaulophacid pore frames. Jud (pers. comm., 1990) suggests that *P. solara* Jud (in press), a similar form, is restricted to the Berriasian.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22).

**Genus** *PATULIBRACCHIUM* Pessagno


**Type Species:** *Patulibrachium davisi* Pessagno, 1971, p. 30, pl.1, figs. 1-4.

**Remarks:** Pessagno describes members of this genus as possessing a bracchiopyle, but although specimens recovered here, and described below, agree with those first described by Pessagno with respect to external morphological features of the test no specimens showing a bracchiopyle were recovered. Baumgartner (1980) also notes the absence of this feature in Jurassic specimens from Argolis, Greece. De Wever (pers. comm., 1990) has suggested that the bracchiopyle may be a temporary reproductive feature.

*Patulibrachium californiaensis* Pessagno

Plate 21, Figures 4 - 6

*1971* *Patulibrachium californiaensis* Pessagno, p. 29, pl. 11, fig. 6, pl. 12, figs. 1, 2.

1976 *Patulibrachium californiaensis* Pessagno; Pessagno, p. 30, pl. 10, fig. 13.
1984 *Patulibracchium californiaensis* Pessagno; Empson Morin, p. 101, text fig. 9A-C.

1988a *Patulibracchium californiaensis* Pessagno; Thurow, p. 403, pl. 2, fig. 9.

1988 *Patulibracchium californiaensis* Pessagno; Abin, p. 45, pl. 4, figs. 1 - 2.

**Remarks:** No forms with a brachioptyle present were recorded although one ray tip is always apparently broader than the other two (Pl. 21, figs. 5/6). *P. californiaensis* is easily recognisable even in poorly-preserved material due to its distinctive shape.

**Size range:** 140 - 150 \(\mu\text{m}\) (tertiary ray [measurement TX of Pessagno, 1971], 10 specimens).

**Occurrence [publications]:** Campanian, California; Campanian, Cyprus, Austria, Venezuelan Basin; Campanian, North Atlantic; Campanian, Cuba.

**Occurrence [this work]:** Campanian, Cyprus.

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*Patulibracchium sp.A*

Plate 21, Figures 7 - 9

**Description:** Test disc-shaped with three arms or rays of approximately equal length in lateral view. The area between the rays is infilled by a patagium giving the test a triangular outline in lateral view. The rays are slender at their proximal ends, expanding rapidly at the distal ends forming bulbous tips. One triradiate spine base is present at the tip of each ray, although on some specimens this is not distinguishable on all three rays. No positive evidence of a brachioptyle has been observed on any of the specimens recorded here although this feature may have existed but not been preserved. The pore frames on the surface of the three rays are relatively coarse, polygonal and irregular while the surface of the patagium is of finer spongy meshwork.

**Size range:** 145 - 155 \(\mu\text{m}\) (tertiary ray [measurement TX of Pessagno, 1971], 10 specimens). N.B. although the tertiary ray is referred to here all rays are approximately equal in length as discussed above.

**Remarks:** This form differs from other species of this genus found in that the area between the arms or rays is entirely infilled by a patagium with spongy meshwork.
**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC18/CC22).

*Patulibrachium sp.B*
Plate 21, Figures 10 - 12

**Description:** Test disc-shaped with three arms or rays in lateral view. Two of the rays are equal in length and the third is very slightly longer and slightly slimmer. The rays originate from a small central area, becoming very slender proximally and then bulbous in the distal part of the length. A triradiate spine base is usually present at ray tips although no specimens with spines preserved have been recovered from this material. The inter-ray area is infilled with a spongy patagium of fine meshwork, whilst retaining a lobate outline. The surface of the rays or arms is covered with irregular, subrounded and subangular meshwork. No examination of the internal structure of this form has been made here. No evidence of a bracchiopyle has been found on any specimen in this study.

**Size range:** 100 - 110 μm (tertiary ray [measurement TX of Pessagno, 1971], 10 specimens).

**Remarks:** These forms are very similar to *Patulibrachium* sp.A, differing by their slightly smaller size and in lacking the triangular shape produced by the straight sided patagium of the latter form.

**Occurrence [this work]:** Campanian, Cyprus.

*Patulibrachium sp.C*
Plate 22, Figures 1 - 2

**Description:** Test disc-shaped with three arms or rays in lateral view. No specimens were recovered with spines preserved although single spine bases which are circular in axial section at ray tips are sometimes present. The test surface is uniformly covered with a delicate spongy meshwork. In transmitted light the chambers of the central area of the test appear to form a pattern of concentric rings, whilst the ray chambers appear to be arranged in a sublinear fashion.

**Size range:** 90 - 110 μm (tertiary ray [measurement TX of Pessagno, 1971], 5 specimens).
Remarks: There is no evidence of a brachioype in any of the species recorded herein.

Occurrence [this work]: Campanian, Cyprus.

*Patulibracchium* sp.D
Plate 22, Figure 3

**Description:** Test disc-shaped with three arms or rays in lateral view, one of the arms being slightly longer. The arms are relatively short in relation to the diameter of the central area, and are of a similar thickness throughout their length and rounded at the proximal ends. Spines/spine bases, when present, are triradiate in axial section. When complete, spines are relatively short and pointed distally. The chambers of the central area appear to be arranged in a circular pattern whilst chambers on the arms are arranged sublinearly. The test surface is covered with irregular, subround to subangular meshwork.

Size range: 70 - 85 µm (tertiary ray [measurement TX of Pessagno, 1971], 4 specimens).

Remarks: No specimens with all three spines/spine bases present have been observed.

Occurrence [this work]: Campanian, Cyprus. Campanian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblages CC16/CC22; CC25A).

*Patulibracchium* sp.E
Plate 22, Figures 4 - 6

**Description:** Test disc-shaped with three arms or rays in lateral view. The rays originate from a very small central area and become expanded at their distal terminations forming inter-ray depressions. The periphery of the test in lateral view is triangular due to a raised rim joining the distal ends of the rays. The test surface is covered with regular, coarse, angular meshwork, similar to that found on specimens of *P. californiensis* Pessagno. No specimens with spines preserved were recovered here but spine bases, when present at ray tips, are circular in axial section. Size range: 135 - 150 µm (tertiary ray [measurement TX of Pessagno, 1971], 6 specimens).
**Remarks:** Apart from the (?)patagium (or infilled inter-ray areas) this form is similar to *P. californiensis* Pessagno.

**Occurrence [this work]:** Campanian, Cyprus.

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**Genus PHASELIFORMA** Pessagno

*Phaseliforma* PESSAGNO 1972, p. 274.

Type Species: *Phaseliforma carinata* Pessagno, 1972, p. 274, pl. 22, figs. 1-3, 8, pl. 23, fig. 1.

**Remarks:** Members of this genus form the larger components of Campanian radiolarian assemblages. Species are distinguished on overall test shape and on the texture of the test surface. In this investigation the internal structures of specimens have not been examined in section.

*Phaseliforma* has been reported from Senonian sediments in California, Russia, Cuba, Central Atlantic, Pacific, Austria, Mexico, Puerto Rico, Texas, Cyprus and Romania and from Cenomanian sediments in Romania.

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*Phaseliforma laxa* Pessagno

*Plate 22, Figure 7*

*1972* *Phaseliforma laxa* Pessagno, p. 276, pl. 23, figs. 7 - 9.

*1976* *Phaseliforma laxa* Pessagno; Pessagno, p. 26, pl. 9, fig. 16.

**Remarks:** Specimens recorded here are all of a similar size and although smaller than the holotype [360\(\mu\)m] fall within the size range of paratypes recorded by Pessagno (1972).

Size range: 270 - 300\(\mu\)m (measured along greatest length of test, 10 specimens).

**Occurrence [publications]:** Campanian, California; Campanian, California.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22). Campanian/Maastrichtian, Central Atlantic.
**Phaseliforma aff. P. laxa** Pessagno
Plate 22, Figures 10 - 12

**Remarks:** The forms included here are similar in shape to *P. laxa* but differ in possessing thicker pore frames which produce a coarser texture on the test surface. The present material also differs in being generally smaller than the holotype of *P. laxa* (measurement of the latter = 360 μm), although Pessagno (1972) does record a smaller paratype (measurement = 200 μm).

*Size range:* 200 - 260 μm (measured along greatest length of test, 10 specimens).

**Occurrence [this work]:** Campanian, Cyprus.

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**Phaseliforma sp.A**
Plate 22, Figure 8

**Description:** Test sub-ellipsoidal in shape being flattened along the lateral plane. In lateral view the test has an oval shape except for a rapid expansion and then contraction of the test approximately two thirds down the length and on one side only. This produces an angled (c. 130°) margin to one side of the test. Pore frames are approximately uniform in size, predominantly sub-rounded to sub-angular and not distributed in a regular pattern.

*Size range:* 230 - 260 μm (measured along greatest length of test, 10 specimens).

**Remarks:** This form differs from *Phaseliforma carinata* Pessagno (1972), from the Campanian of California, by lacking a developed keel or angled periphery and by being less elongate in overall shape. Detailed examination of the internal structures of this form has not been undertaken during this study.

**Occurrence [this work]:** Campanian, Cyprus.

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**Phaseliforma sp.B**
Plate 22, Figure 9

**Description:** Test sub-ellipsoidal in shape, flattened along the lateral plane and sub-ovoid to sub-rounded in lateral view, slightly inflated along the median plane. Although
the test is flattened the periphery is rounded rather than angular, i.e. no keel-like features are present. Pore frames are moderately fine, sub-angular to sub-rounded and irregularly distributed over the surface of the test.

Size range: 320 - 350μm (measured along greatest length of test, 10 specimens).

Remarks: This form differs from Phaseliforma sp.A in having a more circular outline in lateral view and in possessing predominantly sub-angular pore frames. No detailed examination of internal structures has been made during this study.

Occurrence [this work]: Campanian, Cyprus.

Genus *PRAECONOCARYOMMA* Pessagno(?)


Type Species: *Praeconocaryomma universa* Pessagno, 1976, p. 42.

Remarks: Pessagno erected the genus *Praeconocaryomma* in 1976 to distinguish between Cretaceous specimens and those belonging to the Tertiary genus *Conocaryomma* Lipman, 1969. Pessagno believed that the Mesozoic species are different in that they invariably have only 3 rather than 4 or 5 medullary shells. Empson Morin (1981) disagreed and restored the genus *Conocaryomma* on the basis that those specimens with fewer medullary shells may be juveniles. The distinction between juveniles and adults is difficult but it is unlikely that an assemblage of relatively large sized individuals would consist entirely of juveniles. It is also unlikely, although admittedly not impossible, that this genus crossed the K/T boundary unchanged. Pessagno (1976) is followed here but species published as *Conocaryomma* have been compared. Thurow (1988a) and De Wever (1988) follow Empson Morin (1981) in considering these forms as *Conocaryomma*.

All specimens need to be examined carefully for an aperture, the size and shape of pores and pore frames, and the presence or absence of spines and spines bases with reference to the shape of the spine if present. Spines are not preserved on any members of this genus recovered during this work. Since all specimens are infilled and it is not possible to determine the number of medullary shells present, or other internal structures such as connecting beams, these forms have been questionably assigned to the genus *Praeconocaryomma*.
**Praeconocaryomma(?) dauerhafta** (Empson Morin)

Plate 23, Figures 1 - 3

*1981* *Conocaryomma dauerhafta* Empson Morin, p. 260, pl. 2, figs. 3 - 4.

**Remarks:** The specimen in Plate 23, fig. 2, shows an aberration of the test wall in which a small area of the cortical shell structure is less undulating and resembles that of *Conocaryomma glatta* Empson Morin (1981). This feature is only seen on a few specimens recovered during this work (co-occurring in samples with forms with uniform shell structure) and they may represent transitional forms between *P. dauerhafta* and *C. glatta* Empson Morin.

Size range: 120 - 160 μm (measured across maximum diameter of cortical shell, 10 specimens).

**Occurrence [publications]:** Campanian, North Pacific.

**Occurrence [this work]:** Campanian, Cyprus.

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**Praeconocaryomma(?) universa** Pessagno

Plate 23, Figures 4 - 6

1973b *Actinommid gen. et sp. indet.*, Foreman, pl. 1, fig. 6.

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

1981 *Conocaryomma universa* (Pessagno); Empson Morin, p. 260, pl. 3, fig. 5.

1982 *Praeconocaryomma universa* Pessagno; Taketani, p. 47, pl. 1, figs. 3a, b, 4, pl. 9, fig. 4.

1986 *Praeconocaryomma universa* Pessagno; Thurow & Kuhnt, text fig. 9.22.

1988a *Conocaryomma universa* (Pessagno); Thurow p. 398, pl. 2, fig. 18.

1988a *Conocaryomma universum* (Pessagno); De Wever *et al.*, p. 169, pl. 3, fig. 7.

**Remarks:** Thurow (1988a) states that Campanian forms do not show triradiate clearly spines, if at all, and cites Empson Morin (1981, pl. 3, fig. 5). Her figure seems to show triradiate spine bases, as far as can be determined from a photograph. A more accurate decision needs to be made from the actual specimen. Pessagno’s holotype shows a triradiate spine whilst the paratypes show triradiate spine bases (Coniacian material).
No specimens with spines intact were recovered in this work, but the surfaces of the nodes are approximately triangular in shape and have small papillae-like structures (see Plate 23, fig. 5) which may represent bases of triradiate spines.

Size range: 160 - 185 μm (measured across maximum diameter of cortical shell, 10 specimens).

Occurrence [publications]: Valanginian/Hauterivian, North Pacific; Coniacian - Campanian, California; Campanian, North Pacific; Coniacian - Santonian, Japan; Cenomanian/Turonian, Central Atlantic; Turonian - Campanian, North Atlantic; Coniacian - Campanian, Oman.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22; CC22; CC22/CC23A).

Genus **PRAESTYLOSPHAERA** Empson Morin


Type Species: *Sphaerostylus hastatus* Campbell & Clark, 1944, p. 5.

1944 *Sphaerostylus* Haeckel, Campbell & Clark, p. 5.
1974 *Stylosphaera* Ehrenberg, Renz, p.798 (in part), pl. 9, fig. 20.
1978b *Ellipsoxiphus* Dunikowski, Foreman, p. 742.

Remarks: Empson Morin (1981) recombined ellipsoidal and spherical forms at generic level, placing primary importance on shell structure, and suggested that the test shape is important only at specific level. *Praestylosphaera* is therefore distinguishable from other bi-polar genera such as *Acaeniotyle*, *Archaeospongoprunitum* and *Protoxiphotractus* by external characteristics of test structure.

**Praestylosphaera hastata** (Campbell & Clark)

Plate 23, Figures 7 - 9

*1944 Sphaerostylus (Sphaerostylantha) hastatus* Campbell & Clark, p. 5, pl. 1, fig. 1.
1978b *Ellipsoxiphus hastatus* (Campbell & Clark); Foreman, p. 742, pl. 2, fig. 13.
1981 *Praestyllosphaera hastata* (Campbell & Clark); Empson Morin, p. 262, pl. 4, figs. 4-5C.

**Remarks:** *P. hastata* is most easily distinguished from other species of *Praestyllosphaera* by its near spherical test shape. The forms recovered from Cyprus are generally larger than those recovered from site 369A in the Central Atlantic. The distinguishing features between *P. hastata* and *P. pusilla* are described under the latter species.

Size range: 90 - 105 μm (body of test [measurement AA' of Pessagno, 1973a], 10 specimens).

**Occurrence [publications]:** ?Campanian, California; Campanian - Maastrichtian, Central Atlantic; Campanian, North Pacific.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22). Maastrichtian, Central Atlantic.

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1972 *Stylatractus (?)* sp. Petrushesvskaya & Kozlova, pl. 4, figs. 3 - 4.

*1978b* *Ellipsoxiphus privus* Foreman, p. 743, pl. 2, figs. 14 - 16.

**Remarks:** Specimens found here agree well with the description of Foreman (1978b). The specimen figured in Plate 23, fig. 10, illustrates the presence of by-spines (arrowed) at the junctions of the pore frames. *P. privus* differs from *P. hastata* and *P. pusilla* by having an ellipsoidal test shape with much larger pores and pore frames.

Size range: 90 - 105 μm (measured along greatest axis of test body [measurement AA' of Pessagno, 1973a], 10 specimens).

**Occurrence [publications]:** Maastrichtian, Central Atlantic; Campanian - Maastrichtian, Central Atlantic.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22). Campanian/Maastrichtian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC23B).
Praestylosphaera pusilla (Campbell & Clark)
Plate 24, Figures 1 - 3

*1944 Stylosphaera (Stylosphaerella) pusilla Campbell & Clark, p. 5,
   pl. 1, figs. 2, 4, 5.
1974 Stylosphaera pusilla Campbell & Clark; Renz, p. 798, pl. 9, fig. 20.
1978b Ellipsoxiphus pusilla (Campbell & Clark); Foreman, p. 743, pl. 2,
   figs. 9, 10, 17.
1981 Praestylosphaera sp. aff. P. pusilla (Campbell & Clark); Empson Morin,
   p. 262, pl. 4, fig. 6.

Remarks: P. pusilla differs from P. hastata in having a slightly ellipsoidal test
shape. The bi-polar spines are unequal in length on both species but in P. hastata this
inequality is more exaggerated, the shorter spine being sometimes only half the length of
the longer one.
Size range: 140 - 145 μm (body of test [measurement AA' of Pessagno, 1973a], 10
specimens).

Occurrence [publications]: ?Campanian, California; Aptian /Maastrichtian, Indian
Ocean; Campanian - Maastrichtian, Central Atlantic; Campanian, North Pacific.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil
assemblage dated as CC20/CC22). Campanian - Maastrichtian, Central Atlantic (co-
occurs with calcareous nannofossil assemblages dated as CC23B; CC25A).

Praestylosphaera sp.A
Plate 24, Figures 4 - 6

Description: Ellipsoidal test with bi-polar spines which are circular in axial section.
The surface of the test shows round pores set in angular pore frames. The polar spines are
unequal in length and slightly out of alignment with each other.
Size range: 70 - 100 μm (body of test [measurement AA' of Pessagno, 1973a], 10
specimens).

Remarks: Praestylosphaera sp.A differs from P. privus in having a more
rounded shape to the ellipsoidal test body and differs from P. pusilla in having larger
and fewer pores and pore frames per unit area of test surface.
Occurrence [this work]: Campanian, Cyprus.

Genus PROTOXIPHOTRACTUS Pessagno

Protoxiphotractus PESSAGNO 1973a, p. 81.
Type Species: Protoxiphotractus perplexus Pessagno, 1973a, p. 83, pl. 15, figs. 1-3.

Remarks: The internal structure of members of this genus has not been examined in section. The genus differs from Praestylosphaera by including forms which have large angular pore frames subdivided by slightly depressed, more fragile bars.

Protoxiphotractus kirbyi Pessagno
Plate 24, Figures 7 - 9

*1973a* Protoxiphotractus kirbyi Pessagno, p. 83, pl. 14, fig. 6.
1976 Protoxiphotractus kirbyi Pessagno; Pessagno, p. 40, pl. 12, fig. 5.

Remarks: Differences in test shape and pore frame structure and density of pore distribution between *P. kirbyi* and the genotype *P. perplexus* are apparent from illustrations of the respective holotypes (Pessagno, 1973). Although the ranges of these two species seem to be identical only forms identified as *P. kirbyi* were recorded in this work, which may indicate provincialism or environmental influence. Taketani (1982) illustrates a similar form, *P. cf. P. perplexus* from Coniacian - Campanian sediments of the western Pacific, but states that it is slightly smaller in size than the typical form. Size range: 100 - 130 μm (measured along greatest axis of test and excluding spines, 12 specimens).

Occurrence [publications]: Campanian, California; Campanian, California.
Occurrence [this work]: Campanian, Cyprus. Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC25A).
Genus **PROTUNUMA** Ichikawa & Yao


**Remarks:** *Protunuma* differs from the genus *Unuma* in lacking a basal appendage with large pores.

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*Protunuma (?) sp. A*

**Plate 24, Figures 10 - 12**

1971  *Theoperid gen. et sp. indet.* Kling, p. 1089, pl. 8, fig. 15.
1971  *Theoperid gen. et sp. indet.* Foreman, p. 1676, pl. 3, fig. 1.
1973  *Dicolocapsa* sp. A Moore, p. 826, pl. 11, fig. 10.
1973b *Theoperid gen. et sp. indet.* Foreman, pl. 15, fig. 17.
1978b *Gen. et sp. indet.* Foreman, p. 748, pl. 2, fig. 4.
1982 *Cryptocapsular theoperid gen. et sp. indet.* Kling, p. 548, pl. 2, fig. 22

**Description:** Two-chambered ellipsoidal test with longitudinal ridges or plicae. The cephalis is partly encased in the test wall. Pores are small, round and arranged in approximate rows sub-parallel to plicae. The distal end of the test constricts into a small, short, tube-like aperture (Pl. 24, figs. 10/12). Size range: 90 - 120 μm (measured along greatest length of test, 10 specimens).

**Remarks:** This form is very similar to *Cyrtophormis spiralis* Haeckel (1887, p. 1166, pl. 51, fig. 9). Identification is tentative because the original description of Ichikawa & Yao (1976) states that at least three chambers are present and the forms recovered here apparently only have two.

**Occurrence [publications]:** Campanian, North Pacific; ?Campanian, Central Pacific; Cenomanian - Maastrichtian, Central Pacific; Campanian, North Pacific; Jurassic, Central Atlantic; Campanian, North Pacific.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22).
Genus *PSEUDOAULOPHACUS* Pessagno


Type Species: *Pseudoaulophacus floresensis* Pessagno, 1963, p. 200, pl. 2, figs. 2, 5, pl. 4, fig. 6, pl. 7, figs. 1, 5.

??*Pseudoaulophacus floresensis* Pessagno

Plate 25, Figures 1 - 3

*1963* *Pseudoaulophacus floresensis* Pessagno, p. 200, pl. 2, figs. 2, 5, pl. 4, fig. 6, pl. 7, figs. 1, 5.

?1971 *Pseudoaulophacus floresensis* Pessagno; Foreman, p. 1675, pl. 2, fig. 6.

?1972 *Pseudoaulophacus floresensis* Pessagno; Pessagno, p. 304, pl. 26, fig. 6, pl. 28, figs. 4-6, pl. 29, figs. 1-2, pl. 31, fig. 1.

?1973a *Pseudoaulophacus floresensis* Pessagno; Foreman, p. 429, pl. 13, fig. 8.

?1973 *Pseudoaulophacus floresensis* Pessagno; Moore, p. 824, pl. 12, figs. 2, 3.

?1976 *Pseudoaulophacus floresensis* Pessagno; Pessagno, p. 28, pl. 9, fig. 6.

?1980 *Pseudoaulophacus floresensis* Pessagno; Okamura, pl. 23, fig. 3.

?1981 *Pseudoaulophacus floresensis* Pessagno; Nakaseko & Nishimura, p. 158, pl. 2, fig. 4.

?1982 *Pseudoaulophacus floresensis* Pessagno; Kling, p. 548, pl. 1, fig. 11.

?1985 *Pseudoaulophacus floresensis* Pessagno; Sanfilippo & Riedel, p. 595, text fig. 6.3a, b.

?1988a *Pseudoaulophacus floresensis* Pessagno; Thurow, p. 404, pl. 2, fig. 5.

?1988 *Pseudoaulophacus floresensis* Pessagno; Abin, p. 39, pl. 3, fig. 1.

Remarks: Size range: 160 - 210 μm (measured across maximum width of test excluding spines, 10 specimens).

This form has been questionably included under the name *P. floresensis* because it sometimes possesses spine bases which are triradiate in axial section, as opposed to circular in the holotype, and because the overall shape is slightly more triangular than the holotype figured by Pessagno (1963). No specimens with the spines intact were recovered and it is possible that the spines are only triradiate at the proximal end, becoming circular.
in axial section distally. This form is not included under *P. praefloresensis* Pessagno (1972) from the Turonian/Coniacian - Campanian of California, because it lacks an acutely angled margin.

**Occurrence [publications]:** Campanian, Puerto Rico; Santonian/Campanian, Central Pacific; Campanian, Mexico, Puerto Rico, Cyprus, California; Campanian, Gulf of Mexico; Cenomanian - Campanian, Central Pacific; Santonian - Campanian, California; Santonian - Campanian, Japan; Coniacian - Santonian, Japan; Campanian, North Pacific; Campanian - Maastrichtian, Bavaria, California; Campanian - Maastrichtian, North Atlantic; Campanian, Cuba.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC18/CC22; CC20/CC22; CC22). Campanian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblages dated as CC16/CC22).

*Pseudoaulophacus aff. P. floresensis* Pessagno

**Plate 25, Figures 4 - 6**

1972 *Pseudoaulophacus* sp. A Pessagno, p. 312, pl. 30, fig. 6.

1982 *Pseudoaulophacus* sp. cf. *P. floresensis* Pessagno; Taketani, p. 51, pl. 2, figs. 7a - b; pl. 10, figs. 9 - 10.

**Remarks:** This form differs from *P. floresensis* Pessagno (and from *P. floresensis* Pessagno as described above) by possessing a test which is more rounded in lateral view and spines which are triradiate at the proximal end.

Size range: 170 - 220 \(\mu m\) (measured across maximum width of test excluding spines, 10 specimens).

**Occurrence [publications]:** Turonian/Coniacian - Coniacian, California; Turonian - Campanian, Japan.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22).

*Pseudoaulophacus* sp. A

**Plate 25, Figures 7 - 9**

- A99 -
**Description:** Test disc-shaped, lenticular in peripheral view and sub-rounded in lateral view. Tholi are present and the meshwork of the test consists of pore bars forming equilateral triangles. Three primary spines are located at equidistant points on the equatorial margin. A fourth spine is also located on the equatorial margin forming an angle of approximately 25° with one of the primary spines. All four spines are of equal width and are apparently circular in axial section. No specimens with complete spines preserved are recorded. Size range: 190 - 230 μm (measured across maximum width of test excluding spines, 10 specimens).

**Remarks:** This form is very similar to *P. aff. P. floresensis* (figured in Pl. 25, figs. 4 - 6) but differs in possessing a fourth spine. The form is probably transitional (e.g. it may represent part of a possible *P. floresensis* - *P. lenticulatus* lineage) and because of its common occurrence in different sections in Cyprus it is not considered an aberrant form. Thurow (*pers. comm.*, 1991) also reports this form from Cyprus, his specimens are well-preserved and possess spines which are circular in axial section.

**Occurrence [this work]:** Campanian, Cyprus.

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**Pseudoaulophacus sp.B**

Plate 25, Figures 10 - 12

**Description:** Test disc-shaped, lenticular in peripheral view and sub-triangular in lateral view. Each side of the triangle is divided approximately mid-way by an obtuse-angled/convex bend. Tholi are present and the surface of the test consists entirely of pore frames forming equilateral triangles. Three primary spines are present, located at equidistant points on the equatorial margin and which are triradiate at the proximal ends. No specimens have been recovered with spines intact. Size range: 160 - 200 μm (measured across maximum width of test excluding spines, 10 specimens).

**Remarks:** This form is similar to *P. floresensis* Pessagno but differs in having each of the three sides of the triangular test sub-divided by obtuse angles, suggesting a tendency towards a hexagonal as opposed to a triangular symmetry. Pessagno records a similar form, *Pseudoaulophacus* sp.B, (1972, pl. 30, fig. 5) from the Campanian of California.
Occurrence [publications]: Santonian/Maastrichtian, California.
Occurrence [this work]: Campanian, Cyprus.

*Pseudoaulophacus lenticulatus* (White)
Plate 26, Figures 1 - 3

1928 *Baculogypsina* (?) *lenticulata* White, p. 306, pl. 41, figs. 9, 11.
1962 *Aulophacus lenticulatus* (White); Pessagno, p. 364, pl. 6, figs. 1, 2.
1963 *Pseudoaulophacus lenticulatus* (White); Pessagno, p. 202, pl. 2, figs. 8, 9.
1972 *Pseudoaulophacus lenticulatus* (White); Pessagno, p. 306, pl. 2, figs. 5, 6, pl. 3, figs. 1-3.
1973 *Pseudoaulophacus lenticularis* (White); Moore, p. 824, pl. 12, fig. 1.
1976 *Pseudoaulophacus lenticulatus* (White); Pessagno, p. 28, pl. 9, figs. 11, 12.
1981 *Pseudoaulophacus lenticulatus* (White); Nakaseko & Nishimura, p. 158, pl. 2, figs. 7a, b.
1982 *Pseudoaulophacus lenticulatus* (White); Kling, p. 548, pl. 1, fig. 12.
1982 *Pseudoaulophacus lenticulatus* (White); Taketani, p. 51, pl. 10, fig. 11.
1985 *Pseudoaulophacus lenticulatus* (White); Sanfilippo & Riedel, p. 596, text figs. 6.4a, b.
1988a *Pseudoaulophacus lenticulatus* (White); Thurow, p. 404, pl. 2, fig. 6.
1988 *Pseudoaulophacus lenticulatus* (White); Abin, p. 39, pl. 2, fig. 7.

Remarks: If spines are missing and dissolution has attacked the spine bases then this species can easily be confused with *P. pargueraensis* (see below). Intra-specific morphological variation occurs in: 1) relative width of the tholi to the overall test diameter; 2) presence/absence of a depression around the tholus; 3) thickness of the test at the equatorial margin (which can vary from an acute, almost keel-like, angled margin to a thin but blunt margin); and 4) length and number of equatorial spines. Morphological variation may be a feature of provincialism as Sanfilippo & Riedel (1985, text-figs. 6.4a - 6b) illustrate variation in the size of the tholus and of the test in specimens from California and Bavaria. Alternatively, variants may be transitional forms in an evolutionary lineage. Specimens with all spines preserved intact were not found. Size range: 190 - 250μm (measurement of diameter of test excluding spines, 10 specimens).
Occurrence [publications]: Cretaceous, Mexico; Santonian - Campanian, Puerto Rico, Mexico, Cyprus; Campanian, Puerto Rico; Turonian/Coniacian - Campanian, California; Cenomanian - Campanian, Central Pacific; Coniacian - Campanian, California; Coniacian - Campanian, Japan; Campanian, North Pacific; Turonian - Campanian, Japan; Campanian, Composite; Campanian, North Atlantic; Campanian, Cuba.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22; CC22; CC22/CC23A). Campanian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC16/CC22).

_Pseudoaulophacus pargueraensis_ Pessagno

Plate 26, Figures 4 - 6

*1963* _Pseudoaulophacus pargueraensis_ Pessagno, p. 204, pl. 2, figs. 4, 7, pl. 6, figs. 4, 5.

1971 _Pseudoaulophacus pargueraensis_ Pessagno; Foreman, p. 1675, pl. 2, fig. 7.

1972 _Pseudoaulophacus pargueraensis_ Pessagno; Pessagno, p. 309, pl. 30, fig. 4.

1973a _Pseudoaulophacus pargueraensis_ Pessagno; Foreman, p. 429.

1973b _Pseudoaulophacus pargueraensis_ Pessagno; Foreman, pl. 15, fig. 18.

1973 _Pseudoaulophacus pargueraensis_ Pessagno; Moore, p. 824, pl. 12, figs. 6, 7.

1974 _Pseudoaulophacus pargueraensis_ Pessagno; Riedel & Sanfilippo, p. 780, pl. 2, figs. 12-14.

1975 _Pseudoaulophacus pargueraensis_ Pessagno; Foreman, p. 613, pl. 5, fig. 8.

1978b _Pseudoaulophacus pargueraensis_ Pessagno; Foreman, p. 744, pl. 3, fig. 9.

1980 _Pseudoaulophacus pargueraensis_ Pessagno; Okamura, pl. 22, fig. 12.

1981 _Pseudoaulophacus pargueraensis_ Pessagno; Nakaseko & Nishimura, p. 158, pl. 2, fig. 5.


1985 _Pseudoaulophacus pargueraensis_ Pessagno; Sanfilippo & Riedel,
Remarks: Sanfilippo & Riedel (1985) illustrate intra-specific variation from different areas. Difficulties in identifying poorly preserved material are discussed under *P. lenticulatus*. Koutsoukos & Hart (1990) report *P. pargueraensis* from the latest Cenomanian to earliest Turonian of Brazil as having 9 lobes. The number of lobes may vary through time or may be a feature of provincialism. Specimens recorded here have between 9 and 12 lobes. In some specimens the thickened petal-like areas which produce the lobate nature of the equatorial margin are difficult to count in transmitted light.

Size range: 190 - 250 μm (measured across maximum width of test excluding spines, 10 specimens).

Occurrence [publications]: Campanian, Puerto Rico; ?Campanian, Central Pacific; Santonian - Campanian, California; ?Campanian, Gulf of Mexico; Campanian, North Pacific; Coniacian - Santonian, Central Pacific; Coniacian - Campanian, Indian Ocean; Santonian, North Pacific; Campanian, Central Atlantic; Santonian - Campanian, Japan; Campanian, Japan, Campanian, North Pacific; Campanian, Austria, Bavaria, Japan; Campanian - Maastrichtian, North Atlantic; Campanian, Cuba; Cenomanian/Turonian, Brazil.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nanofossil assemblages dated as CC20/CC22; CC22/CC23A).

*Pseudoaulophacus vielseitigus* Empson Morin
Plate 26, Figures 7 - 9

1898 *Conosphaera oligoconus* Rust, p. 13, pl. 4, fig. 4.

?1973 *Pseudoaulophacus* sp. *P. lenticulatus* (White); Dinkleman, p. 790, pl. 1, fig. 12.

?1981 *Pseudoaulophacus? sulcatus* (Rust); Schaaf, p.436, pl. 14, figs. 3a - b.

*1981 *Pseudoaulophacus vielseitigus* Empson Morin, p. 257, pl. 1, fig. 3.
Remarks: The development of the petal-like thickened areas or lobes varies between specimens. Rust (1898) did not illustrate pseudoaulophacid triangular meshwork on his specimen but this omission is not here considered conclusive. Dinkleman (1973) and Schaaf (1981) do not give detailed descriptions of the specimens illustrated but because they have included these forms in the genus *Pseudoaulophacus* it is here assumed that the morphotypes have a meshwork consisting entirely of triangular pore frames. As a consequence of these uncertainties synonymy entries listed here are questionable.

Schaaf's (1981) specimen has seven sides, but although the species has commonly only six sides the original diagnosis allows for between 5 and 7 sides.

Size range: 190 - 220 μm (measured across maximum width of test excluding spines, 10 specimens).

Occurrence [publications]: Campanian, Central Pacific; Aptian, North Pacific; Campanian, North Pacific, Caribbean, Cyprus, Puerto Rico, Austria; Campanian, Cuba.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22).

### Pseudoaulophacid sp.C

Plate 26, Figures 10 - 12

Description: Test disc-shaped, lenticular in peripheral view and sub-circular to polygonal in lateral view. Tholi are present, equal in diameter and elevation on both sides of the test, but vary between specimens from an elevated to a depressed position, and in size from half to one-third the diameter of the test. The meshwork on the tholi is true pseudoaulophacid meshwork but the peripheral area of the test is covered by atypical, angular pore frames. Equatorial spines are present, sometimes triradiate in axial section at the extreme proximal ends but usually circular. No specimens with complete spines have been observed. Size range: 200 - 230 μm (measured across maximum width of test excluding spines, 10 specimens).

Remarks: This form has affinities to the genus *Orbiculiforma* Pessagno in possessing spongy meshwork on part of the test, and a disc-shaped test with central
depression and equatorial spines. It has here been included in the Family Pseudoaulophacidae because of its general conformity to the architecture of this group in the presence of tholi and the presence of pseudoaulophacid meshwork on part of the test. Inclusion in the genus Pseudoaulophacus is inhibited by the presence of irregular meshwork on part of the test and because internal structures have not yet been examined.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22).

Pseudoaulophacid sp.D
Plate 27, Figures 1 - 3

Description: Test disc-shaped, lenticular in peripheral view and sub-polygonal to rounded in lateral view. Tholi are present on both sides and are relatively small - less than 1/3 diameter of test. The surface of the test has 6, regularly spaced, petal-like swellings arranged around each tholus, in the same plane, and extending to the periphery of the test. Triradiate spine bases are present around the periphery of the test but no specimens with complete spines have been observed in this material. The surfaces of the tholi are covered with "pseudoaulophacid" triangular pore frames but pore frames on the remainder of the test are sub-triangular to rounded.

Size range: 210 - 270|/*m (measured across maximum width of test excluding spines, 10 specimens).

Remarks: This form has not been formally assigned to the genus Pseudoaulophacus because true pseudoaulophacid triangular pore frames are not present on all of the test surface. The hexagonal symmetry of the petal-like swellings centered around the tholi suggest an affinity with Pseudoaulophacus vielseitigus. Pseudoaulophacid sp.D differs from P. vielseitigus by lacking a well-defined hexagonal outline in lateral view, i.e. by possessing a polygonal to sub-rounded outline. Pseudoaulophacid sp.D may be a transitional form between P. pargueraensis and P. vielseitigus or its form may be due to local environmental adaptation. Pseudoaulophacid sp.D occurs in three sections in Cyprus (Akamas, Paralimni and Kritou Marottou) and is therefore not considered an aberrant form.

Occurrence [this work]: Campanian, Cyprus.

- A105-
Pseudoaulophacid sp.E
Plate 27, Figures 4 - 6

Description: Test disc-shaped, lenticular in peripheral view, angular in lateral view with usually nine, sometimes ten sides. Tholi are present on both sides of the test and are small - usually about one-third the diameter of the test. These tholi are slightly convex, depressed and surrounded by a raised, angular rim. Raised areas or swellings are arranged in a petal-like pattern between the rim and the test periphery, the centre of the distal point of each coinciding with the junction of two of the peripheral angular sides. Equatorial spine bases are also present at these junctions but no specimens with spines preserved have been recovered here. The surfaces of the tholi are covered with characteristic pseudoaulophacid meshwork and the remainder of the test is covered with a more irregular, angular meshwork.
Size range: 200 - 270 μm (measured across maximum width of test excluding spines, 10 specimens).

Remarks: This form is here excluded from the genus Pseudoaulophacus because of the irregular angular meshwork on the surface of the test periphery. Inclusion in the Family Pseudoaulophacidae is based on overall shape and test design including the presence of two opposing tholi which are covered with true pseudoaulophacid meshwork.

Occurrence [this work]: Campanian, Cyprus.

Pseudoaulophacus riedeli Pessagno
Plate 27, Figures 7 - 9

*1976 Pseudoaulophacus riedeli Pessagno, p. 28, pl. 9, figs. 7-8.

Remarks: Size range: 140 - 210 μm (measured across maximum width of test excluding spines, 10 specimens).

Occurrence [publications]: Campanian, California.
Occurrence [this work]: Campanian, Cyprus.
**Pseudoaulophacid sp. F**  
Plate 27, Figures 10 - 12

**Description:** Test disc-shaped with three arms or rays in lateral view. Arms or rays converge at central tholi, present on opposing sides of the test. One spine is present at each ray tip and is circular in axial section. Meshwork consists of triangular pore frames throughout although aberrant forms (see below) can occur.

Size range: 150 - 200 µm (measured across maximum width of test excluding spines, 10 specimens).

**Remarks:** Forms similar in external appearance (Pl. 27, fig. 12) but lacking the pseudoaulophacid meshwork and possessing irregularly arranged meshwork are found rarely in assemblages together with *P. riedeli* Pessagno. This form has not been included in the genus *Patulibracchium* Pessagno because of the presence of tholi.

**Occurrence [this work]:** Campanian, Cyprus.

**Pseudoaulophacid sp. G**  
Plate 28, Figures 1 - 3

**Description:** Test disc-shaped, lenticular in peripheral view and hexagonal in lateral view. No distinct tholi present, although when viewed in transmitted light the structure of the test appears denser in the central area. Externally the test seems to have a slightly raised central area (see Plate 28, fig. 3) although the size of the meshwork is uniform over the whole test surface. The meshwork consists of bars forming equilateral triangles with nodes at the junctions. These triangles join in hexagonal symmetry. Six spines are present at the angles of the test on the equatorial margin. Specimens with spines preserved have not been recovered here but spine bases indicate the spines are, at least proximally, triradiate in axial section. Size range: 160 - 225 µm (measured across maximum width of test excluding spines, 10 specimens).

**Remarks:** This form has not been placed in the genus *Pseudoaulophacus* Pessagno because of the absence of distinct tholi and it has not been placed in the genus *Alievium* Pessagno because the test has more than three sides.

**Occurrence [this work]:** Campanian, Cyprus.
Genus *PSEUDODICTYOMITRA* Pessagno

*Pseudodictyomitra* PESSAGNO 1977b, p. 50.

Type Species: *Pseudodictyomitra pentacolaensis* Pessagno, 1977b, p. 50, pl. 8, figs. 3, 17, 23; pl. 12, fig. 10.

**Remarks:** *Pseudodictyomitra* is distinguished from *Archaeodictyomitra* and *Dictyomitra* by possessing costae which are discontinuous and are not usually aligned over segmental divisions. Species are determined on the overall shape of the test, the surface ornamentation, and the number and distribution of pores.

*Pseudodictyomitra ?lodogaensis* Pessagno

Plate 28, Figures 4 - 6

?1975 *Dictyomitra* sp., Dumitrica, text-fig. 2.8.

*?1977c Pseudodictyomitra lodogaensis* Pessagno, p. 50. pl 8, fig. 4, 21, 28.

?1981 *Pseudodictyomitra lodogaensis* Pessagno; Nakaseko & Nishimura, p. 159, pl. 9, fig. 5.

?1982 *Dictyomitra urakawensis* Taketani, p. 59, pl. 4, figs. 8a - b; pl. fig. 16.

?1987 *Pseudodictyomitra lodogaensis* Pessagno; Gorican, p. 186, pl. 3, fig. 20.

**Remarks:** This species is similar to *P. lodogaensis* Pessagno as figured by Pessagno (1977c), Nakaseko and Nishimura (1981) and Gorican (1987). *Dictyomitra urakawensis* Taketani from the Coniacian to Campanian of Japan, and specimens recovered here which are questionably included in this species, however, have only a single row of pores at the strictures. *P. lodogaensis* and taxa included in the synonymy above figured by Dumitrica, Nakaseko & Nishimura and Gorican have two rows of pores at the strictures.

Size range: 120 - 175 μm (measured along the greatest length of test, 10 specimens with between six and nine segments).

**Occurrence [publications]:** Cenomanian, Romania; Albian - Cenomanian, California; Upper Jurassic/Cretaceous, Japan; Cenomanian - Coniacian, Japan; Albian - Cenomanian, Yugoslavia.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22C).

Genus *PYRAMISPONGIA* Pessagno

*Pyramispongia* PESSAGNO 1973a, p. 78.

Type Species: *Pyramispongia magnifica* Pessagno, 1973a, p. 80, pl. 19,
figs. 5-6, pl. 20, figs. 1-6, pl. 21, fig. 1.

Remarks: Species of *Pyramispongia* have been distinguished by Pessagno (1973a) on the basis of the general test shape and by the number, character and position of the spines.

*Pyramispongia?* sp.A

Plate 28, Figures 7 - 9

1984 *Pyramispongia?* sp. A, Empson Morin, pl. 1, figs. 7, 8.
1988 *Pyramispongia(?)* sp.A Empson Morin; Abin, p. 52, pl. 3, fig. 8.

Remarks: Specimens recovered from Cyprus are very similar to those recorded from Austria by Empson Morin (1984, Pl. 1, fig. 8). No specimens with spines intact have been recovered from Cyprus in this work. These morphotypes are tentatively included in the genus *Pyramispongia* because they have similar wall structure and comparable overall test shape but lack the cupola type structures described by Pessagno (1973a).

Size range: 140 - 170 \( \mu \text{m} \) (measured across maximum width of test, 10 specimens).

Occurrence [publications]: Campanian, Cyprus, Austria, Mexico, North Pacific, Central Venezuelan Basin, Puerto Rico; Campanian, Cuba.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22C).
Genus *RHOPALOSYRINGIUM* Campbell & Clark, emend. Foreman


**Type Species:** *Rhopalosyringium magnificum* Campbell & Clark, p. 30, pl. 7, figs. 16, 17.

1968 *Rhopalosyringium* Campbell & Clark; emend. Foreman, p. 54.

**Remarks:** Complete forms with an antapical tube were rare in this work, most specimens being broken.

*Rhopalosyringium kleinum* Empson Morin

Plate 28 Figures 10 - 12

1972 Unnamed sp. Petrushevskaya & Kozlova, pl. 7, fig. 13.
1973 *Rhopalosyringium* sp., Dinkleman, p. 790, pl. 1, fig. 1.
*1981* *Rhopalosyringium kleinum* Empson Morin, p. 265, pl. 8, figs. 2A-3.
1988 *Rhopalosyringium kleinum* (?) Empson Morin; Abin, p. 65, pl 7, fig. 12.

**Remarks:** Empson Morin (1981) distinguishes *R. kleinum* by characters such as the possession of a small perforate cephalis, an elongate triradiate horn, and the absence of a well-defined collar stricture. The forms recorded here agree well with this definition although some morphotypes included have a more pronounced collar stricture than those illustrated by Empson Morin (see Plate 28, figs. 10, 11). In outline these forms with more pronounced collar stictures are distinguishable from *R. magnificum* as externally they retain the consolidated unified appearance described by Empson Morin. The externally triradiate apical horn consists of three hollow tubes.

Size range: 150 - 190 μm (measured along greatest length of test excluding apical horn, 10 specimens).

**Occurrence** [publications]: Campanian/Maastrichtian, Central Atlantic; *Campanian*, Central Pacific; Campanian, North Pacific; Campanian, Cuba.
Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22; CC22). Campanian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC16/CC22).

*Rhopalosyringium magnificum* Campbell & Clark
Plate 29, Figures 1 - 3

*1944* *Rhopalosyringium magnificum* Campbell & Clark, p. 30, pl. 7, figs. 16, 17.

*1968* *Rhopalosyringium* (?) *magnificum* Campbell & Clark; Foreman, p. 55, pl. 6, fig. 7b.

*1968* *Rhopalosyringium elasson* Foreman; Foreman, p. 55, pl. 5, fig. 8.

*1972* *Rhopalosyringium* sp. aff. *R. magnificum* Campbell & Clark; Petrushevskaya & Kozlova, p. 537, pl. 7, fig. 15.

*1973* *Rhopalosyringium* sp., Dinkleman, p. 790, pl. 1, fig. 2.

*1981* *Rhopalosyringium magnificum* Campbell & Clark; Empson Morin, p. 265, pl. 8, figs. 1A-D.

*1988* *Rhopalosyringium magnificum* Campbell & Clark; Abin, p. 65, pl. 7, figs. 13 - 15.

Remarks: Size range: 125 - 150μm (measured along greatest length of test excluding the apical horn, 10 specimens). *R. magnificum* differs from *R. kleinum* in outline because the difference in width of the cephalis and thorax is greater in the former species.

Occurrence [publications]: Campanian, California; Campanian? - Maastrichtian, California; Maastrichtian, California; Campanian - Maastrichtian, Central Atlantic; Campanian, Central Pacific; Campanian, Western Brazil Basin, North Pacific, Central Pacific, Central Venezuelan Basin, Puerto Rico, Austria, Cyprus; Campanian, Cuba.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC20/CC22C).

Genus *SEPTINASTRUM* Gorbovets

*Septinastrum* GORBENETS 1966, p. 86.

Type Species: *Septinastrum dogeli* Gorbovets, 1966, p. 86, pl. 4, figs. 4 - 5.
Remarks: Members of this genus are flat, discoidal and have the general shape of a seven pointed star. The points of the "star" vary in symmetrical arrangement and in length and shape; some appear as relatively minor projections from the otherwise subcircular shape of the central area, whereas others form arms which are long in relation to the size of the central area. These latter forms may have arms terminating in small spines. This variation in shape may be due to the presence/absence of a patagium. The structure of the test in forms recovered in this work is generally difficult to determine because of poor preservation but seems to consist of a central area of relatively dense angular pore frames surrounded by a peripheral area of larger angular pore frames.

The genus would appear to be related to the genera *Pentinastrum* Haeckel and *Hexinastrum* Ehrenberg which have a 5-fold and 4-fold symmetry respectively. The diverse forms described below are currently grouped into the same genus pending future investigation of internal structures.

The number of arms is probably not important at generic level and may vary through time or in different environments.

*Septinastrum dogeli* Gorbovets

Plate 29, Figures 4 - 6

*1966* *Septinastrum dogeli* Gorbovets, p. 86, pl. 4, figs. 4 - 5.

Remarks: Equatorial spine bases suggest that spines are ovoid in axial section with longitudinal grooves, at least at the proximal end. No specimens with spines preserved are recorded here. Size range 200 - 230 μm (measured across maximum width of test excluding spines, 10 specimens).

Occurrence [publications]: Campanian, Western Siberia.

Occurrence [this work]: Campanian, Cyprus.

*Septinastrum cf. S. dogeli* Gorbovets

Plate 29, Figures 7 - 9

Remarks: These form differ from *S. dogeli* in possessing a more distinctly defined central area which is slightly raised and convex and encircled by a minor depression. The surface meshwork on these specimens is also relatively finer than on *S. dogeli*. Size
range: 240 - 290 μm (measured across the maximum width of the test excluding spines, 10 specimens).

Occurrence [this work]: Campanian, Cyprus.

**Septinastrum** sp.A
Plate 29, Figures 10 - 11

1982 Hagiastridae gen. et sp. indet. Taketani, p. 50, pl. 10, fig. 3.
1984 *Septinastrum* sp. A. Empson Morin, pl. 1, fig. 3.
1988 *Septinastrum* (?) sp. A. Empson Morin; Abin, p. 51, pl. 3, fig. 6.

Description: Test disc-shaped with seven arms or rays in lateral view, extending from a circular central area. The central area has regularly arranged angular pore frames. The rays have a rectilinear arrangement of pore frames with spine bases at the distal ends. No specimens with spines intact have been recovered here. Size range: 270 - 310 μm (measured across maximum width of test [i.e. from the tip of a ray or arm to the opposite margin of the central area] but excluding spines at ray tips, 5 specimens).

Remarks: This form differs from *S. dogeli* in that more distinct arms or rays form the peripheral part of the test. Remnants of a patagium are present on all illustrated species both in this report and in the synonymous forms listed above. Taketani (1982) reports variation in the number of arms of between seven and eight on the forms found in Japan. In this investigation only seven-armed forms have been recovered.

Occurrence [publications]: Coniacian - Campanian, Japan; Campanian, North Pacific, Central Venezuelan Basin, Austria, Cyprus; Campanian, Cuba.

Occurrence [this work]: Campanian, Cyprus.

**Septinastrum** sp.B
Plate 29, Figure 12

Remarks: Differs from *Septinastrum* sp.A in having longer free arms or rays which become slightly bulbous at the distal end. Spines at ray tips are short and circular.
in axial section. Size range: 320 - 350 μm (measured across maximum width of test, including arms but excluding spines, 2 damaged specimens).

**Occurrence [this work]:** Campanian, Cyprus.

Genus *Siphocampe* Haeckel

*Siphocampe* HAECKEL 1881, p. 438.

Type Species: *Siphocampe annulosa* Haeckel, 1887, p. 1500, pl. 79, fig. 10.

*Siphocampe daseia* (Foreman)

Plate 30, Figures 1 - 3

*1968* *Theocampe daseia* Foreman, p. 48, pl. 6, figs. 9a, b.

1972 *Theocampe?* sp. aff. *T. daseia* Foreman; Petrushevskaya & Kozlova, p. 537, pl. 7, fig. 8.

1978b *Theocampe daseia* Foreman; Foreman, p. 745, pl. 5, fig. 26.

1985 *Siphocampe daseia* (Foreman); Sanfilippo & Riedel, p. 604, text figs. 9.3a - b.

**Remarks:** Sanfilippo & Riedel (1985) place this species in the genus *Siphocampe* on the basis of the presence of a distinct internal shelf at the lumbar stricture.

Size range: 90 - 110 μm (measured along greatest length of test, 10 specimens).

**Occurrence [publications]:** Campanian - Maastrichtian, California; Maastrichtian, Central Atlantic; Campanian - Maastrichtian, Central Atlantic; Campanian - Maastrichtian, Composite.

**Occurrence [this work]:** Campanian, Cyprus.

Genus *Spongodiscus* Ehrenberg

*Spongodiscus* EHRENBERG 1854b, p. 237.

Type Species: *Spongodiscus resurgens* Ehrenberg, 1854b, p. 246, pl. 35B, fig. 16.
Description: Test lenticular, circular in lateral view, with double row of bladed spines around the equatorial margin. Triradiate spine bases are present on the remainder of the test surface. No tholi are recorded. Size range: 210 - 240 µm (measured across maximum width of test excluding spines, 5 specimens).

Occurrence [this work]: Campanian, Cyprus. Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC25A).

Genus SPONGOSTAURUS Haeckel

Spongostaurus HAECKEL 1881, p.461
Type Species: Spongostaurus cruciatus Haeckel, 1887, p. 582.

Remarks: Unfortunately Haeckel (1887) does not figure any species belonging to the genus Spongostaurus and therefore the degree of inflation of the test he envisaged is difficult to estimate. The description given by Haeckel (1887, p. 582), however, suggests that the test is not spherical as is implied by Campbell (1954, p. 595, fig. 46.2) in his illustration of S. circulus Rust.

?Spongostaurus(?) hokkaidoensis Taketani
Plate 30, Figures 7 - 9

*1982 Spongostaurus(?) hokkaidoensis Taketani, p. 49, pl. 2, fig. 6; pl. 9, figs. 12 - 14.

Remarks: These forms are tentatively placed in this genus and species because of doubt over the degree of inflation of the test. It is difficult to estimate the degree of inflation from the illustration of Taketani but his S.E.M. photograph (1982, pl. 9, fig. 14) and his description suggest a greater degree of inflation than observed on specimens recovered in this work. It may be that the present specimens have been flattened during burial, but this theory would have to be applied to all specimens. As Taketani (1982) used this species to
identify a biozone at the base of the Campanian it is particularly important to be able to
define the species accurately.
Size range: 140 - 200 µm (measured across maximum width of test, 6 specimens).

Occurrence [publications]: Campanian, Japan.
Occurrence [this work]: Campanian, Cyprus. Maastrichtian, Central Atlantic.

Genus **STAURODICTYA** Haeckel

*Stauroidictya* HAECKEL 1881, p. 460.
Type Species: *Stauroidictya beneckeii* Rust, 1885, p. 26, pl. 32(7), fig. 1.

Remarks: The species included below differ from the type species in possessing a more
uniform test structure throughout, whilst *S. beneckeii* Rust has a central area of finer
meshwork.

*Stauroidictya* sp.A
Plate 30, Figures 10 - 12

1966 *Stauroidictya(?)* sp. Kozlova & Gorbovets, pl. 4, fig. 2.

Description: Test flat, disc-shaped, circular in lateral view with 4 radial spines. The
radial spines are triradiate proximally, becoming circular in axial section distally. One
pair of opposing spines is shorter than the other pair. The chambers are arranged in a
concentric circular pattern in transmitted light. The external surface of specimens
recovered here is always poorly-preserved but appears to have relatively large,
subrectangular meshwork. Size range: 100 - 140 µm (measured across maximum width of
test excluding spines, 10 specimens).

Occurrence [publications]: Campanian, Western Siberia.
Occurrence [this work]: Campanian, Cyprus.
**Staurodictya sp.B**  
Plate 31, Figures 1 - 3

**Description:** Test flat, disc-shaped, oval in lateral view with four radial spines. All four spines, when preserved, are approximately equal in length and are circular in axial section, except at the extreme proximal ends. In transmitted light the small round chambers of the test appear to be arranged concentrically. Externally, the test surface is always poorly-preserved in recovered specimens and round to subrounded pores are surrounded by angular to subangular pore frames. Size range: 170 - 190 μm (measured along greatest length of test excluding spines, 10 specimens).

**Remarks:** Differs from *Staurodictya* sp.A in having a more diamond-shaped outline and by possessing spines which are circular in axial section. Similar to *Staurodictya* sp.D (below) with regard to spines, surface texture and chamber arrangement but differs in having an oval rather than a square outline in lateral view.

**Occurrence [this work]:** Campanian, Cyprus. Campanian/Maastrichtian, Central Atlantic.

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**Staurodictya sp.C**  
Plate 31, Figures 4 - 6

**Description:** Test is flat, disc-shaped, slightly rhombic in lateral view with spines produced externally at the four corners on the equatorial margin. Spines are triradiate in axial section. In transmitted light, small rounded chambers appear to be arranged in a concentric pattern. In reflected light and with the SEM, all specimens are very poorly-preserved and the surface texture of the test is indistinguishable. Size range: 175 - 200 μm (measured across maximum width of test excluding spines, 10 specimens).

**Remarks:** Differs from *Staurodictya* sp.A and *Staurodictya* sp.B by possessing a more irregular spongy meshwork. Although specimens recovered here are poorly-preserved, it is interesting to note that the four primary spines are always at least partially represented.
Occurrence [this work]: Campanian, Cyprus. Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC25A).

**Staurodictya sp.D**
Plate 31, Figures 7 - 9

Description: Test flat, discoidal, quadrate in lateral view. The surface of the test is covered with fine, sub-hexagonal, irregularly sized pore frames. Four primary spines are present, one at each corner of the test. These spines are never recorded here intact but broken proximal ends are circular in axial section.

Size range: 260 - 290 μm (measured across maximum width of test excluding spines, 10 specimens).

Remarks: The test of this form is more inflated than other members of this genus recorded here.

Occurrence [this work]: Campanian, Cyprus.

Genus *STICHOMITRA* Cayeux

*Stichomitra* CAYEUX 1897, p. 204.

Type Species: *Stichomitra costata* Cayeux, 1897, p. 204, pl. 8, fig. 68. (Subsequent designation by Chediya 1959, p. 232).

Remarks: Species are differentiated primarily on overall test shape and external character, and on the distribution pattern of pores.

*Stichomitra asymbatos* Foreman
Plate 31, Figures 10 - 12

*1968* *Stichomitra asymbatos* Foreman, p. 73, pl. 8, figs. 10a - c.

1974 *Stichomitra asymbatos* Foreman group; Riedel & Sanfilippo, p. 780, pl. 10, figs. 1 - 7; pl. 15, fig. 5.
1975  *Stichomitra asymbatos* Foreman; Dumitrica, p. 87, text-fig. 2.13.
1978b *Stichomitra asymbatos* Foreman group; Foreman, p. 748, pl. 4, fig. 15.
1982 *Stichomitra asymbatos* Foreman; Taketani, p. 54, pl. 4, fig. 13; pl. 11, figs. 3 - 4.

**Remarks:**

Size range: 200 - 240 \( \mu m \) (measured along greatest length of test, 10 specimens with between seven and eight segments).

**Occurrence [publications]:** Campanian? - Maastrichtian, California; Campanian/Maastrichtian, South Atlantic; Cenomanian, Romania; Campanian - Maastrichtian, Central Atlantic; Coniacian - Campanian, Japan.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22; CC22/CC23A). Campanian - Maastrichtian, Central Atlantic (co-occurs with calcareous nannofossil assemblage dated as CC25A).

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*Stichomitra communis* Squinabol

Plate 32, Figures 1 - 3

*1903* *Stichomitra communis* Squinabol, p. 141, pl. 8, fig. 40.

1981 *Stichomitra communis* Squinabol; Nakaseko & Nishimura, p. 162, pl. 11, fig. 11, pl. 16, fig. 14.

1982 *Stichomitra communis* Squinabol; Taketani, p. 54, pl. 3, fig. 9, pl. 11, fig. 5.

1988a *Stichomitra communis* Squinabol; Thurow, p. 406, pl. 4, fig. 10.

**Remarks:** Differs from *Amphipyndax conicus* by having a thinner test wall in cephalo-thoracic region. Size range: 250 - 300 \( \mu m \) (measured along greatest length of test, 10 specimens with between nine and eleven segments).

**Occurrence [publications]:** N/G, Italy; Albian - Cenomanian, Japan; Cenomanian - Coniacian, Japan; Albian - Turonian, North Atlantic.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nannofossil assemblages dated as CC20/CC22; CC22). Maastrichtian, Central Atlantic.

- A119-
Genus *STYLODICTYA* Ehrenberg, emend. Kozlova

*Stylocytya* EHRENBERG 1847b, p. 54.


Type Species: *Stylocytya gracilis* Ehrenberg, 1854b, p. 246, pl.36, fig. 28.

Remarks: Kozlova (1972) emended the Family Porodiscidae Haeckel including the re-assignment of some members of the genera *Porodiscus* Haeckel and *Stylocytya* Ehrenberg to different genera and erecting a new genus *Tholodiscus* Kozlova. However, in this study the format of Campbell (1954) is followed pending further investigation.

*Stylocytya* sp.A

Plate 32, Figures 4 - 6

Description: Test flat, disc-shaped, subcircular in lateral view. Triradiate spine bases are present on the equatorial margin. Pores are sub-rounded, arranged in concentric rings and surrounded by irregular pore frames forming a spongy meshwork. Size range: 160 - 180 μm (measured across diameter of test excluding spines, 10 specimens).

Remarks: No specimens with spines intact have been recovered here.

Occurrence [this work]: Campanian, Cyprus. Campanian - Maastrichtian, Central Atlantic.

*Stylocytya* sp.B

Plate 32, Figures 7 - 9

Description: Test flat, disc-shaped, subcircular in lateral view. The central area is slightly convex and denser than the surrounding area. Pores in the central area are rounded and surrounded by sub-triangular pore frames which form nodes at junctions. Pores in the peripheral area are larger and surrounded by rectangular pore frames. Primary and secondary spines connect in the central area and occur on the equatorial
margin as short broken spines or spine bases which are subrectangle in axial section. Size range: 170 - 190\(\mu\)m (measured across diameter of test excluding spines, 6 specimens).

**Remarks:** *Stylodictya* sp.B differs from *Stylodictya* (?) sp.C in that the variety of pore frame design is greater in *Stylodictya* sp.B, which also has non-uniform angular pore frames.

**Occurrence [this work]:** Campanian, Cyprus. Campanian/Maastrichtian, Central Atlantic.

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**Stylodictya(?) sp.C**

Plate 32, Figures 10 - 12

**Description:** Test flat, disc-shaped, subcircular in lateral view. Delicate beams originating in the central area extend to the equatorial margin and occur as spine bases which are rectangular in axial section. No specimens with externally preserved spines have been observed. Pores are rounded and arranged in concentric rings, becoming larger and more open towards the periphery. Size range: 130 - 160\(\mu\)m (measured across maximum width of the test excluding spines, 7 specimens).

**Remarks:** Difficult to distinguish between *Stylodictya* Ehrenberg and *Porodiscus* Haeckel in poorly preserved material but *Stylodictya(?)* sp.C appears to have minute marginal spines (marked by arrows on Plate 32, fig. 11). *Stylodictya(?)* sp.C is thus questionably assigned to the genus *Stylodictya*.

**Occurrence [this work]:** Campanian, Cyprus.

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**Genus THEOCAMPE** Haeckel

*Theocampe* HAECKEL 1887, p. 1422.

*Type Species:* *Dictyomitra ehrenbergi* Zittel, 1876, p. 82, pl. 2, fig. 5.
Theocampe altamontensis (Campbell & Clark)
Plate 33, Figures 1 - 3

*1944 Tricolocampe (Tricolocamptra) altamontensis Campbell & Clark,
p. 33, pl. 7, figs. 24, 26.
1975 Theocampe sp. aff. T. altamontensis (Campbell & Clark);
Pessagno, p. 1016, pl. 4, fig. 10.
1978b Theocampe altamontensis (Campbell & Clark); Foreman, p. 745, pl. 5,
fig. 27.
1981 Theocampe altamontensis (Campbell & Clark); Empson Morin, p. 262,
pl. 6, figs. 1A-D.
1984 Theocampe altamontensis (Campbell & Clark); Empson Morin, pl. 2,
fig. 6.

Remarks: This species is distinguishable in both reflected and transmitted light by its
distinctive smooth outline and by the thickened, regularly arranged pore frames.
Size range: 110 - 130 μm (measured along greatest length of test, 10 specimens).

Occurrence [publications]: ?Campanian, California; Campanian, Tasman Sea;
Campanian - Maastrichtian, Central Atlantic; Campanian, North Pacific; Campanian,
California.
Occurrence [this work]: Campanian, Cyprus. Campanian/Maastrichtian, Central
Atlantic.

Theocampe salillum Foreman
Plate 33, Figures 4 - 6

1971 Theocampe sp. Kling, pl. 7, figs. 1, 5.
*1971 Theocampe salillum Foreman, p. 1678, pl. 4, fig. 5.
1973a Theocampe salillum Foreman; Foreman, p. 430, pl. 13, fig. 2.
1973b Theocampe salillum Foreman; Foreman, p. 256, pl. 15, fig. 12.
1973 Theocampe salillum Foreman; Moore, p. 826, pl. 11, fig. 2.
1974 Theocampe salillum Foreman; Riedel & Sanfilippo, p. 780, pl. 11,
figs. 8-10.
1981 Theocampe salillum Foreman; Empson Morin, p. 263, pl. 5, figs. 4A-C.
1981 Theocampe salillum Foreman; Nakaseko & Nishimura, p. 164, pl. 13,

- A122-
1981 *Theocampe* cf. *T. salillum* Foreman; Schaaf, p. 440, pl. 24, fig. 7.

1982 *Theocampe salillum* Foreman; Kling, p. 548, pl. 1, fig. 19.

1982 *Theocampe salillum* Foreman; Taketani, p. 53, pl. 2, fig. 14.

1985 *Theocampe salillum* Foreman; s.s., Sanfilippo & Riedel, p. 605, text figs. 9.4a-c.

1988 *Theocampe* sp. cf. *T. salillum* Foreman; Abin, p. 57, pl. 7, fig. 10.

**Remarks:** All specimens ovoid in axial section (similar to *T. ascalia* Foreman, 1971 from the Santonian - Campanian of the central Pacific) although this shape may be due to post-burial compaction/distortion. Details of the cephalic structure, including cephalic tube and pores were obscured by recrystallization in this material.

Size range: 140 - 160 μm (measured along greatest length of test, 10 specimens).

**Occurrence [publications]:** Campanian, North Pacific; Santonian/Coniacian, Central Pacific; Campanian, Gulf of Mexico; Campanian, North Pacific; Cenomanian - Campanian, Central Pacific; Coniacian - Maastrichtian, Indian Ocean; Campanian, North Pacific; Campanian, Japan; Albion - Cenomanian, North Pacific; Campanian, North Pacific; Coniacian - Campanian, Japan; Santonian - Campanian, Composite; Campanian, Cuba.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nanofossil assemblages dated as CC20/CC22; CC22/CC23A).

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*Theocampe* sp. A, aff. *T. salillum* Foreman

Plate 33, Figures 7 - 9

**Remarks:** This form is very similar to *T. salillum* but differs in the relatively shorter, fatter abdomen and the rate and degree of constriction of the abdomen at the distal end. As in specimens of *T. salillum* Foreman (above), all material examined here is ovoid in axial section.

Size range: 120 - 155 μm (measured along greatest length of test, 10 specimens).

**Occurrence [this work]:** Campanian, Cyprus.
Theocampe sp.B, aff. T. salillum Foreman
Plate 33, Figures 10 - 12

Remarks: This form differs from Theocampe salillum and Theocampe sp.A in the more elongate, smoother (i.e. less locally constricted) shape and the gradual tapering to a relatively small aperture in the distalmost part of the test. This form was rare in material examined during this study but all specimens are circular in axial section.
Size range: 150 - 160 µm (measured along greatest length of test, 3 specimens).

Occurrence [this work]: Campanian, Cyprus.

Genus TRIACTOMA Rust

Triactoma RUST 1885, p. 289. [ = Triactis Haeckel 1881, p. 457.]
Type Species: Triactoma tithonianum Rust, 1885, p. 289, pl. 28(3), fig. 5.
(Subsequent designation by Campbell, 1954, p. D81).

Triactoma sp.A
Plate 34, Figures 1 - 3

Description: Test cylindrical, "asprin" shaped with convex top and base. Three equidistant, bladed spine bases are located around the equatorial margin. No specimens with spines preserved are recorded in this study. The surface of the test is always poorly-preserved in this material but appears to be covered with angular pore frames on the top and base with an irregular spongy meshwork around the equatorial surface. Size range: 160 - 190 µm (measured across maximum width of test excluding spines, 10 specimens).

Remarks: The number of spine bases present on a specimen is an important generic diagnostic feature. If there were only two spine bases present then the specimen would not belong to the genus Triactoma and would resemble Acanthocircus sp. nov. Kuhnt et al. (1986, pl. 8, fig. M)

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22/CC23A).
Triactoma sp.B
Plate 34, Figures 4 - 6

**Description:** Subspherical/subcylindrical test with three equidistant spines around the equatorial plane. Spines are approximately equal in length, smooth, tapering at distal ends and circular in axial section. Subrounded pores are surrounded by a regular pattern of angular pore frames.

Size range: 120 - 140 μm (measured across maximum width of test excluding spines, 10 specimens).

**Remarks:** This form differs from *T. echoides* Foreman (1973, from the Valanginian - Hauterivian of NW Pacific) in the design and arrangement of the three spines.

**Occurrence [this work]:** Campanian, Cyprus (co-occurs with calcareous nanofossil assemblage dated as CC20/CC22C). Campanian, Central Atlantic.

Genus *Xitus* Pessagno

*Xitus* PESSAGNO 1977c, p. 55.

Type Species: *Xitus plenus* Pessagno, 1977c, p. 55, pl. 9, figs. 15, 21, 22, 26, pl. 12, fig. 15.

**Remarks:** Species are differentiated by variation in test shape and by surface characteristics. The post-abdominal tubular extension is an important diagnostic feature of this genus and complete specimens should be used for illustrations when possible.

*Xitus* sp.A
Plate 34, Figures 7 - 9

**Description:** Test conical with between 2 and 4 post-abdominal chambers. These chambers increase gradually in size as added. Apical horn present, usually in an off-centre position. No specimens with a single layered tubular extension preserved at the antapical end of the test have been recorded in this material. The outer layer of the wall structure of the test is produced into an irregular pattern of anastomising nodes and bars on the abdominal and post-abdominal segments whilst the inner layer consists of
approximately equally sized subrounded pore frames. Size range: 175 - 210 μm (measured along greatest length of test but excluding apical horn, 5 specimens with seven segments).

Remarks: This species is distinctive because of the presence of the thick, subrectangular outer cephalic wall. The antapical view (Pl. 34, fig. 9) shows that the internal structure of the post-abdominal segments is similar to the structure seen in the genus *Amphipyndax* Foreman.

Occurrence [this work]: Campanian, Cyprus. Campanian/Maastrichtian, Central Atlantic.

*Xitus* sp. B

Plate 34, Figures 10 - 12

Description: Test conical with usually 5 - 7 segments. Post-abdominal chambers increase gradually in size as added. The cephalis is thick-walled with an imperforate proximal part, becoming perforate with small round pores in the lower part. A short, pseudodiamond-shaped apical horn is present (Pl. 34, fig. 12). The outer test wall is produced into approximately regularly spaced rows of nodes with one row on the abdominal wall and two rows on each successive, post-abdominal chamber. All specimens are infilled and no examination could be made of internal structures with the SEM or in reflected light. In transmitted light the internal wall layer appears to consist of approximately equal-sized, rounded pores. No specimens with a distal, terminal, single-layered, tubular extension were recovered from this material.

Size range: 270 - 310 μm (measured along greatest length of test excluding apical horn, 4 specimens with seven segments).

Remarks: This form differs from *Xitus* sp.A above in having a rounded cephalis externally, in the symmetrically placed, distinctively shaped apical horn, and in the more regular arrangement of the surface wall structure.

Occurrence [this work]: Campanian, Cyprus (co-occurs with calcareous nannofossil assemblage dated as CC22/CC23A).
APPENDIX 2.5

Plates and plate descriptions

Plates 1 - 34 are selected micrographs taken using transmitted light and the scanning electron microscope. With two exceptions the specimens figured in the plates are arranged in the same order as in the systematic descriptions. Plate 35 shows S.E.M. photographs of specimens which illustrate the range of relative sizes of forms recorded from this study.

The transmitted light micrographs were taken using a Leitz Laborlux 12 microscope (illustrations indicated by (L.M.) in the plate descriptions) and a JEOL T200 scanning electron microscope was used for the S.E.M. micrographs (indicated by (S.E.M.) in the plate descriptions).

As far as possible light micrographs and scanning electron micrographs of the same specimen are included, together with occasional specimens showing morphological variation within the same species. These can be identified by reference to the specimen numbers included in the plate descriptions.

The specimens were individually measured with a graticule using a Wild M4 microscope. The scale bars in respective illustrations correspond with the measurements taken from the graticule for each specimen in the case of the transmitted light micrographs and for the S.E.M. micrographs when the stage was in the horizontal position. The automatic scale bar produced by the S.E.M. has been used the calculate the length of the scale bars on S.E.M. micrographs where the stage has been tilted at an angle to illustrate the specimen from a different angle. Apparent size variation between illustrations of the same specimen is due to photographing the specimen in different focal planes in the case of the transmitted light micrographs and to the angle at which the specimen was tilted in the scanning electron micrographs.

Illustrations of a specimen using transmitted light and illustrations using the S.E.M. do not always show the same orientation. This is sometimes useful if one side of the specimen differs from the opposite side, but usually it has occurred in cases where it was difficult to identify the orientation with reflected light when transferring the specimens to the S.E.M. stubs for mounting.
Interesting but not immediately obvious morphological features are indicated on the illustrations by arrows and referred to in the text of the systematic descriptions and in the plate descriptions.

The specimens were photographed using two different methods for the following reasons:
1) small surface details which are only clearly visible when viewed with a S.E.M. may not be useful in routine analyses using transmitted or reflected light unless the material is well-preserved; appreciation of these features is, however, important for an understanding of radiolarian morphology and is also significant for taxonomic and phylogenetic studies.
2) similarly, internal structures seen with the L.M. technique are not usually visible in S.E.M. or reflected light unless the specimen is broken, or in the case of reflected light, moistened temporarily with water.
3) published reports of the species recorded here occasionally describe and illustrate specimens using both L.M. and S.E.M., notably Empson Morin (1981) and Schaaf (1984), but usually authors have been biased towards either the external or the internal morphological features of specimens; for example, Helen Foreman usually illustrated specimens using transmitted light whilst most of Emile Pessagno’s publications show specimens photographed using the S.E.M. - this hinders comparative study and compilation of synonymy lists.

The material illustrated here is deposited in the collection of University College London. The catalogue numbers refer to one of the film negatives used for each specimen.
Figures 1 - 3 *Acaeniotyle starka* Empson Morin
Specimen No. 3186/11: Sample: 9827, Paleomylon Valley, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; view along the axis of primary spines (S.E.M.), showing triradiate spine base.
3. Scale Bar = 10 microns; pore frames (S.E.M.).

Figures 4 - 6 *Actinomma* (?) *douglasi* Pessagno
Specimen No. 3038/19: Sample: 9827, Paleomylon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.).
5. Scale Bar = 10 microns; surface of test (S.E.M.) showing triradiate spine base
6. Scale Bar = 50 microns; lateral view (L.M.)

Figures 7 - 9 *Actinomma* (?) *aff. A. douglasi* Pessagno
Specimen No. 2854/22: Sample: 10126, Akamas, Cyprus.
7. Scale Bar = 100 microns; lateral view (S.E.M.), arrow indicates large pore frame
8. Scale Bar = 25 microns; lateral view (S.E.M.), arrow indicates large pore frame
9. Scale Bar = 20 microns; lateral view (L.M.)

Figures 10 - 12 *Actinomma* sp.A
Specimen No. 3061/32: Sample: 9827, Paleomylon Valley, Cyprus.
10. Scale Bar = 50 microns; lateral view (S.E.M.)
11. Scale Bar = 10 microns; lateral view of spine base (S.E.M.)
12. Scale Bar = 50 microns; lateral view (L.M.)
Figures 1 - 3 *Actinomma* sp.B  
Specimen No. 3010/33: Sample: 9827, Palemylon, Cyprus.  
1. Scale Bar = 50 microns; lateral view (S.E.M.)  
2. Scale Bar = 50 microns; lateral view (L.M.)  
3. Scale Bar = 25 microns; lateral view (S.E.M.)

Figures 4 - 5 *Afens liriodes* Riedel & Sanfilippo  
Specimen No. 3090/19: Sample: 9829, Paleomylon Valley, Cyprus.  
4. Scale Bar = 100 microns; lateral view (S.E.M.)  
5. Scale Bar = 100 microns; lateral view (L.M.)

Figure 6 *Afens liriodes* Riedel & Sanfilippo  
Specimen No. 2938/17: Sample: DSDP 369A-38CC, Atlantic.  
6. Scale Bar = 100 microns; lateral view (S.E.M.)

Figure 7 *Alievium gallowayi* (White)  
Specimen No. 3061/25: Sample: 9825, Paleomylon Valley, Cyprus.  
7. Scale Bar = 100 microns; oblique lateral view (S.E.M.)

Figures 8 - 9 *Alievium gallowayi* (White)  
Specimen No. 3019/15: Sample: 10121, Akamas, Cyprus.  
8. Scale Bar = 100 microns; lateral view (L.M.)  
9. Scale Bar = 20 microns; lateral view of spine (S.E.M.)

Figures 10 - 12 *Alievium praegallowayi* Pessagno  
Specimen No. 3041/24: Sample: 10121, Akamas, Cyprus.  
10. Scale Bar = 50 microns; lateral view of spine (S.E.M.)  
11. Scale Bar = 50 microns; oblique lateral view (S.E.M.)  
12. Scale Bar = 50 microns; lateral view (L.M.)
Figure 1 *Alievium superbum* (Squinabol)
Specimen No. 3187/29: Sample: 9827, Paleomylon Valley, Cyprus. Scale Bar = 100 microns; oblique lateral view (S.E.M.)

Figures 2 - 3 *Alievium superbum* (Squinabol)
Specimen No. 3040/20: Sample: 9827, Paleomylon Valley, Cyprus.
2. Scale Bar = 100 microns; lateral view (S.E.M.)
3. Scale Bar = 50 microns; lateral view (L.M.)

Figure 4 *Alievium zartum* Empson Morin
Specimen No. 2693/5: Sample: 9827, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figures 5 - 6 *Alievium zartum* Empson Morin
Specimen No. 3184/1: Sample: 9825, Paleomylon Valley, Cyprus.
5. Scale Bar = 25 microns; lateral view (S.E.M.)
6. Scale Bar = 10 microns; test surface (S.E.M.)

Figures 7 - 9 *Alievium* aff. *A. zartum* Empson Morin
Specimen No. 3064/32: Sample: 9827, Paleomylon Valley, Cyprus.
7. Scale Bar = 100 microns; oblique lateral view (S.E.M.)
8. Scale Bar = 20 microns; lateral view of test surface (S.E.M.)
9. Scale Bar = 100 microns; lateral view (L.M.)

Figures 10 - 12 *Amphipyndax conicus* Nakaseko & Nishimura
Specimen No. 3090/3: Sample: 9829, Paleomylon Valley, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 20 microns; lateral view of papillose surface of cephalis (S.E.M.)
12. Scale Bar = 100 microns; lateral view (L.M.)
Figures 1 - 3 Amphipyndax mediocris (Tan Sin Hok)
Specimen No. 3008/21: Sample: 9825, Paleomylon Valley, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; lateral view (L.M.)
3. Scale Bar = 3 microns; antapical internal view showing base of cephalis (S.E.M.)

Figure 4 Amphipyndax pseudoconulus (Pessagno)
Specimen No. 3008/7: Sample: 9827, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figure 5 Amphipyndax pseudoconulus (Pessagno)
Specimen No. 3143/22: Sample: 9827, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figure 6 Amphipyndax pseudoconulus (Pessagno)
Specimen No. 3062/19: Sample: 9827, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (L.M.)

Figures 7 - 9 Amphipyndax (?) pyrgodes Renz
Specimen No. 3010/8: Sample: 9825, Paleomylon Valley, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view (L.M.)
9. Scale Bar = 50 microns; antapical view showing wide aperture and internal chamber divisions (S.E.M.)

Figures 10 - 12 Amphipyndax stocki (Campbell & Clark)
Specimen No. 3184/33: Sample: 9827, Paleomylon Valley, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 20 microns; apical view (S.E.M.), showing internal cephalic shelf-like structure
12. Scale Bar = 50 microns; antapical view (S.E.M.)
Figures 1 - 2 *Amphipyndax tylotus* Foreman
Specimen No. 3040/25: Sample: 9825, Paleomylon Valley, Cyprus.
1. Scale Bar = 30 microns; lateral view (L.M.)
2. Scale Bar = 50 microns; lateral view (S.E.M.)

Figure 3 *Amphipyndax tylotus* Foreman
Specimen No. 3051/17: Sample: 9827, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figures 4 - 6 *Archaeodictyomitra lamellicostata* (Foreman)
Specimen No. 3184/27: Sample: 9825, Paleomylon Valley, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 50 microns; oblique antapical view (S.E.M.)
6. Scale Bar = 30 microns; view of proximal part of test (S.E.M.)

Figures 7 - 9 *Archaeodictyomitra ?sliteri* Pessagno
Specimen No. 3035/19: Sample: 9827, Paleomylon Valley, Cyprus.
7. Scale Bar = 100 microns; lateral view (S.E.M.)
8. Scale Bar = 25 microns; lateral view of proximal part of test (L.M.)
9. Scale Bar = 100 microns; lateral view (L.M.)

Figures 10 - 12 *Archaeodictyomitra* sp.A, aff. *Dictyomitra striata* Lipman
Specimen No. 3040/26: Sample: 9825, Paleomylon Valley, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 10 microns; lateral view of proximal part of test showing clockwise torque on costae (S.E.M.)
12. Scale Bar = 100 microns; lateral view (L.M.)
Figures 1 - 3 *Archaeodictyomitra* sp.B
Specimen No. 3071/25: Sample: 9829, Paleomylon Valley, Cyprus.
1. Scale Bar = 100 microns; lateral view (S.E.M.)
2. Scale Bar = 10 microns; lateral view of cephalo-thoracic region (S.E.M.)
3. Scale Bar = 100 microns; lateral view (L.M.)

Figures 4 - 6 *Archaeospongoprunum andersoni* Pessagno
Specimen No. 3064/19: Sample: 9826, Paleomylon Valley, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 10 microns; view along axis of primary spines (S.E.M.), showing tetraradiate spine base
6. Scale Bar = 100 microns; lateral view (L.M.)

Figures 7 - 9 *Archaeospongoprunum* cf. *A. bipartitum* Pessagno
Specimen No. 3090/20: Sample: 9825, Paleomylon Valley, Cyprus.
7. Scale Bar = 100 microns; lateral view (S.E.M.)
8. Scale Bar = 20 microns; view along axis of primary spines (S.E.M.), showing triradiate spine base
9. Scale Bar = 100 microns; lateral view (L.M.)

Figures 10 - 11 *Archaeospongoprunum hueyi* Pessagno
Specimen No. 3108/16: Sample: 9827, Paleomylon Valley, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 100 microns; lateral view (L.M.)

Figure 12 *Archaeospongoprunum hueyi* Pessagno
Specimen No. 3038/13: Sample: 9825, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (L.M.)
Figures 1 - 3 *Bisphaerocephalina(?) amazon* (Foreman)
Specimen No. 3090/26: Sample: 9827, Paleomylon Valley, Cyprus.
1. Scale Bar = 100 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; oblique antapical view (S.E.M.)
3. Scale Bar = 50 microns; lateral view (L.M.)

Figure 4 *Bisphaerocephalina(?) heros* (Campbell & Clark)
Specimen No. 2696/21: Sample: 9825, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figures 5 - 6 *Bisphaerocephalina(?) heros* (Campbell & Clark)
Specimen No. 3090/24: Sample: 9829, Paleomylon Valley, Cyprus.
5. Scale Bar = 100 microns; lateral view (S.E.M.)
6. Scale Bar = 50 microns; lateral view (L.M.)

Figures 7 - 9 *Clathropyrgus titthium* Riedel & Sanfilippo
Specimen No. 3088/15: Sample: 10124, Akamas, Cyprus
7. Scale Bar = 100 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; oblique lateral view (S.E.M.)
9. Scale Bar = 50 microns; lateral view (L.M.)

Figures 10 - 11 *Clathropyrgus aff. C. titthium* Riedel & Sanfilippo
Specimen No. 3040/13: Sample: 9828, Paleomylon Valley, Cyprus.
10. Scale Bar = 50 microns; lateral view (L.M.)
11. Scale Bar = 50 microns; lateral view (S.E.M.)

Figure 12 *Clathropyrgus aff. C. titthium* Riedel & Sanfilippo
Specimen No. 3088/28: Sample: 10124, Akamas, Cyprus. Scale Bar = 50 microns; lateral view (L.M.)
Figures 1 - 3  *Comutella californica* Campbell & Clark
Specimen No. 3108/2: Sample: 9829, Paleomylon Valley, Cyprus.
1. Scale Bar = 25 microns; oblique antapical view
2. Scale Bar = 50 microns; lateral view (S.E.M.)
3. Scale Bar = 50 microns; lateral view (L.M.)

Figures 4 - 5  *Crucella aster* (Lipman)
Specimen No. 3089/15: Sample: 10121, Akamas, Cyprus.
4. Scale Bar = 100 microns; planar view (L.M.)
5. Scale Bar = 100 microns; planar view (S.E.M.)

Figure 6  *Crucella aster* (Lipman)
Specimen No. 3059/33: Sample: 10175, Perapedhi, Locality 10, Cyprus. Scale Bar = 100 microns; planar view (S.E.M.)

Figure 7  *Crucella cachensis* Pessagno
Specimen No. 3199/22: Sample: 10121, Akamas, Cyprus. Scale Bar = 100 microns; planar view (S.E.M.)

Figures 8 - 9  *Crucella cachensis* Pessagno
Specimen No. 3185/16: Sample: PV1, Paleomylon Valley, Cyprus.
8. Scale Bar = 100 microns; oblique planar view (S.E.M.)
9. Scale Bar = 50 microns; planar view of one ray (S.E.M.)

Figures 10 - 12  *Crucella espartoensis* Pessagno
Specimen No. 3088/2: Sample: 10124, Akamas, Cyprus.
10. Scale Bar = 100 microns; planar view (S.E.M.)
11. Scale Bar = 100 microns; planar view (L.M.)
12. Scale Bar = 100 microns; oblique view (S.E.M.)
Figures 1 - 3  *Crucella irwini* Pessagno
Specimen No. 3186/16: Sample: 9827, Paleomylon, Cyprus.
1. Scale Bar = 100 microns; oblique view (S.E.M.)
2. Scale Bar = 100 microns; planar view (S.E.M.)
3. Scale Bar = 30 microns; central lacuna (S.E.M.)

Figures 4 - 5 *Crucella(?) sp.A*
Specimen No. 3088/8 (asymmetric form): Sample: 10124, Akamas, Cyprus.
4. Scale Bar = 100 microns; planar view (S.E.M.)
5. Scale Bar = 100 microns; planar view (L.M.)

Figure 6 *Crucella(?) sp.A*
Specimen No. 2827/34: Scale Bar = 100 microns.

Figures 7 - 9 *Crucella(?) sp.B*
Specimen No. 3088/18: Sample: 10124, Akamas, Cyprus.
7. Scale Bar = 50 microns; planar view (S.E.M.)
8. Scale Bar = 100 microns; oblique view (S.E.M.)
9. Scale Bar = 50 microns; planar view (L.M.)

Figures 10 - 12 *Crucella(?) sp.C*
Specimen No. 3088/21: Sample: 10124, Akamas, Cyprus.
10. Scale Bar = 50 microns; planar view (S.E.M.)
11. Scale Bar = 50 microns; planar view (L.M.)
12. Scale Bar = 50 microns; oblique view (S.E.M.)
Figures 1 - 3 *Cryptamphorella conara* (Foreman)
Specimen No. 3071/35: Sample: 9829, Paleomylon Valley, Cyprus.
1. Scale Bar = 100 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; lateral view (L.M.)
3. Scale Bar = 50 microns; apical view (S.E.M.) showing large sutural pore

Figures 4 - 6 *Cryptamphorella macropora* Dumitrica
Specimen No. 3063/5: Sample: 10130, Akamas, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.) showing damaged sutural pore
5. Scale Bar = 50 microns; lateral view (L.M.)
6. Scale Bar = 25 microns; cephalis and thorax (L.M.)

Figures 7 - 9 *Cryptamphorella sp.A*
Specimen No. 3019/33: Sample: 10121, Akamas, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view (L.M.)
9. Scale Bar = 20 microns; lateral view of pore frames (S.E.M.)

Figures 10 - 12 *Cryptamphorella sp.B*
Specimen No. 3018/10: Sample: 9825, Paleomylon Valley, Cyprus.
10. Scale Bar = 50 microns; lateral view (S.E.M.)
11. Scale Bar = 50 microns; lateral view (L.M.)
12. Scale Bar = 10 microns; lateral view of ridged cephalis (S.E.M.)
Figures 1 - 2 **Cyrtocalpis compacta** Haeckel
Specimen No. 3028/26: Sample: 9827, Paleomyelon Valley, Cyprus.
1. Scale Bar = 30 microns; lateral view (L.M.)
2. Scale Bar = 30 microns; lateral view (S.E.M.)

Figure 3 **Cyrtocalpis compacta** Haeckel
Specimen No. 3028/14: Sample: 9827, Paleomyelon Valley, Cyprus. Scale Bar = 30 microns; lateral view (S.E.M.)

Figures 4 - 6 **Diacanthocapsa acanthica** Dumitrica
Specimen No. 3040/15: Sample No. 9825, Paleomyelon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.), arrow shows larger sutural pore
5. Scale Bar = 50 microns; lateral view (L.M.)
6. Scale Bar = 10 microns; lateral view of apical horn (S.E.M.)

Figures 7 - 9 **Diacanthocapsa acuminata** Dumitrica
Specimen No. 3010/14: Sample: 9825, Paleomyelon Valley, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view (L.M.)
9. Scale Bar = 50 microns; lateral view (L.M.) showing thick test wall

Figures 10 - 12 **Diacanthocapsa cf. D. ancus** (Foreman)
Specimen No. 3108/17: Sample: 9829, Paleomyelon Valley, Cyprus.
10. Scale Bar = 50 microns; lateral view (S.E.M.)
11. Scale Bar = 50 microns; lateral view (L.M.)
12. Scale Bar = 50 microns; antapical view (S.E.M.) showing aperture
Figures 1 - 3  *Diacanthocapsa euganea* Squinabol
Specimen No. 3089/1: Sample: 10124, Akamas, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; lateral view (L.M.)
3. Scale Bar = 10 microns; lateral view of cephalis (S.E.M.)

Figures 4 - 6  *Diacanthocapsa* (?) sp.A
Specimen No. 3008/15: Sample: 9825, Paleomylon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.) arrows indicate small spines at pore frame junctions
5. Scale Bar = 30 microns; oblique view (L.M.) showing degree of inflation and size of aperture
6. Scale Bar = 10 microns; lateral view of cephalis (S.E.M.)

Figures 7 - 9  *Dictyomitra andersoni* (Campbell & Clark)
Specimen No. 3007/29: Sample: 9825, Paleomylon Valley, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view (L.M.)
9. Scale Bar = 20 microns; lateral view of pores and costae (S.E.M.)

Figures 10 - 12  *Dictyomitra formosa* Squinabol
Specimen No. 3041/15: Sample: 10121, Akamas, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.), showing inter-costal ridges
11. Scale Bar = 100 microns; lateral view (L.M.)
12. Scale Bar = 50 microns; anatpical view (S.E.M.) showing a chamber division and central aperture
Figures 1 - 3  *Dictyomitra koslovaes* Foreman  
Specimen No. 3038/24: Sample: 9827, Paleomylon Valley, Cyprus.  
1. Scale Bar = 50 microns; lateral view (S.E.M.) showing inter-costal ridges  
2. Scale Bar = 40 microns; lateral view (L.M.) showing relatively thicker test wall on earlier chambers  
3. Scale Bar = 10 microns; lateral view of cephalo-thoracic region showing single row of pores at the base of each chamber  

Figures 4 - 6 *Dictyomitra multicostata* (Zittel)  
Specimen No. 3006/6: Sample: 9825, Paleomylon Valley, Cyprus.  
4. Scale Bar = 50 microns; lateral view (S.E.M.)  
5. Scale Bar = 50 microns; lateral view (L.M.)  
6. Scale Bar = 40 microns; antapical view showing a chamber division and central aperture  

Figures 7 - 8 *Dictyomitra sagitafera* Kh. Aliev  
Specimen No. 3041/3: Sample: 10121, Akamas, Cyprus.  
7. Scale Bar = 100 microns; lateral view (S.E.M.)  
8. Scale Bar = 100 microns; lateral view (L.M.)  

Figure 9 *Dictyomitra sagitafera* Kh. Aliev  
Specimen No. 3088/31: Sample: 10124, Akamas, Cyprus. Scale Bar = 50 microns; lateral view (L.M.)  

Figures 10 - 12 *Dictyomitra sp.A, aff. D. sagitafera* Kh. Aliev  
Specimen No. 3064/17: Sample: 9826, Paleomylon Valley, Cyprus.  
10. Scale Bar = 50 microns; lateral view (S.E.M.) showing lateral ribs between costae  
11. Scale Bar = 50 microns; lateral view (L.M.) showing almost free cephalis  
12. Scale Bar = 20 microns; antapical view (S.E.M.)
Figures 1 - 3 *Dictyomitra* sp.B, aff. *D. sagitafera* Kh. Aliev
Specimen No. 3090/21: Sample: 9829, Paleomylon Valley, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; antapical view showing central aperture
3. Scale Bar = 50 microns; lateral view (L.M.) showing thickening of test wall in proximal segments

Figures 4 - 6 *Eostichomitra warzigita* Empson Morin
Specimen No. 2692/29: Sample: 9825, Paleomylon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.)
5. Scale Bar = 20 microns; lateral view of test surface texture (S.E.M.)

Figure 6 *Eostichomitra warzigita* Empson Morin
Specimen No. 3028/30: Sample: 9827, Paleomylon Valley, Cyprus.
Scale Bar = 50 microns; lateral view (L.M.)

Figures 7, 8, 12 *Eucyrtidium* (?) sp.A
Specimen No. 3088/25: Sample: 10124, Akamas, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view (L.M.) showing asymmetrical position of apical horn
12. Scale Bar = 40 microns; oblique antapical view (S.E.M.)

Figures 9 - 11 *Eucyrtidium* (?) sp.B
Specimen No. 3038/30: Sample: 9827, Paleomylon Valley, Cyprus.
9. Scale Bar = 50 microns; oblique lateral view (S.E.M.)
10. Scale Bar = 50 microns; lateral view (S.E.M.), arrows indicate keel-like structure
11. Scale Bar = 50 microns; lateral view (S.E.M.), arrows indicate keel-like structure
Figures 1 - 3  *Eucyrtis* sp. A

Specimen No. 3184/8: Sample: 10127, Akamas, Cyprus.
1. Scale Bar = 100 microns; lateral view (S.E.M.)
2. Scale Bar = 25 microns; lateral view of proximal part of test (S.E.M.) showing papilllose surface of cephalis
3. Scale Bar = 20 microns; oblique antapical view (S.E.M.)

Figures 4 - 6  *Foremanina schona* Empson Morin

Specimen No. 3006/27: Sample: 9825, Paleomylon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.)
5. Scale Bar = 20 microns; oblique antapical view (S.E.M.) showing large aperture and septal divisions
6. Scale Bar = 50 microns; lateral view (L.M.)

Figures 7 - 9  *Gongylothorax* (?) sp. A

Specimen No. 3189/30: Sample: 10128, Akamas, Cyprus.
7. Scale Bar = 100 microns; apical view (S.E.M.), arrow shows cephalis
8. Scale Bar = 30 microns; lateral view of papilllose cephalis (S.E.M.)
9. Scale Bar = 50 microns; lateral view (L.M.), arrow shows cephalic region

Figures 10 - 12  *Heliocryptocapsa* sp. A

Specimen No. 3040/14: Sample: 10129, Akamas, Cyprus.
10. Scale Bar = 50 microns; oblique apical view (S.E.M.), arrow locates position of cephalis
11. Scale Bar = 10 microns; apical view of pore frames (S.E.M.)
12. Scale Bar = 50 microns; apical view (L.M.)
Figures 1 - 3  *Hexapyramid pantanellii* Squinabol
Specimen No. 3090/36: Sample: 10128, Akamas, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; oblique lateral view (S.E.M.)
3. Scale Bar = 100 microns; oblique lateral view (L.M.)

Figures 4 - 6 *Mita gracilis* (Squinabol)
Specimen No. 3061/10: Sample: 9809, Anadhiou, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.), pores occur in double rows on
distal chambers between arrows
5. Scale Bar = 100 microns; lateral view (L.M.)
6. Scale Bar = 20 microns; lateral view (S.E.M.) of change from a double to a single
row of inter-costal pores at the distalmost part of test

Figures 7 - 8 *Mita* sp.A
Specimen No. 3071/27: Sample: 9829, Paleomylon Valley, Cyprus.
7. Scale Bar = 100 microns; lateral view (L.M.)
8. Scale Bar = 100 microns; lateral view (S.E.M.), arrow marks point where single
rows of inter-costal pores change to double rows

Figure 9 *Mita* sp.B
Specimen No. 3063/34: Sample: 10130, Akamas, Cyprus.
9. Scale Bar = 50 microns; lateral view (L.M.)

Figures 10 - 12 *Novixitus* sp.A
Specimen No. 3061/24: Sample: 9827, Paleomylon Valley, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 100 microns; lateral view (L.M.)
12. Scale Bar = 40 microns; lateral view of cephalo-thoracic region (S.E.M.)
Figures 1 - 3 *Novixitus* sp.B
1. Specimen No. 2854/17: Sample: 9825, Paleomylon Valley, Cyprus.
   Scale Bar = 100 microns; lateral view (S.E.M.)
2. Specimen No. 2854/12: Sample: 9825, Paleomylon Valley, Cyprus.
   Scale Bar = 100 microns; lateral view (S.E.M.)
   Scale Bar = 100 microns; oblique lateral view (S.E.M.) showing large aperture

Figures 4 - 6 *Novodiacanthocapsa* (?) *manifesta* (Foreman)
Specimen No. 3006/11: Sample: 9825, Paleomylon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.) showing papillose cephalic region
5. Scale Bar = 50 microns; lateral view (L.M.)
6. Scale Bar = 20 microns; antapical view (S.E.M.) showing wide aperture and chamber divisions

Figures 7 - 9 *Orbiculiforma australis* Pessagno
Specimen No. 3185/11: Sample: 10128, Akamas, Cyprus.
7. Scale Bar = 100 microns; lateral view in S.E.M
8. Scale Bar = 20 microns; oblique lateral view of test surface (S.E.M.)
9. Scale Bar = 100 microns; oblique peripheral view (S.E.M.)

Figures 10 - 12 *Orbiculiforma maxima* Pessagno
Specimen No. 3019/21: Sample: 9825, Paleomylon Valley, Cyprus.
10. Scale Bar = 50 microns; lateral view (S.E.M.)
11. Scale Bar = 100 microns; lateral view (L.M.)
12. Scale Bar = 100 microns; peripheral view (S.E.M.)
Figures 1 - 3 *Orbiculiforma persenex* Pessagno
Specimen No. 3185/8: Sample: 9830, Paleomylon Valley, Cyprus.
1. Scale Bar = 10 microns; lateral view of test surface (S.E.M.)
2. Scale Bar = 50 microns; lateral view (S.E.M.)
3. Scale Bar = 100 microns; oblique peripheral view (S.E.M.)

Figures 4 - 6 *Orbiculiforma* (?) aff. *O. quadrata* Pessagno
Specimen No. 3090/31: Sample: 10127, Akamas, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 100 microns; lateral view (L.M.)
6. Scale Bar = 100 microns; oblique peripheral view (S.E.M.)

Figures 7 - 9 *Orbiculiforma* aff. *O. railensis* Pessagno
Specimen No. 3018/16: Sample: 9825, Paleomylon Valley, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view (L.M.)
9. Scale Bar = 50 microns; peripheral view (S.E.M.)

Figures 10 - 12 *Orbiculiforma sacramentoensis* Pessagno
Specimen No. 3184/24: Sample: 9825, Paleomylon Valley, Cyprus.
10. Scale Bar = 10 microns; lateral view of spine (S.E.M.) showing bladed, proximal end
11. Scale Bar = 50 microns; lateral view (S.E.M.)
12. Scale Bar = 50 microns; oblique peripheral view (S.E.M.)
Figures 1 - 3 *Orbiculiforma* sp.A
Specimen No. 3041/9: Sample: 10121, Akamas, Cyprus.
1. Scale Bar = 50 microns; peripheral view (S.E.M.)
2. Scale Bar = 50 microns; lateral view (S.E.M.)
3. Scale Bar = 50 microns; lateral view (S.E.M.)

Figures 4 - 6 *Orbiculiforma* sp.B
Specimen No. 3018/26: Sample: 10124, Akamas, Cyprus.
4. Scale Bar = 100 microns; lateral view (L.M.)
5. Scale Bar = 100 microns; lateral view (S.E.M.)
6. Scale Bar = 100 microns; peripheral view (S.E.M.)

Figures 7 - 9 *Paronaella venadoensis* Pessagno
Specimen No. 3089/21: Sample: 10121, Akamas, Cyprus.
7. Scale Bar = 100 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view of primary and secondary spines at ray tip in L.M.
9. Scale Bar = 100 microns; lateral view (L.M.)

Figures 10 - 12 *Paronaella* sp.A
Specimen No. 3019/12: Sample: 10121, Akamas, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 100 microns; lateral view (L.M.)
12. Scale Bar = 10 microns; axial view of structure of damaged spine (S.E.M.)
Figures 1 - 3 *Paronaella* sp.B
Specimen No. 3064/11: Sample: 10127, Akamas, Cyprus.
1. Scale Bar = 100 microns; peripheral view (S.E.M.)
2. Scale Bar = 50 microns; lateral view (S.E.M.)
3. Scale Bar = 50 microns; lateral view (L.M.)

Figures 4 - 6 *Paronaella* sp.C
Specimen No. 3059/30: Sample: 10121, Akamas, Cyprus.
4. Scale Bar = 100 microns; oblique lateral view (S.E.M.)
5. Scale Bar = 30 microns; oblique lateral view (S.E.M.) showing projecting tube
6. Scale Bar = 100 microns; oblique peripheral view (S.E.M.)

Figure 7 *Patellula euessceei* Empson Morin
Specimen No. 2691/7: Sample: 9829, Paleomylon Valley, Cyprus. Scale Bar = 100 microns; oblique lateral view (S.E.M.)

Figure 8 *Patellula euessceei* Empson Morin
Specimen No. 2803/14: Sample: 9827, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figure 9 *Patellula euessceei* Empson Morin
Specimen No. 2691/11: Sample: 9829, Paleomylon Valley, Cyprus. Scale Bar = 40 microns; peripheral view (S.E.M.) showing opposing tholi

Figures 10 - 12 *Patellula verteroensis* (Pessagno)
Specimen No. 3089/18: Sample: 10127, Akamas, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 100 microns; lateral view (L.M.)
12. Scale Bar = 100 microns; peripheral view (S.E.M.)
Figures 1 - 3 *Patellula* sp.A  
Specimen No. 3088/12: Sample: 10124, Akamas, Cyprus.  
1. Scale Bar = 50 microns; lateral view (S.E.M.)  
2. Scale Bar = 50 microns; lateral view (L.M.)  
3. Scale Bar = 100 microns; peripheral view (S.E.M.)

Figures 4 - 6 *Patulibracchium californiensis* Pessagno  
Specimen No. 3061/22: Sample: 10177, Perapedhi, Locality 10, Cyprus.  
4. Scale Bar = 100 microns; lateral view (S.E.M.)  
5. Scale Bar = 100 microns; lateral view (L.M.)  
6. Scale Bar = 15 microns; oblique axial view of broadest ray tip (S.E.M.)

Figures 7 - 9 *Patulibracchium* sp.A  
Specimen No. 3061/13: Sample: 10165, Perapedhi, Locality 10, Cyprus.  
7. Scale Bar = 100 microns; lateral view (S.E.M.)  
8. Scale Bar = 100 microns; lateral view (L.M.)  
9. Scale Bar = 100 microns; peripheral view (S.E.M.)

Figures 10 - 12 *Patulibracchium* sp.B  
Specimen No. 3064/10: Sample: 10178, Perapedhi, Locality 10, Cyprus.  
10. Scale Bar = 100 microns; lateral view (S.E.M.)  
11. Scale Bar = 100 microns; lateral view (L.M.)  
12. Scale Bar = 100 microns; peripheral view (S.E.M.)
Figures 1 - 2 *Patulibrachium* sp.C
Specimen No. 3071/14: Sample: 9825, Paleomylon Valley, Cyprus.
1. Scale Bar = 100 microns; lateral view (S.E.M.)
2. Scale Bar = 100 microns; lateral view (L.M.)

Figure 3. *Patulibrachium* sp.D
Specimen No. 3071/23: Sample: 9829, Paleomylon Valley, Cyprus.
Scale Bar = 100 microns; lateral view (L.M.)

Figures 4 - 6 *Patulibrachium* sp.E
Specimen No. 2827/7: Sample: 10121, Akamas, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 20 microns; oblique peripheral view showing spine base (S.E.M.)
6. Scale Bar = 100 microns; oblique peripheral view (S.E.M.)

Figure 7 *Phaseliforma laxa* Pessagno
Specimen No. 3156/23: Sample: 9825, Paleomylon Valley, Cyprus.
Scale Bar = 100 microns; lateral view (S.E.M.)

Figure 8 *Phaseliforma* sp.A
Specimen No. 3187/10: Sample: 9825, Paleomylon Valley, Cyprus.
Scale Bar = 100 microns; lateral view (S.E.M.)

Figure 9 *Phaseliforma* sp.B
Specimen No. 3187/9: Sample: 9825, Paleomylon Valley, Cyprus.
Scale Bar = 100 microns; lateral view (S.E.M.)

Figures 10 - 12 *Phaseliforma* aff. *P. laxa* Pessagno
Specimen No. 3143/29: Sample: 10121, Akamas, Cyprus.
10. Scale Bar = 50 microns; lateral view (S.E.M.)
11. Scale Bar = 20 microns; peripheral view along long axis (S.E.M.)
12. Scale Bar = 50 microns; peripheral view along short axis (S.E.M.)
Figure 1 *Praeconocaryomma* (?) *dauerhafta* (Empson Morin)
Specimen No. 3188/27: Sample: 10124, Akamas, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figure 2 *Praeconocaryomma* (?) *dauerhafta* (Empson Morin)
Specimen No. 2803/22: Sample: 9829, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.) arrow shows aberrant test surface

Figure 3 *Praeconocaryomma* (?) *dauerhafta* (Empson Morin)
Specimen No. 3188/27: Sample: 10124, Akamas, Cyprus. Scale Bar = 50 microns; lateral view (L.M.)

Figures 4 - 6 *Praeconocaryomma* (?) *universa* Pessagno
Specimen No. 3184/17: Sample: 10175, Perapedhi, Locality 10, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.)
5. Scale Bar = 10 microns; planar view of one node (S.E.M.) showing hexagonal symmetry
6. Scale Bar = 10 microns; lateral view of node (S.E.M.) showing papillose-like apex

Figures 7 - 9 *Praestylosphaera hastata* (Campbell & Clark)
Specimen No. 3041/33: Sample: 9827, Paleomylon Valley, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view (L.M.)
9. Scale Bar = 50 microns; peripheral view along axis of primary spines showing triradiate spine (S.E.M.)

Figures 10 - 12 *Praestylosphaera privus* (Foreman)
Specimen No. 3028/18: Sample: 10178, Perapedhi, Locality 10, Cyprus.
10. Scale Bar = 25 microns; lateral view (S.E.M.), arrows show by-spines at pore frame junctions
11. Scale Bar = 10 microns; pore frames (S.E.M.)
12. Scale Bar = 40 microns; lateral view (L.M.)
Figures 1 - 3 *Praestylosphaera pusilla* (Campbell & Clark)
Specimen No. 3038/26: Sample: 9825. Paleomylon Valley, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; lateral view (L.M.)
3. Scale Bar = 10 microns; pore frames (S.E.M.)

Figures 4 - 6 *Praestylosphaera* sp.A
Specimen No. 3040/32: Sample: 9825, Paleomylon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.)
5. Scale Bar = 50 microns; lateral view (L.M.)
6. Scale Bar = 10 microns; pore frames (S.E.M.)

Figures 7 - 9 *Protoxiphotractus kirbyi* Pessagno
Specimen No. 3064/24: Sample: 9825, Paleomylon Valley, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view (L.M.)
9. Scale Bar = 10 microns; pore frames (S.E.M.)

Figures 10 - 12 *Protunuma(?) sp.A*
Specimen No. 3010/1: Sample: 9827, Paleomylon Valley, Cyprus.
10. Scale Bar = 50 microns; oblique lateral view (S.E.M.)
11. Scale Bar = 50 microns; lateral view (L.M.)
12. Scale Bar = 25 microns; antapical view (S.E.M.)
Figures 1 - 2 *Pseudoaulophacus floresensis* Pessagno
Specimen No. 3062/12: Sample: 9827, Paleomylon Valley, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; lateral view (L.M.)

Figure 3 *Pseudoaulophacus floresensis* Pessagno
Specimen No. 3199/19: Sample: 10121, Akamas, Cyprus. Scale Bar = 40 microns; lateral view (S.E.M.)

Figures 4 - 6 *Pseudoaulophacus* aff. *P. floresensis* Pessagno
Specimen No. 2854/20: Sample: 9829, Paleomylon Valley, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 50 microns; peripheral view (S.E.M.)
6. Scale Bar = 20 microns; lateral view (S.E.M.) of proximally triradiate spine

Figures 7 - 9 *Pseudoaulophacus* sp.A
Specimen No. 3062/7: Sample: 10106A, Akamas, Cyprus.
7. Scale Bar = 100 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; oblique peripheral view (S.E.M.)
9. Scale Bar = 100 microns; lateral view (L.M.)

Figures 10 - 12 *Pseudoaulophacus* sp.B
Specimen No. 3035/7: Sample: 9825, Paleomylon Valley, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 100 microns; lateral view (L.M.)
12. Scale Bar = 100 microns; peripheral view (S.E.M.)
Figure 1  *Pseudoaulophacus lenticulatus* (White)
Specimen No. 2827/9: Sample: 9830, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figures 2 - 3  *Pseudoaulophacus lenticulatus* (White)
Specimen No. 3061/28: Sample: 10178, Perapedhi, Locality 10, Cyprus.
2. Scale Bar = 50 microns; lateral view (L.M.)
3. Scale Bar = 50 microns; lateral view (S.E.M.)

Figures 4 - 6  *Pseudoaulophacus paragueraensis* Pessagno
Specimen No. 3019/22: Sample: 10121, Akamas, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 100 microns; lateral view (L.M.)
6. Scale Bar = 100 microns; oblique peripheral view (S.E.M.)

Figures 7 - 9  *Pseudoaulophacus vielseitigus* Empson Morin
Specimen No. 3061/17: Sample: 10164, Perapedhi, Locality 10, Cyprus.
7. Scale Bar = 100 microns; lateral view (S.E.M.)
8. Scale Bar = 100 microns; lateral view (L.M.)
9. Scale Bar = 100 microns; peripheral view (S.E.M.)

Figures 10 - 11  Pseudoaulophacid sp.C
Specimen No. 3064/16: Sample: 9825, Paleomylon Valley, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 100 microns; lateral view (L.M.)

Figure 12  Pseudoaulophacid sp.C
Specimen No. 3184/5: Sample: 9830, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; oblique peripheral view (S.E.M.)
Figures 1 - 3  *Pseudoaulophacid sp.D*
Specimen No. 3071/10: Sample: 10127, Akamas, Cyprus.
1. Scale Bar = 100 microns; lateral view (S.E.M.)
2. Scale Bar = 100 microns; lateral view (L.M.)
3. Scale Bar = 100 microns; peripheral view (S.E.M.)

Figures 4 - 6  *Pseudoaulophacid sp.E*
Specimen No. 3064/12: Sample: 10167, Perapedhi, Locality 10, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 100 microns; lateral view (L.M.)
6. Scale Bar = 100 microns; peripheral view (S.E.M.)

Figure 7  *Pseudoaulophacus riedeli* Pessagno
Specimen No. 2786/14: Sample: 9825, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; oblique lateral view (S.E.M.)

Figures 8 - 9  *Pseudoaulophacus riedeli* Pessagno
Specimen No. 3071/13: Sample: 10164, Perapedhi, Locality 10, Cyprus.
8. Scale Bar = 50 microns; lateral view (S.E.M.)
9. Scale Bar = 50 microns; lateral view (L.M.)

Figure 10  *Pseudoaulophacid sp.F*
Specimen No. 2786/26: Sample: 9827, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figure 11  *Pseudoaulophacid sp.F*
Specimen No. 2692/23: Sample: 9830, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; lateral view (S.E.M.)

Figure 12  *Pseudoaulophacid sp.F*
Specimen No. 2696/15: Sample: 9830, Paleomylon Valley, Cyprus. Scale Bar = 50 microns; oblique peripheral view (S.E.M.)
Figures 1 - 3  Pseudoaulophacid sp.G
Specimen No. 3188/28: Sample: 10124, Akamas, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 100 microns; lateral view (L.M.)
3. Scale Bar = 75 microns; peripheral view (S.E.M.)

Figures 4 - 6  Pseudodictyomitra ?Iodogaensis Pessagno
Specimen No. 3018/7: Sample: 9825, Paleomylon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.)
5. Scale Bar = 50 microns; lateral view (L.M.)
6. Scale Bar = 20 microns; antapical view (S.E.M.)

Figures 7 - 8  Pyramispongia(?) sp.A
Specimen No. 3040/10: Sample: 10121, Akamas, Cyprus.
7. Scale Bar = 50 microns; lateral view (L.M.)
8. Scale Bar = 50 microns; oblique lateral view (S.E.M.)

Figure 9  Pyramispongia(?) sp.A
Specimen No. 3199/29: Sample: 10177, Perapedhi, Locality 10, Cyprus. Scale Bar = 50 microns; oblique lateral view (S.E.M.)

Figures 10 - 11  Rhopalosyringium kleinum Empson Morin
Specimen No. 3062/28: Sample: 10178, Perapedhi, Locality 10, Cyprus.
10. Scale Bar = 50 microns; lateral view (L.M.)
11. Scale Bar = 50 microns; lateral view (S.E.M.)

Figure 12  Rhopalosyringium kleinum Empson Morin
Specimen No. 3188/2: Sample: 9829, Paleomylon Valley, Cyprus. Scale Bar = 100 microns; lateral view (S.E.M.)
Figures 1 - 3 *Rhopalosyringium magnificum* Campbell & Clark
Specimen No. 3062/34: Sample: 9825, Paleomylon Valley, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; lateral view (L.M.)
3. Scale Bar = 20 microns; lateral view of cephalis (S.E.M.)

Figures 4 - 6 *Septinastrum dogeli* Gorbovets
Specimen No. 3019/4: Sample: 10121, Akamas, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 100 microns; lateral view (L.M.)
6. Scale Bar = 50 microns; oblique peripheral view of spine base (S.E.M.)

Figure 7 *Septinastrum cf. S. dogell* Gorbovets
Specimen No. 3187/23: Sample: 10127, Akamas, Cyprus. Scale Bar = 100 microns; lateral view (S.E.M.)

Figures 8 - 9 *Septinastrum cf. S. dogeli* Gorbovets
Specimen No. 3187/14: Sample: 10127, Akamas, Cyprus.
8. Scale Bar = 100 microns; oblique peripheral view (S.E.M.)
9. Scale Bar = 100 microns; lateral view (S.E.M.)

Figures 10 - 11 *Septinastrum sp.A*
Specimen No. 3089/12: Sample: 10167, Perapedhi, Locality 10, Cyprus.
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 100 microns; lateral view (L.M.)

Figure 12 *Septinastrum sp.B*
Specimen No. 2826/14: Sample: 10124, Akamas, Cyprus. Scale Bar = 100 microns; lateral view (S.E.M.)
PLATE 30

Figures 1 - 3 Siphocampe daseia (Foreman)
Specimen No. 3008/32: Sample: 9825, Paleomylon Valley, Cyprus.
1. Scale Bar = 30 microns; lateral view (S.E.M.)
2. Scale Bar = 30 microns; lateral view (L.M.)
3. Scale Bar = 20 microns; antapical view (S.E.M.)

Figures 4 - 6 Spongiscid sp.A
Specimen No. 3061/6: Sample: 10121, Akamas, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 50 microns; lateral view (L.M.)
6. Scale Bar = 50 microns; central area of test in lateral view showing triradiate spine bases (S.E.M.)

Figures 7 - 9 ?Spongostaurus(? hokkaidoensis Taketani
Specimen No. 3186/27: Sample: PARA-A, Paralimni, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 10 microns; test surface texture (S.E.M.)
9. Scale Bar = 50 microns; peripheral view (S.E.M.)

Figures 10 - 12 Staurodictya sp.A
Specimen No. 3018/19: Sample: 9825, Paleomylon Valley, Cyprus.
10. Scale Bar = 40 microns; lateral view (L.M.)
11. Scale Bar = 40 microns; lateral view (S.E.M.)
12. Scale Bar = 40 microns; oblique peripheral view (S.E.M.)
Figures 1 - 3  *Staurodictya* sp.B  
Specimen No. 3041/27: Sample: 10121, Akamas, Cyprus.  
1. Scale Bar = 100 microns; lateral view (S.E.M.)  
2. Scale Bar = 100 microns; lateral view (L.M.)  
3. Scale Bar = 10 microns; oblique lateral view of spine base (S.E.M.)

Figures 4 - 6  *Staurodictya* sp.C  
Specimen No. 3089/30: Sample: 10124, Akamas, Cyprus.  
4. Scale Bar = 100 microns; oblique peripheral view (S.E.M.)  
5. Scale Bar = 50 microns; lateral view (S.E.M.)  
6. Scale Bar = 50 microns; lateral view (L.M.)

Figures 7 - 9  *Staurodictya* sp.D  
Specimen No. 3186/4: Sample: 9825, Paleomylon Valley, Cyprus.  
7. Scale Bar = 100 microns; lateral view (S.E.M.)  
8. Scale Bar = 10 microns; test surface texture (S.E.M.)  
9. Scale Bar = 100 microns; oblique peripheral view (S.E.M.)

Figures 10 - 12  *Stichomitra asymbatos* Foreman  
Specimen No. 3035/24: Sample: 9827, Paleomylon Valley, Cyprus.  
10. Scale Bar = 50 microns; lateral view (S.E.M.)  
11. Scale Bar = 50 microns; lateral view (L.M.)  
12. Scale Bar = 20 microns; lateral view of cephalo-thoracic region (L.M.)
Figures 1 - 3 Stichomitra communis Squinabol
Specimen No. 3062/6: Sample: 10175, Perapedhi, Locality 10, Cyprus.
1. Scale Bar = 100 microns; lateral view (S.E.M.), cf. Amphipyndax conicus, pl. 3, fig. 10
2. Scale Bar = 100 microns; lateral view (L.M.), cf. Amphipyndax conicus, pl. 3, fig. 12
3. Scale Bar = 10 microns; lateral view of pore frames (S.E.M.)

Figures 4 - 6 Stylodictya sp.A
Specimen No. 3184/13: Sample: 9825, Paleomylon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.)
5. Scale Bar = 100 microns; peripheral view (S.E.M.)
6. Scale Bar = 10 microns; oblique peripheral view of triradiate spine base (S.E.M.)

Figures 7 - 9 Stylodictya sp.B
Specimen No. 3028/6: Sample: 9825, Paleomylon Valley, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 50 microns; lateral view (L.M.)
9. Scale Bar = 60 microns; peripheral view of broken edge (S.E.M.)

Figures 10 - 12 Stylodictya(?) sp.C
Specimen No. 3007/13: Sample: 9825, Paleomylon Valley, Cyprus.
10. Scale Bar = 25 microns; lateral view (S.E.M.)
11. Scale Bar = 50 microns; lateral view (L.M.), arrows indicate marginal spines
12. Scale Bar = 50 microns; peripheral view (S.E.M.)
Figures 1 - 3 *Theocampe altamontensis* (Campbell & Clark)
Specimen No. 3071/33: Sample: 10121, Akamas, Cyprus.
1. Scale Bar = 50 microns; lateral view (S.E.M.)
2. Scale Bar = 50 microns; lateral view (L.M.)
3. Scale Bar = 50 microns; lateral view (L.M.) (different focal plane from above)

Figures 4 - 6 *Theocampe salillum* Foreman
Specimen No. 3038/2: Sample: 9825, Paleomylon Valley, Cyprus.
4. Scale Bar = 50 microns; lateral view (S.E.M.)
5. Scale Bar = 50 microns; lateral view (L.M.)
6. Scale Bar = 20 microns; antapical view (S.E.M.)

Figures 7 - 9 *Theocampe* sp.A, aff. *T. salillum* Foreman
Specimen No. 3040/33: Sample: 9827, Paleomylon Valley, Cyprus.
7. Scale Bar = 50 microns; lateral view (S.E.M.)
8. Scale Bar = 25 microns; antapical view (S.E.M.)
9. Scale Bar = 50 microns; lateral view (L.M.)

Figures 10 - 12 *Theocampe* sp.B, aff. *T. salillum* Foreman
Specimen No. 3185/17: Sample: 9825, Paleomylon Valley, Cyprus.
10. Scale Bar = 20 microns; antapical view (S.E.M.)
11. Scale Bar = 20 microns; lateral view (S.E.M.)
12. Scale Bar = 20 microns; lateral view of cephalo-thoracic region (S.E.M.)
Figures 1 - 3 *Triactoma* sp.A
Specimen No. 3064/25: Sample: 10130, Akamas, Cyprus.
1. Scale Bar = 50 microns; peripheral view (S.E.M.)
2. Scale Bar = 50 microns; peripheral view (L.M.)
3. Scale Bar = 50 microns; oblique lateral view (S.E.M.)

Figures 4 - 6 *Triactoma* sp.B
Specimen No. 3071/17: Sample: 9829, Paleomylon Valley, Cyprus.
4. Scale Bar = 100 microns; lateral view (S.E.M.)
5. Scale Bar = 100 microns; lateral view (L.M.)
6. Scale Bar = 100 microns; peripheral view (S.E.M.)

Figures 7 - 9 *Xitus* sp.A
Specimen No. 3089/27: Sample: 10124, Akamas, Cyprus.
7. Scale Bar = 100 microns; lateral view (S.E.M.)
8. Scale Bar = 100 microns; lateral view (L.M.)
9. Scale Bar = 100 microns; antapical view (S.E.M.) showing aperture and chamber divisions

Figures 10 - 12 *Xitus* sp.B
Specimen No. 3063/12: Sample: 10130, Akamas, Cyprus:
10. Scale Bar = 100 microns; lateral view (S.E.M.)
11. Scale Bar = 100 microns; lateral view (L.M.)
12. Scale Bar = 100 microns; lateral view of proximal chambers (L.M.)
Selected species, mainly from plates 1 - 34 showing, relative sizes. The plate numbers for each specimen, when given, refer to the plates in this work. Scale Bar = 100 microns; lateral views (S.E.M.)

Figure 1  *Noviodiacanthocapsa(?) manifesta* (Foreman) [Pl.17, fig. 4]
Figure 2  *Protunuma* sp.A [Pl. 24, fig. 10]
Figure 3  *Cyrtoascalps compacta* Haeckel [Pl.11, fig. 3]
Figure 4  *Siphocampe daseia* (Foreman) [Pl.30, fig. 1]
Figure 5  *Pseudoaulophacus vielsietigus* Empson Morin, Specimen No. 2786/6: Sample: 9824, Paleomylon Valley, Cyprus.
Figure 6  *Rhopalosyringium kleinum* Empson Morin, Specimen No. 3059/9: Sample: 10126, Akamas, Cyprus.
Figure 7  *Protoxiphotractus kirbyi* Pessagno [Pl.24, fig. 7]
Figure 8  *Theocampe salillum* Foreman [Pl.33, fig. 4]
Figure 9  *Dictyomitra koslovae* Foreman [Pl.13, fig. 1]
Figure 10  *Pyramisponge(?)* sp.A [Pl.28, fig. 9]
Figure 11  *Patulibracchium californi aensis* Pessagno [Pl.21, fig. 4]
Figure 12  *Crucella espartoensis* Pessagno [Pl.8, fig. 10]
Figure 13  *Orcbiculiforma maxima* Pessagno [Pl.17, fig. 10]
Figure 14  *Pseudoaulophacus lenticulatus* (White), Specimen No. 2696/10: Sample: 9829, Paleomylon Valley, Cyprus.
Figure 15  *Paronaella venadoensis* Pessagno [Pl.19, fig. 7]
Figure 16  *Phaseliforma laxa* Pessagno [Pl.22, fig. 7]
Figure 17  *Novixitus* sp.A [Pl.16, fig. 10]
Figure 18  *Archeao spongopruronum hueyi* Pessagno [Pl.6, fig.10]
Figure 19  *Mita gracilis* (Squinabol) [Pl.16, fig. 4]
Figure 20  *Septinastrum* sp.A, Specimen No. 3059/13: Sample: 10124, Akamas, Cyprus.
THE END