

Thesis submitted for the degree of Doctor of Philosophy, University of Oxford

**Palynofacies, palaeoenvironmental
change and sequence stratigraphy of the
Middle Jurassic, Cleveland Basin and
Brent Group of the UK**

by

C. ELIZABETH ROSS



Department of Earth Sciences

and

St. Cross College

University of Oxford

Hilary Term 1999



Palynofacies, palaeoenvironmental change and sequence stratigraphy of the Middle Jurassic, Cleveland Basin and Brent Group of the UK

C. Elizabeth Ross

St. Cross College

Thesis submitted to the University of Oxford for the degree of Doctor of Philosophy

Hilary term 1999

Short Abstract

Palynofacies analysis, which is the study of microscopic organic matter can, in association with sedimentological and palaeoecological data, provide temporal and spatial resolution in the characterisation of sedimentary environments and potentially, vegetation and climate. However, the reliability of palynofacies analysis as a tool for environmental reconstruction has been questioned recently. This uncertainty is due a number of factors, including the lack of standardisation in the processing and counting of organic matter, subjective and vague terminology used to classify organic matter, and existence of numerous classification schemes. These have all restricted comparison between studies and hence hampered the advance of palynofacies analysis. The most important factor is, however, limited understanding of the controls which govern the genesis of particular associations of particulate organic matter.

These issues were addressed using a two-fold approach. Firstly, the particulate organic matter classification scheme created by Lewis in 1995 was tailored to produce a robust hierarchical classification scheme. Secondly, multivariate statistical analysis was applied to a Middle Jurassic data set. This revealed that the primary control upon the nature of the organic matter associations is preservation potential which is affected by redox status, and to a lesser extent by the degree and duration of transportation and disturbance to which the organic-matter has been subjected. The secondary influence was determined to be a change in the nature of organic matter through time. Following this analysis 19 different organic-matter assemblage groups were defined to decipher palaeoenvironmental changes during the Middle Jurassic.

Variations in the associations of organic matter through the Aalenian to Bathonian reflect changes in the redox status, proximity to source, salinity and hydrodynamics. This investigation suggests that aridity and/or pronounced seasonality commenced during the early Bajocian of the region which is earlier than the findings of previous investigations. This is based principally on the concomitant increase in black fragments (charcoal) and acme of *Classopollis* pollen in both the Cleveland Basin and Brent Group. The black fragments are probably charcoal rather than post-depositionally altered fragments because they occur in a range of oxic and anoxic environments, in conjunction with brown fragments, and in a range of lithofacies. These results not only permit the characterisation of the environment of deposition but also illustrate that palynofacies yields a discernible climatic signal.

**Palynofacies, palaeoenvironmental change and sequence stratigraphy of the Middle Jurassic,
Cleveland Basin and Brent Group of the UK**

Extended Abstract

The Middle Jurassic climate in Britain has traditionally been regarded as warm and humid. Recent published evidence including palynological, stable-isotopic and palaeobotanical data yield indications that the late Bajocian and Bathonian may have contained one or more periods of relative aridity and/or more pronounced seasonality, in comparison to the early Bajocian and Aalenian. The primary aim of this thesis was to conduct a palaeoenvironmental study of the Middle Jurassic of the UK. This was achieved by a fully integrative sedimentological, stratigraphical and palynofacies study of the Middle Jurassic, Cleveland Basin. The findings from this investigation were compared with a time-equivalent section from the Middle Jurassic, Brent Province of the Northern North Sea. In relation to the overall goal of the present investigation, the specific aims of this thesis are two-fold: firstly, to determine the usefulness of palynofacies analysis as a tool for environmental reconstruction and, secondly, to infer the spatial and temporal environmental variations derived from the palynofacies and sedimentological studies within the British Middle Jurassic stratigraphic framework.

Palynofacies analysis is the quantitative study of insoluble organic matter that is believed to reflect a particular set of environmental conditions. Palynofacies analysis can, in association with sedimentological and palaeoecological data, provide temporal and spatial resolution in the characterisation of the sedimentary environment and potentially vegetation and climate. It is paradoxical, however, that the nature of organic matter is often used as an environmental indicator but the way in which organic matter, in particular palynodebris, changes between environments, and the mechanisms which govern the development of particular associations of organic matter, are not well understood. Taphonomic processes impose a significant overprint. Hence, the degree to which acid-insoluble organic matter yields a reliable depositional, and potentially vegetational and climatic signal, has not been exhaustively explored. The controls on the distribution of palynomorphs and palynodebris through a sedimentary succession are complex. It has been suggested that the variations in assemblages of organic matter are related to preservation, lithology and proximity to source. No published work has, however, made any quantitative distinction between major and minor influences. In addition, a number of workers (*e.g.*, Gastaldo in 1996) have demonstrated that different lithofacies may display the

same associations of organic matter and, conversely the same lithofacies may reveal different associations. These issues have hampered the advance of palynofacies analysis as a tool for environmental reconstruction. In addition, variations in processing and counting techniques, the use of subjective and vague terminology used to classify organic matter, and the existence of numerous classification schemes and methods of analysis have also hindered the advance of palynofacies analysis.

A review of the plethora of particulate organic-matter classification schemes available led to the development of designated classification procedures. These were used to tailor a classification scheme devised by Lewis in 1995 rather than promulgate yet another scheme and add to the confusion. The essence of Lewis's scheme was maintained, with some restructuring, to maximise the amount of detail obtained, expedite the application of the classification scheme, and permit integration and comparison with other investigations. The modifications resulted in the generation of a hierarchical scheme with increasing detail and different modes of microscope illumination being incorporated at each successive phase. This sequential style of classification permits the operator to expand the categories if desired whilst allowing comparison with other schemes. Thus, in the present study, more attention was paid to palynodebris in comparison to palynomorphs, in order to maximize the amount of information available from this type of organic debris.

The conventional approach of defining assemblage-types in palaeoenvironmental reconstruction studies as outlined by Batten in 1973 and employed by many other workers, including Whitaker and Lewis, was initially used in this study. This technique involves the recognition of recurrent associations of particular types and proportions of organic matter which are then qualitatively related to specific environmental conditions. After initial use of the conventional method, it was believed, however, that it could bias the data by forcing the samples into rigid and inelastic groups and impose structure on the data where none existed, thus masking the true nature of the data. Moreover, this approach would make it very difficult to address the question: 'what controls the development of particular types of palynofacies assemblages in the sedimentary record?'

Thus, in the present study, the complex relationships between the samples and categories of organic matter were evaluated quantitatively using multivariate statistical analysis, namely Correspondence Analysis (CA), an indirect ordination technique. CA was also used to test the validity of the conventionally defined assemblages and gain an appreciation of the underlying controls which govern

the genesis of the associations of organic matter. It is important to identify the different assemblages of organic matter and gain an appreciation of the underlying controls for two reasons; 1) to improve the reliability of the interpretation, and 2) the recognition of assemblages of organic matter and their respective environmental indicators forms the framework for any palaeoenvironmental study which is based on palynofacies analysis.

The multivariate statistical analysis clearly highlights that the organic matter, investigated in this study, does not form discrete groups but instead comprises a great diversity of individual components whose associations form a natural continuum. Detailed examination of the organic-matter associations and superimposition of the conventionally defined assemblages on the sample scores from the CA analysis revealed the underlying controls. The primary control is redox potential which is linked to energy-levels (*e.g.*, degree of transportation and disturbance to which the particulate organic matter has been subjected). It was also evident that the nature of the organic matter varied through time and this may reflect climatic changes. In addition, this analysis revealed that the majority of the assemblage groups defined by the conventional method were identifiable as parcels in the statistical output. A number of conventionally defined groups did not, however, occur as packages, primarily because these were defined using palynomorphs. The latter are minor in mathematical terms, thus the more abundant, or more obvious, components were stressed statistically at the expense of palynomorphs.

To extend the assessment of the controls, output from statistical analysis was compared to stratigraphic position, grain size and 'environmental descriptors' of the host sediment (*e.g.*, presence or absence of macroscopic floral remains and burrowing). The latter investigation was carried out using Canonical Correspondence Analysis (CCA), a direct ordination technique. CCA was also used to test the significance and validity of the CA results. Finally, to evaluate the reliability of palynofacies, as an environmental tool, the statistical output was compared to an independently established lithofacies scheme which was developed using sedimentological and ichnological information. This evaluation revealed that organic matter is not a precise indicator of lithofacies. However, in the case of deltaic sediments, it has proved to be very useful because the nature of the organic matter provides extra information about the degradation process, and hence the water-saturation, productivity, bioturbation and/or amount of transportation. As neither the statistical nor the conventional method is perfect, the results from both methods, including the appreciation of the underlying controls, were integrated and used to define the 19 assemblage groups employed in the palaeoenvironmental analysis.

The integration of sedimentological and palynofacies data permitted the documentation of the nature of the depositional environment and the stratigraphical distribution enabled the identification of change through time. Variations in the palynofacies assemblages through the Aalenian to Bathonian, UK reflect changes in the redox status, proximity to source, salinity and hydrodynamics. Variations in the thickness and lithofacies of each section and individual members were also recognised. This implies that the palaeogeography, and hence accommodation space, sediment supply and drainage pattern changed during the deposition of these predominately fluvio-deltaic sediments.

An increase in the abundance of black fragments (charcoal) and *Classopollis* pollen, an indicator of increased intensity of warmth or seasonally dry periods, was detected in the early-middle Bajocian, in comparison to the Aalenian. The increased abundance of charcoal is based upon the detection of an increase in the ratio of black to brown fragments in the early-middle Bajocian, in comparison to the Aalenian. This increase in black fragments was detected in three sections, in the Cleveland Basin, which were probably sourced from different parts of the basin. The black fragments occur; in both oxic and anoxic sediments, in conjunction with brown fragments, and in a range of lithologies. These varied associations suggest that the black fragments are probably charcoal rather than post-depositionally altered organic matter. The lower ratio of black to brown fragments in the upper Aalenian, which contains similar depositional environments to the Bajocian, implies that the change is due to an increase in production of carbonised material, probably in response to increased fires, and is not a result of preferential deposition. This suggests that the early-middle Bajocian probably included warmer periods and/or was more seasonal, which is earlier than the recently published palynological, stable-isotopic and palaeobotanical data.

Contents

1	Introduction	1
1.1	Palynofacies	1
1.2	Study Areas and Setting	4
1.3	Cleveland Basin	7
1.3.1	Structural Framework of the Cleveland Basin	7
1.3.2	Stratigraphy of the Cleveland Basin	8
1.4	Brent Province	17
1.4.1	Lithostratigraphy and Depositional History	17
1.4.2	Broom Formation	18
1.4.3	Rannoch and Etive Formations	19
1.4.4	Ness Formation	19
1.4.5	Tarbert Formation	20
1.5	Biostratigraphic Framework	21
1.5.1	Marine units	23
1.5.2	Non-marine units	26
1.6	Specific Objectives	29
2	Materials and Methods	31
2.1	Introduction	31
2.2	Collection and Processing	32

2.2.1	Sampling Strategy	32
2.2.2	Processing Procedure	32
2.3	Classification of Particulate Organic Matter	34
2.3.1	Critique of the Classification of Particulate Organic Matter	34
2.3.2	Amsterdam Palynological Organic Matter Classification	40
2.4	Lewis’s Classification Scheme	40
2.4.1	Palynomorphs	41
2.4.2	Non-Palynomorph Matter	41
2.5	Appraisal and Rationalisation of Lewis’s Scheme and Classification Protocol	47
2.5.1	Appraisal	47
2.5.2	Modifications	48
2.6	Description of Categories	51
2.6.1	Palynomorphs	51
2.6.2	Discrete Fragments and Structureless Organic Matter	56
2.6.3	Non-Vita Fragments	56
2.6.4	Vita-Fragments	57
2.7	Data Extraction	59
2.7.1	Qualitative versus Quantitative	59
2.7.2	Selection of the Type of Raw Data and Methods of Data Extraction	61
2.8	Analysis	65
2.8.1	Selection of Statistical Techniques	65
2.9	Conclusions	67
3	Controls and Assemblages	68
3.1	Introduction	68
3.2	Background	70
3.3	Conventional Analysis	76

3.4	Statistical Analysis	78
3.4.1	Indirect Ordination	79
3.4.2	Correspondence Analysis (CA) method and plots	80
3.5	Distribution of samples and <i>species</i>	83
3.5.1	Variability in the samples	83
3.5.2	Inverted Arch	83
3.5.3	Interpretation of CA sample scores	89
3.5.4	<i>Species</i> (organic matter) associations	91
3.5.5	Distribution of particulate organic matter in the samples	93
3.5.6	Synopsis	103
3.6	Validation of Assemblage Groups	104
3.6.1	Synopsis	110
3.7	Outliers	110
3.8	Controls	118
3.8.1	Stratigraphic distribution	118
3.8.2	Synopsis	122
3.8.3	Relationship to grain-size	122
3.8.4	Synopsis	126
3.8.5	Environmental Variables: Canonical Correspondence Analysis	126
3.8.6	Synopsis	137
3.9	Range of organic matter within particular lithofacies	137
3.9.1	Synopsis	140
3.10	Implications of Results	140
3.11	Assemblage Groups	141
3.12	Conclusions	144

4	Temporal and Spatial Environmental Change in Aalenian to Bathonian	145
4.1	Introduction	145
4.2	Dogger and Saltwick Formations	146
4.2.1	Dogger Formation	146
4.2.2	Saltwick Formation	149
4.2.3	Boulby	151
4.2.4	West Whitby	153
4.2.5	High Hawsker	154
4.2.6	Blea Wyke Point	160
4.2.7	Synopsis	164
4.3	Iron Scar: uppermost Saltwick Formation, Eller Beck Formation and basal part of the Sycarham Member	165
4.3.1	Synopsis	167
4.4	Cloughton Formation	169
4.4.1	Synopsis	181
4.5	Scarborough Formation	181
4.5.1	Synopsis	183
4.6	Scalby Formation	188
4.6.1	Synopsis	191
4.7	Aalenian to Bathonian	192
4.8	Conclusions	196
5	Conclusions	199
	Bibliography	203

A	Processing Technique	226
A.1	Processing Technique	226
A.2	Calculation of Absolute Abundances	230
A.2.1	Method	230
A.3	Index of absolute abundance per gram of sediment	231
B	Scanned Images of Organic Matter	232
B.1	Introduction	232
C	<i>Classopollis</i> pollen systematics	247
C.1	Systematics	247
C.1.1	Occurrence and possible depositional environment	247
C.1.2	Possible affinities of <i>Classopollis</i> pollen	249
D	Relative Abundances and Environmental Data	251
D.1	Data from Dogger and Saltwick Formations	251
D.2	Data from Eller Beck to Scalby Formations: Iron Scar to Scalby Ness	258
D.3	Data from Osgodby Nab and Yons Nab	269
D.4	Brent Core data	276
E	Assemblage Groups and Descriptions of Assemblage-types	280
E.1	Introduction to Assemblage Descriptions	282
E.2	Assemblage Group 1: Abundant Fluorescent Transparent-Yellow SOM	285
E.2.1	Assemblage Group 1A: Abundant Transparent-Yellow, Fluorescent, Non-Fibrous SOM	286
E.2.2	Assemblage Group 1B: Very-Common to Abundant Transparent-Yellow, Fluorescent, Non-Fibrous & Very-Occasional to Occasional Brown-Equidimensional Fragments	287
E.2.3	Assemblage Group 1C: Very Common to Abundant Transparent Yellow, Fluorescent, Non-Fibrous SOM and greater than rare sporomorphs	289

E.3 Assemblage Group 2: Fluorescent SOM 290

E.3.1 Assemblage Group 2A: Transparent-Yellow, Fluorescent, Fibrous and Non-Fibrous SOM 291

E.3.2 Assemblage Group 2B: Transparent-Yellow Fluorescent, Non-Fibrous and Yellow-Brown, Fluorescent, Fibrous SOM 293

E.3.3 Assemblage Group 2C: Transparent-Yellow, Fluorescent, Non-Fibrous, Yellow-Brown, Fluorescent, Fibrous, SOM and Brown-Black Fluorescent, Fibrous SOM 297

E.3.4 Assemblage Group 2D: Brown-Black, Fluorescent, Fibrous SOM 298

E.4 Assemblage Group 3: Non-Fluorescent and Fluorescent SOM 299

E.4.1 Assemblage 3A: Transparent-Yellow, Fluorescent and Non-Fluorescent, Non-Fibrous SOM 299

E.4.2 Assemblage Group 3B: Black-Brown, Non-Fluorescent, Fibrous and Transparent-Yellow, Fluorescent, Non-Fibrous SOM 299

E.5 Assemblage Group 4: Non-Fluorescent SOM 300

E.5.1 Assemblage Group 4A: Transparent-Yellow, Non-Fluorescent, Non-Fibrous and Transparent-Yellow, Fluorescent, Non-Fibrous SOM 300

E.5.2 Assemblage Group 4B: Transparent Yellow, Non-Fluorescent, Non-Fibrous and Brown-Black, Non-Fluorescent SOM 302

E.5.3 Assemblage Group 4C: Brown-Black, Fluorescent, Fibrous SOM and Non-Fluorescent, Transparent-Yellow and Yellow-Brown Non-Fluorescent SOM . 303

E.5.4 Assemblage Group 4D: Brown-Black, Non-Fluorescent, Fibrous SOM . . . 304

E.6 Assemblage Group 5: Fluorescent SOM and Fragments 305

E.6.1 Assemblage Group 5A: Transparent-Yellow, Fluorescent, Fibrous SOM & Non-Vita Fragments 305

E.6.2 Assemblage Group 5B: Transparent-Yellow and Yellow-Brown, Fluorescent, Non-Fibrous SOM and Non-Vita Fragments 308

E.6.3 Assemblage Group 5C: Transparent-Yellow and Brown-Black Fluorescent, Non-Fibrous SOM and Non-Vita Fragments 309

E.6.4 Assemblage Group 5D: Transparent-Yellow, Yellow-Brown, Brown-Black
SOM and Non-Vita Fragments 310

E.6.5 Assemblage Group 5E: Brown-Black, Fluorescent, Fibrous SOM and Non-
Vita Fragments 310

E.7 Assemblage Group 6: Fragments, Fluorescent SOM and Sporomorphs 311

E.7.1 Assemblage Group 6A: Transparent-Yellow Fluorescent, Non-Fibrous SOM
and Equidimensional, Non-Fluorescent, Non-Cellular Fragments and Sporo-
morphs 311

E.7.2 Assemblage Group 6B: Transparent-Yellow Fluorescent, Non-Fibrous SOM,
Equidimensional and -Bladed, Non-Fluorescent, Non-Cellular Fragments and
Sporomorphs 312

E.8 Assemblage Group 7: Non-Fluorescent and Fluorescent SOM and Non-Vita Fragments313

E.8.1 Assemblage Group 7A: Transparent-Yellow, Non-Fluorescent, Non-Fibrous
SOM and Non-Vita Fragments 313

E.8.2 Assemblage Group 7B:1 Transparent-Yellow, Non-Fluorescent, Non-Fibrous,
Yellow-Brown, Fluorescent, Fibrous SOM and Black-Equidimensional, Non-
Fluorescent, Non-Cellular Fragments 313

E.9 Assemblage Group 8: Non-Fluorescent SOM and Fragments 314

E.9.1 Assemblage Group 8A: Transparent-Yellow, Non-Fluorescent, Non-Fibrous
SOM and Non-Vita Fragments 314

E.9.2 Assemblage Group 8B:1 Transparent-Yellow, Non-Fluorescent and Fluores-
cent, Non-Fibrous SOM, Brown-Black, Non-Fluorescent, Non-Fibrous SOM
and Non-Vita Fragments 315

E.9.3 Assemblage Group 8C: Brown-Black, Non-Fluorescent, Non-Fibrous SOM
and Non-Vita Fragments 316

E.10 Assemblage Group 9: Discrete Non-Vita Fragments and Fluorescent SOM 317

E.10.1 Assemblage Group 9A: Fragment Dominated and Fluorescent SOM 317

E.11 Assemblage Group 10: Discrete Non-Vita Fragments, Fluorescent and Non-Fluorescent
SOM 319

E.11.1	Assemblage Group 10A: Fragment Dominated and Fluorescent and Non-Fluorescent SOM	319
E.12	Assemblage Group 11: Discrete Non-Vita Fragments and Non-Fluorescent SOM . .	322
E.12.1	Assemblage Group 11: Fragment Dominated: Fluorescent and Non-Fluorescent SOM	322
E.13	Assemblage Group 12: Discrete Non-Vita Fragments and Sporomorphs	324
E.13.1	Assemblage group 12A: Discrete Non-Vita Fragments, Sporomorphs and Fluorescent SOM	324
E.13.2	Assemblage Group 12B: Discrete Non-Vita Fragments, Sporomorphs and Fluorescent and Non-Fluorescent SOM	326
E.14	Assemblage Group 13: Transparent-Yellow, Fluorescent SOM & $\geq$ Very-Occasional Dinoflagellate Cysts	326
E.14.1	Assemblage Group 13A: Transparent-Yellow, Fluorescent, Fibrous and Non-Fibrous SOM and Occasional dinoflagellates cysts	326
E.14.2	Assemblage Group 13B: Transparent-Yellow, Fluorescent, Non-Fibrous SOM and Occasional Dinoflagellates Cysts	327
E.15	Assemblage Group 14: Trans.-Yellow, Fluorescent, Non-Fibrous SOM, Yellow-Brown, Fluorescent, Fibrous SOM	329
E.16	Assemblage Group 15 : Trans.-Yellow, Yellow-Brown & Brown-Black, Fluorescent SOM, Fragments & Sporomorphs	330
E.17	Assemblage Group 16: Trans.-Yellow, Fluorescent and Non-Fluorescent SOM and $\geq$ V.O. dinoflagellate cysts	331
E.18	Assemblage Group 17: Transparent-Yellow, Fluorescent, Non-Fibrous SOM and Non-Vita Fragments	332
E.19	Assemblage Group 18: Transparent-Yellow, Fluorescent SOM, Fragments and Sporomorphs	335
E.20	Assemblage Group 19: Non-Vita Fragments and $\geq$ very-occasional dinoflagellate cysts	337

F	Sedimentary Logs	338
F.1	Lithological descriptions	338

Chapter 1

Introduction

This thesis forms part of on-going research by various workers at Oxford into the stratigraphic development of Mesozoic Basins, particularly in North-West Europe. A variety of approaches including, stratigraphical, sedimentological, palaeobotanical and geochemical studies have been used in this endeavour. The primary goal of the present work was to develop a more detailed understanding of the depositional and environmental history of the Middle Jurassic, UK. This was achieved by an integrative sedimentological, stratigraphical and palynofacies study of the Middle Jurassic, Cleveland Basin. The findings from this investigation were compared with a time-equivalent section from the Middle Jurassic, Brent Province of the Northern North Sea. In relation to the overall goal, the aim of this thesis is two-fold: firstly, to determine the usefulness of palynofacies for environmental reconstruction and, secondly, to infer the spatial and temporal environmental variations derived from the palynofacies and sedimentological studies within the British Middle Jurassic stratigraphic framework. The remainder of this chapter comprises an introduction to palynofacies, followed by a discussion of the depositional environments and stratigraphic framework of the Middle Jurassic, Cleveland Basin and the Brent Province of the Northern North Sea.

1.1 Palynofacies

Palynofacies analysis is a branch of palaeontology that is concerned with the qualitative and quantitative variations of total acid-insoluble microscopic organic matter. This material, which forms the bulk of most sedimentary organic matter, and includes palynomorphs and plant tissues, was almost entirely ignored until 1959 when Muller recognised that, unlike conventional palynology, it could be used to

characterise sedimentary depositional environments. Simplistically, organic debris acts in a similar manner to inorganic sedimentary grains: woody fragments act like sand and silt, whereas amorphous material acts more like clay particles. Hence, different sedimentary facies should contain distinctive assemblages of organic matter.

Prior to Muller's formative work, such investigations were almost entirely concerned with the study of palynomorphs for palaeobotanical and biostratigraphical purposes. In 1964, Combaz coined the term 'palynofacies' to describe studies of the organic content of sedimentary rock that yield information about environment of deposition and the producing biosphere elements. However, as noted by Traverse [1994], much of the application since the early 1960's has been geologically oriented, and palynofacies analysis has been primarily used to indicate information about the enclosing rock, especially its environment of deposition. Traverse termed this type of study 'palynolithofacies' reflecting that the assemblages are rarely used to extract biological information.

More specifically, the 'palynolithofacies' division is mainly employed in the hydrocarbon sector, in conjunction with palaeoecological and sedimentological information, where it is used to determine source potential and aid lithofacies interpretation, and to assist in determining the areal pattern of environments that provide a key to the palaeogeography of a basin. For instance, Fisher [1980] suggested that channel sands are dominantly inertinitic, and non-rooted coals are characterised by humic associations and a high vitrinite:inertinite ratio. He stated, however, that crevasse splays and point bars also have a high inertinitic content. He also observed that the organic residues from lagoonal and interdistributary shales are quite similar. Both yield relatively high vitrinite:inertinitic ratios, abundant pollen, spores, and autochthonous microplankton. He only distinguished the shales by different types of microplankton; he noted that *Botryococcus* was common in non-marine lagoons and acritachs, or more rarely tasmanitids, were almost ubiquitous in marine interdistributary bays. Moreover, a number of studies [e.g., Gastaldo, 1996] have demonstrated that different lithofacies may display the same 'kerogen' associations and, conversely, the same lithofacies may reveal different 'kerogen' associations. Hence, in reality, acid-insoluble assemblages of organic matter are not distinct groups, but instead comprise a great diversity of individual components whose associations form a natural continuum. This has led many workers to question the reliability of palynofacies as a tool for environmental reconstruction.

This lack of confidence arises from a combination of factors. One of the principal reasons is that the palynofacies technique is mainly employed in the industrial sector of geosciences where the opportunity for exhaustive investigations is limited and hence the advance of the technique may be hampered. Tyson [1995] noted that many of the earlier studies were qualitative and in some cases secondary to the main geological investigation, *e.g.*, the primary focus was sedimentological and the palynofacies analysis was a more minor component. Variations in preparation techniques, counting techniques, data sets (relative or absolute), existence of numerous classification schemes, and problems associated with analysing large data sets have all also acted to inhibit the advance of palynofacies analysis as a tool for environmental reconstruction.

The occurrence and composition of organic matter reflect the enormous number of variables that influence the terrestrial or aquatic environments in which it is generated, its transport to the depositional site and its alteration once deposited [Batten, 1996]. At present, the way in which palynofacies assemblages, in particular the palynodebris, changes, and the controls that govern the development of assemblages, especially in a proximal to distal gradient, are not well understood. Taphonomic processes impose a significant overprint and, hence, the degree to which acid-insoluble organic matter yields a reliable depositional, and potentially vegetational and climatic signal, has not been exhaustively explored. It has been suggested that the variations in assemblages are related to preservation, lithology and proximity to source; no distinction being made between the minor and major influences. This is a paradoxical situation, given that the 'palynolithofacies' technique relies on the belief that specific lithofacies contain distinctive assemblages and that these must be governed by factors associated with that environment.

The reliability of palynofacies may be improved if an appreciation of the taphonomic processes that impose a significant overprint on the primary vegetational and climatic signal can be obtained. Analysis of the taphonomic processes may be achieved by appraising post-mortem information loss, but this is a very difficult to quantify and it is more useful to concentrate on what has been preserved [Batten, 1996]. Thus, the key questions, in the present investigation, are; 1) what are the various different types of organic matter associations?, 2) what controls the development of different associations of organic matter, in particular the palynodebris?, and 3) what is the relationship of particular types of organic matter and assemblages of organic-matter, especially the palynodebris to specific environments of deposition? However, before these questions are considered, other problems must

be addressed, *i.e.*, the lack of standardisation between classification schemes and methods of analysis hampers comparison between studies.

1.2 Study Areas and Setting

The Middle Jurassic Cleveland Basin, the major study area for this work, provided a useful test case for evaluating the applicability of palynofacies to palaeoenvironmental studies. The Cleveland Basin, which contains a range of fluvio-deltaic environments that were influenced by relative changes in sea level, has been the focus of attention of many geologists including Williams, Seward and Harris. On the basis of their work, and that of others, the Cleveland Basin has been recognised as a classic area for Middle Jurassic floras. More recently it has been used as an analogue for the hydrocarbon-producing Brent Province, Viking Graben, North Sea, the second, more minor, study area in the present work.

The Lower-Middle Jurassic around Britain records a major change in basin-forming processes, with the evolution of two distinct tectonic provinces. In the Early Jurassic the Central North Sea was characterised by a period of regional uplift, with associated volcanism [Smith & Ritchie, 1993]. This uplift is now interpreted as a pre-rift thermal bulge pre-dating the Late Jurassic rifting which centred on the evolving Witch Ground, Central and Viking Graben Triple Junction, [Underhill & Partington, 1993], which lay approximately 30-35° north of the equator. There is now a general consensus amongst North Sea workers that this trilete system was formed by reactivation of a series of Early Permian, essentially north-south trending, extensional half grabens and the north-east—south-west Caledonide trends [Ziegler, 1982; Knott *et al.*, 1993].

During the Middle Jurassic, sediments were deposited during a major regressive deltaic pulse in the Cleveland Basin and Viking Graben, the location of which are illustrated in Figure 1.1 (A). The Cleveland Basin developed in the intra-rift zone, on the southern edge of the landmass. To the North, the Viking Graben formed between the Central North Sea Graben and the Moray Firth. Both areas were positioned on the edge of the low-lying landmass open to marine influences. The rocks reflect these conditions, comprising largely fluvatile and deltaic sediments with subordinate marine intercalations as illustrated in Figure 1.1 (B & C).

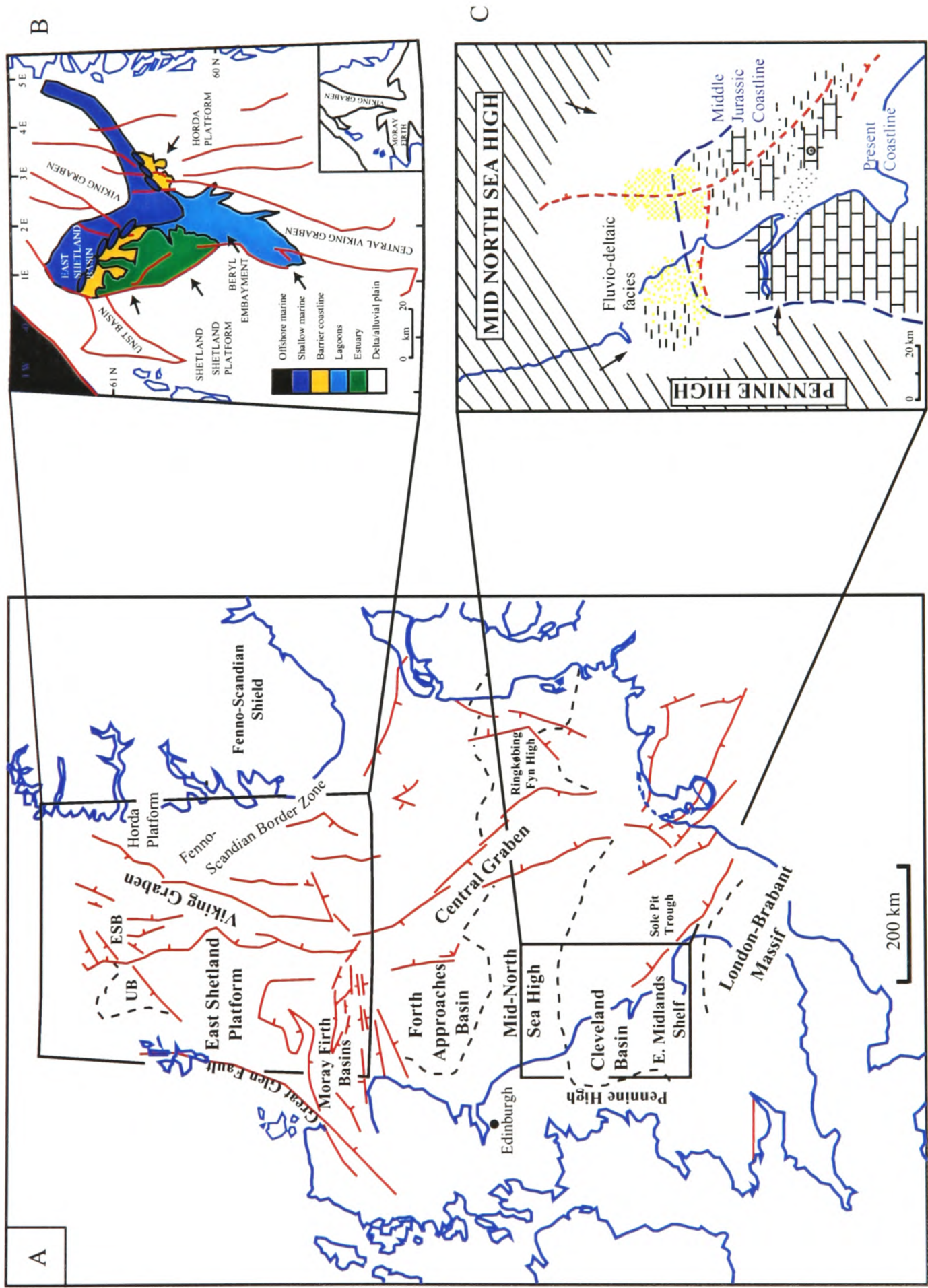


Figure 1.1: Location and palaeogeography of the Cleveland Basin and Brent Province. Figure A shows the location of the Cleveland Basin and the structural elements of the North Sea basins (ESB – East Shetland Basin; UB – Unst Basin) modified after [Brown, 1990]. Figure B displays the palaeogeographical model of the Brent Group postulated by Richards [1992] for the Aalenian to earliest Bajocian. Figure C shows the postulated palaeogeographical setting of the Cleveland Basin during the Middle Jurassic (early Bajocian) [after Bradshaw *et al.*, 1992].

There has been controversy in the literature concerning the climate of the Jurassic due mainly to a paucity of data. The conventional view has been that the Mesozoic climate was globally relatively homogeneous and was characterized by a degree of equability seldom seen elsewhere in geological history. This view was questioned by Barnard [1973] and Vakhrameev [1982] who plotted the distribution of selected taxa. Vakhrameev [1982] suggested that plants indicated overall warming through the Jurassic with a geographic shift in what he termed the Indo-European and Siberian floral provinces. Many workers have, however, criticised these studies [e.g., Krassilov, 1981] as being poorly constrained both stratigraphically and palaeogeographically.

Ziegler *et al.* [1996] have proposed that the changes in floral distribution were a result of plate motions through climatic zones. They partially concurred with the Vakhrameev [1982] proposal of warming in Asia during the Jurassic. They suggested that the floras in North America showed that the climate became seasonally wet over the same period. They postulated that a poleward shift of North America and drift of Asia towards the Equator about an axis in Europe would produce these variations. If this is true, it may be inferred that the latitudinal position of Britain during the Middle Jurassic did not change significantly. It is therefore unlikely that any temporal changes detected in the Cleveland Basin and Viking Graben are symptomatic of climate change resulting from plate motions. Hence, any temporal variations may be attributable to one or a combination of regional variations in the palaeogeography, palaeo-oceanography, and global climate change.

Currently, the sediments of the Cleveland Basin are thought to have been deposited within a warm-temperate biome during the Middle Jurassic Period [Ziegler *et al.*, 1993]. Recent palynological work by Boulter & Windle [1993] and stable-isotopic evidence of Hendry [1997] yield tentative indications that the late Bajocian and Bathonian may have included one or more periods of relative aridity in comparison to the early Bajocian and Aalenian. In addition, a possible climate event in the Middle Jurassic upper Ness Formation of the Brent Group has been recognized by Helland-Hansen *et al.* [1992], Bray *et al.* [1995] and Abbink [1998]. Both Helland-Hansen *et al.* [1992] and Bray *et al.* [1995] considered the peak of *Classopollis* pollen found in the early Bajocian across the Brent Group as a response to a temporary increase in palaeotemperature. Moreover, Helland-Hansen *et al.* [1992] used the acme of *Classopollis* pollen as a timeline and regarded it as an isochronous event. Abbink [1998] recognised four climatic cycles during the deposition of the Brent; each cycle comprising a colder and warmer interval. Abbink [1998] considered the *Classopollis* acme to correspond with his

third warm interval (climatic cycle C) based on its stratigraphic position. More recently, Morgans *et al.* [1999] suggested that the Bathonian climate was more seasonally pronounced than the Aalenian and Bajocian.

1.3 Cleveland Basin

1.3.1 Structural Framework of the Cleveland Basin

The Cleveland Basin was a major depocentre during the Jurassic. Clastic sediments poured off the newly uplifted 'dome' (thermal bulge) into the slowly subsidising basin that was bound to the north by the Mid-North Sea High and to the west by the Pennine High. To the east and south the basin had partial connections with both the north-west—south-east trending Sole Pit Trough, a marginal sub basin of the Southern North Sea, and the East Midlands shelf. The southern margin of the Cleveland Basin was formed by the Market Weighton High. This was a particularly stable feature over which sediment accumulation was more or less limited to times of highest sea level [Kent, 1980]. During the Tertiary Period [Hemingway & Riddler, 1982] the basin underwent inversion resulting in a broad uplift of the basin along a east-north-east—west-south-west trending plane, termed the Cleveland Axis, flanked to either side by minor domes and basins, for example Robin Hood's Bay Dome [Rawson & Wright, 1992]. Hemingway & Riddler [1982] deduced that, prior to the inversion, Middle Jurassic strata were buried to 2-2.5 km. At present, Jurassic rocks dominate the coastline from Loftus, in the north, to Filey, in the south, as the majority of the late Jurassic and Tertiary sediments have been stripped off [Hemingway & Riddler, 1982].

The basin is cut by a number of north-south trending faults, as illustrated in Figure 1.2, some of which were active during the Middle Jurassic causing variations in lithofacies and thickness. Offshore seismic-reflection studies have indicated that the larger faults are associated with a narrow, 5 km wide, north-south trending graben, the Peak Trough [Milsom & Rawson, 1989]. This is bound to the west by the Peak Fault and the east by the Cayton Bay Fault System [Milsom & Rawson, 1989]. Alexander [1986] suggested that these north-south trending faults controlled the flow of rivers from the hinterland in a north-south direction.

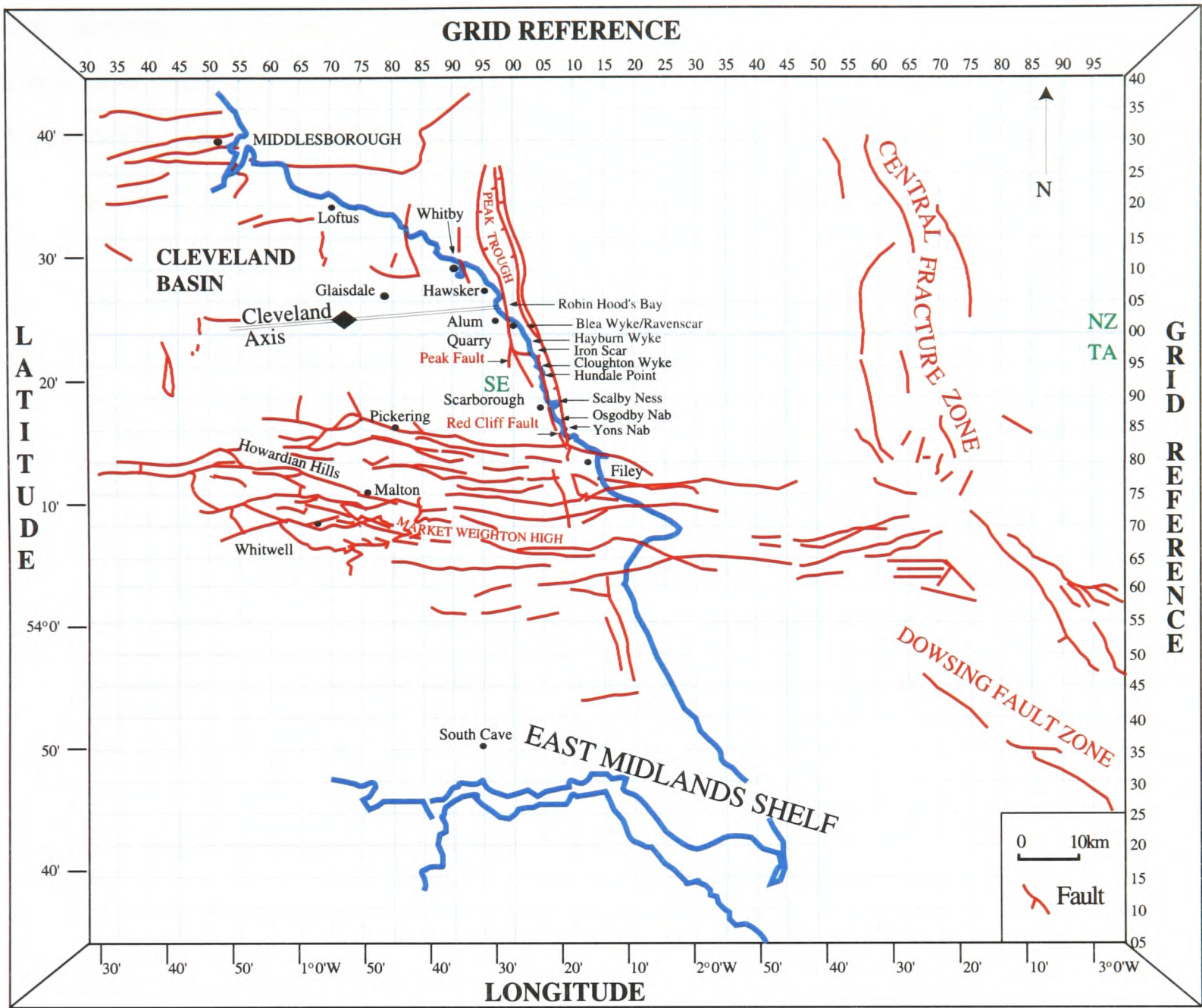


Figure 1.2: Location of study areas and structural map of the Cleveland Basin, digitised from Ordnance Survey, Landranger Maps 94 and 101 with data from Kirby & Swallow [1984] and Milsom & Rawson [1989].

1.3.2 Stratigraphy of the Cleveland Basin

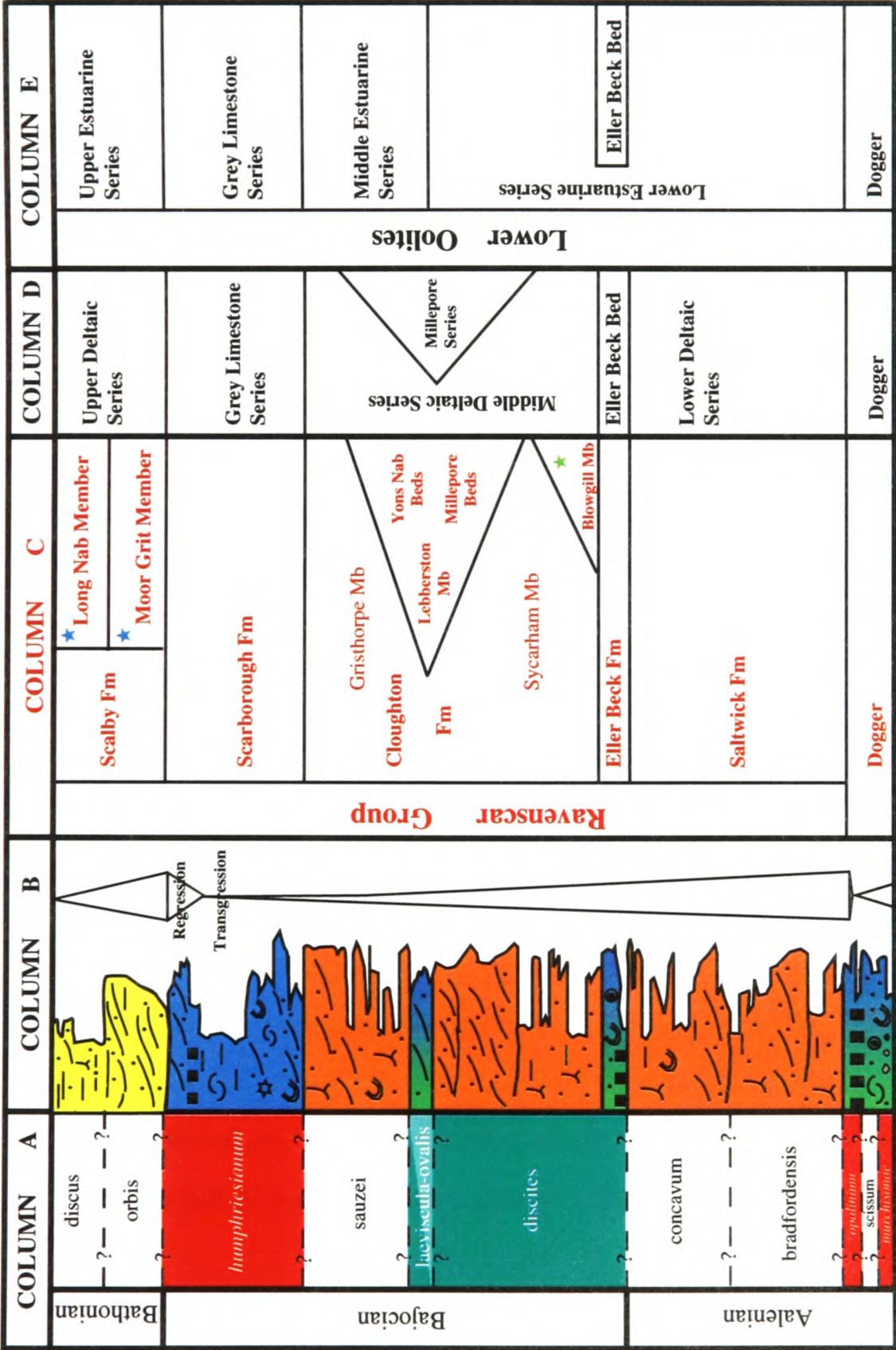
Although the basin has been extensively studied since the earliest days of geological investigations the nomenclature of the Middle Jurassic, predominantly fluvio-deltaic deposits, has always been complex because of the discontinuous and laterally variable nature of the strata. Fox-Strangways, who conducted a comprehensive survey in 1892 of the stratigraphy in the nineteenth century, originally named the group ‘Lower Oolites’ and parcelled the sequence into Lower, Middle and Upper Estuarine Series divided by the marine units as illustrated in Column E, Figure 1.3. On the basis of work by Kendall & Wroot [1924] and Black [1928, 1929, 1934b], Hemingway [1949] modified the lithostratigraphic scheme of Fox-Strangways to use the term ‘Deltaic’ instead of ‘Estuarine’. Although this lithostratigraphic scheme was criticised [e.g., Sylvester-Bradley, 1949] it remained in use

until Hemingway & Knox [1973] replaced it with the non-genetic ‘Ravenscar Group’ with formational subdivisions. The present study follows the essence of the scheme devised by Hemingway & Knox [1973], where the Aalenian to Bathonian sediments are divided into the basal Dogger Formation and overlying Ravenscar Group as illustrated in Column C, Figure 1.3. The Ravenscar Group, which achieves a thickness of 250 metres, is separated into the five formations: the predominantly non-marine Saltwick, Cloughton and Scalby Formations are partitioned by two regionally extensive marine units, the Eller Beck and the Scarborough Formations. The only minor modifications to the Hemingway & Knox [1973] scheme are: 1) the rejection of the Blowgill Member as a stratigraphically distinct unit from the Eller Beck Formation on the basis of work by Powell & Rathbone [1983], which is discussed on pages 11-12, and 2) the separation of the Scalby Formation into the basal Moor Grit Member and upper Long Nab Member following the work of Nami & Leeder [1978] which is discussed on pages 15-16. A synopsis of the corresponding biostratigraphy is shown in Figure 1.3 to provide the reader with a framework for the remainder of this section. A more detailed discussion is given in Section 1.5.

Dogger Formation (*opalinum-murchisonae* Zones)

This basal, condensed, heterolithic bioturbated shallow-marine unit, generally rests unconformably on folded marine upper Toarcian strata (uppermost *moorei* subzone at youngest; Cope *et al.* 1980a). Knox [1984] and Underhill & Partington [1993] related the development of this surface to domal upwarping and accompanying volcanism in the central North Sea area. To the east, the planar characteristic of the peneplain is attributed to marine erosion [Hemingway, 1974] whereas the strong relief to the west is attributed to the incision of river valleys [Black, 1934b]. Pebbles, commonly fossiliferous, are present in the lower part of the Dogger Formation at many localities. This widespread feature is believed to have resulted from extensive erosion of the Lias which preceded deposition of the Dogger Formation.

Slow deposition during the initial transgression is recognised near Whitby where the lower part of the Dogger Formation is represented by heavily bioturbated ironstone with phosphatic pebbles. This area has yielded ammonites of the *opalinum* Zone [Cope *et al.*, 1980b; Kent, 1980; Riding, 1984]. In the west, at Loftus, and in the hills west of Bilsdale in the deepest part of the palaeovalleys, ammonite faunas are from the younger *murchisonae* Zone [Black, 1934b].



★ Rejection of the Blowgill Member as a stratigraphically distinct unit [after Powell & Rathbone 1983]
★ Separation of the Scalby Formation into the basal Moor Grit Member and upper Long Nab Member [after Nami & Leeder 1978]

Figure 1.3: Changing lithostratigraphic schemes of the Yorkshire Middle Jurassic succession shown against Ammonite Zones and lithological description of Middle Jurassic, Cleveland Basin. Column A shows Stages and Ammonite Zones. Red shading indicates presence of age-defining ammonite fauna in the Cleveland Basin. Dark green indicates presence of age-defining ammonites in lateral equivalents to the south. Light green indicates that the biostratigraphical significance of the ammonites (collected from outside the Cleveland Basin) is questionable. White shading indicates that no age-defining ammonites have been retrieved from these sediments or their equivalents. Column B depicts the lithological description of IFP core RV18 (Basal Dogger to Top of Scarborough Formation) and IFP core LN16 (Scalby Formation) (Ross and Morgans, 1996, unpublished). Scale: 1 cm = 16 m. These lithological descriptions are used as a stratigraphic framework in this thesis. Detailed descriptions are contained in Appendix F. Columns C-E show the lithostratigraphic schemes of Hemingway & Knox [1973], Hemingway [1949] and Fox-Strangways [1892] respectively. The essence of the scheme proposed by Hemingway & Knox [1973] is employed in this thesis. Minor modifications used in the present work are shown in this figure and discussed in the text.

Over much of the basin, the Dogger Formation is a calcareous or berthierine (chamositic) sandstone one to two metres thick, but on the coast at Blea Wyke, in the Peak Fault Trough, it expands to 12 metres and contains two shell-rich beds. Immediately to the east, across the Peak Fault, the thickness of the Dogger Formation is reduced: the shell beds are usually replaced by conglomerate horizons and the berthierine (chamositic) development by sideritic sandstones. Further north, near Boulby Quarry, the Dogger Formation coarsens upwards from dark grey marine shales with ironstone nodules into siltstones and fine-grained sandstones.

Ravenscar Group (Aalenian-Bathonian)

Saltwick Formation (? bradfordensis-concavum Zone)

Prior to the deposition of the plant-bearing shale- and sandstone-rich Saltwick Formation, the Dogger Formation was removed in the western part of the basin. This hiatus suggests that there was a fall in sea level and/or uplift. The Saltwick Formation reaches a maximum thickness of 57 metres, and its base consists of composite channel sandstones, and overbank sediments which contain desiccation pavements, plant-rich horizons and rootlets. The upper units comprise locally stagnant floodbasin backswamps, laterally discontinuous sand bodies, which contain fewer rooted horizons and show less evidence for desiccation, localised concentrations of plant material, particular in the shales in this predominantly sandstone sequence. Hancock & Fisher [1981] found marine microplankton including acritarchs, leiospheres and the dinocysts *Nannoceratopsis gracilis* in the upper part of the formation around Hayburn Wyke. According to Livera & Leeder [1981] and Hancock & Fisher [1981] this vertical transition in lithofacies provides evidence of a temporal change from a well-drained-floodplain environment, at the base, towards more poorly drained, marshy or tidally influenced, distal-saline swampy conditions respectively. In the upper parts there is more soft-sediment deformation, and early siderite cement indicating suboxic conditions after deposition [Morgans, 1997]. Livera & Leeder [1981] stated that this overall lithofacies succession is consistent with a gradual abandonment of a delta lobe which Alexander [1986] related to a relative sea-level rise.

Eller Beck Formation (? discites Zone)

Marine waters subsequently flooded across the low-lying delta plain [Knox, 1973]. Following the initial incursion, marine waters transgressed from the south and south-east to form a basin-wide shallow sea that was no deeper than seven metres in which the thin (4.5-8 metres) regionally extensive

Eller Beck Formation was deposited [Knox, 1973; Hemingway, 1974; Powell & Rathbone, 1983]. The basal units consist of bioturbated, locally chamositic (berthierine) oolitic ironstones and siltstones which are overlain by a thicker unit of shale with subordinate limestone. This unit coarsens upwards as a result of progradation into bioturbated wave-generated sandstones that are rooted at the top [Knox, 1973]. This coarsening-up sequence shows only modest geographic variations, probably due to deposition in extremely shallow water that had little to no tidal activity [Knox, 1973] and limited tectonic activity. Leeder & Gowland [1985] indicated that there was no evidence of a lagoonal sequence, suggesting that the unit represents a linear beach shoreline and was not formed behind a barrier island lagoon.

Regional mapping of the Eller Beck by the Geological Survey [Fox-Strangways *et al.*, 1896] established that the ironstone-shale interval becomes progressively more calcareous southwards, until a true limestone occurs which is termed the Basal Hydraulic Limestone. This spatial distribution was initially supported by Hemingway [1949], but later rejected [Hemingway & Knox, 1973; Hemingway, 1974]. Instead, Hemingway & Knox [1973] established the stratigraphically younger, marine Blowgill Member at the base of the Cloughton Formation. They described the member as largely composed of shales with nodules and thin beds of concretionary limestone overlain by sandstone. According to Hemingway & Knox [1973], the Eller Beck Formation and the Blowgill member are separated by beds, of variable lithology, which are clearly non-marine in the north but change in lithofacies towards the south, where they contain small marine bivalves. They therefore considered the thin beds of concretionary limestone within the shales of the Blowgill Member, to be the lateral equivalents of the Basal Hydraulic Limestone of the south-western escarpment and Howardian Hills.

Powell & Rathbone [1983] reviewed the distribution of the sequence and suggested that the Basal Hydraulic Limestone is a local development within the Eller Beck Formation, and that the Blowgill Member is a lateral equivalent of the formation's mudstone and succeeding sandstone beds. On this evidence they rejected the term Blowgill Member. Hence, the Eller Beck Formation is considered, in concordance with Fox-Strangways's proposal, to be the lateral equivalent of the Basal Hydraulic Limestone which, on the basis of similar ostracod faunas [Bate, 1964, 1967], is believed to be the equivalent to the Lower Lincolnshire Limestone [Bate, 1965]. The present study accepts the Powell & Rathbone [1983] proposal.

Cloughton Formation (? discites-sauzei Zone)

In the south of the basin the Cloughton Formation is divided into three members: lower Sycharham Member and an upper Gristhorpe Member separated by a marine unit, which developed in the south, the Lebberston Member. In northern exposures the Lebberston Member loses its distinctive character.

Sycharham Member

This 50-metre-thick, non-marine, relatively poorly exposed sequence is more shale-rich than the preceding Saltwick Formation, but is also similar in that it contains laterally accreted and cross-bedded channel sandstones. Fragmented plant remains, mainly conifer leaves and spores, occur in the intercalations of mud and siltstone, reflecting renewed delta-plain progradation [Livera & Leeder, 1981]. The plant remains are clearly drifted, (*i.e.*, transported) more so than at any other level of the Ravenscar Group. Eschard [1989] interpreted this as a package of crevasse splays in a delta plain of palaeosols with an overall aggradational aspect.

Lebberston Member: Millepore and Yons Nab Beds

The northward expansion of a shallow sea from the south of the basin resulted in the deposition of the Lebberston Member. This heterolithic poorly fossiliferous, bioturbated unit is typical of beach deposits and lagoonal environments [Livera & Leeder, 1981]. In the east of the basin the lower part of the Lebberston Member is traditionally divided into a lower calcareous-rich Millepore Bed, and an upper siliclastic-rich unit, the Yons Nab Beds, which have been described as the transgressive and regressive phases of the Lebberston Member respectively. The lower unit shows contiguity across the Cleveland Basin; the Whitwell Oolite exposed in the Howardian Hills to the west is equivalent to the Millepore Beds on the coast, and all these are laterally equivalents of the Cave Oolite exposed to the south of the Market Weighton High, and thence to the Lincolnshire Limestone (Hibaldstow Beds of North Lincolnshire) to the south [Bate, 1964, 1967; Cope *et al.*, 1980b].

The Millepore Beds, from Yons Nab northwards, show a continuing facies change in the widely separated exposures from calcareous facies to more arenaceous, ferruginous facies. Overlying these beds is a 7.5 metre thick sequence of shales and sandstones with thin sideritic mudstones. At Yons Nab, these beds have yielded bivalves, ostracods, *Pentacrinus* ossicles, plant debris and 'soft jet'

[Hemingway, 1974]. Towards the north, these beds thin and are not recognised beyond Common Cliff (NZ 993 008) [Hemingway, 1974]. Rawson & Wright [1992] noted that, because it was very difficult to differentiate between the Yons Nab Beds and overlying Gristhorpe Member, the Yons Nab Beds may be better considered as the quasi-marine lower part of the Gristhorpe Member. In the west a flaggy oolitic limestone, termed the Upper Limestone, overlies the Whitwell Oolite, from which it is separated by a bed of unconsolidated sand [Bate, 1964].

Gristhorpe Member

Delta-top conditions resumed with the deposition of the Gristhorpe Member, which is up to 30 metres thick. A regime of marsh flats and shifting river channels resulted in the deposition of a succession of crevasse-splay sandstones, intercalated with plant-bearing mudstones and siltstones. Occasional marine influence is evident from the presence of *Diplocraterion* and *Teichichnus* burrows. One horizon containing burrows is a basin-wide phenomenon suggesting that it resulted from a minor rise in relative sea level rather than delta-lobe switching.

Scarborough Formation (? sauzei-humphriesianum Zone)

The third and largest marine incursion in the Ravenscar Group took place during all three subzones of the *humphriesianum* Zone [Parsons, 1977] and led to the deposition of the Scarborough Formation. This formation, which contains some evidence of cyclic deposition, shows marked variations in thickness reaching a maximum of 32 metres at Ravenscar [Fox-Strangways, 1892]. South of Hundale Point the thickness decreases rapidly; a comparable succession at Cayton Bay is represented by three metres of shale [Hemingway & Knox, 1973]. Correlation by lithology in the east is usually possible [Farrow, 1966]. The formation at Hundale Point and Ravenscar comprises calcareous sandstone, sandy limestone, siltstone and calcareous mudstone, containing sideritic ironstones and nodules in bedded horizons. This broad range of lithologies reflects a range of environments that include; brackish sandy embayment, nearshore sandy and muddy shelf, and offshore mud-dominated shelf [Gowland & Riding, 1991].

Following work done by Parsons [1977] and Gowland & Riding [1991] the marine Scarborough Formation was subdivided into seven members. The Helwarth Beck Member, the first member, was originally considered to be the upper segment of the Gristhorpe Member [Parsons, 1977]. Gowland & Riding [1991] recognized its marine affinities and placed the base of the Scarborough Formation at the

base of this unit. The precise level at which the maximum transgression occurred within the Scarborough Formation is unclear because of conflicting evidence. The overall trends indicate a level within the Ravenscar Shale Member [Hesselbo & Jenkyns, 1995]; however, indigenous marine species of dinoflagellates cysts reach their maximum abundance in the overlying Bogmire Gill Member (*blagdeni* subzone) according to Gowland & Riding [1991]. The latter inferred that this discrepancy could be due to minor dilution around the delta front by a contemporaneous fluvial system of the Scalby Formation, enabling marine microplankton to become concentrated. This implies that deposition between the Scarborough and Scalby Formation was continuous which in itself is a contentious subject as highlighted in Section 1.5.

Scalby Formation (? orbis-discus Zone)

Fox-Strangways originally referred to the upper non-marine interval as the Upper Estuarine Series. Black [1929] divided the sequence into a lower Current-Bedded Series (comprising the Moor Grit below and the Current Bedded Sandstone above) and an upper Level-Bedded Series. Hemingway & Knox [1973] revamped the litho-stratigraphy and instead established the non-genetic term 'Scalby Formation' for the uppermost non-marine interval in the Ravenscar Group. Nami & Leeder [1978] further sub-divided the Scalby Formation into the Moor Grit and Long Nab Members. The former is equivalent to the Moor Grit and the latter to the Current Bedded Sandstone and Level Bedded Series [*sensu* Black, 1929].

The basal Moor Grit Member, on the coast, consists of medium- to coarse-grained sand, commonly strongly cross-bedded, with well-developed troughs, channelling, tree casts and occasional dinosaur footprints [Hemingway, 1974; Nami & Leeder, 1978]. The sandstone is often multistorey in character; units range between 0.5-2.5 metres thick. Each unit shows a basal scoured surface with quartz pebbles, mudstone and ironstone intraclasts and carbonised plant debris [Nami & Leeder, 1978]. To the south of Scarborough, the Moor Grit Member is absent [Black, 1929]. Nami & Leeder [1978] found no evidence of deposition by lateral accretion and inferred that the channels were of low sinuosity, possibly braided.

Erosively overlying the Moor Grit Member is a complex sigmoidally bedded sandstone body termed the Current Bedded Sandstone by Black [1929]. This spectacular low-sinuosity complex,

which is well exposed on the foreshore of Burniston Wyke for 2 miles, features cross-cutting point-bars trending southwards [Nami, 1976; Rawson & Wright, 1992]. Nami [1976] suggested that this feature was a complex stream meander belt with point-bar lateral accretion deposits. The remainder of the overlying Long Nab Member is generally finer-grained, comprising mainly planar-bedded micaceous shales and silts, with thin laterally extensive sheets of fine sandstone [Rawson & Wright, 1992]. The occasionally rooted, micaceous shales contain drifted plant material; including leaves of *Ginkgoale*, and occasional pinnules of ferns, twigs and cone-scales of conifers. Well-preserved plants also occur in fine silts and sands associated with the channel fillings, although tree logs have only been preserved in the coarser sands.

The nature of the contact between the top of the formation and overlying marine Cornbrash Formation is similar to the lower junction, in that it has created substantial debate in the literature concerning its characteristics. Contrary to the view of Wright [1977] both Riding & Wright [1989] and Lott & Humphreys [1992] suggested that the contact was an irregular undulating erosive surface and not a gradual transition into the marine beds. Riding & Wright [1989] also inferred that the Scalby Formation sediments were compacted or lithified, slightly uplifted, eroded and burrowed, before the Cornbrash was deposited.

Fox-Strangways in 1892 considered that the Scalby Formation was deposited in an estuarine setting. Black [1929] in contrast suggested a deltaic environment, and Leeder & Nami [1979] proposed an alluvial environment. In the light of further evidence (presence of large concentrations of mud-grade sediments in the channels and *Ophiomorpha* burrows) Livera & Leeder [1981] questioned the Leeder & Nami [1979] proposal. Instead of the entirely non-marine setting proposed by Leeder & Nami [1979], Livera & Leeder [1981] favoured the interpretation that some tidal contribution to the channel and floodplain processes (tidal prism 'backup' and storm surges on the coastal plain respectively) occurred. This, therefore, refocused thoughts on the century-old proposal of Fox-Strangway [Livera & Leeder, 1981]. The discovery of marine palynomorphs in the shales of the Long Nab Member [Hancock & Fisher, 1981], which also contain rooted horizons appears to support this re-revision.

1.4 Brent Province

1.4.1 Lithostratigraphy and Depositional History

The Brent province is geographically co-incident with the northern Viking Graben and its flanking platforms which are also termed the East Shetland Basin (ESB) [Brown, 1990; Yielding *et al.*, 1992]. The Viking Graben is a north-south trending linear trough bounded to the west by the East Shetland Platform as illustrated in Figure 1.1. The axis of the Viking Graben shifts in the north to a north-north-east—south-south-west trend and diverges from the edge of the East Shetland Platform. Middle Jurassic strata in this intermediate area consist of a sand-dominated broadly deltaic sequence overlain by marine shales which continue into the Upper Jurassic [Brown, 1990].

Limited biostratigraphical control, the sparse nature of core material and the diversity of depositional environments encountered within the East Shetland Basin *e.g.*, coastal plain, shallow marine, slope and basin floor, have led to considerable controversy in the literature concerning virtually every aspect of the geology, including the precise age, nature and palaeogeographic setting of the Middle Jurassic Brent Group. It is only the lithostratigraphy which is relatively uncontroversial. Bowen [1975] recognised a five-fold subdivision of the sediments. This was modified and formalised by Deegan & Scull [1977] who gave the succession group status and divided the sequence into five formations which are from the base upwards: the Broom, Rannoch, Etive, Ness and Tarbert Formations, as illustrated in Figure 1.4. However, a proliferation of separate lithostratigraphic terminology for individual lithofacies in each sub-basin has hindered the overall understanding of the Middle Jurassic Brent Group.

Morton *et al.* [1992] mentioned that the sequence was originally interpreted to have been deposited during a period of active rifting and basin subsidence. Yielding *et al.* [1992] has since suggested that the major phase of rifting occurred earlier, with the Brent Group being deposited during a subsequent thermal subsidence phase. Debate also exists as to the precise palaeogeographical setting. The Brent Group has been described as a regressive-transgressive wedge [Brown & Thomson, 1987; Graue *et al.*, 1987]. The northwards prograding, regressive part of the succession is considered to be the Broom, Rannoch, Etive Formations and the lower part of the Ness Formation, with the succeeding upper part of the Ness Formation and Tarbert Formation deposited during retreat of the system, in response to a relative rise in sea level. Cannon *et al.* [1988] and Helland-Hansen *et al.* [1989], in contrast, consider

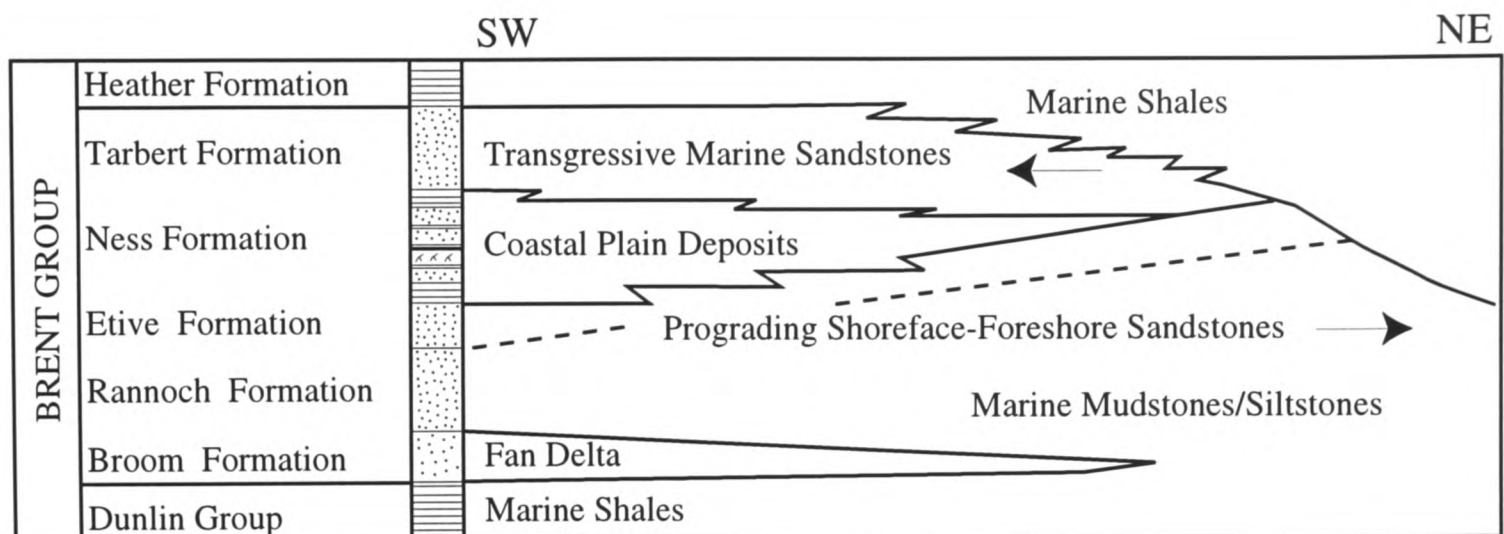


Figure 1.4: Lithostratigraphy of the Brent Group. This schematic diagram also illustrates the relative geometries of the individual formations across a south-west–north-east section of the Brent Group in the East Shetland Basin and their possible interpretation, modified [after Brown, 1990].

the sequence as a prograding delta, supported by the detailed work of Scott [1992] on the nearshore and coastal Rannoch-Etive successions. Alternatively, Richards [1992] invokes a significant estuarine component which is illustrated in Figure 1.1.

1.4.2 Broom Formation

The Broom Formation is found in the East Shetland Basin area to the west of the north Viking Graben axis. The unit varies in thickness from 48 metres along the west margin of the basin, and thins to the east and northeast, pinching out on to the basin margin faults [Richards, 1992]. Thickness variations also occur across intra-basinal faults, although the general sparseness of data limits the identification of intra-basinal lithofacies variations across these intra-basinal faults. The formation base is commonly defined by a sharp, coarse to very coarse-grained sandstone interpreted as a transgressive lag deposit above a ravinement surface [Brown & Thomson, 1987]. Overlying sandstones are locally fine-grained and highly bioturbated, with rare, planar, dipping laminae developed in places. Some of the fine-grained units are highly bioturbated and Livera [1989] indicated that they probably represent shelf ridges. The finer, laminated, sands locally pass up into micaceous, parallel laminated to hummocky cross-stratified, shoreface sandstones identical to those of the Rannoch Formation [Brown & Thomson, 1987].

The Broom Formation was probably derived by erosion of the Shetland Platform area [Richards, 1990] and has been variously interpreted as cliff-base beach [Eynon, 1981] and offshore sheet sands

[Budding & Inglin, 1981]. In contrast, Cannon *et al.* [1988] suggested that the eastward reduction in thickness of the succession, coupled with an eastward change from shallow- to deeper-water deposits, may indicate that the formation was deposited as some form of fan-delta system like the coeval, but geographically separate, Oseberg Formation on the opposing eastern side of the Viking Graben.

1.4.3 Rannoch and Etive Formations

These formations are generally considered together as one genetic package. According to Brown & Thomson [1987] and Graue *et al.* [1987] the two formations are conventionally regarded as representing the main coastal progradation of the Brent delta, reaching a maximum thickness of approximately 154 metres in the UK sector. These formations form a variable, but generally coarsening-upwards succession. Over most of the East Shetland Basin, the Rannoch Formation has a basal micaceous siltstone and coarsens up to very-fine sandstone [Richards, 1992]. The sandstone is interpreted as shallow marine, with Brown & Thomson [1987] and Graue *et al.* [1987] postulating storm-influenced deposition. The Etive Formation overlies the Rannoch Formation either as part of an upwards coarsening succession, or as a distinct fining-upwards unit above a sharp base. In some areas the Etive Formation is missing or limited in thickness [Richards, 1992]. Where the Etive Formation occurs as part of a coarsening upwards succession, it usually consists of massive, fine-grained, moderately well-sorted sands. Such packages have been interpreted as sub-environments of a barrier-bar complex [Budding & Inglin, 1981]. The sharp-based, fining-upwards variations of the Etive Formation usually comprise parallel laminated or planar cross-bedded sandstones, and have been interpreted as channel deposits [Brown & Thomson, 1987].

1.4.4 Ness Formation

This is the most lithologically variable unit of the Brent Group, consisting of interbedded sandstones, shales and coals, and occurs in successions up to about 180 metres thick in the East Shetland Basin. In a detailed study of the Ness Formation [Livera, 1989] characterized the formation as a complex of deltaic and coastal-plain sediments. The deltas are believed to have been relatively small, building into lagoons behind a protective barrier formed by the Rannoch-Etive Formations. Three units within the Ness Formation (north of 61 N) were given member status by Cannon *et al.* [1988]; a Lower Ness Unit, a Middle Ness Unit which is regarded as an isochronous stratigraphically correlatable horizon, and an Upper Ness Unit.

The Lower Ness Unit is about a 60 metres thick siltstone, with wavy bedding and a brackish to marine microflora. Minor coal seams with rootlets below, beach and washover sandstones with wave ripples, parallel lamination and flaser bedding are also present. Budding & Inglin [1981] interpreted this as a lagoonal or lower-delta plain deposit, although [Livera, 1989] observed localised development of upper delta-plain environments. The Middle Ness Unit, often informally termed the mid-Ness Shale, typically ranges from 4.5 to 8 metres thick [Richards, 1992] This unit consists predominantly of mid- to dark-grey, lenticular to wavy bedded siltstones with some sharp-based, possibly wave-rippled, cross-laminated sands. Budding & Inglin [1981] showed that this unit comprises a vertical succession similar to the underlying Lower Ness Unit and interpreted these facies as forming in a large, high-energy lagoon which developed when subsidence temporarily outpaced sediment supply. The Upper Ness Unit usually ranges in thickness from 10 to 15 metres, up to a maximum thickness of up to 41 metres. The top of the unit is often eroded and this may obscure the original thicknesses.

1.4.5 Tarbert Formation

The lowest part of the formation is commonly marked by a sharp-based, coarse- to very-coarse-grained sandstone interpreted as a transgressive lag deposit developed above a ravinement surface [Brown & Thomson, 1987]. The overlying arenaceous sandstones are fine-grained and highly bioturbated, in places, with rare planar, dipping laminae developed in places. Some of the fine-grained units are highly bioturbated, and Livera [1989] has suggested they are similar to the Upper Jurassic sandstones found in the central North Sea, and probably represent shelf-ridge deposits. The finer, laminated sands sometimes pass up to micaceous, parallel-laminated to hummocky cross-stratified, shoreface and shallow-marine sandstones identical to those in the Rannoch Formation [Brown & Thomson, 1987].

Ronning & Steel [1987], Graue *et al.* [1987] and Falt *et al.* [1989] demonstrated that the Tarbert Formation consists of stacked transgressive-regressive couplets during the overall, southward retreat of Brent delta shorelines. Graue *et al.* [1987] suggested that a decrease in sediment supply and an over-extension of the deltaic system may have been sufficient to promote the drowning of the Brent delta. This view was modified by Helland-Hansen *et al.* [1989] who postulated that Tarbert deposition was initiated by an increase in subsidence rates, and that the regressive pulses evident in the succession were promoted, at least in part, by eustatic sea-level falls. The Tarbert Formation is commonly thin

or absent near the crests of tilted fault-blocks in the East Shetland Basin where the upper parts of the Brent Group may have been removed by erosion.

1.5 Biostratigraphic Framework

The precise age of the sediments in both basins is debatable because of poor biostratigraphical evidence. The section in the Cleveland Basin is dated principally by ammonites and the North Sea zonations by a number of other biostratigraphical indices: calcareous nanofossils, foraminifera, ostracods, miospores and dinoflagellate cysts. The stratigraphic framework of the Brent Group is presented in Chapter 4. On the basis of work by Callomon & Chandler [1990, 1994] on the Jurassic Dorest Section Morgans [1997] re-evaluated the conventional tables provided by [Cope *et al.*, 1980a,b] and presented a slightly different biostratigraphic scheme for the Lower-Middle Jurassic Yorkshire area. Morgans's scheme is used in the present study and is illustrated in Figure 1.5.

The main modification made by Morgans was the use of ammonite zonal scheme proposed by Callomon & Chandler for the Lower Bajocian and Aalenian in 1990 and 1994 respectively. The differences between Cope *et al.*'s and Callomon & Chandler's ammonite zonal schemes are illustrated in Figure 1.6. Other alterations included: 1) re-assignment of the Eller Beck Formation to the *discites* Zone instead of the *concaum* Zone; 2) a suggestion that the Millepore Beds (Lebberston Member) is of uppermost *discites* to lowermost *laeviscula* in age, and 3) an assumption of a major hiatus between the Scarborough and Scalby Formation [*sensu* Leeder & Nami, 1979; Hesselbo & Jenkyns, 1995], in contrast to the traditional view of continuous deposition through the Upper Bajocian, entire Bathonian and a small part of the Callovian.

Figure 1.5: Biostratigraphic Framework for Toarcian-Callovian, Cleveland Basin modified [after Morgans, 1997]. Column A depicts absolute ages [after Underhill & Partington, 1993]; Column B shows Stages and Formations; Ammonite Zones were compiled from [Cope *et al.*, 1980a,b; Callomon & Chandler, 1990, 1994; Morgans, 1997]. Red shading indicates presence of age-defining ammonite fauna in the Cleveland Basin. Dark green indicates presence of age-defining ammonites in lateral equivalents to the south. Light green indicates that the biostratigraphical significance of the ammonites (collected from outside the Cleveland Basin) is questionable. White shading indicates that no age-defining ammonites have been retrieved from these sediments or their equivalents; Columns C-G were compiled from Morgans [1997]. Column C shows the Miospore Zonation [after Koppelhus, 1991; Koppelhus & Nielsen, 1994]; Column D shows the Dinoflagellate Cyst Zonation based on Woollam & Riding [1983] and amended using Riding & Thomas [1992]; Column E contains the Calcareous Nannofossil Zones from Hamilton [1982]; Column F shows the Foraminiferal Zones for the Bathonian from Morris [1989], other foraminiferal zones are from Norling [1972] and Column G shows the Ostracod Zonation for Yorkshire based on Bate [1967].

A	B				Ammonite Zones		Subzones		C	D	E	F	G										
157		CALL-OVIAN			macrocephalus		kamptus ----- macrocephalus			C.ornatum- C.continuum Zone													
					BATHONIAN	Scalby Formation	Clydoniceras discus	C.(C.) discus ----- C. (C.) Hollandi		Ctenidodinium combazii- Ctenidodinium sellwoodii Zone	b			S.bigoti	Soford- iana & S.phaedra								
							Oxycerites orbis																
							Procerites hodsoni																
							Morrisiceras morrisi																
							Tulites subcontractus																
							Procerites progracilis																
							Aspinctinctites tenuiplicatus																
							Zigzagiceras zigzag	Oppelia (Oxycerites) yeovilensis M. (Morphoceras) macrescens P. (Parkinsonia) convergens															
							165										Upper	Parkinsonia parkinsoni	P.bomfordi ----- Strigoceras truellei ----- P.acris	Callialasporites-Perinopollenites Zone		Acanthaulax crispa Zone	S.speciosum
Strenoceras (Garantiana) garantiana	St. (Garantiana) tetragona ----- St.(Pseudogarantiana) dichtoma																						
Strenoceras subfurcatum	St. (G.) baculata Caumontisphinctes polygyralis Teloceras banksi																						
Scarborough Formation	Stephanoceras humphriesianum	T. blagdeni S. humphriesianum ----- Dorsetensia cycloides																					
	Cloughton Formation	Emileia sauzei																					
		Witchellia laeviscula	W. laeviscula ----- W. trigonalis																				
168				Lower	Sommia ovalis				Nannoceratopsis gracilis Superzone		Nannoceratopsis gracilis Zone	E.keptalrepti	Epistomina parastelligera & Reinholdella dreheri	Glyptocythere scitula ----- G.polina ----- Cytheropteria plana ----- ? ----- C.comica & C.gravis									
	Hyperlioceras discites																						
	Saltwick Formation				Graphoceras concavum	G. forosum ----- G. concavum																	
					Brasilia bradfordensis	B.gigantea ----- B. bradfordensis																	
	Dogger Formation				Ludwigia murchisonae	L.murchisonae ----- L.obtusiformis ----- L.haugi																	
					Tmetoceras scissum	T.comptum ----- T.lineatum																	
					Leioceras opalinum	L.opalinum																	
	171							Blea Wyke Sandstone							Yellow Beds	Dumortieria levesquei	Pleydellia aalenis ----- D. moorei ----- D. levesquei ----- Phlyseogrammoceras dispansum	Spheripollenites-Leptolepidites Zone		Mancodinium semitubulatum Zone		E.britannica	Citharina clathrata
															Grey Beds								
								Whitby Mudstone							Grammoceras thouarsense	Pseudogrammoceras fallaciosum ----- G. striatulum							
Haugia variabilis																							
Hildoceras bifrons		Catacoeloceras crassum ----- Peronoceras fibulatum ----- Dactylioceras commune																					
Harpoceras falciferum		H. falciferum ----- H. exaratum																					
Dactylioceras tenuicostatum		D.semicelatum ----- D.tenuicostatum ----- D.clevelandicum ----- Protoqrammoceras paltum																					
181																	no zonation defined						

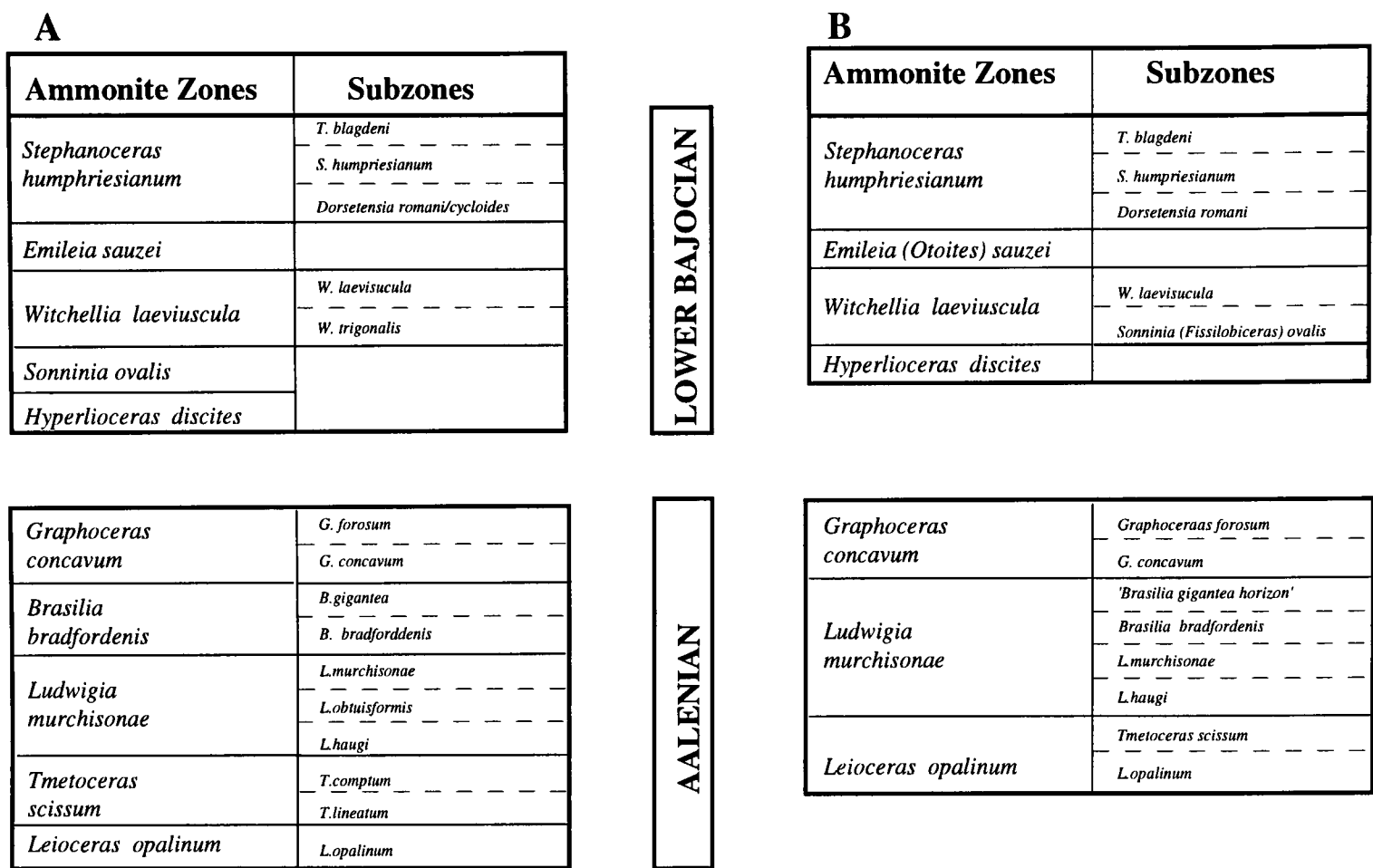


Figure 1.6: Differences between the ammonite zonal schemes proposed by Callomon & Chandler [1990, 1994] and Cope *et al.* [1980a] for the Aalenian and Bajocian. Column A is compiled from Callomon & Chandler [1990, 1994] and column B is after Cope *et al.* [1980a]. In column A *Tmetoceras scissum*, *Brasilia bradfordenis* and *Sonninia ovalis* are given zonal status. Cope’s scheme essential follows the suggestion of Contini *et al.* [1971] for the Aalenian, the Lower and Upper Bajocian follows Parsons [1974, 1977].

The age of the Ravenscar Group, Cleveland Basin is constrained by ammonites found in the Dogger Formation of the Aalenian *opalinum* to *murchisonae* Zones and the overlying Callovian Cornbrash Limestone Formation of the *macrocephalus* Zone [Cope *et al.*, 1980b]. Ages for the constituent units of the group rely primarily on ammonite finds in the marine units or their lateral equivalents. The non-marine units contain little biostratigraphic information and as a consequence are best constrained by the bounding marine units. Hence, the biostratigraphy for the marine units is presented prior to the biostratigraphy for the non-marine units.

1.5.1 Marine units

Ammonites belonging to the Aalenian *opalinum* Zone have been found from the middle of the Dogger Formation, within the Peak Fault Trough at Ravenscar, with ammonites of the *murchisonae* Zone [Cope *et al.*, 1980b] or, probably, *haugi* Subzone having been found in more western areas [Kent, 1980; Parsons, 1980]. Although no ammonites have been retrieved from the intervening *scissum* Zone this does not preclude deposition occurring during this time. This may suggest that the con-

densified heterolithic Dogger Formation spans a considerable time period.

As mentioned earlier, Bate [1965, 1967] and Powell & Rathbone [1983] infer that the marine transgression that led to the deposition of the Eller Beck Formation, the Basal Hydraulic Limestone and the ammonite-rich Lower Lincolnshire Limestone was the same [Bate, 1964, 1967; Ashton, 1980; Parsons, 1980]. Therefore, by inference, Morgans [1997] assigned the Eller Beck Formation to the *discites* Zone.

An age for the transgression of *discites* Zone is based upon the integration of ages proven by both ammonites and ostracods. The maximum and minimum ages proven by ammonites from the Dogger Formation and Silver Beds of the Lower Lincolnshire Limestone only confine the Eller Beck Formation to between upper-*murchisonae* and *discites*-Zone age. According to Kent [1966], who reviewed the correlation of the Lincolnshire Limestone, the Eller Beck Formation and the Basal Hydraulic Limestone are laterally equivalent to the sediments underlying the Raventhorpe Beds/Blue Beds as illustrated in Figure 1.7. Kent & Baker [1938] and Parsons [1980] indicated that the oldest unit of the Lower Lincolnshire Limestone which yields ammonites (*discites*-Zone age), are the Silver Beds or their equivalents, which overlie the Blue Beds. No ammonites have been retrieved from the sediments between the Dogger Formation, its equivalents and the Raventhorpe Beds/Blue Beds of the Lower Lincolnshire Limestone. Thus, ammonite faunas provide a very broad age for the Eller Beck Formation. However, Bate [1967] believed, on the basis of ostracod faunas, that the Eller Beck Formation is of early Bajocian age. Thus, the age of the Eller Beck Formation is confined to the *discites* Zone.

The next marine unit, the Lebberton Member, is divided into the lower Millepore Beds and upper Yons Nab Beds in the east of the basin. To the west, near the Howardian Hills, the lateral equivalents are termed the Whitwell Oolite and the Upper Limestone respectively, as illustrated in Figure 1.7. The Lebberton Member has long been correlated with the Cave Oolite, which is confined to an area south of the Market Weighton High, [Hemingway, 1974], despite their lack of ammonites. This correlation is based upon the presence of similar macrofaunal assemblages and sedimentological features in the basal part of the Lebberton Member, as a whole, and units to the south. Kent [1955] commented on the record of the brachiopod *Acanthothiris broughensis* Muir-Wood at the base of the Cave Oolite, and the occurrence of *Acanthothiris crossi* s.l. in the Whitwell, Cave and Hibaldstow Beds (of the

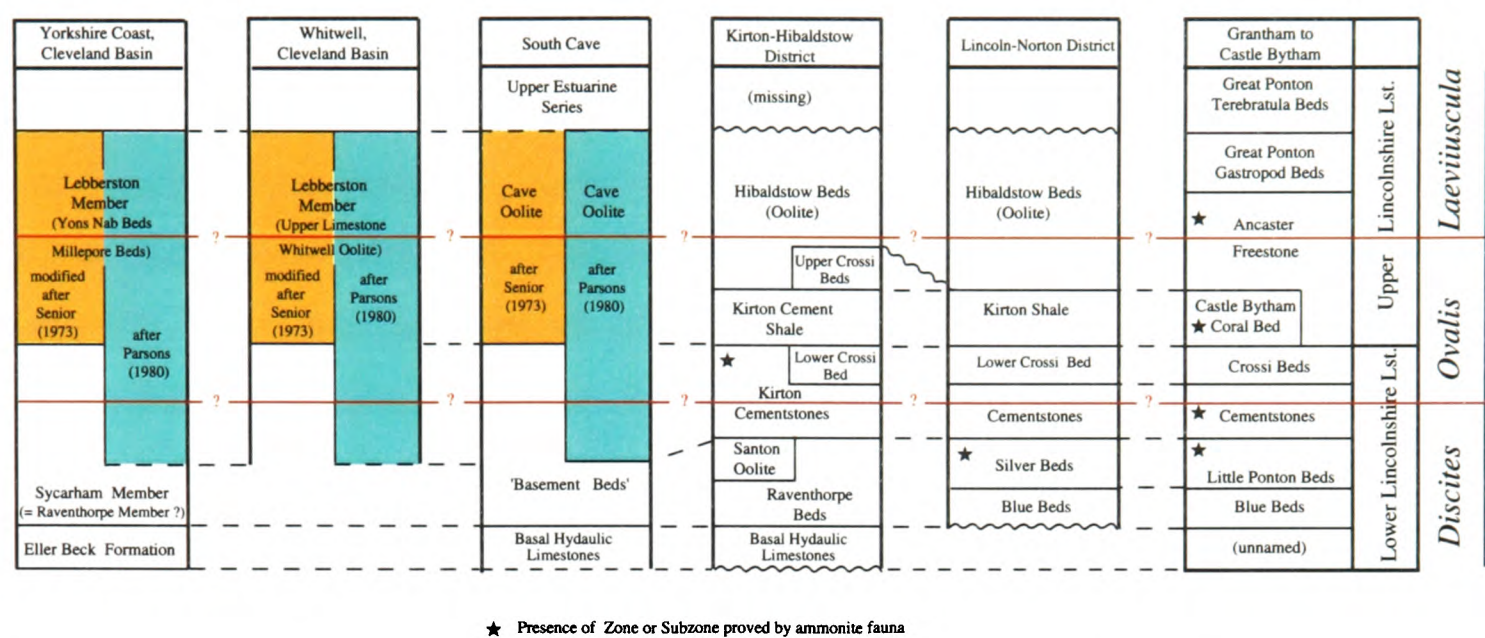


Figure 1.7: Correlation of the Eller Beck Formation to Leberston Member with their equivalents to the south compiled from [Kent & Baker, 1938; Kent, 1955, 1966; Bate, 1967; Senior & Earland-Bennett, 1973; Parsons, 1974, 1980; Ashton, 1975, 1980; Callomon & Chandler, 1990]. No scale is implied.

Upper Linconshire Limestone) towards the south and the Buckmani Grit of the Cotswolds. These units have previously been dated as *discites*-Zone age [Arkell, 1933; Bate, 1967; Senior & Earland-Bennett, 1973]. However, Parsons [1974] disputed the *discites* zonal assignment of the sonniniid ammonite, retrieved from immediately above the *crossi*-beds at Castle Bytham [Kent, 1966; Senior & Earland-Bennett, 1973]. In contrast, Parsons [1974] suggested that this sonniniid ammonite was more characteristic of the *ovalis* Subzone (*laeviuscula*) Zone. In concordance with the revamped scheme of Callomon & Chandler [1990] this now corresponds to *ovalis* Zone, as illustrated in Figure 1.7.

Assignment of a maximum age to the Leberston Member is difficult to define because of the uncertainty associated with correlation of the base of the Leberston Member with its equivalents to the south. Senior & Earland-Bennett [1973] correlate the base of the Cave Oolite with the base of the Ancaster Freestone, whereas Parsons [1980] correlates the base of the Cave Oolite with the basal part of the Kirtton Cementstones of the Lower Lincolnshire Limestone as illustrated in Figure 1.7. Using Senior's correlation scheme, the oldest age assignable to the Leberston Member would be *ovalis* Zone compared with uppermost *discites* by Parsons [1980]. A maximum age of uppermost *discites* and a minimum age of uppermost *laeviuscula* Zone are used in this study after Kent [1966] and Parsons [1980]. Kent [1966] recorded another ammonite from approximately 5 m above the *crossi*-beds which Parsons [1980] assigned to the *laeviuscula* Zone and subzone.

Ammonite evidence from the Scarborough Formation [Fox-Strangways *et al.*, 1896; Buckman, 1915; Hemingway, 1951; Parsons, 1977] show that all three subzones of the mid-Bajocian *Stephanoceras humphriesianum* (*cycloides*, *humphriesianum*, *blagdeni* Subzones) are represented above the Hundale Sandstone Member in the Spindle Thorn Limestone to White Nab Ironstone interval [Parsons, 1977]. Hence, the lower members of the Scarborough Formation are possibly referable to the *cycloides* subzone or upper *sauzei* Zone. Parsons [1980] placed the Hundale Shale Member and the majority of the Hundale Sandstone Member, in the *sauzei* zone (the Helwarth Beck Member was not included in the Cloughton Formation at this time). Arkell [1933] inferred that the ‘initial’ deposition of the Scarborough Formation occurred during the *sauzei* Zone as he retrieved *Belemnites ellipiticus* from the formation and these are commonly found within the *sauzei* Zone in the Cotswolds.

1.5.2 Non-marine units

Despite some evidence for subaerial exposure at the top of the Dogger Formation, Morgans [1997] tentatively suggested that the base of the Saltwick Formation probably corresponds to the *bradfordensis* Zone, (*i.e.*, no stratigraphic gap was inferred). Hence, the *discites*-Zone age given to the Eller Beck Formation constrains the age of the non-marine Saltwick Formation to the Aalenian *bradfordensis* to *concauum* Zones.

Maximum and minimum ages for the top of the Eller Beck Formation and the base of the Millepore Bed imply that the Sycharham Member represents a mid- to uppermost *discites* age. Assuming equal duration for ammonite zones, this appears to represent a very fast rate of deposition [Morgans, 1997]. If this model is correct, it is probable that the rate of subsidence was greater during the deposition of the Sycharham Member than the Eller Beck Formation to provide sufficient accommodation space. Ashton [1975] correlated the regressive Sycharham Member with the Raventhorpe Member: a clastic sequence within the marine Lincolnshire Limestone as illustrated in Figure 1.7. Younger Kirton Cementstones, in Lincolnshire have yielded ammonites of *discites* Zone [Parsons, 1980], thus providing an upper age limit for the Raventhorpe Member, and by implication the Sycharham Member.

Bradshaw & Bate [1982] have shown that attenuated lateral equivalents of the Gristhorpe Member and overlying Scarborough Member occur in South Humberside and Lincolnshire. Minimum and maximum ages for the Lebberton Member and Scarborough Formation constrain the age of the Gristhorpe Member to between uppermost *laeviscula* and uppermost *sauzei* Zone.

The age of the Scalby Formation has created considerable discussion over the years centering around the nature of the bottom and top of the Scalby Formation, and duration of possible hiatuses. A synopsis of the range of the published ages of the Scalby Formation is presented in Figure 1.8. The traditional view held by Arkell [1933], Parsons [1977, 1980] and Torrens [1980] is that the Scalby Formation records continuous deltaic deposition through the Upper Bajocian, entire Bathonian and a small part of the Callovian as illustrated in Column 1, Figure 1.8.

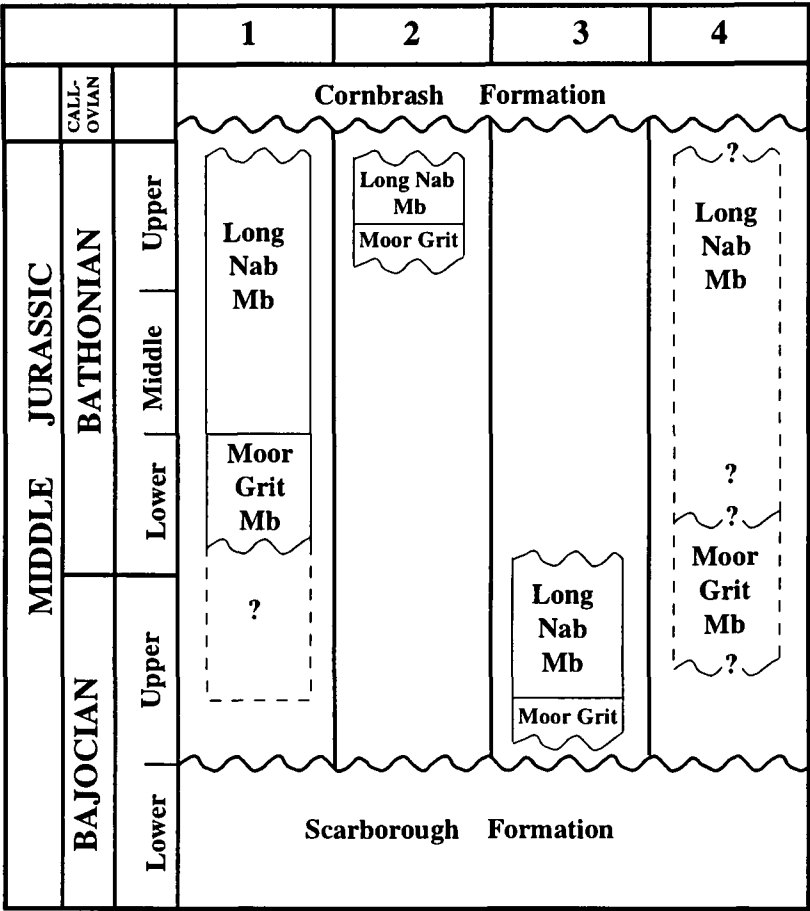


Figure 1.8: Range of different ages postulated for the Scalby Formation after Riding & Wright [1989]. 1. Traditional view *i.e.*, Arkell [1933]; Hemingway [1974]; Parsons [1977, 1980] and Torrens [1980]. 2. Leeder & Nami [1979] — alluvial hypothesis. 3. Hancock & Fisher [1981]; Woollam & Riding [1983] and Fisher & Hancock [1985]. 4. Riding & Wright [1989].

A number of workers including; Leeder & Nami [1979]; Hancock & Fisher [1981]; Fisher & Hancock [1985], and Hesselbo & Jenkyns [1995] have instead implied periods of non-deposition and/or erosion during Late Bajocian to Late Bathonian times. Leeder & Nami [1979] proposed that there was a significant erosive period at the base of the Scalby Formation as illustrated in Column 2, Figure 1.8. They argued for an episode of relatively high depositional rate with the whole of the Scalby Formation having been the result of less than one million years of deposition towards the close of the Bathonian. This proposal was based upon three interpretations: 1) the Scalby Formation is a wholly alluvial deposit; 2) the boundary between the overlying Cornbrash and Scalby Formation is more or less gradual and there is no evidence (*e.g.*, phosphatised faunas) of a prolonged pre-Cornbrash

hiatus, and 3) the average rate of deposition of uninterpreted sedimentation is too low (assuming that the zonal times have a normal distribution frequency).

Torrens [1980] regarded the Leeder & Nami [1979] proposal as plausible but followed the traditional view in the absence of any conclusive palaeontological evidence. Hesselbo & Jenkyns [1995] concurred with the existence of a major hiatus. They inferred that the Scalby Formation was deposited during the final two ammonite zones of the Bathonian and stated that this was compatible with their observations of large-scale sedimentary cycles in the Middle Jurassic in southern England.

Fisher & Hancock's (1985) examination of palynomorphs from the Long Nab Member enabled them to constrain the age of this unit to the Upper Bajocian (*garantiana-parkinsoni* Zones) as displayed in Column 3, Figure 1.8. Riding & Wright [1989] re-examined the palynomorph assemblages collected by Fisher & Hancock [1985] and disputed their interpretations on the absence of *Nannoceratopsis gracilis*. In contrast, they considered that the occurrence of ?*Ctenidodinium sellwoodi* in the basal part of the Long Nab Member indicated an uppermost Bajocian to Bathonian age, and the presence of *C. combazii* and *Adnatosphaeridium caulleryi* in the uppermost beds of the Long Nab Member signified a Bathonian age. On the basis of their implied age for the Long Nab Member and the age of the Scarborough Formation they suggested that the Moor Grit Member was no older than late Bajocian (and possibly as young as Bathonian) in age. They envisaged only a minor stratigraphical break between the Scarborough Formation and Moor Grit Member, and suggested that possible hiatuses occurred between Moor Grit Member and Long Nab junction, and above the meander belt. They proposed that the remainder of the Long Nab Member represents a period of almost continuous deposition followed by the stratigraphical break that separates it from the overlying Cornbrash Formation as illustrated in Column 4, Figure 1.8. Their data, however, does not rule out the interpretation of the major basal hiatus of Leeder & Nami [1979].

It is apparent from the above discussion that the nature of the bottom and top surfaces, duration of possible hiatuses and precise age of the Scalby Formation are still questionable. Until new unequivocal evidence is published the uncertainty concerning the age (and to a lesser extent, the depositional setting) of the Scalby Formation will continue.

In this thesis a major hiatus is assumed following Leeder & Nami [1979], Hesselbo & Jenkyns [1995] and Morgans [1997]. Evidence to support this theory can be observed in sedimentary sequences further afield, including the prolonged hiatus between, the weathered, decalcified and eroded top of the Cave Oolite (Upper Lincolnshire Limestone: minimum age *laeviscula* Zone) and the ‘White Sands’ (Great Oolite Limestone: maximum age *zigzag* Zone, lowermost Bathonian) [Brasier & Brasier, 1978; Parsons, 1980; Fenton *et al.*, 1994].

1.6 Specific Objectives

The goal of this thesis is to elucidate the temporal and spatial environmental variations in the Middle Jurassic of the UK through the integration of palynofacies and sedimentological analysis. As the reliability of palynofacies as a tool for environmental reconstruction has been questioned, the first part of this thesis is concerned with the development of an objective methodology, documentation of palynofacies assemblage groups and evaluation of the reliability of palynofacies as a palaeoenvironmental indicator. The second part discusses the palaeoenvironmental temporal and spatial variations which have been determined from the integration of the data from the palynofacies and sedimentological investigations.

These objectives have been achieved by the adopting the following procedures and structure:

- Samples were collected during lithological logging from a wide range of lithofacies to enable investigation of the intra- and inter-lithofacies variations in the palynofacies assemblage groups.
- An objective classification scheme for particulate organic matter, created by Lewis in 1995, was tailored to meet the needs of this study, and potentially the requirements of other palynofacies investigations. To understand the motivations for these alterations, a critique of previous classification schemes and a description of the palaeoenvironmental significance of the different components of particulate organic matter is presented in the first part of Chapter 2. This is followed by a discussion of the modifications proposed and a review of the different methods of data collection and analysis.
- Chapter 3 determines the underlying controls which influenced the nature of organic matter within the samples investigated in the present study. The classification and recognition of

different assemblage groups forms the main preliminary step towards a palaeoenvironmental study based on palynofacies analysis. In this study, both conventional methods and contemporary techniques (multivariate statistical analysis) were used to quantitatively document and evaluate the palynofacies assemblage groups and their relationship to specific environmental variables.

- Temporal and spatial palaeoenvironmental variations were determined from an integration of the palynofacies assemblage groups data, and sedimentological and stratigraphic information. The findings are discussed in Chapter 4.
- The conclusions drawn from the work are summarised in Chapter 5.

Chapter 2

Materials and Methods

2.1 Introduction

Variability in collection methods, preparation and counting techniques, existence of numerous classification schemes and lack of standard terminology have severely hampered investigators ability to make accurate comparisons and palaeoecological interpretations, and as a result restricted the advance of the palynofacies technique. Therefore, in the present study, a rigorous collection technique and a standard processing method were adopted. These are described in section 2.2. Moreover, a detailed review of the classification of particulate organic matter with special reference to the Amsterdam Classification Scheme and the scheme designed by Lewis [1995] was undertaken. On the basis of this critique, designated procedures for classifying organic matter are proposed. These procedures were used to modified the classification scheme proposed by Lewis [1995] and hence provide a more robust system to classify organic-matter, especially palynodebris. The findings from the literature review, appraisal of Lewis's scheme, development of the procedures and modifications applied to Lewis's scheme are described in sections 2.3 to 2.6. This is followed by a description of the organic matter categories used in the present study coupled with a summary of the palaeoenvironmental significance of the different types of organic matter. As the method of data extraction and analysis are fundamental to the outcome and reliability of the results, the techniques used in this study are evaluated in Section 2.7 and Section 2.8.

2.2 Collection and Processing

2.2.1 Sampling Strategy

For this study, an effort was made not only to address the issues associated with sampling procedures, mentioned in subsection 1.1, but also to maintain a degree of impartiality. A sampling scheme was devised following reconnaissance of the sequence, examination of the lithological descriptions of the Ravenscar Group, Cleveland Basin produced by Morgans [1997] and analysis of the organic matter from a selection of host sediments. Emphasis was placed on the assessment of potential influences by ensuring not only reasonable stratigraphic coverage but sampling of spatial variations along proximal to distal gradients and across synsedimentary faults. To isolate genuine temporal trends, priority was allocated to assessing intra-lithofacies and inter-lithofacies variations. This was achieved by collecting samples from all lithologies and lithofacies types encountered. All sampling was allied with lithological logging and this included the annotation of environmental observations, that were used to enhance the interpretation of the data. Where possible, Morgans's logs were used as a guide. Rock samples ranged from approximately 100-200 grammes of unweathered, uncontaminated material. In areas of particular note, *e.g.*, plant beds, sampling was conducted on a bed-by-bed scale. Each sample to be processed was described in hand specimen to assess the relationships between 'describers' *i.e.*, grain-size, visible organic matter and lithofacies type of the host sediment.

2.2.2 Processing Procedure

Residues were extracted using a slightly modified form of the traditional palynofacies technique, involving hydrochloric and hydrofluoric acid [Traverse, 1988; Moore *et al.*, 1991; Tyson, 1995]. Chemical and physical treatment was kept to a minimum; no oxidation or ultrasonic treatment of the residue was employed, thus reducing the mechanical breakdown of large brittle components, *i.e.*, definite wood and charcoal. Minor alterations to the standard technique of palynofacies preparation were necessary at the acid digestion stage, due to the lack of dedicated facilities in the Department of Earth Sciences and the requirement to meet current COSH regulations. These modifications have proved satisfactory in the past and are summarised in Figure 2.1. A more detailed account is contained in Appendix A.

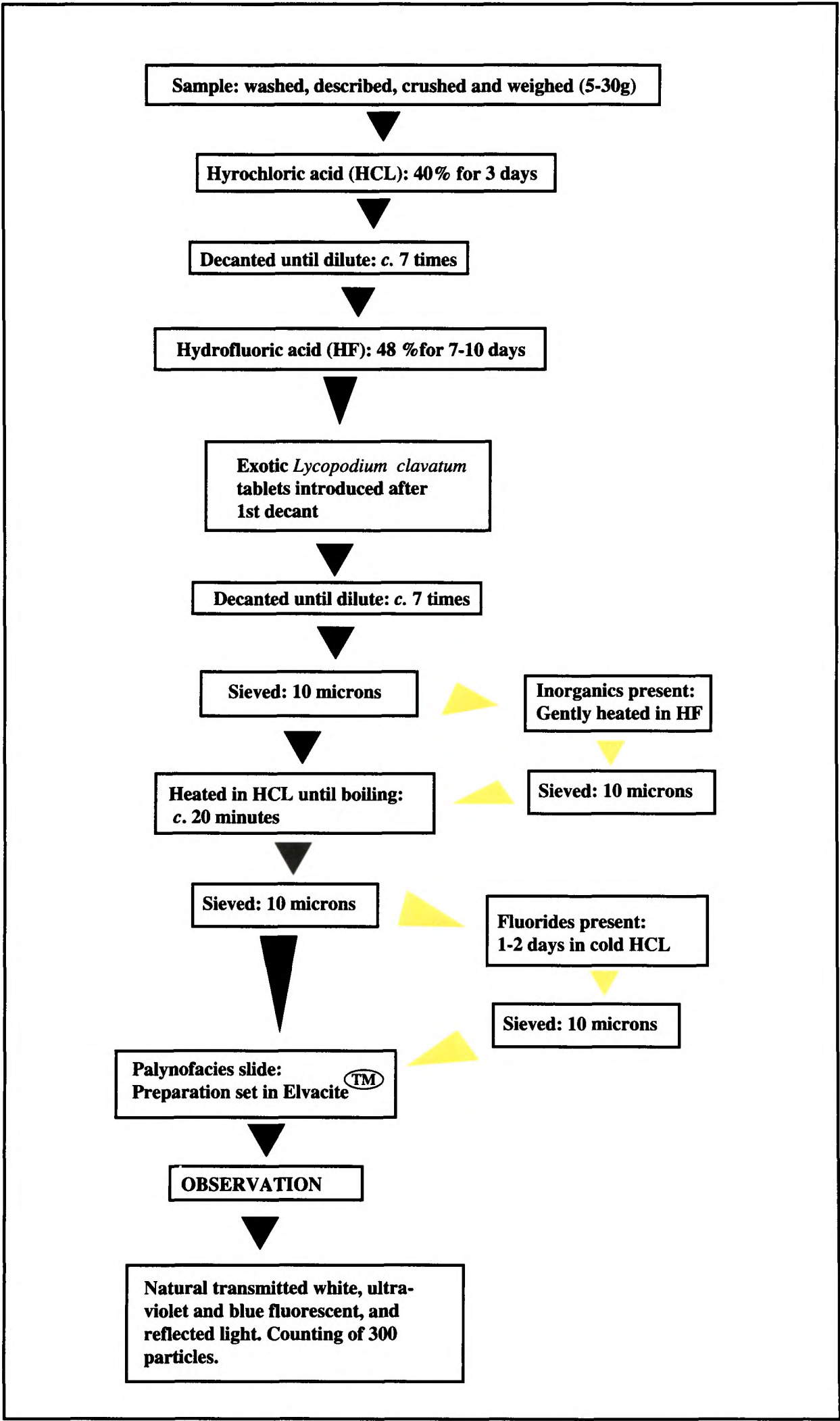


Figure 2.1: Summary of the processing technique employed in this study. A more detailed account is contained in Appendix A.

Occasionally, the hydrofluoric and hydrochloric acid stages were repeated to complete the digestion of sediment and fluoride ions. The preparations were sieved at 10 μm and mounted in elvacite 2044, a xylene-based resin for examination under transmitted light, ultra-violet and blue-incident light, and reflected light. Ultra violet and blue incident light enhance morphological features and permit the quantification of the state of preservation. Reflected light was incorporated to confirm the identity of specific constituents, *e.g.*, the affinity of black fragments to charcoal.

2.3 Classification of Particulate Organic Matter

2.3.1 Critique of the Classification of Particulate Organic Matter

The classification of particulate organic matter is both a complex and subjective task. A survey of published classification schemes indicates that the development of an all-encompassing scheme has proved to be far from simple. Since the early palynofacies studies in the 1960's, there has been considerable nomenclatural and philosophical confusion surrounding the classification of particulate organic matter, especially palynodebris, resulting in the development of numerous schemes. In the decade between 1971 and 1981, 18 new or revised schemes were published [Lewis, 1995]. This problem arises because of a series of issues:

- **Nature of particulate organic matter:**

Many similar types of particulate organic matter have been recognised in deposits of differing age and location [Boulter, 1994]. However, the lack of diagnostic features, heterogeneity and existence of intermediate forms makes it very difficult to distinguish and establish objective criteria to classify particulate organic matter;

- **Discord in approach that arises from variations in:**

- Nature of investigation; the direction of palynofacies investigations have ranged from the evaluation of hydrocarbon potential [*e.g.*, Correria, 1974; Burgess, 1974] to the unravelling of palaeoenvironmental or depositional conditions [*e.g.*, Whitaker, 1984; Boulter & Riddick, 1986; Van der Zwan, 1990];
- Terminology used to define particulate organic matter. Again, this is subjective and largely dependent upon the background of the author;

- Type of equipment employed. For example, the mode of microscope illumination may include ultra-violet (UV) light as well as the more routine transmitted white light.

These problems have been noted by many authors, including Boulter [1994] and Lewis [1995]. These authors also indicated that the prolific number of schemes and lack of standard terminology severely hampers the operators ability to make accurate comparisons and palaeoecological interpretations, thus restricting the advance of the palynofacies technique.

Two broad types of classification scheme currently exist; simple and complex. Simple schemes employ elementary terminology reflecting the simple aims for which they were devised. These schemes use a combination of Stopes [1935] maceral groups; alginite, exinite, vitrinite, inertinite and Kerogen Types I-IV, [Barnard *et al.*, 1981]. These heterogeneous categories are satisfactory in a study of the hydrocarbon potential, but inadequate if the aim is to retrieve palaeoenvironmental or depositional data.

The more complex schemes used in investigations of lithofacies and biofacies contain more categories in reflection of the greater level of detail required. In contrast to the rudimentary schemes, emphasis is placed on botanical source, morphology, preservation state and colour of the particulate organic matter. Many of the early attempts at detailed classification, for instance Staplin [1969] initially divided organic matter into primary and modified material. Staplin *et al.* [1973], Burgess [1974] and Rogers [1979] modified and improved the classifications schemes through further subdivisions [Venkatachala, 1981]. Although the greater number of categories permits a more detailed study, the criteria and terminology used to define the categories are often subjective and highly specific, [e.g., Whitaker, 1984; Habib & Drugg, 1987; Hart, 1986; Van der Zwan, 1990]. For instance, the scheme devised by Habib for the examination of Mesozoic oceanic sediments. His categories only enabled the following environments to be distinguished; reducing ('xenomorphic'), oxidizing ('micrinitic') distal environments, proximal ('tracheal') and very proximal ('exinitic') redeposition. According to Tyson [1995], more variable shelf sediments cannot be categorised into any one of these 'end members'.

Many of the existing schemes contain confusing and ambiguous terms, through the imprecise and misleading use of botanical terms. For example, Boulter [1994] noted that the classification used by Masran & Pocock [1981] contained categories that can not be identified using a conventional light

microscope (*e.g.*, 'charcoal'). Similarly, in Lewis' scheme, the categories 'fresh-water' and 'marine-water' algae refer to the source of the organic matter and may lead to tautological interpretations when dealing with organisms like acritarchs that are of uncertain origin and probably of varied affinity [according to Evitt, 1963]. Furthermore, Lewis did not provide an explanation of type of palynomorphs that should be included in each category. Without precise evidence to justify classification, new categories should not be introduced.

To a certain degree, the results of a palynofacies study are predetermined by the terminology and criteria employed to describe and classify the diverse suite of particulate organic matter encountered [Lewis, 1995]. The existence of vague, highly specific or subjective terminology and criteria led many authors to devise new schemes. For example, Boulter & Riddick [1986] attempted to eliminate subjectivity by devising a scheme based on numerically selected environmentally significant types of particulate organic matter. There are problems with their scheme, most notably the lack of distinction between marine-water algae and fresh-water algae, which are useful palaeoenvironmental indicators.

The number of schemes in existence has further inflated as a result of the recent advancement and refinement of palynofacies, which has deepened the confusion. The main area of contention centres upon the classification of non-palynomorph matter which is the focus of the present study. This material ranges from well-defined fragments with a clear origin, fragments with no distinct affinity, and sheet-like wafers that lack both recognisable internal structure and an outline suggestive of an origin from a larger structured body [Lewis, 1995]. Hence, unlike palynomorphs that usually have diagnostic characteristics and known affinity, it is very difficult to distinguish and establish objective criteria that can be consistently applied to classify non-palynomorph matter. It is thought that material with sharp peripheries represents relatively pristine material of botanical origin. Degraded sheet-like material and gels are thought to have formed from the transformation of marine algae or degradation of land plants. However, since many workers did not acknowledge that palynodebris may have more than one precursor until recently, most of the earlier schemes are inadequate.

There are additional problems besides the nature of the material that hamper its classification. Many of the schemes were designed by investigators, from a range of pursuits, with particular objectives in mind. The schemes are therefore tailored to meet specific purposes. In some instances, operators intentionally removed the gel or sheet-like material by oxidation, [*e.g.*, Waterhouse, 1995]. Others

employed broad categories, for example Bujak *et al.* [1977] who applied the term ‘amorphogen’ to the entire spectrum of amorphous organic matter types derived from different origins, and taphonomic and diagenetic processes. The grouping and particularly removal of this material is unacceptable for palaeoenvironmental studies since valuable information is lost.

Other workers attempted to be more selective. For instance, dividing palynodebris on the basis of modification and thermal alteration, [*e.g.*, Combaz, 1964], depositional environments, botanical classification, degree of terrigenous supply (and thereby distance from land), degree of degradation, proposed origin, and allochthonous and autochthonous fractions, [*e.g.*, Whitaker, 1984]. This range has created an array of terms including: ‘phytoclats’; ‘structured’; ‘structured sapropel’; ‘woody debris’; ‘structureless’; sapropel’, and ‘amorphous’.

Many of these terms are, however, unacceptable. They are vague, subjective and somewhat contentious because of misuse and evolution over time of specific definitions. For example, the definition of ‘Phytoclast’ has varied considerably: Bostick [1971] originally defined Phytoclats as, “clay sized particles of altered plant matter, including plant sporomorphs, material that has a cellular structure and ‘flocules’ ”. Tyson [1995] recently proposed to alter this broad definition to exclude sporomorphs and amorphous materials and restrict its use to clasts. Many other workers had, however, already set a precedent by proposing other definitions. Further confusion was created by the introduction of new terms that were only partially synonymous including, ‘brown wood’ [Parry *et al.*, 1981], ‘paly-nowafers’ [Boulter & Riddick, 1986] and ‘structured terrestrially sourced material’, [Pocock *et al.*, 1988]. Hence, it is very difficult to compare data generated by different workers.

Furthermore, complications have arisen from the inconsistent use of the terms ‘structureless’ and ‘amorphous’. In certain quarters these terms are considered synonymous with organic matter that formed in an anoxic environment from the transformation of marine algae, for example in the Kimmeridge Clay source rocks [Tyson, 1989]. A survey of the literature reveals the existence of further inconsistencies in the application and type of material included in these categories, as exemplified by the discussion below.

In 1984, Whitaker devised a scheme that divided organic content into two major fractions; transported and in-situ. Within the autochthonous fraction he reserved the category ‘structureless (sapro-

pel) organic matter' for material he considered to represent bacterial biomass that only developed in certain depositional conditions. However, the palynomaceral subdivisions of his allochthonous fraction comprised 'structured', 'humic-like gel', 'algal detritus' and 'structureless' material. Whitaker provided no account for the inclusion of structureless matter in both fractions. Furthermore, he supplied no criteria to enable the different types of structureless matter and humic gel that resembles structureless matter, to be distinguished. Thus, it is very difficult to accurately apply his scheme.

Van der Zwan [1990] used Whitaker's scheme and similarly subjectively stipulated that the term structureless organic matter be reserved for material originating from bacterial biomass resulting from the conversion of organic matter. He modified the scheme, however, to include a category of 'dark structureless organic matter' in the allochthonous fraction. No explanation for this modification was provided. A review of his diagram, however, indicates that he considered the structureless organic matter category of Whitaker [1984] and his dark structureless organic-matter to be equivalent, respectively, to Boulter and Riddick's [1986] 'amorphous matter and specks category' and 'communitated debris and degraded debris'.

In 1986, Boulter and Riddick reviewed the suggested affinities of material they considered to be similar to their amorphous matter. They remarked that under transmitted white light, this material resembled what other operators termed sapropel and indicated that the most common precursor of amorphous matter was thought to be algal material, probably marine. They further noted, however, that, according to Rogers [1979], bacterial and thermal degradation of other palynodebris types, *e.g.*, plant matter, could also produce amorphous material. This interpretation is supported by the work of Combaz [1980] and Venkatachala [1981], who noted that structureless organic matter could be derived from terrestrial vegetation. On the basis of this proposal, Venkatachala [1981] developed a five-fold scheme to classify the types of amorphous matter: biodegraded-terrestrial; biodegraded-aqueous; amorphous; bacterial, and grey amorphous. Venkatachala noted, however, that it was very difficult to distinguish whether the source of amorphous and bacterial matter was terrestrial or aquatic. He further indicated that it was very hard to identify his bacterial organic-matter class when other types were present. Although he recognised that different forms and origins exist, his scheme is highly subjective and hence very difficult to employ in practice.

In 1992, Whitaker *et al.*, probably in light of the suggestion that different precursors of structureless organic matter may exist, described two types of structureless organic matter:

- Structureless (sapropelic) organic matter. They indicated that this group consisted of ‘essentially structureless material bearing laminar and a granular surface appearance’. They considered the origin to be variable but generally from bacterially reworked biomass. They also indicated that this material was only preserved in anoxic or dysaerobic conditions;
- Amorphous organic matter (AOM). They used this term to describe material lacking any evidence of structure being uniformly granular or laminar in surface appearance.

They indicated that although their AOM class bore a similar resemblance to their structureless (sapropelic) organic matter, the AOM category could be distinguished by its homogeneous composition and lack of fluorescence under ultra-violet light. They also suggested that these two types would not occur together because of their contrasting origins. However, they provided no suggestion for the origin of AOM or an explanation for the homogeneity and lack of fluorescence in AOM. Even though they acknowledged the existence of various types they made no alterations to the classification scheme.

The group at the Laboratory of Palaeobotany and Palynology, University of Utrecht attempted to devise a more objective scheme. They subdivided structureless organic matter (SOM) into five major groups on the basis of colour differences: Transparent SOM; Yellow-Brown SOM; Black-Brown SOM; Black SOM, and a ‘Rest Group’. Lewis [1995] noted that even though the criteria are more objective than previous terms, the first three categories include both non-discrete particles and sharp-edged discrete particles and globular or rigid-blocky elements in the last two groups.

Clearly the classification of organic matter and especially the categorisation of non-palynomorph matter is plagued by many problems. Hence, the terms phytoclasts, structureless and amorphous should be used and interpreted with caution as their context is ambiguous. For example, the term amorphous (as used in some palynofacies studies) is not suitable as it is obvious that a large amount of particulate organic matter lacking any structure was not formed solely by the transformation of marine algae in an anoxic environment.

2.3.2 Amsterdam Palynological Organic Matter Classification

The lack of a universally accepted scheme and standard terminology stimulated a series of meetings, beginning with the *Amsterdam Palynological Organic Matter Classification* workshop in 1991. The aim of this workshop was to produce a complete working classification scheme and a fully-illustrated atlas with detailed definitions of palynological organic matter types [Lewis, 1995]. It was devised with the intention that it should be used by most investigators. The meeting produced a basic framework that was subsequently refined at two further meetings [Lewis, 1995]. The Amsterdam Scheme was strongly influenced by Van Bergen's detailed and well-illustrated classification scheme] [according to Traverse, 1994]. The scheme comprises four major categories: (I) Palynomorphs; (II) Structured debris; (III) Amorphous and (IV) Intermediate. Groups II, III and IV consist of what many workers in palynofacies refer to as palynodebris. Many workers have, however, found the Amsterdam Scheme inadequate, probably because the debate and conjecture about the philosophy and nomenclature of organic matter is still continuing. Additionally, the advantage of devising a new scheme is that it can be tailored to suit the particulate organic matter encountered and the nature of the investigation. Despite these limitations, the Amsterdam Scheme has removed at least some of the confusion, and in some recent studies has been employed as a basic framework [e.g., Brugman *et al.*, 1994]

2.4 Lewis's Classification Scheme

In 1994, Lewis employed palynofacies to investigate both the environment of deposition and vegetation of the Upper Cretaceous, Alaskan North Slope. Following the realisation that no single scheme, including the Amsterdam Classification was appropriate in its entirety, Lewis established a new scheme which is illustrated in Figure 2.2. The primary reason was that most previous studies focused upon elucidating the environment of deposition, with the documentation of the vegetation only occasionally being included as a secondary aim.

Lewis incorporated, where possible, categories used in existing classification schemes. The categories were devised to be as objective as possible and also indicated the botanical source of the particles. Hence, the category names comprise both descriptive and botanical terms. The properties used to create the various categories, included ecological significance, edge characteristics, colour, shape, fluorescence and absence or presence of internal fibrous or cellular structure. In contrast to

most other schemes, *e.g.*, Batten [1973], Fisher [1980] and Parry *et al.* [1981], Lewis was able to incorporate the properties of fluorescence. Many workers including Grayson [1981] and Van Gijzel [1991] have noted that fluorescence microscopy plays a key role in defining organic matter. Fluorescent light clarifies the morphological features and allows the state of preservation to be quantified. More fluorescent material is usually associated with an environment where degradation has been suppressed or arrested and the best conditions for the preservation of organic matter exist.

Lewis's scheme consists of 23 initial categories, six of which contained hierarchical subdivisions giving 40 in total. A description of the different categories is provided below. The entire scheme is displayed in Figure 2.2.

2.4.1 Palynomorphs

These are discrete organic-walled microfossils, commonly between the size range 5-500 μm . Lewis [1995] separated palynomorphs into eight commonly recognised types, including bisaccate pollen, angiosperm pollen, spores, marine-water algae and fresh-water algae: no further subdivisions were included.

2.4.2 Non-Palynomorph Matter

Lewis decided that none of the terms used in previous studies could be applied without a degree of uncertainty and that the classification of these particles required a set of well-defined objective criteria. To avoid the controversy surrounding the nomenclature and reflect the clear difference between genuine structureless organic matter with diffuse boundaries and homogeneous structureless organic matter with coherent margins, Lewis prudently employed the following objective criteria; edge characteristics; homogeneity or heterogeneity, and colour. On the basis of these criteria, Lewis established the following major categories: brown fragments; black fragments, and structureless organic matter (SOM). Homogeneous material with coherent outlines were classed as 'fragments' and heterogeneous material with indistinct peripheries were defined as structureless organic matter (SOM). Lewis also established ten individual categories to classify genuine plant material and unassignable palynodebris and palynomorphs.

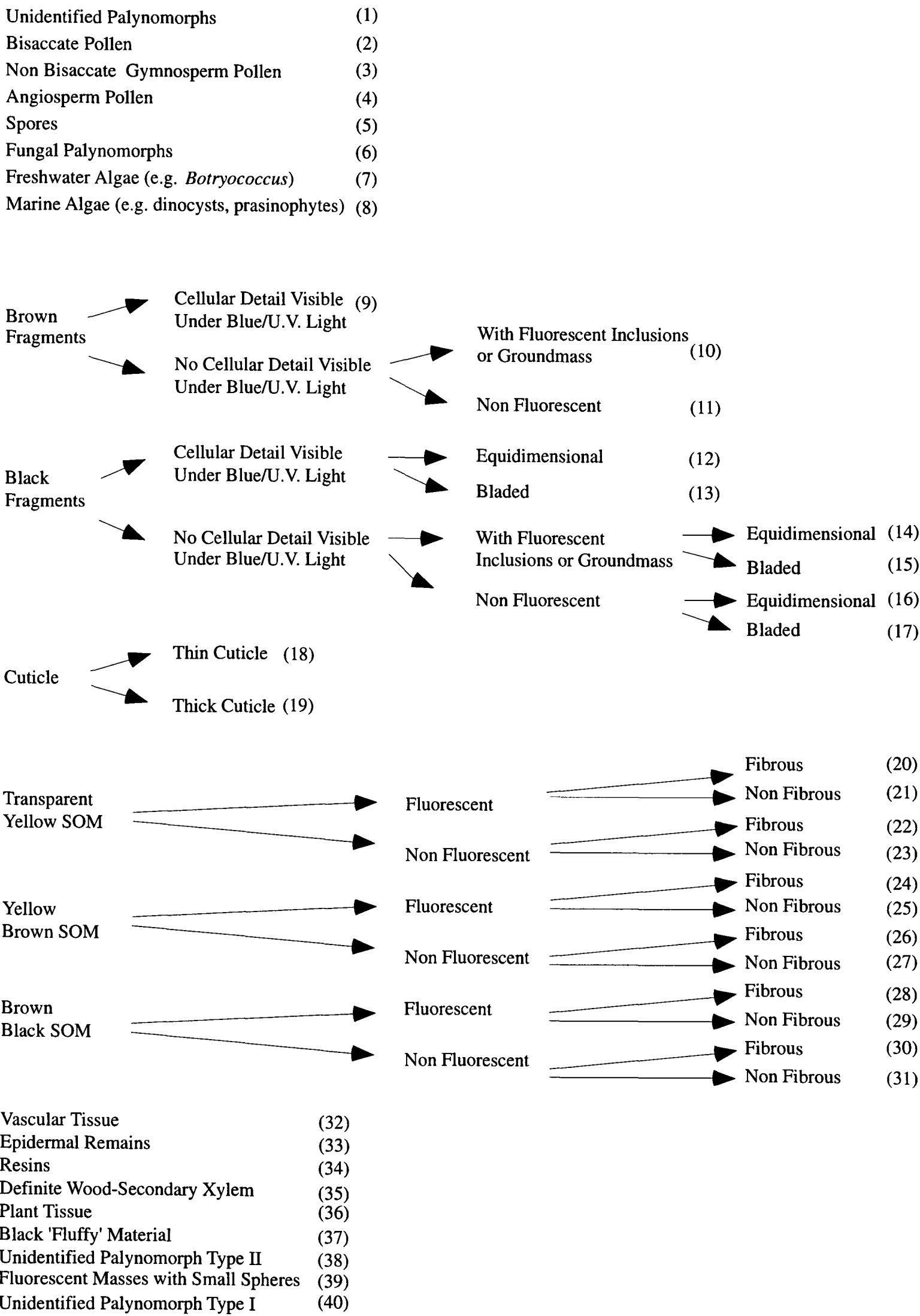


Figure 2.2: Lewis's Classification Scheme of Particulate Organic Matter [1995]

Lewis's Brown and Black Fragments

Lewis recognised the disadvantages of using the term 'Phytoclasts' and instead coined the more felicitous term 'fragments'. The criteria for material to be included in this group are coherent margins and homogeneity. Lewis described 'fragments' as well-defined, discrete particles varying in size from a few μm to a few hundred μm , with a coherent outline, as opposed to diffuse edges. He separated this material on the basis of colour (brown and black), shape (equidimensional or bladed, for black fragments only), fluorescence (present or absent), and presences or absence of 'cellular structure' as described below. He noted that the margins were usually straight, in some cases parallel to other edges, or curved but rarely conchoidal. Lewis also noted that this type of material occasionally displayed a striped nature.

If either Lorente's (1990) scheme or the Amsterdam Classification had been used, then these fragments would have been assigned to 'structureless' and 'amorphous', or 'intermediate' respectively, on the basis of being homogeneous and structureless [Lewis, 1995]. There is a clear difference between genuine structureless organic matter with diffuse boundaries and 'homogeneous-structureless' material with coherent margins. Indeed, Lewis (1995) observed that many of the brown fragments were very similar to fragments of wood encountered, but they lacked the critical diagnostic features. Lewis (1995) also suggested that the majority of black fragments were charcoal, implying that most of these fragments probably had a higher-land-plant origin. Some workers *e.g.*, Batten [1996] have suggested that the striped nature observed in some material is a relict of trachieds and classify these particles as wood. In the present study, rare fragments displaying a combination of tracheids, pits and stripes were observed confirming the existence of this intermediate form.

Colour

Lewis noted that fragments ranged in colour from light brown, black with brown margins to completely black. He indicated that most fragments were homogeneous with colour variations being minor, for instance displaying a striped appearance. On the basis of the dominance of homogeneous colouring he suggested that the origin and governing factors were fairly constant. He defined the major groups on colour differences observed under transmitted light to create two categories; brown and black. Lewis initially inferred that the differences in colour were probably due to variations in thickness. However, after a preliminary investigation under reflected light, he suggested that the majority of his black fragments (non-fluorescent) were charcoal particles and hence had a distinct history.

This was his main reason for establishing the brown- and black-fragment categories. Furthermore, the creation of two groups maximised the amount of information gained. Lewis considered his black fragments to be equivalent to the 'black debris' of Boulter & Riddick [1986], 'charcoal' of Masran & Pocock [1981] and 'indeterminate' of the Amsterdam Classification. Lewis also indicated that he considered the 'humic gel' group of Lorente & Van Bergen [1990] and the 'brown wood' of Parry *et al.* [1981] to be very similar to his brown fragments.

Shape

In 1986, Boulter and Riddick noted that the material included in their black -debris category was usually lath-shaped or equidimensional. In addition, Cope [1981] noted that the mechanical disintegration of charcoal fragments led to the production of small splinter-like clasts. In reflection of this property, Lewis divided his black fragment class into bladed and equidimensional types. Lewis considered black fragments with a length:width ratio of 2:1 to be bladed and those below a ratio of 2:1 to be equidimensional. Lewis suggested that his black-bladed category was equivalent to Whitaker's [1984] bladed-shaped palynomaceral-4 that Whitaker considered to be extremely buoyant and could be transported over long distances. The equidimensional-black fragments are approximately synonymous with palynomacerals 1 and 2 and thus Lewis [1995] interpreted them as having low buoyancy.

Fluorescences

Lewis incorporated this characteristic to provide an indication of the level of preservation and enhance morphological features. Lewis noted that some of the brown fragments in his study fluoresced when exposed to UV or blue excitation. He indicated that his subdivision for brown fragments (non-fluorescent and fluorescent), was analogous to the categories employed by Lorente [1990], who subdivided her 'humic gel' class into two groups: 'pure gels' and 'gels with inclusions'. Lorente indicated that the fluorescence in her 'gels with inclusions' category could be fragments of cuticle and sporomorphs. Lewis suggested that the fluorescence in his brown fragments may be the result of bacterial degradation. Lewis also applied this characteristic to black fragments, although no explanation was provided. He did, however, suggest that brown and black fragments that display analogous fluorescence properties were even more likely to be of a similar origin. This proposal is slightly contradictory since he suggested that non-fluorescent black fragments represented charcoal. Thus, this would imply by default that non-fluorescent brown fragments were also charcoal.

Cellular Structures

Lewis occasionally observed the presence of cellular structure or features resembling the presence of anatomical detail under transmitted white light and blue/UV light in brown fragments. In recognition of this, Lewis established two subdivisions: presences of 'cellular' material and absences of 'cellular' material under transmitted white light and blue/UV light. He suggested that these fragments were derived from vitrain and fusain coals containing cuticular material, perhaps as a result of small-scale splitting and fracturing along planes of weakness formed by layers of cuticle. The cuticle was probably embedded in the layers bounding it and upon splitting formed the surface of these fragments. He also separated the black fragments but supplied no explanation for this subdivision.

Cuticle

Cuticle is the veneer that coats leaves and shoots, and to a limited extent, roots of mature vascular plants. The major component of cuticle sheets present in palynofacies preparations are derived from leaves [Tyson & Pearson, 1991]. Lewis only included material displaying imprints of the cellular structure of the underlying epidermis in his cuticle category. Moreover, he stated that such fragments must fluoresce under incident Blue or UV light. He considered that the presence of stomata or papillae was not sufficient to be included in this group. Lewis subdivided cuticle fragments into two broad categories primarily on the basis of colour: virtually transparent to yellow; and medium to dark brown in colour and dense in appearance. Lewis believed that these reflected the thickness of the fragments and hence termed the groups 'thin' and 'thick' respectively.

Lewis's Structureless Organic Matter (SOM)

Lewis described these constituents as 'heterogenic translucent to black material varying considerably in size from a few μm to a few hundred μm '. The outline is indistinct and sheet like. Folds are often present and often associated with black specks 1-20 μm in diameter. These are probably pyrite. These types lack both recognisable internal structure and an outline suggestive of an origin from a larger structured body. Further subdivisions were established on the basis of colour; fluorescence (present or absent) and presence or absence of internal structure/fibres.

Colour

In contrast to brown and black fragments, Lewis noted that SOM was internally quite variable and

commonly displayed a heterogeneous mottled appearance. He observed that the colour variation across an individual particle could range from transparent to black. Lewis thought that this was related to variations in thickness. He indicated that SOM often possessed a darker and more solid-looking central portion surrounded by a lighter and apparently thinner periphery. Furthermore, he recognised that the darker examples displayed opaque areas though they were never completely opaque. To highlight these colour differences, Lewis established three structureless organic-matter categories based on this criterion. The colour ranges used to define these three categories were: 'transparent-yellow'; 'yellow-brown'; and 'brown-black'. Lewis noted that his groups were not synonymous with the categories employed by Utrecht University.

Fluorescence

Lewis further subdivided his three structureless organic matter categories into fluorescent and non-fluorescent classes. He found it difficult to consistently apply an arbitrary division, for example only including fragments with areas in excess of 10 % in the former category. Hence, he decided that any amount of fluorescence would afford inclusion in the class, which in his investigation included the majority of the SOM.

Fibrous or cellular structure

Lewis observed that some of the SOM displayed a fibrous appearance and hence felt that it was beneficial to make a separate record. While the terms fibrous and structureless seem incompatible, Lewis further divided each of the fluorescent sub-categories into fibrous and non-fibrous. In total, Lewis established 12 structureless organic matter sub-categories, thus maximising the amount of available data.

Assorted Material

Lewis's scheme also contains a list which comprises a variety of material, including genuine plant material and unassignable organic matter. He individually categorised material that contained botanical features under transmitted white light or fluorescent light. This range comprised vascular tissue, epidermal remains, resins, definite wood-secondary xylem and plant material. The characteristic features of each type are describe in subsection 2.5.6. Lewis listed four other categories: unidentified palynomorph type I; unidentified palynomorph type II; 'black fluffy' material; and 'fluorescent masses with small spheres'. However, he only described the latter two.

'Black Fluffy'

He noted that this rare material displayed most of the characteristics of brown-black, fluorescent, non-fibrous SOM. He felt, however, that there were enough distinguishing features to merit the establishment of a new category. He indicated that this material probably originated from algal or bacterial degradation of some other material, perhaps cuticle. Lewis further noted, however, that as this material was rare its affinity remained ambiguous.

Fluorescent masses with small spheres

He indicated that this rare material resembled yellow-brown or brown-black, non-fibrous SOM under transmitted white light. In contrast, when exposed to UV or blue light, the material fluoresced intensely and was observed to contain small spherical bodies. Lewis thought that since these spherical bodies denoted structure, this material was distinguishable from SOM. Hence, he established a separate category. Furthermore, he suggested that the small spherical bodies were either algal bodies or bacteria.

2.5 Appraisal and Rationalisation of Lewis's Scheme and Classification Protocol

2.5.1 Appraisal

On the basis of the success of Lewis's investigation and due to the similarities in aims between his study and the present one, it appeared prudent to use Lewis's scheme. Lewis's objective criteria permit comparison with other schemes, reflect the level of preservation and avoid the subjectivity of previous categories. However, a review of Lewis's scheme revealed some reservations concerning its employment in this investigation, including:

- Lack of designated procedure for identifying and classifying material; no previous authors have nominated a set procedure in conjunction with a classification scheme;
- Large number of initial categories, not only making the scheme cumbersome to use, but also difficult to compare with other schemes. The lack of complementary reference plates enhanced

this problem, as it was difficult to be entirely certain about the nature of the material included in each category;

- Presence of ambiguous terminology in the palynomorph category. For example, Lewis's headings of 'fresh-water' and 'marine-water algae' are too specific because certain organisms, for example acritarchs, are of uncertain origin and probably of varied affinity according to Evitt [1963];
- Initial investigations in this study revealed the existence of a gradient of organic matter between Lewis's fragments, certain types of organic matter that contain some botanical anatomy, (*e.g.*, definite wood and cuticle) and SOM. As discussed earlier, Lewis strongly suggested that 'fragments' originated from higher plants. Furthermore, in his study, cellular structures were occasionally observed under fluorescent light in 'fragments' (*sensu* Lewis 1995). However, Lewis did not reflect these associations in his scheme or provide a clear explanation to distinguish between the three major types. This may be due to the fact that a minority of biostructured materials have semi-coherent boundaries;
- Use of colour as a criterion. It is known that colour is slightly ambiguous since it may depend on thickness, texture and thermal alteration of the material;
- Selective application of shape criteria to black fragments. Lewis suggested that only the non-fluorescent black fragments could possibly be charcoal particles. Therefore, he believed that it was sufficient to just apply this morphological term to that sub-division. Parry *et al.* [1981], however, noted that some brown fragments display longitudinal structural thickening and thus will have a tendency to form bladed material as well as equidimensional particles. Thus, bladed and equidimensional categories should be applied to both brown and black fragments.
- Use of the categories such as 'black fluffy' and 'fluorescent masses with small spheres' that are rare and of uncertain affinity.

2.5.2 Modifications

In light of these considerations, it was difficult to use the Lewis scheme unmodified. However, instead of establishing another new scheme and thus adding to the confusion, Lewis's scheme has been tailored to suit the needs of this study and potentially other investigations. The essence of

Lewis's scheme has been maintained, with some restructuring, to maximise the amount of detail obtained, expedite the application of the classification scheme, and permit integration and comparison with other investigations. Where possible, Lewis's criteria and categories were maintained to permit comparison.

The main alterations were guided by the development of designated classification procedures. The aim was to develop a robust protocol that permitted the operator to expand the categories if desired, whilst allowing comparison with other schemes. The resultant scheme is hierarchical with increasing detail and different modes of microscope illumination being incorporated with each successive phase. The criteria and classification phases are illustrated in Figure 2.3, and the scheme is illustrated in Figure 2.4.

The particulate organic matter was initially classified into one of three categories; Palynomorphs, Discrete Fragments and Structureless Organic Matter, following the essence of Combaz's [1964] three-fold scheme. After Phase 1, the criteria used to identify components depended upon the particular subgroup. A summary of the criteria outlined in Figure 2.3 are listed below:

- Phase 1: Organic-walled microfossils were classified as palynomorphs. Remaining material was classified as either Discrete Fragments or SOM, respectively, on the basis of a distinct or diffuse boundary;
- Palynomorphs were separated into particular types using taxonomic and morphological features from Phase 1 onwards;
- Discrete Fragments and SOM were subdivided upon the presence or absence of the following features from Phase 1 onwards;
- Phase 2: botanical features; relevant only to material displaying botanical structures (vita fragments);
- Phase 3: colour/homogeneity, relevant only to material displaying no botanical affinity under transmitted white light (non-vita fragments and SOM);
- Phase 4: shape; equidimensional or lath-shaped, applicable only to 'non-vita fragments';
- Phase 5: presence or absence of internal 'fibrous' or 'cellular structure';

PHASE 1	Discrete organic walled body —————> Palynomorph Discrete fragment with coherent margin —————> Discrete Fragment 'Structureless' material with diffuse edges —————> Structureless Organic Matter
PHASE 2	<i>Material separated on basis of taxonomic and botanical features</i> Palynomorphs divided into five groups—————> e.g., Sporomorph Discrete Fragments —————> 'Vita' or 'Non-Vita' Fragment SOM —————> No separation
<i>The criteria used to classify palynomorphs is different from phase 2 onwards.</i>	
PHASE 3	Vita Fragments separated into specific types of plant material ———> e.g., Cuticle and Definite Wood Colour of Non-Vita Fragments and SOM —————> e.g., Yellow*, Brown and Black
PHASE 4	Cuticle separated —————> Thin or Thick** Shape of Non-Vita Fragments —————> Equidimensional or Bladed (No application to SOM; observed in a wide variety of shapes)
PHASE 5	Presence or absence of Internal Structure —————> Cellular /Fibrous or in Non-Vita Fragments and SOM Non-Cellular Fibrous
PHASE 6	Fluorescent properties of SOM and —————> Fluorescent or Non-Vita Fragments Non-Fluorescent
<i>Further detail may be obtained from reflected light and SEM at this juncture.</i>	

Figure 2.3: Criteria employed to define Classification Procedures. (* Yellow criterion only applies to SOM. ** Criteria not used in present study.)

- Phase 6: fluorescent properties.

These procedures gave rise to the modification of Lewis’s scheme, a synopsis of which is listed below. Occasionally the categories were expanded to included observations under SEM and reflected light. The complete scheme is displayed in Figure 2.4.

- Regrouping of the 23 primary components into three major categories: Palynomorphs, Discrete Fragments and Structureless Organic Matter (SOM);
- Restructuring and expansion of Palynomorph category;
- Assimilation of material showing botanical features with those that displayed no botanical structures under the blanket term ‘Discrete Fragments’ in Phase 1. In reflection of these differences this group was subdivided respectively, into ‘vita fragments’ and ‘non-vita fragments’ at phase 2. These terms were favoured as they are perspicuous and no tautological inferences can be made, unlike the ‘charcoal’ category of Masran & Pocock [1981]. Any material displaying evidence of life under transmitted and fluorescent light was classified as ‘vita fragments’ and those without as ‘non-vita fragments’;

- Separation of discrete fragments and SOM respectively, on the basis of the presence of a distinct or diffuse outline. In a few cases some vita fragments, for example poorly preserved cuticle, possessed semi-coherent peripheries. Under the criteria of ‘edge characteristics’ employed to separate SOM and discrete fragments these intermediate forms could either have been classified as discrete fragments or SOM. As these intermediate forms were rarely encountered, and a continuum was identified between particles devoid of anatomical features and material possessing botanical structures they were classified under vita fragments;
- Use of SOM. Lewis’s usage of SOM is acceptable since he stipulated that the term structureless organic matter (SOM) only be applied to a certain type of material rather than using the term to include all material lacking structure. No alterations were made to any of the criteria employed. The only modification was the sequence of classification;
- A holistic approach of applying all criteria, where relevant, to all categories, was employed to maximise the amount of potential information and avoid subjectivity;
- Colour: Although ambiguous, colour has proved to be a workable characteristic [Brugman *et al.*, 1994];
- Removal of Lewis superfluous categories including ‘black fluffy’ and ‘fluorescent masses with small spheres’. A preliminary investigation in this study revealed that these forms were exceedingly rare. Furthermore, because Lewis was uncertain about the affinity and relevance of this material to palaeoenvironmental reconstruction, it was felt that these groups were unnecessary.

2.6 Description of Categories

This section shadows the order displayed in Figure 2.4. Each category is defined and followed by a discussion of the modifications and an outline of the attributes employed to decipher the palaeoenvironment. Scanned images showing a range of the different types of organic matter, especially the palynodebris, encountered in the present study are contained in Appendix ??.

2.6.1 Palynomorphs

Lewis [1995] mainly focused on botanical significance, with more minor consideration being given to ecological significance. For the purposes of this study Lewis’s palynomorph group was probably

Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Palynomorphs	Sporomorphs	Pollen	Bisaccate Pollen	Active describers selected <i>e.g.</i> , <i>Classopollis</i> spp.	
			Non Bisaccate Pollen		
		Spores	Megaspores		
			Ornate Spores		
			Smooth Spores		
			Monolete Spores		
		Reworked sporomorphs			
		Unidentified			
	Phytoplankton	Chlorococcales	Single Bodied	<i>e.g.</i> , <i>Botryococcus</i> spp.	
			Colonial		
		Prasinophytes	<i>e.g.</i> , Tasmanitids, Leiospheres		
		Dinoflagellate cysts	Proximate		
			Chorate		
			Cavate		
		Acritarchs		Short Processes	
				Long Processes	
	Zoomorphs	<i>e.g.</i> Foraminiferal linings			
	Fungal Bodies				
	Unidentified				
Discrete Fragments	Vita Fragments	Cuticle	Thin		
			Thick		
		Epidermal Remains			
		Definite Wood			
		Vascular Bundles			
		Resin			
		Plant Tissue			
	Non-Vita Fragments	Brown	Equidimensional	Internal Structure	Fluorescent
		Black	Bladed	No Internal Structure	Non-Fluorescent
Structureless Organic Matter (SOM)		Transparent-Yellow		Fibrous	Fluorescent
		Yellow-Brown		Non-Fibrous	Non-Fluorescent
		Brown-Black			

Figure 2.4: Particulate Organic Matter Classification Scheme employed in this study, modified [after Lewis 1995].

suitable with minor changes. However, for an investigation which wishes to focus upon palynomorphs insufficient detail was paid to the composition and morphological properties of palynomorphs which reflect the hydrodynamic and sedimentological systems, especially in a marine setting [Muller, 1959]. As previously indicated Lewis’s categories of ‘fresh-water algae’ and ‘marine-water algae’ are not appropriate for all algal types. Consequently, employment of Lewis’s Palynomorph categories may result in the loss of much potentially useful information.

Thus, the palynomorph category was restructured with particular reference to ecological significance, hydrodynamics and botanical affinity. Five categories were scored in the second phase; sporomorphs; (*sensu* Traverse, 1994), phytoplankton; zoomorphs; fungal bodies; and unidentified palynomorphs. As this is not a palynological study, a full description of the morphology and taxonomy is not given. However, in the third, fourth and fifth phases, attention may be focused on the identification of specific ‘active describers’ (*sensu* Mussard *et al.*, 1994) which are ‘environmentally sensitive’. For example, in the present study *Classopollis* pollen was selected to enhance the data set.

The expansion of these categories, if desired, can be channelled to meet the level of detail and specific requirements of each study. The sub-categories of the palynomorph group are described below. Bibliographic references used in the present study to assign the various different palynomorph types into their respective categories, includes Couper [1958]; Dettman [1963]; Muir [1964]; Tralau [1968]; Guy [1971]; Filatoff [1975]; Pocock [1970]; van Konijnenburg-van Cittert [1971, 1978, 1987, 1989, 1996]; van Konijnenburg-van Cittert & van der Burgh [1996]; Guy-Ohlson [1992]; Riding & Thomas [1992]; Boulter & Windle [1993]; Fensome *et al.* [1993].

Sporomorphs (*sensu* Traverse, 1994)

In Phase 3, the components were segregated into pollen and spores. The subdivisions in Phase 4 are bisaccate pollen, non-bisaccate pollen, megaspores, ornate trilete spores, smooth trilete spores, monolete spores and reworked sporomorphs, being based on a combination of those classifications employed by Boulter & Riddick [1986] and Whitaker [1984]. Depending on the nature of the host sediment, these categories may reflect the hydrodynamics of the system and to a lesser extent, proximity to the source and nature of the vegetation found within the basin.

Sedimentation of sporomorphs generally depends on a complex relationship between pollen size, specific gravity and current patterns. Many sporomorphs are thought to be sensitive hydrodynamical indicators. For example, studies of contemporary basins by Muller [1959] and Traverse & Ginsburg [1967a,b] have demonstrated that higher abundances of bisaccate pollen occur in distal areas of the basin. Conversely, ornate spores with high specific gravities are found in higher abundances in proximal environments that have high energy levels at the time of deposition. Weight was added to this concept of hydrodynamic overprint by [Schopf, 1975], who demonstrated that mere proximity to source was not a guarantee of finding the spores and pollen of the dominant vegetation in the sediment, any more than the absence of a particular nearby species precluded its occurrence in the sediment.

This strongly suggests that floral controls on production and distribution decline in marine sediments, in comparison to hydrodynamic and sedimentological factors, thus indicating that the pollen and spore rain that finally reaches these sediments is not an direct reflection of the vegetation found within the basin. Furthermore, the record is not only altered by taphonomic processes but by the

productivity rates and volumes of spores and pollen. Hence, caution must be employed in the interpretation of preserved sporomorphs as an indicator of proximity to source or basinal vegetation.

Phytoplankton

In an attempt to address the issue of classifying marine-water algae and fresh-water algae discussed earlier, these categories were reassigned under the heading 'Phytoplankton'. The distribution of phytoplankton is very-wide in the marine and paralic environments. At the fourth phase of classification, to gain more environmentally significant information, phytoplankton are separated into: *chlorococcales*; prasinophyte phycomata; acritarchs; dinoflagellates cysts and unidentified algae [after Tyson, 1995]. The range recorded within and between the different groups echoes changes in morphology, environment, water depth and turbulence. In addition, the detail of the classification scheme may be increased to incorporate variations in morphological features *e.g.*, long/short spines. This would reflect the findings of Scull *et al.* [1966] and Williams & Sarjeant [1967], who recognised that thick-walled, small-spined phytoplankton were associated with shallow water, in contrast to thin-walled, long-spined phytoplankton that were observed in deeper water.

Chlorococcales

These comprise colonial or single celled bodies, *e.g.*, colonial fresh-water algae, *Botryococcus* and *Pediastrum*. Traverse [1995] outlined the preferred habitat of *Botryococcus* as being low-energy, fresh water with well-aerated surface water and low humic acid content. It has been demonstrated, however, that *Botryococcus* can exist in a wide range of salinities [Guy-Ohlson, 1992]. In contrast, *Pediastrum* is more stenohaline and prefers a higher nutrient loading [Chu, 1943; Masters, 1971]. These attributes can be employed to identify environmental changes *e.g.*, variations in salinity [Chu, 1943; Masters, 1971].

Prasinophyte phycomata

This subgroup of simple spherical vesicles that possess no spines or crests, mainly occur in shallow marine-brackish environments [Brasier, 1980]. After Tyson [1995,] the following may be recognised in this group: tasmanitids (100-700 μ m); crassosphaera, and leiospheres. The precise taxonomic status of these genera is somewhat controversial. However, there is consensus that the extant representatives have evolved from an ancestry that included the above fossil genera (Wall, 1962; Guy-Ohlson 1992a).

Variations in the diversity can be used to identify particular environmental conditions. Modern forms range from open marine to inter-tidal mudflats [Fisher, 1980]. In the fossil record, tasmanitids are frequently associated with shallow brackish and marine assemblages [Guy-Ohlson & Bolach, 1982]. Undifferentiated leiospheres are also considered to be good indicators of brackish and shallow marine conditions [Scull *et al.*, 1966]. Thus, a low diversity and monospecific assemblage of tasmanitids and leiospheres is characteristic of lagoonal facies [Brasier, 1980].

Acritarchs

Evitt [1963] coined the term Acritarch, from the Greek 'unknown origin' to replace hystrichosphaerids. It is an informal 'rag-bag' group to which any hollow, organic-walled, unicellular vesicles may be assigned until their true affinities are discovered [Evitt, 1963]. Size ranges between 10-150 μm , and most comprise a single-layered wall enclosing a central cavity. The majority identified in this study were *Micrhystridium* spp., which is typical of inshore facies. As mentioned previously, the length of processes is related to particular environments. For example, acritarchs with longer, more delicate and elaborate processes and crests are recorded in quieter offshore facies [Wall *et al.*, 1977]. In recognition of this characteristic, a distinction was made between long and short processes in Phase Five. This criterion was not used because acritarchs were not observed in sufficient quantities to enable the investigation to be statistical valid.

Dinoflagellate cysts

Dinoflagellates are a very diverse group of protists, usually between 20-150 μm long. Only those with a complex life cycle, including a non-motile, thick-walled encysted stage are important to palaeopalynology. The walls of the cyst are composed of dinosporin [*sensu* Fensome *et al.*, 1993] which is very similar or identical to sporopollenin. Most extant encysting dinoflagellate cysts are marine, some brackish and a few fresh-water species. Dinoflagellate cysts range from structurally complicated, reflecting the 'parent' theca, to more-or-less unadorned and uncomplicated 'bags' that are more typical of fresh and brackish water [Traverse, 1988].

As with sporomorphs, different morphological groups show different hydrodynamic behaviour. In Phase 4, three basic types of cysts may be distinguished; proximate, chorate and cavate. Proximal cysts are single-walled and lack significant processes, chorate cysts are essentially single-walled and have long processes; cavate cysts have two or more separated wall layers. Like other phytoplank-

ton, the morphology and diversity can be used to help distinguish between nearshore and offshore sediments [Downie *et al.*, 1971; Wall *et al.*, 1977].

Zoomorphs

Foraminiferal linings are the chitinous remains of the internal chamber. In the present study, these rare specimens were found mainly in shallow-marine sediments. The majority were planispiral forms.

2.6.2 Discrete Fragments and Structureless Organic Matter

The next two subsections follow the format employed for the palynomorph category. Subsections 2.6.3 and 2.6.4 define and discuss the alterations used to classify non-vita fragments and vita fragments respectively. As Lewis's SOM categories have been maintained without alteration, no description is included.

2.6.3 Non-Vita Fragments

The criteria used by Lewis have been maintained to classify well-defined discrete particles with coherent margins. The only alterations are, the holistic application of all criteria to the various sub-groups in order to maximise the amount of information obtained and the change in nomenclature of this category. This group is synonymous with Lewis's 'fragments'.

Colour

In this study, only material that was completely black was incorporated in the black category. Any material that possessed a brown periphery was included in the brown group to permit the categorisation of carbonised particles. As this study progressed, the importance of charcoal as an environmental indicator became apparent. Therefore, routine observations using reflected light were incorporated to differentiate between reworked coal fragments, pyrite and charcoal. There is some debate concerning the formation of carbonised (fusinized debris) particles. This is discussed in Chapter 4.

Shape

Parry *et al.* [1981] observed a similar morphological distribution among both their black and brown wood fragments. They noted that the buoyancy characteristics of lath-shaped or equidimensional

fragments were different, resulting in the preferential accumulation of each type in different sedimentary regimes. They suggested that fragments of wood found in the pro-delta clay (shallow marine) were lath-shaped and angular because they have floated out and then dropped, rather than having been caught up in the bedload of a river. In light of this proposal, and in an effort to be consistent and maximise the amount of recoverable information, the shape criterion was applied to all black- and brown, non-vita fragments.

Fluorescence

This criterion was maintained. However, caution was employed when interpreting the data. If non-fluorescent black fragments do represent charcoal, then the presence of analogous fluorescent characteristics in brown fragments cannot imply that the material has a similar origin as proposed by Lewis [1995].

2.6.4 Vita-Fragments

In this study, vita fragments were subordinate to non-vita black and brown fragments. The subdivisions incorporated for vita fragments include cuticle, epidermal remains, definite wood, vascular bundles, unassigned plant tissue and resins, which have a range of buoyancy. Hence, these categories not only reflect the botanical nature of the material but also variations in the energy of the depositional site. The group is comparable to Boulter and Riddick's [1986] 'palynofauna' and 'structured terrestrially sourced material of Pocock *et al.*, [1998].'

Cuticle

The major component of cuticle sheets present in palynofacies preparations are derived from leaves [Tyson & Pearson, 1991]. Cross *et al.* [1966] suggested that cuticle distribution was similar to that of sporomorphs in their deposits because the specific gravity of cuticle is thought to be very similar to sporomorphs. Cuticle is dispersed easily and is most abundant in high-energy systems of deposition and is regularly present in sandstones, though not restricted to sediments of this grain size [Boulter & Riddick, 1986]. Its highly buoyant form causes it to remain in suspension at low-energy. In high-energy conditions cuticle may be trapped within the sandflows. In 1981, Parry *et al.*, observed that cuticle dominated the preparations from pro-delta clay of the North Sea Brent Formation and was also common in the marine basal sands and in marginal marine facies. Cross *et al.*, (1966) showed that recent sediments in the Gulf of California contained high concentrations of cuticle near river mouths

and the near-shore.

Colour ranges from pale yellow through to brown, though the former is more common. This spectrum of colour is thought to be related to the thickness of the fragment [Lewis, 1995]. The internal colour variations are limited reflecting the consistent thickness of the particles. Lewis used this property as a climatic indicator, thicker cuticle indicating the existence of an extreme climate. In this study, cuticle was rarely recorded. Thus, any conclusions based on the thick and thin categories would be statistically invalid. Occasionally, stomatal cells, which occur on the lower surface, were identified. These, usually oval stomata, were arranged in rows within randomly orientated large cells, which is typical of gymnosperms.

Epidermal Remains

These fragments display a similar cellular structure to cuticle but as noted by Lewis [1995] may be distinguished by the lack of fluorescence. Epidermal fragments were rarely encountered in this study.

Definite Wood–Secondary Xylem

Tracheids are vertical conducting cells found in the xylem tissue of nearly all vascular plants. They have thick lignified walls and often have annular spiral thickening and bordered, scalariform, and other types of ‘pits’, pores by which the elements communicate with adjacent cells. Many of these structures were preserved in the fragments found in shallow marine/marginal marine environments in the present study. The highly stable, resistant and hydrophobic nature of lignin enhances the preservation of this material. Decay is associated with slow-growing lignolytic white-rot fungi under oxic subaerial conditions [Tyson, 1995].

Vascular Bundles

These are yellow or brown fragments that show some degree of lineation but not as extensive as secondary xylem.

Plant Tissue

This category, which is analogous to the plant tissue group of Van Bergen *et al.* [1990] was established to include fragments that displayed anatomical features that strongly suggested some sort of function but with a different arrangement to that observed in cuticle, epidermal tissue and definite wood. In

this study, these particles possessed a range of colours from yellow to dark brown, displayed no fluorescent properties and had no regular shape [Lewis, 1995]. If no cellular structure was present, these fragments would be counted as SOM. It has been suggested that these fragments are collenchyma, parenchyma and cortex by Parry *et al.* [1981] and Van Bergen *et al.* [1990]. As no clear distinction exists between these types, Lewis's classification was maintained in this study to categorise these rare fragments.

Resins

Resins vary in appearance from spherical to tube-like as noted by Lorente [1990] but may be recognised by their vitreous nature. Colour ranges from a light-golden-yellow to red. Often these grains possessed internal reflections. Under fluorescent light the grains fluoresced intensely. Grimaldi *et al.* [1989] suggested that darker red grains represented older more oxidised material because they show more internal fracturing. Gastaldo & Huc [1994] inferred that these features probably reflected the nature and degree of oxidation and transport rather than the actual age of the grains. These rare particles are often rounded due to their soft physical durability and are often observed in oolitic settings.

2.7 Data Extraction

To derive significant results, it is necessary to employ a meaningful counting strategy and correct statistical techniques. Subsection 2.7.1 evaluates the merits of qualitative, and absolute and relative quantitative data. Subsection 2.7.2 describes the nature and generation of the raw data used in this thesis.

2.7.1 Qualitative versus Quantitative

Qualitative visual estimation was until recently the most common method used to define the type and abundance of an assemblage; [*e.g.*, Dennison & Fowler, 1980; Parry *et al.*, 1981; Pocock, 1982; Whitaker, 1984]. These observations, however, tend to be subjective, create scepticism in the reliability of the dataset and inhibit the application of statistical techniques. Recently the trend has been towards obtaining semi-quantitative abundance data for each of the organic matter particle types from a predetermined count total as these provide more reliable values, [*e.g.*, Waterhouse, 1995; Lewis, 1995]. Two types of semi-quantitative data are available, relative and absolute.

Relative Abundances

Results obtained from relative abundances are presented as relative numeric frequencies of particles expressed as a percentage of a given sum [Tyson, 1995]. Although this technique is the most commonly used there are many problems, the most important being 'data closure' as discussed by Moore *et al.* [1991] and Tyson [1995]. Percentages are a property of the population, not an individual component within that population. The abundance of each category is, therefore, dependent upon the fluctuations in other groups [Tyson, 1995]. The outcome of such analysis is that each category can only be expressed as a proportion of a selected total sum and this can lead to many problems of interpretation. The application of relative percentage abundances should not, however, be disregarded. Ratios of percentage data are considered to be an effective means of displaying stratigraphic trends because these type of data do not suffer from data closure [Tyson, 1995]. Ratios may also be applied to absolute data.

Absolute Abundances

More recently, there has been a move towards calculating absolute abundance values. One particular advantage of using absolute particle abundance is that any particle type may be studied in isolation from the complete suite, or compared between samples. This avoids the 'data closure' effects and the ambiguities inherent in using percentage data. Absolute abundance data can provide information on the numbers of particles deposited per unit area per unit of time (absolute accumulation rates) and the absolute volumetric/weight frequency of the particles deposited per unit volume/weight of sediment [Tyson, 1995]. As the sedimentation rate has to be known to calculate the absolute accumulation rate of particles per unit of time, this measure has usually been restricted to Holocene studies [Davies, 1973]. Volumetric/weight frequency measures have, however, been calculated for older sediments Waterhouse [1995]. A variety of techniques has been proposed for the calculation of absolute abundances which can be divided into three basic types. They are discussed by Traverse [1988], Moore *et al.* [1991] and Peck [1974] who tested the relative merits of these techniques and illustrated that each method has its own limitations:

1. Volumetric methods [Davis & Deevey, 1964];
2. Weighing methods [Jorgensen, 1967];
3. Exotic marker grain methods [Benninghoff, 1962; Matthew, 1969; Bonny, 1972].

2.7.2 Selection of the Type of Raw Data and Methods of Data Extraction

Nature of raw data collected

A combination of both relative and absolute quantitative data were employed to meet the requirements of this study. As previously mentioned, one of the main objectives was to define the various palynofacies assemblages and examine the relationship of these to sedimentary facies and the environment. Batten [1973], Tyson [1989], Willams [1992] and Lewis [1995] successfully applied relative count data to define different palynofacies assemblages. The subsequent correlation of these with specific sedimentary environments has usually been possible. Furthermore, both Batten's and Lewis's assemblage types formed the preliminary step towards studying the vegetation in a fluvial and deltaic setting respectively, which is relatively similar to the aims of this study. Hence, it was decided for this study to establish the different palynofacies assemblages based on the relative abundances of the organic matter particle types. Ratio data were used on particular subsets to highlight changes in the environment.

Absolute abundance data were calculated for all samples to eliminate the problems of data closure and ambiguity. Absolute abundance values also:

- proved a useful addition to differentiate between certain associations of organic matter;
- aided in the recognition of palaeoenvironmental controls on palynofacies;
- enhanced the appraisal of palynofacies assemblages through the use of the organic matter content;

The exotic marker technique devised by Stockmarr [1971] was selected to facilitate absolute counts as this has proved to be an extremely valuable and labour-saving method. Tablets containing known amounts of marker grains (*Lycopodium clavatum*) were added to a known weight, thus avoiding the necessity of preparing an exotic marker suspension, which is time consuming and prone to errors. Further details regarding the calculation of absolute abundance values are contained in Appendix A.

Generation of raw data: number of particles counted per sample

The required amount of particles to count per sample to produce statistically valid results has always been a subject of much debate. The number of particles counted per palynofacies sample varies

greatly between workers ranging from 200 [Traverse, 1988], to between 300-500 [Maher, 1972, 1981; Tyson, 1995] to over 1000 Lorente [1990]. The aim of any counting strategy is to count the minimum number possible to obtain statistically reliable results. This situation becomes more complicated when absolute abundances are required. Several workers have recognised that for relatively rare palynodebris categories or palynomorph taxa, large counts are needed, but for abundant forms, low counts will suffice.

In the formative years of pollen analysis, only limited attention was paid to the problem of obtaining statistically reliable data. Traverse [1988] noted that 200 grains had become the accepted count among many palynologists, although he suggested the choice of 200 particles was not made on any statistical basis. Maher [1972] presented nomograms for calculation of the confidence limits of pollen analytical data based on calculations by Mosimann [1965]. This approach was mathematically rigorous but the procedure is extensive. On the basis of the work of Maher [1972] & Maher [1981], White [1989] concluded that counts of 300-500 grains probably provided reliable data on the relative abundance of different taxa. A similar view was also held by Rull [1987] and Traverse [1988], who both indicated that a count of 200 hundred grains would be sufficient to produce reliable results for relative abundances. However, in agreement with Farley [1988], they noted that to provide data for rare forms, counts far in excess of 200 grains were necessary. Traverse suggested that the number of specimens that must be counted to achieve a desired standard deviation depended on the abundance of the least abundant form that was critical in defining the assemblage-type. Unlike earlier suggestions that were either based upon folklore or prolix mathematics his approach was to apply the simple but effective Rittenhouse curve. This technique was devised by Gordon Rittenhouse of Shell Development Company in 1957 to calculate the uncertainty in proportions in mineralogical counts. This method enables the calculation of the required number of specimens to count in order to obtain a reliable estimation of the percentage of a certain species in a sample.

Lewis [1995] made use of three separate mathematical techniques to determine the appropriate count number:

1. Running mean average. In this technique, similar to that employed by Spicer [1988], Lewis [1995] selected a sample at random and constructed a graph that related the mean value of each palynomorph or debris to sample size. Lewis determined that, for abundant forms, the point at which fluctuations

in cumulative mean decreased significantly was a count of approximately 150 particles. However, Lewis indicated that the level at which rare forms would stabilize would be different between samples. Lewis concluded that this method gave a good indication of the count size needed to provide reliable data for the abundant forms and that large counts would be necessary to achieve viable data for uncommon forms, which is consistent with the views of earlier workers.

2. Quadrat doubling. This technique is frequently employed in botanical studies to ascertain the size of a sample when no new species or particles are detected. Lewis calculated that no new particles were encountered in counts above approximately 200 particles. This provided a useful estimate of the minimum count size needed to detect all the particle types, even the rare forms in a strew slide. However, he also noted that this figure is likely to fluctuate between samples and even between strew slides of the same samples. The results provide an inconclusive but useful indicator of the total count required to give statistically accurate abundances of the most common types and a measure of the number of particle types present on a strew slide.

3. Rittenhouse curve. After Lewis had obtained all his count data, he determined that differing proportions of the various types of structureless organic matter were critical in defining the different palynofacies types. However, he indicated that the presence of other palynomorphs or palynodebris in lesser amounts would also be, critical in several instances, in defining the particular palynofacies type. As no single type could be selected as the least critical form, Lewis decided to define a relative percentage, such that when the count was sufficiently large, it could be considered statistically valid and thereby satisfy the criteria defined by Farley [1988]. In an effort to maximise the information that could be gained from the less common forms, but avoiding the need to make large counts, Lewis chose a relative abundance of 5 percent. Using the Rittenhouse graph a count of 150 grains indicates that a relative percentage of 5 percent has a standard deviation of 38 percent (5 ± 1.9 percent = 7.5 counts $\pm$ 2.85 counts). A count of 200 grains reduces the standard deviation to approximately 32 percent (5 ± 1.6 = 10 counts $\pm$ 3 counts) and a total of 300 indicates a standard deviation of approximately 25 percent (5 ± 1.25 = 15 counts $\pm$ 3.75 counts). A total count of 400 grains only reduces the standard deviation on a relative abundance of 5 percent to 23 (5 ± 1.15 = 20 counts $\pm$ 4.6). In a total count of 500, a component of 5 percent of the total count has a standard deviation of 20 percent.

The above discussion indicates that there is still some disagreement between workers. However, the majority suggest that counts between 200 and 300 are sufficient. Lewis [1995] decided that a total count of 300 represented a good compromise between effort in counting and satisfactory results. This total count number is considered acceptable and was maintained for this study for the following reasons:

- Counting more than 300 hundred particles would not reduce the standard deviation of the data significantly. The uncertainty in proportions is also acceptable;
- A count of 300 is double the size considered sufficient to ensure accuracy for the abundant forms [Lewis, 1995];
- One further advantage of counting 300 particles is that, according to Lewis's calculation using the double quadrat technique, all of the rare types should be encountered by this figure.

Counting Procedure

Many palynofacies workers favour electronic point counters to stepping stages for recording the abundance of palynomorphs and debris on a strew slide [*e.g.*, Nøhr-Hansen, 1989; Waterhouse, 1995; Tyson, 1995]. Edwards & Gunson [1978] recommended using an electronic Coulter Counter to count the marker grain in absolute abundance studies. The total sum chosen does not include the marker grains, but all indigenous grains can be expressed in terms relative to the marker grain. This approach was selected in the present study. Isolation of the twelfth channel on a Swift Model-F-12 channel point-counter attached to a light microscope enabled a separate and concurrent account of the occurrence of the *L. clavatum* grains used as a marker.

The counts were always commenced in the north-west part of the slide, traversing eastward until the count total was reached. Stage coordinates were recorded for both the first and final fields of view using an England Slide Finder. The slide was advanced five increments between fields of view. Within each field of view, counting commenced in the north-east and proceeded clockwise per quarter until the total count was reached. Particles straddling the edges of the field of view were included in the count if more than 50 percent of their surface was inside the boundary. If the edge of the slide was reached before the total was obtained, the slide was returned to the start position and moved two

quadrants north using an England Slide Finder. At the end of each count, the slide was scanned for any features/rare forms that were not included in the count but were palaeoenvironmentally significant.

2.8 Analysis

2.8.1 Selection of Statistical Techniques

The raw data generated by counting are strongly multivariate and comprise a large primary matrix. Traditionally, the relative values have been displayed alongside a lithological log in order to gain a subjective appreciation of the spatial and temporal variations. To obtain more objective quantitative results, prior to assessing the stratigraphic distributions, it was decided in the present study to employ multivariate statistical analysis, as this is one of the most profitable methods of identifying meaningful trends in large data sets. The choice of a specific multivariate statistical technique depends mainly on the type of information required from the data set. Two major groups of multivariate analysis exist; classification and ordination. Both summarise complex multidimensional data sets, however, they differ in strategy and outcome. Classification is based on the recognition of discrete groups within a data set and assumes discontinuities exist. It was decided not to use cluster analysis in the determination of the sample groupings, because such analysis probably forces the samples into clusters and thus may impose structure on the data where none exists. The limitations of clustering methods is briefly discussed by Gordon [1981]. Ordination is a more advanced technique for ecologists, as it can arrange variables in ecological space in relation to environmental gradients and produce ordination diagrams. Two types of ordination exist: indirect and direct. Indirect ordination is concerned with assessing the internal variability of a data set independent of environmental data, which in this study can be considered to be relevant to a variety of factors including sedimentary facies and grain-size. Direct ordination methods or canonical analysis permits the dual analysis of environmental variables and data sets to display associations between assemblages and environmental variables. This method makes a separation on the basis of intra-and inter-group variations, in comparison to indirect ordination that makes a separation of total variation [Farley, 1988].

In the statistical analysis, three goals were identified: firstly, to gain an appreciation of the underlying controls on the genesis of particular associations of organic matter; secondly, to test the usefulness of palynofacies as an environmental indicator, and thirdly, to determine the palynofacies assemblages

based on the similarity and dissimilarity of the type and content of organic matter. The identification of different palynofacies assemblage-types, on the basis of identifying discrete samples from their palynomorph/debris composition, is similar to the recognition of plant communities, in vegetation analysis. Therefore many of the ideas and philosophies used in ecology, for example the application of multivariate statistics relating to the recognition of trends and patterns in plant communities, have been considered in the interpretation of the statistical output. Several good accounts on this method of analysis are available, for example Pielou [1975]; Digby [1987]; Kent & Coker [1992]. Furthermore, Kovach [1988] and Kovach & Batten [1994] reviewed the application of multivariate statistical techniques to palaeoecological data.

Correspondence Analysis, an indirect ordination technique and Canonical Correspondence Analysis, a direct ordination technique, were selected following their successful application in many palynological studies, [e.g., Lewis, 1995; Mussard *et al.*, 1994]. Both programmes are one of several techniques available on CANOCO [ter Braak, 1988].

An advantage of applying correspondence analysis to the count data is the simultaneous analysis of the palynomorphs/palynodebris categories and the samples. In turn, the scores from correspondence analysis provide axes for the construction of a palynomorph/palynodebris ordination diagram and a sample ordination diagram. The result of this is that the sample ordination is a measure of the samples' palynomorph/palynodebris composition, and the palynomorph and palynodebris ordination diagram is a measure of their distribution across the samples. Further attributes of these diagrams and their interpretation are explained in Chapter 3.

Canonical Correspondence Analysis was selected to investigate the relationship between environmental data and the associations of organic matter. This method was also chosen to test the significance of the interpretations from CA as these are subjectively assigned. Scatter plots of the canonical variables show how well the samples/species separated and enable the group or groups which characterise various environments to be documented. In this study, a combination of both particle frequencies and classification of samples by environment were used to elucidate the presence of trends or patterns between the assemblages and environmental variables. The detailed methodology of this technique is explained later using a data set that exemplifies its capabilities. To evaluate the significance of the data set, the Monte Carlo test, available on Ter Braak's programme, was applied.

2.9 Conclusions

This primary aim of the work presented in this chapter was to develop a robust classification scheme and evaluate the merits of different data analysis techniques. A review of the plethora of classification schemes available led to the development of designated classification procedures. These were used to tailor Lewis's [1995] classification scheme rather than promulgate yet another scheme. The modifications resulted in the generation of a hierarchical scheme with increasing detail and different modes of microscope illumination being incorporated at each successive phase. This sequential style of classification permits the operator to expand the categories if desired whilst allowing comparison with other schemes. Thus, in the present study, more attention was paid to palynodebris, in comparison to palynomorphs, in order to maximize the amount of information available from this type of organic debris. Finally, a consistent effort was made to ensure confidence in the data set, ranging from the careful sampling strategy and processing method employed to the selection of the most suitable statistical method.

Chapter 3

Controls and Assemblages

3.1 Introduction

It is paradoxical that the nature of organic matter is often used as an environmental indicator but the way in which organic matter, in particular palynodebris, changes between environments, and the mechanisms which govern the development of particular associations, are not well understood. The controls on the distribution of palynomorphs and palynodebris through a sedimentary succession are very complex, and different workers have made a number of different qualitative proposals regarding the nature of the controls. For example, Farley [1988] divided the controls into three major groups: stratigraphic, geographic and depositional. Stratigraphic factors include differences due to evolution, migration of taxa in or out of the depositional basin and long-term climatic shifts. Geographic factors include effects on a limited area of the depositional basin, for example, rainfall, local elevation and/or water-table variations within a depositional environment. Depositional factors include all effects due to differences between local components of sedimentary environments [Farley, 1988], *e.g.*, transportation to the depositional site and alteration of the organic matter once deposited. Tyson [1989], in contrast, focused upon the depositional controls and identified the most important as: grain-size of sediment, proximity of depositional site to fluvio-deltaic sources and prevalent redox conditions. No published work has, however, made any quantitative distinction between major and minor influences. In addition, a number of workers [*e.g.*, Gastaldo, 1996] have demonstrated that different lithofacies may display the same associations of organic matter and, conversely the same lithofacies may reveal different associations. Hence, the degree to which organic matter yields a reliable depositional and, potentially, vegetational and climatic signal is equivocal.

This chapter concerns the quantitative evaluation of the relationships between the different categories of particulate organic matter, the controls which govern the development of particular types of organic matter, the reliability of palynofacies as an environmental indicator, and the determination of the assemblages of organic matter and their relationship to environmental variables. It is important to identify the different assemblages of organic matter and gain an appreciation of the underlying controls on the genesis of particular associations of organic matter for two reasons; 1) to improve the reliability of the interpretation, and 2) to recognize the of assemblages of organic matter and their respective environmental indicators which form the framework for any palaeoenvironmental study based on palynofacies analysis. The remainder of this section provides the reader with an overview of the directions and approaches employed herein.

The conventional approach, outlined by Batten [1973] and employed by many other workers, including Whitaker [1984] and Lewis [1995] in palaeoenvironmental reconstruction studies, was initially used in this study. This technique involves the recognition of recurrent associations of particular types and proportions of organic matter which are then qualitatively related to specific environmental conditions. These associations of organic matter are termed assemblages. After initial use of the conventional method, it was believed, however, that it could bias the data by forcing the samples into rigid groups and impose structure on the data where none existed, thus masking the true homogeneous nature of the data. Moreover, this approach would make it very difficult to address the question: ‘what controls the development of particular types of palynofacies assemblages in the sedimentary record?’

In the present study, the complex relationships between the samples and categories of organic matter were evaluated quantitatively using multivariate statistical analysis, namely Correspondence Analysis (CA), an indirect ordination technique. In this investigation, this technique summarises the information in the data matrix and arranges the samples in relation to each other along axes on the basis of their organic matter composition. The CA output is plotted in either two or three dimensions. In accordance with previous researchers in palynofacies, it is assumed that there is underlying structure in the data, *i.e.*, that the occurrence and nature of the organic matter under consideration is determined by environmental variables. Thus, assessment of the configuration of the data, (*i.e.*, arrangement of the organic matter categories and samples along the axes) may permit the formulation of ideas about the form as well as causal relationships between organic matter associations and possible controls.

CA was also used to test the validity of the conventionally defined assemblages by categorising sample scores according to their previously defined assemblage group. In addition, the possible controls, identified from the configuration of the organic matter and sample score data were superimposed on the graphical output. To extend the assessment of the controls, output from statistical analysis was compared to stratigraphic position, grain-size of the host sediment and 'environmental variables' (*e.g.*, presence or absence of macroscopic floral remains and burrowing). The latter investigation was carried out using Canonical Correspondence Analysis (CCA), a direct ordination technique which permits the dual analysis of organic matter-environmental relationships and selects the environmental variables that best explain the variations in the organic matter composition. Finally, to evaluate the reliability of palynofacies as an environmental tool, the statistical output was compared to an independently established lithofacies scheme.

The findings from both the conventional approach and statistical analysis were integrated to define the assemblage groups/types employed in the palaeoenvironmental study discussed in Chapter 4. It is important to realise that the output from the statistical analysis comprises an enormous amount of information. This chapter discusses only the salient points. However, the assemblage groups/types used in the palaeoenvironmental reconstruction in Chapter 4 are based on a detailed examination of the primary data and statistical output.

3.2 Background

258 samples were used to investigate the palynofacies characteristics of the Middle Jurassic, Cleveland Basin and Brent Group of the East Shetland Basin. To provide a framework for this chapter, summary lithological descriptions of the main sections investigated for palynofacies analysis are presented in Figures 3.1 to 3.3. Details of the Ravenscar cores which was used as a framework are contained in Appendix F, along with details of the core from the Brent Group. These graphical descriptions show the range of environmental settings investigated, location of the sample points and lithofacies categories defined by Morgans [1997] and Ichron [1996]. The results of the count data are presented in Appendix D. These tables contain the relative percentage abundance for each individual category, as a matrix of samples by palynomorph/palynodebris categories. A selection of parameters associated with the index of organic matter per gram of sediment are also included. Details of the calculation of the index of organic matter are contained in Section A.3.

Figure 3.1: Summary lithological descriptions of Loftus, Whitby, High Hawsker and Blea Wyke. Key to the sedimentary descriptions is contained in Appendix F. No horizontal scale implied. Location of sections shown in inset map. Numbered sample points are shown on the left of the graphical descriptions for each section. New sedimentary description for the Whitby Mudstone Formation, Dogger Formation and first 10 metres of the Saltwick Formation exposed in Boulby Quarry. New sedimentary description for the lower part of the Saltwick Formation, West Cliff Whitby. The Dogger Formation lies two-three metres below the basal sandstone (pers. comm. Alexander, 1986). Sedimentary description of Dogger and Saltwick Formations exposed at High Hawsker, [after Morgans, 1997] (lithofacies categories defined by Morgans [1997] are included). Section at Blea Wyke comprises Dogger and Saltwick Formations. Description of the Dogger Formation, Blea Wyke, [after Hesselbo, 1995, unpublished].

Figure 3.2: Lithological description and correlation of the sections of Cloughton Formation examined in this thesis. From left to right: IFP core RV18, [Ross and Morgans, 1996, unpublished]; Cloughton Wyke (TA 020 951) [after Morgans, 1997]; Osgodby Nab (TA 064 854), [after Morgans, 1997] and Yons Nab (TA 081 843) [after Morgans, 1997]. Location of the sections is shown in the inset map. No horizontal scale is implied. Numbers beside lithological description correspond to sample numbers.

Figure 3.3: Sedimentary description of Scarborough Formation. From left to right: IFP core RV18 [Ross and Morgans, 1996 unpublished], Hundale Point [after Morgans, 1997] and Yons Nab [after Morgans, 1997]. No horizontal scale is implied. Numbers beside description correspond to sample numbers.

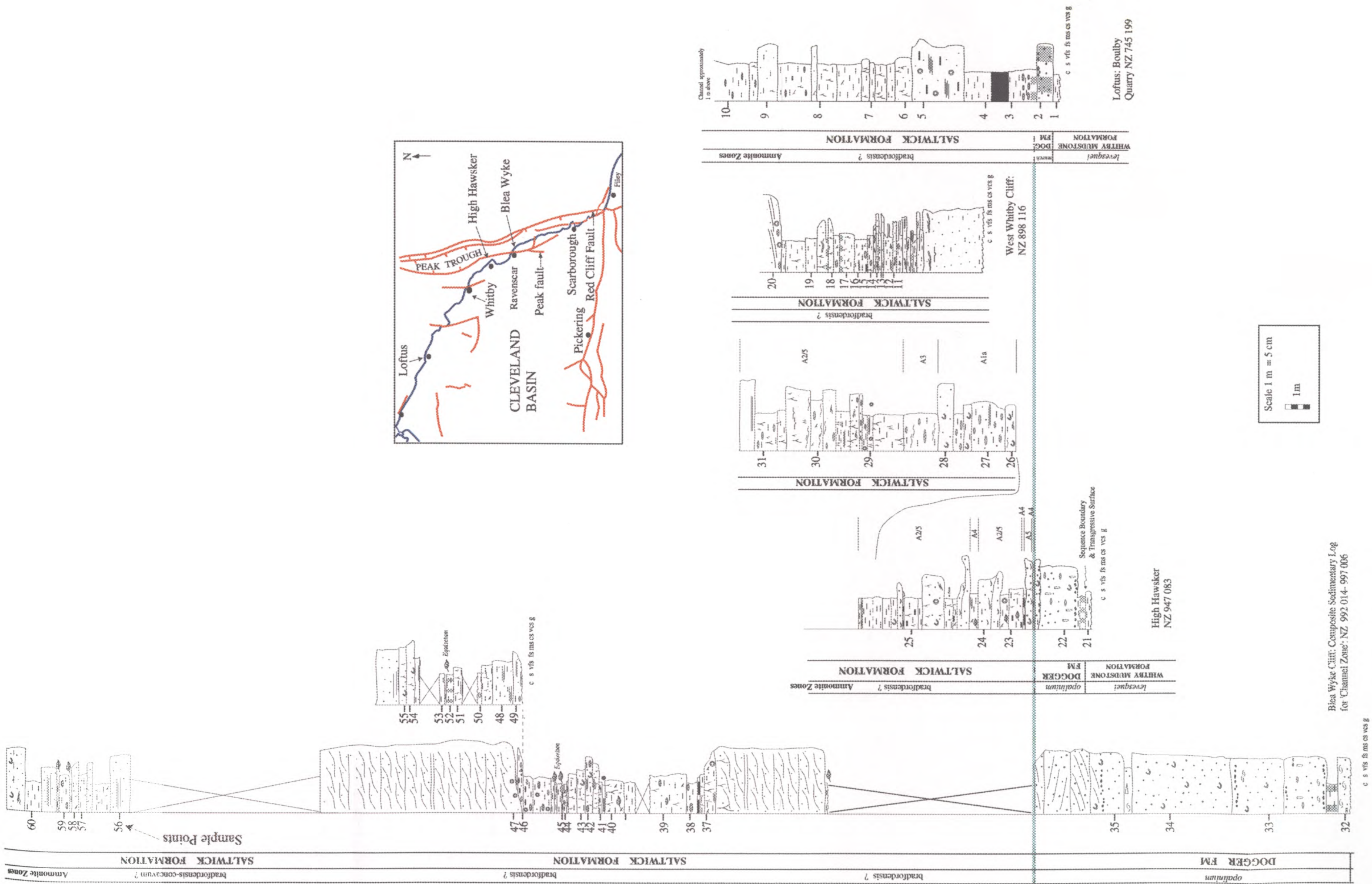


Figure 3.4:

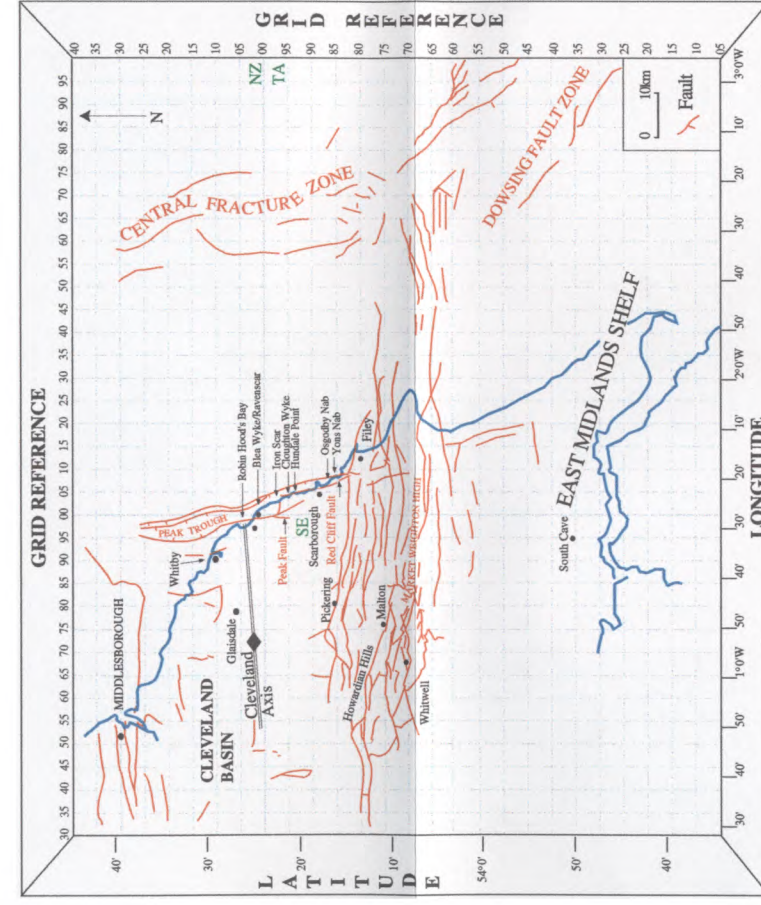
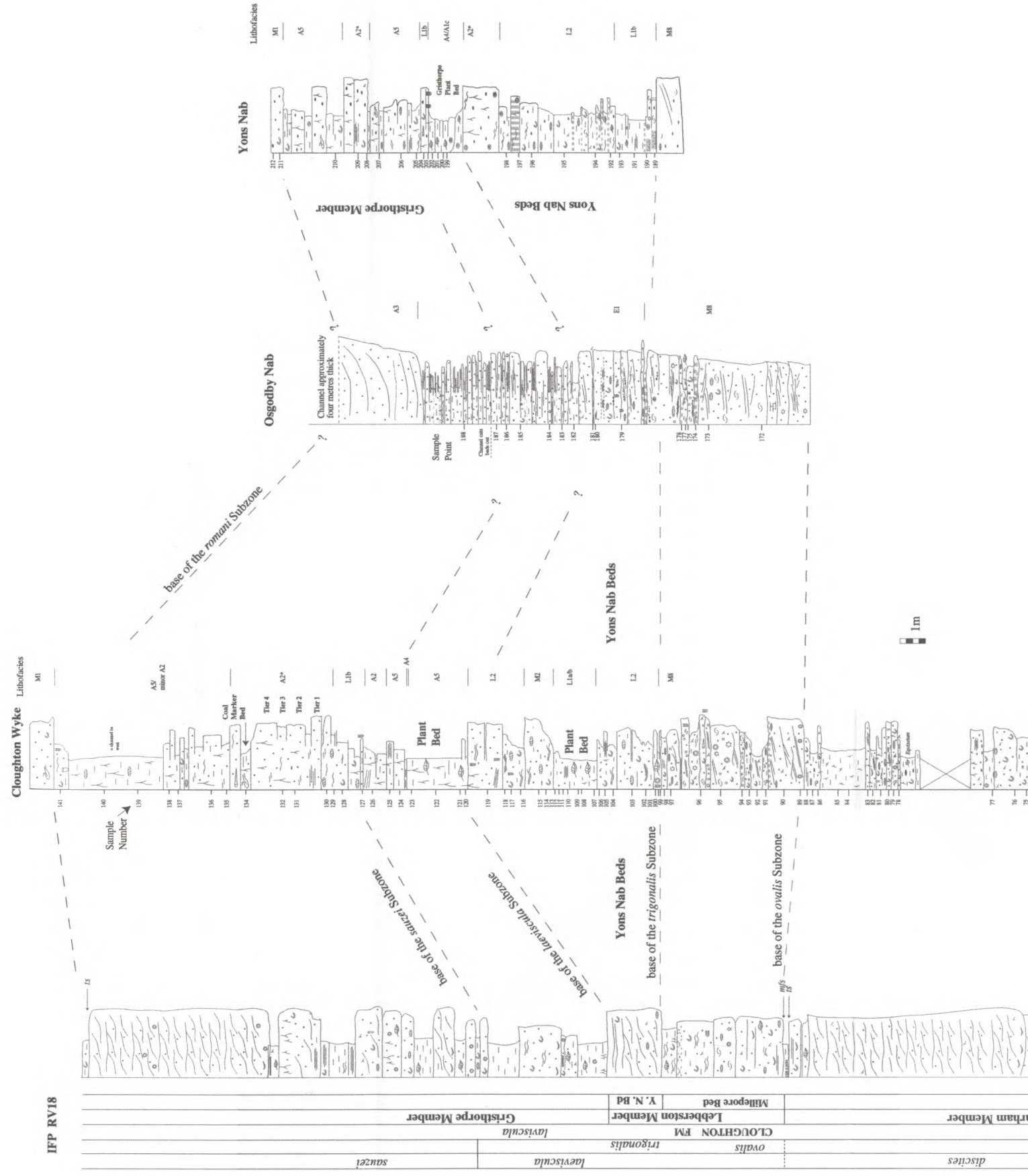


Figure 3.5:

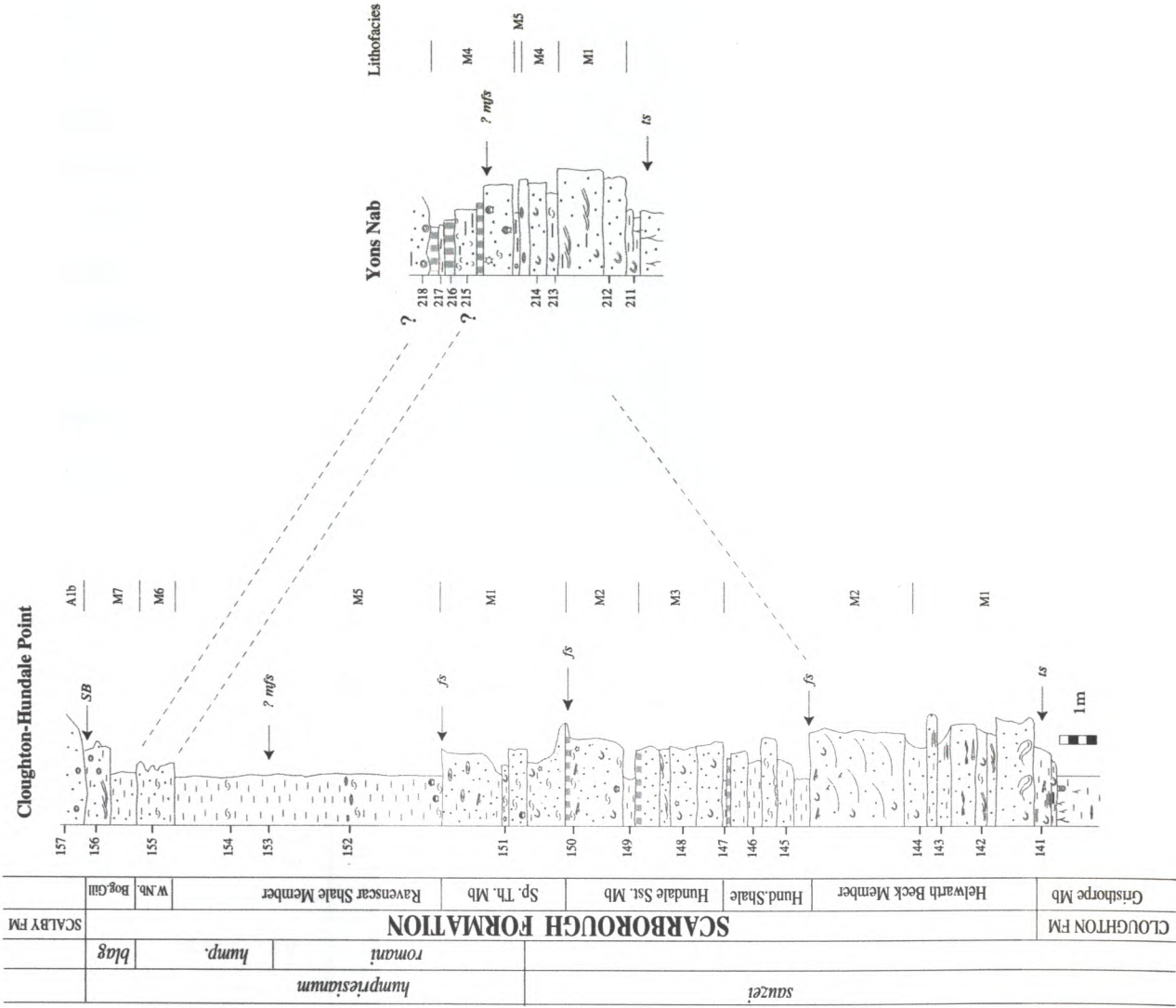
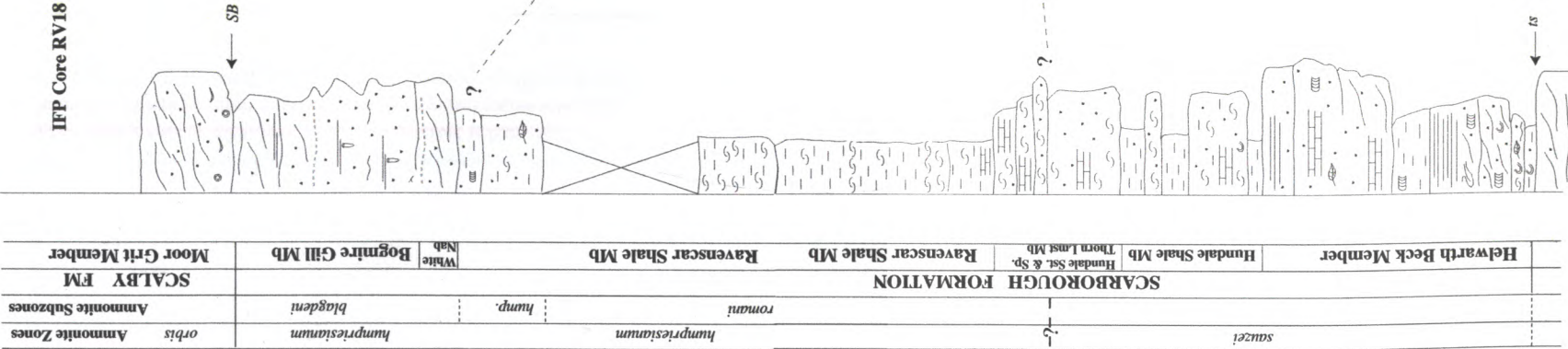
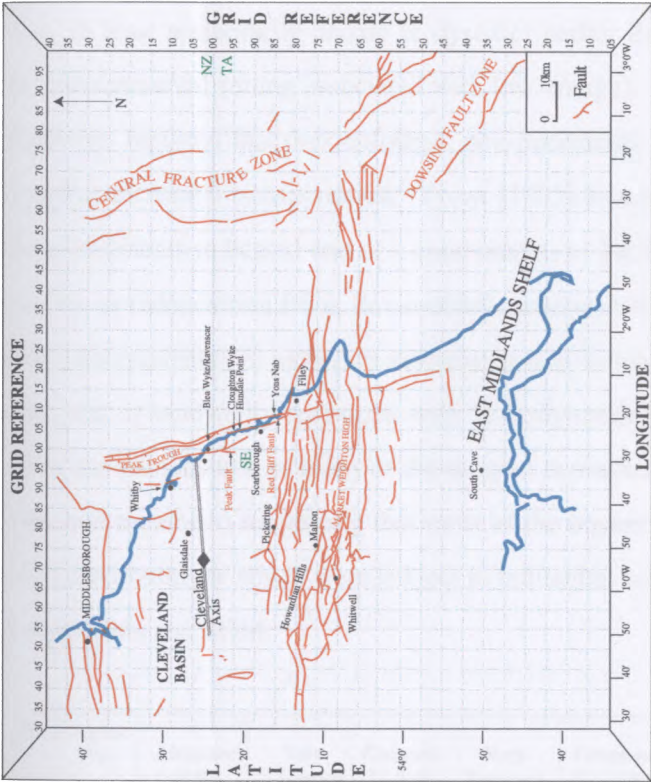


Figure 3.6:

To provide an overview of the major patterns observed in the preparations, the proportion of each *major* type of particulate organic matter is displayed in Table 3.1: palynomorphs, discrete fragments and structureless organic matter (SOM). This clearly demonstrates that structureless organic matter is the most frequent component, followed by discrete fragments and finally palynomorphs. Tyson [1995] suggested that large proportions of SOM indicate either, accumulation in a reducing environment (*i.e.*, at least temporarily anoxic to dysoxic) and/or limited exposure to physical degradation (*e.g.*, an environmental setting associated with low-energy). Many workers, including Lewis [1995] have, however, reported that dark-coloured, non-fluorescent SOM is indicative of well-aerated sediments and/or increased transportation. Tyson [1995] also indicated that relatively large quantities of discrete fragments indicated one or a combination of the following factors: a) deposition in close proximity to, or redeposition from, fluvio-deltaic source(s) of terrestrial organic matter (which would dilute other components), b) oxidizing environments in which other components have been selectively destroyed, and c) sandy/silty sediments with hydrodynamic equivalence. It is also evident from Table 3.1 that the composition of many of the samples is transitional, in that they contain fragments and SOM (the end members) suggesting that most of the organic matter investigated in this study accumulated in environments which were subject to influential controls associated with the accumulation of both fragments and SOM.

No. samples (%) Category	Abundant (>50%)	Very Common (31-50%)	Common (21-30%)	Very Frequent (16-20%)	Frequent (11-15%)	Occasional (6-10%)	Very Occasional (1-5%)	Rare (0-1%)	Absent (0%)
Palynomorphs	0.39	2.7	10.8	13.6	15.2	18.9	21.7	12.8	3.9
Fragments	11.6	34.5	18.9	12.0	12.0	5.8	3.87	0.7	0.39
Structureless Organic Matter (SOM)	65.9	25.9	5.8	0.7	1.2	0	0.39	0	0

Table 3.1: Percentage number of samples which occur within each ‘abundance’ category of either palynomorphs, discrete fragments or SOM. SOM is the most frequent fraction, followed by discrete fragments and finally palynomorphs. Many of the preparations contain relatively similar concentrations of SOM and discrete fragments.

3.3 Conventional Analysis

During the course of this study it became apparent that certain samples contained similar assemblages of particulate organic matter which could be recognised visually. The term ‘assemblage’ refers to total organic content of a preparation which contains a combination of recurrent associations of characters that form the basis of an ‘assemblage’ [Batten, 1973]. Batten [1973] also noted that the classification and recognition of different assemblages forms the main preliminary step towards a palaeoenvironmental study based on palynofacies analysis. These data can then be integrated with other stratigraphic and sedimentological information to provide a more comprehensive palaeoenvironmental study.

Samples were initially distinguished into assemblages by employing a conventional approach, similar to that devised by Batten [1973], who examined the predominantly terrestrial material from the Cretaceous of southern England. This technique has been employed by a number of workers who investigated a variety of different settings, for example, Whitaker [1984] and Lewis [1995]. Batten [1973] defined assemblages on the basis of particle types that form the key characteristics of the assemblage, either by virtue of their abundance, absence, or by their very distinct appearance. Thus, each assemblage consists of a set of recurrent associations of ‘key characters’ or identifiers. Both Batten [1973] and Lewis [1995] recognised six ranges of relative abundance. In the present study, nine relative abundance classes were used, as illustrated in Table 3.2, to enable a more detailed investigation of the different assemblages of organic matter.

The conventional technique of separating the data into assemblages on the basis of key characteristics led to the identification of seven groups of assemblages, A-G. The proportions of key components are expressed qualitatively as illustrated in Table 3.2. This method highlights the abundance of particular components more effectively than if the ranges of relative abundances were presented [Lewis, 1995]. Assemblage groups A-F all comprise absent or rare dinoflagellate cysts, *i.e.*, dinoflagellate cysts are less than or equal to ¹ rare relative percentage abundance. Samples in assemblage group G contain more than rare dinoflagellate cysts, *i.e.*, dinoflagellate cysts are greater than or equal to ² very-occasional dinoflagellate cysts. The assemblage groups are described below. Details of the samples assigned to each assemblage groups are displayed in Figure E.1.

¹less than or equal to is herein after referred to as ($\leq$)

²greater than or equal to is herein after referred to as ($\geq$)

Relative Percentage Abundance	Qualitative Nomenclature	Code
0%	Absent	AS
0-1 %	Rare	R
1-5 %	Very-Occasional	V O
6-10 %	Occasional	O
11-15 %	Frequent	F
16-20 %	Very-Frequent	VF
21-30 %	Common	C
31-50 %	Very-Common	V C
>50 %	Abundant	AB

Table 3.2: Relationship between relative percentage abundance, qualitative terms and codes. The relative percentage abundance values were rounded up or down to the nearest whole number.

- Assemblage Group A: abundant SOM, which comprises $\geq$ very-common transparent-yellow, fluorescent, non-fibrous SOM, and $\leq$ very-frequent for any other component;
- Assemblage Group B: abundant SOM, which consists of a range of different fractions of SOM, (*i.e.*, transparent-yellow, fluorescent, non-fibrous SOM, usually $\leq$ very-common), total fragments $\leq$ common, and palynomorphs $\leq$ occasional;
- Assemblage Group C: Very-common discrete fragments, total of fragments are always $\leq$ total SOM, and total palynomorphs $\leq$ occasional;
- Assemblage Group D: Palynomorphs $\geq$ occasional, total SOM $\geq$ total discrete fragments;
- Assemblage Group E: Total discrete fragments $\geq$ total SOM, and palynomorphs $\leq$ occasional;
- Assemblage Group F: Total discrete fragments $\geq$ total SOM, and palynomorphs $\geq$ frequent;
- Assemblage Group G : Dinoflagellate cysts $\geq$ very-occasional.

These assemblage groups were separated into subgroups using variations in abundance and types of SOM, nature of non-vita discrete fragments and, to a lesser extent, the abundance of different types of palynomorphs. For example, variations in the relative percentage abundance of fluorescent

and non-fluorescent SOM were used to segregate the samples, in each assemblage group, into three subgroups. Details of the criteria are displayed in Table 3.3.

Subgroup	Criteria
Strongly-Fluorescent	Total fluorescent SOM 11% greater than total non-fluorescent SOM
Intermediate Fluorescence	Difference between total fluorescent and total non-fluorescent SOM less than or equal to 10%
Weakly-Fluorescent	Total non-fluorescent SOM 11% greater than total fluorescent SOM

Table 3.3: Fluorescent subgroups and classification criteria. Details of the samples assigned to the different subgroups are contained in Figure E.1

The rigid and inelastic nature of the groups defined by the conventional method probably impose structure on the data where none existed and conceal its true nature. In this form, it is therefore very difficult to appreciate the mechanisms which govern the genesis of the different associations of organic matter. Thus, to identify quantitatively the complex relationships between all samples and particulate organic-matter categories, determine the relative influences of the driving mechanisms and test the validity of the above assemblage groups, multivariate statistical analysis was performed on the dataset.

3.4 Statistical Analysis

Multivariate statistical techniques have proven to be very useful in investigating large data sets [Kent & Coker, 1992] because they enable simultaneous examination of the various different constituents. A number of workers, including Lewis [1995], who examined the nature of the particulate organic matter from Late Cretaceous terrestrial deposits, have used multivariate statistics to display the relationships between individual components of organic matter and samples. In statistical studies the standard nomenclature used to describe the variables under investigation are ‘species’ and ‘samples/sites’ [Kent & Coker, 1992; Jongman *et al.*, 1987; ter Braak, 1990]. For example, Lewis [1995], who used multivariate statistics, employed the term ‘species’ to describe the organic matter components in his samples. According to William *et al.* [1972] the term species has both ‘logic’ ³

³The common attributes or essential qualities of a class of persons or things

and ‘zoological/biological’⁴ meanings. In the present study, the term species has previously been used in the biological sense (Chapter 2). Thus, to distinguish between the biological and statistical use of the term, the word ‘*species*’ is italicised when it is used in the statistical sense, *i.e.*, *species*⁵. Prior to discussing the findings from the present study a brief synopsis of the assumptions, method and properties of multivariate tri- and bi-axial plots is provided.

3.4.1 Indirect Ordination

Ordination is a method of data reduction and exploration leading to hypothesis generation. The methods are essentially descriptive and enable researchers to formulate ideas about the nature and form of the different associations of organic-matter categories (*species*) as well as causal relationships. Indirect ordination is based on analysis of data independently of any preconceived notions of controlling environmental factors [Kent & Coker, 1992]. The indirect ordination method selected in this study was Correspondence Analysis (CA). This technique assumes the response curves are unimodal, as illustrated in Figure 3.7B, (*i.e.*, the response of the community variables are non-linear and non-monotone). Earlier statistical methods, for example principal-component analysis, either assumed linear relationships, as illustrated in Figure 3.7A, or were restricted to regression analysis of the response of each variable separately [ter Braak, 1988]. Thus, CA escapes the assumption of linearity and is able to detect unimodal relationships. The latter is more suitable because it is very unlikely that the community response of organic matter is linear, given the magnitude and complexity of the environmental controls.

CA examines the similarity or dissimilarity of the composition of the samples: *i.e.*, the concern is with the internal variability of the data. Jongman *et al.* [1987] and Kent & Coker [1992] stated that it may be assumed that variability in the data will inevitably reflect variations in the environmental controls. Thus, the purpose of ordination, in the present study, is to recover the latent structure and in the process show how organic-matter associations develop in response to environmental factors.

⁴A group or class of animals or plants (usually constituting a subdivision of a genus) having certain common and permanent characteristics which clearly distinguish it from other groups

⁵In this study, species refers to the organic matter categories and index of organic matter per gram of sediment

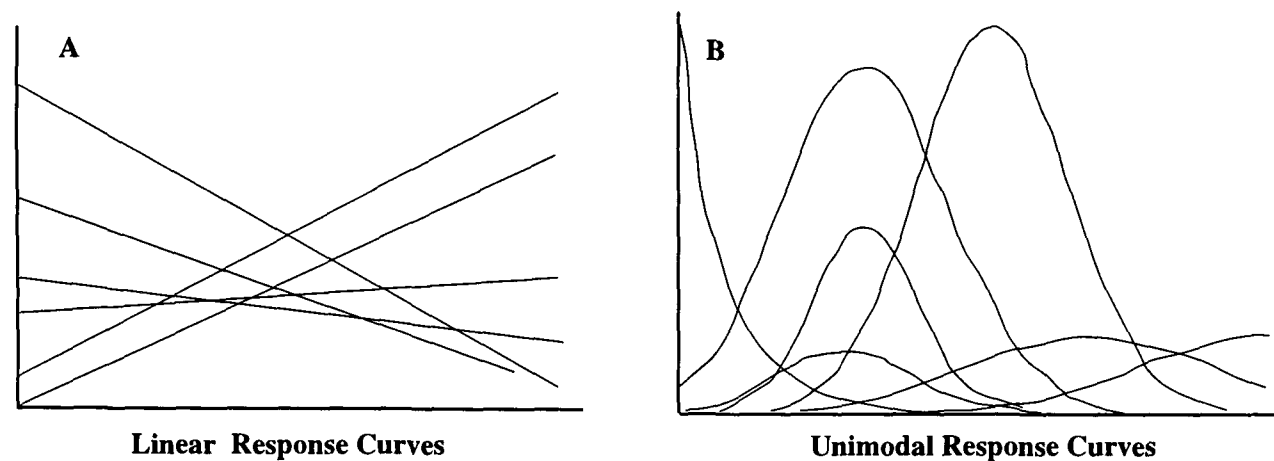


Figure 3.7: Figure A shows a typical range of linear responses and Figure B illustrates a range of unimodal response curves [after ter Braak, 1988]

3.4.2 Correspondence Analysis (CA) method and plots

The data matrix contained in Appendix D was altered to meet the requirements of CA which is a fortran-based programme. CA was conducted on this new matrix and the resultant score data were used to construct the axes of either the two- or three-dimensional plots. A synopsis of the method is provided in the discussion below and in Figure 3.8. For a more detailed overview the reader is referred to Kent & Coker [1992].

Method

The starting point is the allocation of weighted averages for the *species* and sample data as outlined in Figure 3.8. The calculation of weighted averages is applied to the data matrix so that sample scores are derived from *species* scores and weightings and conversely, *species* scores can be similarly derived from sample scores and weightings. These calculations are carried out successively using an iterative procedure, initially from arbitrary sample scores and continues until the data stabilizes to give a set of scores for the *species*. This gives axes for the *species* ordination and a set of scores for the samples which constitute the first CA axis. This axis maximally separates the data by maximizing the dispersion.

A second ordination axis can also be extracted from the data. These are calculated by the same iteration process, with one extra step termed orthogonalization [Jongman *et al.*, 1987] which makes the trial scores for the second axis uncorrelated with the first axis. This procedure, which is performed by the CA programme, can be explained by the following method outlined by Jongman *et al.* [1987]. The new set of initial scores are made uncorrelated with the scores of the first axis by plotting in

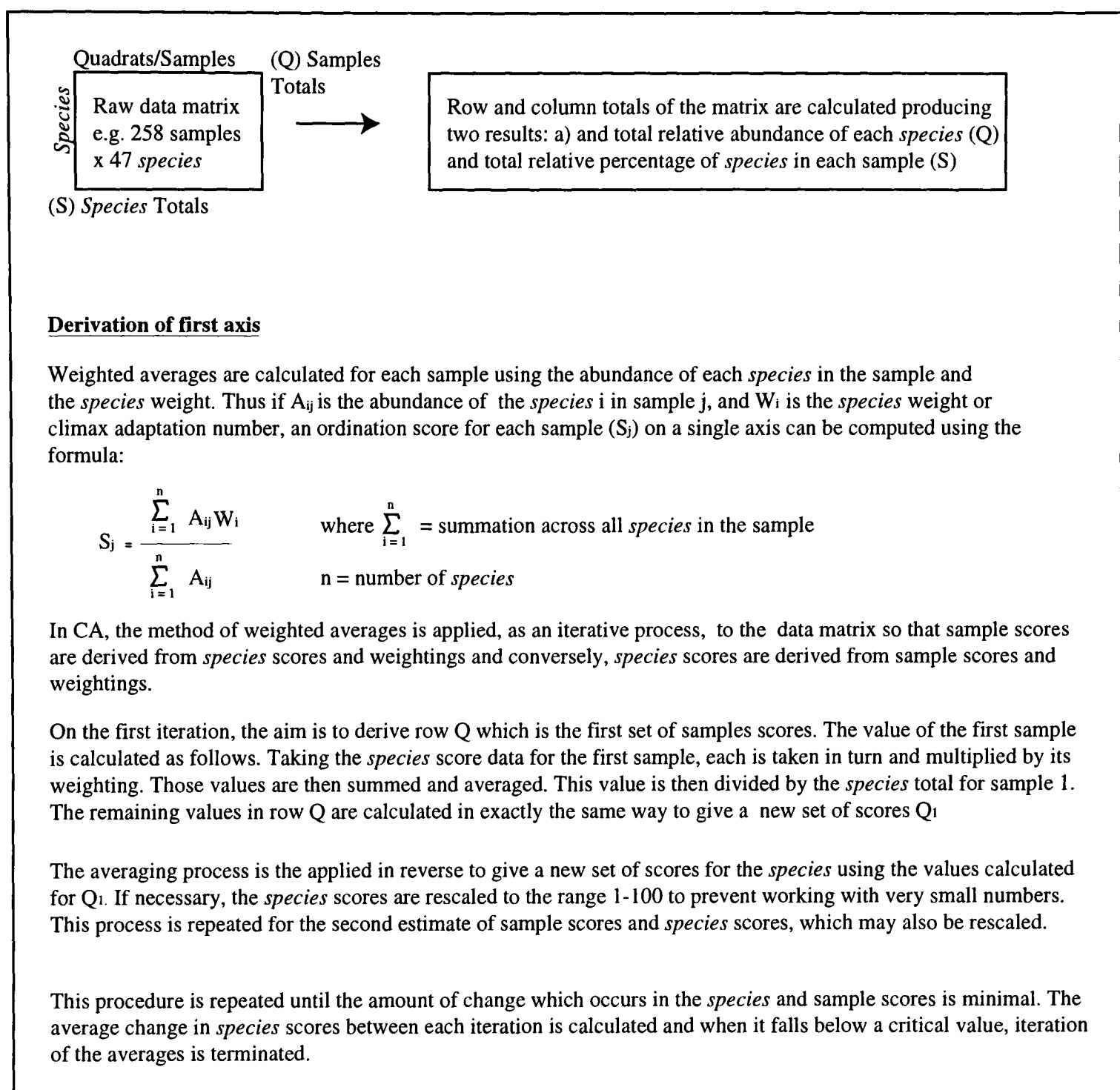


Figure 3.8: Summary of the procedures used in CA to calculate the first ordination axis, (after Kent & Coker [1992]).

each cycle the trial sample scores for the second axis against the sample scores of the first axis and fitting a straight line by a (weighted) least-squares regression. The residuals from this regression (*i.e.*, the vertical deviations from the fitted line) are the new trial scores. Without this orthogonalization procedure the iteration process would lead to the first axis. This extra step is included to ensure that new information is expressed on the second axis. A third and fourth axis and so on can be derived in the same way by making the scores uncorrelated with the scores of the first two axes, and so forth.

It is important to realise that axes may be calculated until the number of axes equals the number of *species* categories (palynomorph/palynodebris and index of organic matter content) which in this

study is 47. In mathematics, the ordination axes of CA are termed eigenvectors. If an extra iteration cycle is performed, the scores remain the same, so the vector is transformed into itself, hence the term eigenvector. In CA each eigenvector has a corresponding eigenvalue which is a measure of separation of the *species*’ distribution along the ordination axis and is thus a measure of ‘importance’ of the ordination axis. Eigenvalues of 0.3 and higher are quite common in ecological applications [ter Braak, 1988]. In palaeobotanical studies values of 0.1 are quite common. The sum of all the eigenvalues across all axes is equal to one. The higher the value the more important the axis, and the greater the dispersion on that axis. As eigenvalues generally reduce in size and importance with successive axes, it is not necessary to consider the higher axes. In this study three axes were considered sufficient to explain the variance in the data set.

The CANOCO program provides the operator with several options for scaling the *species* and sample ordination. All the scaling options provide an identical summary of the ordination and the same ordering of the ordination axis [ter Braak, 1990]. The different scalings do, however, influence the amount of scatter of the *species* and sample points in the ordination diagram, and hence affect the interpretation of the plots.

- Scaling-option one: sample scores are weighted mean *species* scores
- Scaling-option two: *species* scores are weighted mean sample scores.

Scaling-option one should be used if the configuration of the *species* is of prime interest, whereas scaling-option two is employed if the focus of attention is on the configuration of the samples. Scaling-option one provides a better representation of the *species* composition of the samples. In joint plots of *species* and sample points, the range of *species* scores is greater than that of the sample scores [ter Braak, 1987].

Plots

The CA plots contain a scatter of data points which represent the samples or *species*. In these plots (three- and two-dimensional) the distance between points on the graph is taken as a measure of their degree of similarity or difference. Sample or *species* entities which are close together represent samples that are similar in *species* composition and *species* which are found in association in the samples respectively. The further apart any two points are the more dissimilar or different the samples/*species*

will be [Gauch, 1982]. From CA, it should therefore be possible to assess the relationships between various elements of the samples and *species* and ascertain the underlying controls. No scale is implied on the three-dimensional diagrams because it is the spatial configuration, not the values, that are important. As noted by Farley [1988] it is important to be aware that statistical significance may not necessarily imply biological or geological significance. Appraisal of the statistical output was conducted in conjunction with visual examination of the raw data, assemblages defined by the traditional method and comparison with the findings from other palynofacies investigations.

3.5 Distribution of samples and *species*

3.5.1 Variability in the samples

Figure 3.9A displays the three-dimensional CA sample score ordination results for all the samples investigated in this study. Each individual point in Figure 3.9 represents a summary of the *species* (organic matter) composition found within a particular sample. Few discrete clusters of points are recognisable. There is a large cluster of points in the central region of the plot and a scatter of points towards the outer margins. A minority of these latter points form small discrete clusters, the majority are transitional.

Plots B to D in Figure 3.9 show the planes of the various axes. These two-dimensional plots enable the configurations along the different axes to be envisaged more clearly. They are, however, akin to geological cross-sections or seismic profiles, in that they represent only one plane of a complex inter-related spatial pattern. Thus, interpretation of the spatial distribution has been conducted using both the three- and two-dimensional plots. For convenience, the two-dimensional plots are divided into four ‘quadrants’, SE, SW, NE and NW. It must be noted that this does not signify any geographical relationship.

3.5.2 Inverted Arch

The scatter of points in Figure 3.9B reveals a trend which forms the left side of an ‘inverted arch’ from the NW quadrant to the SE quadrant. The remainder of points occur in an array on the right side of the ‘inverted arch’ towards the NE quadrant. Hill & Gauch [1980] suggested that this arch shape

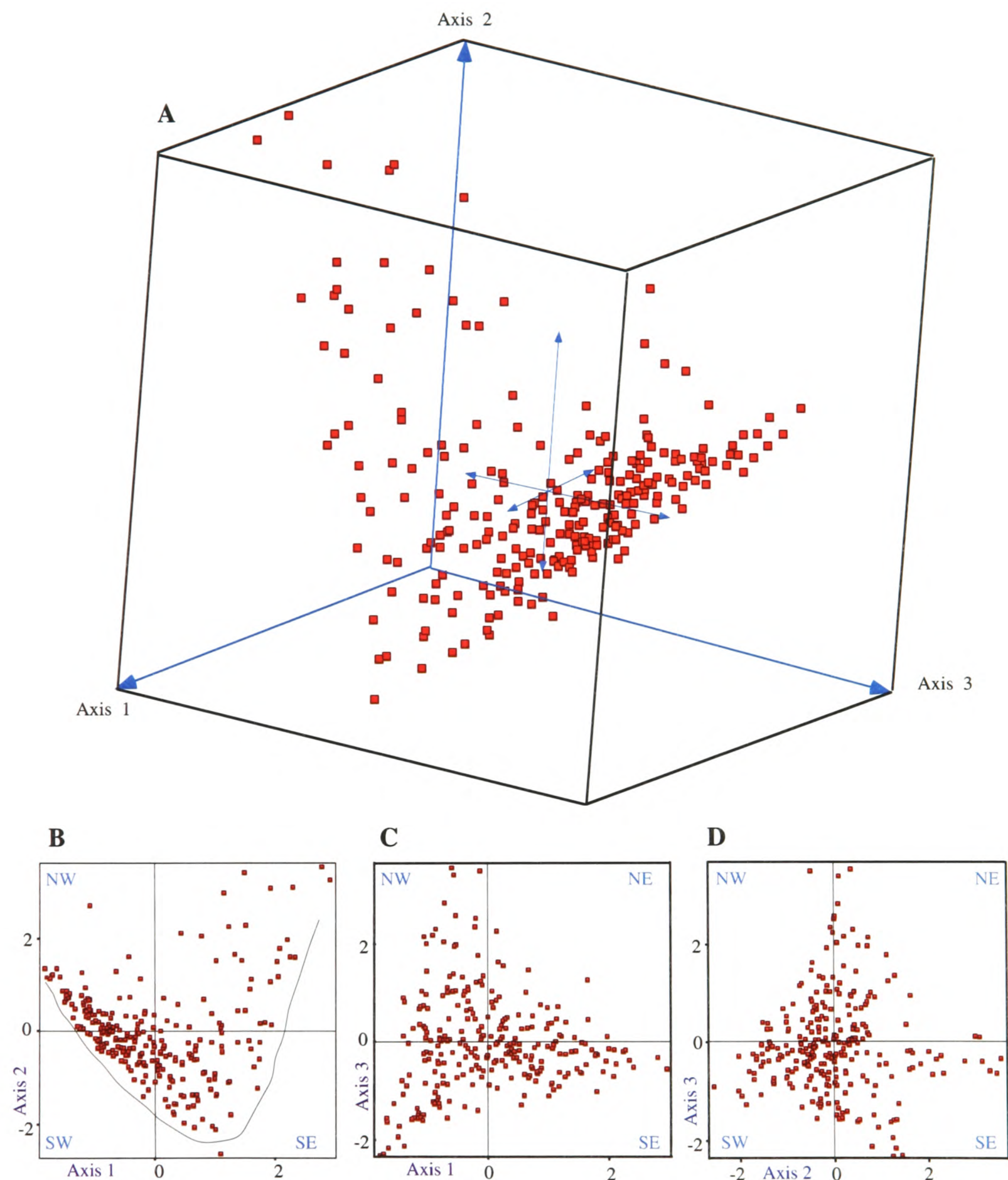


Figure 3.9: Figure A displays the three-dimensional Correspondence Analysis ordination plot of sample scores for all the samples investigated within this study with scaling option one applied. Figure B shows the scatter of points on axes 1 v 2 which occur in the shape of an inverted arch. Figure C shows the plane of axes 1 v 3 and Figure D shows the plane of axes 2 v 3.

may be a mathematical artefact of the orthogonalization process and so not represent any underlying natural controls.

Jongman *et al.* [1987] suggested that the arch is caused by the folding of the first axis, as illustrated in Figure 3.10. In mathematical terms the arch effect is produced when the second axis is approximately a quadratic distortion of the first axis. Kent & Coker [1992] suggested that this problem may continue into higher dimensions *i.e.*, the third axis may have a cubic distortion, the fourth a quartic and so on. Gauch [1982] noted that under the influence of the arch effect, important secondary gradients in the data may not emerge until higher axes because the eigenvalue of the distortion may be greater than the eigenvalue of the actual secondary gradient, particularly when the secondary gradient is less than about half the extent of the primary gradient. Kent & Coker [1992] suggested that under this condition interpretation becomes problematic, and it is difficult to predict which axes may be environmental meaningful.

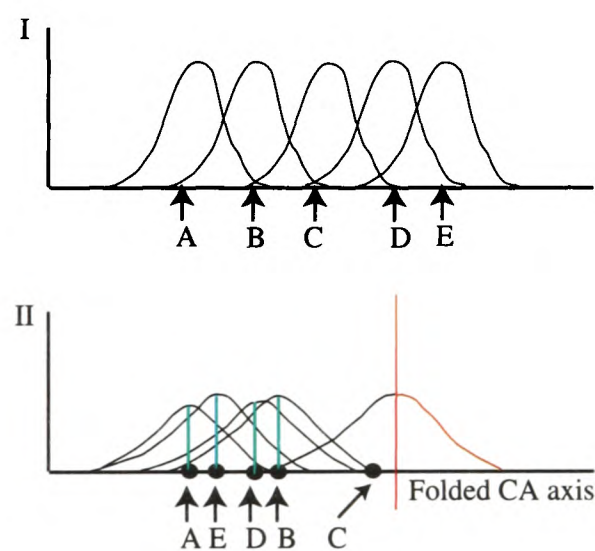


Figure 3.10: Artificial example of unimodal response curve of five species (A-E). Figure I shows the first axis and Figure II displays the first axis of CA folded in the middle [after Jongman *et al.*, 1987].

Detrended correspondence analysis (DCA) was designed by Hill [1979] and Hill & Gauch [1980] in an attempt to correct the arch effect. In DCA, the arch effect is eliminated by a ‘detrending’ process which replaces the usual orthogonalization procedure. This detrending involves dividing the first axis into a number of segments and within each segment the sample scores on Axis 2 are adjusted by subtracting their mean as illustrated in Figure 3.11. Subsequent axes are derived by detrending with respect to each of the existing axes [ter Braak, 1987].

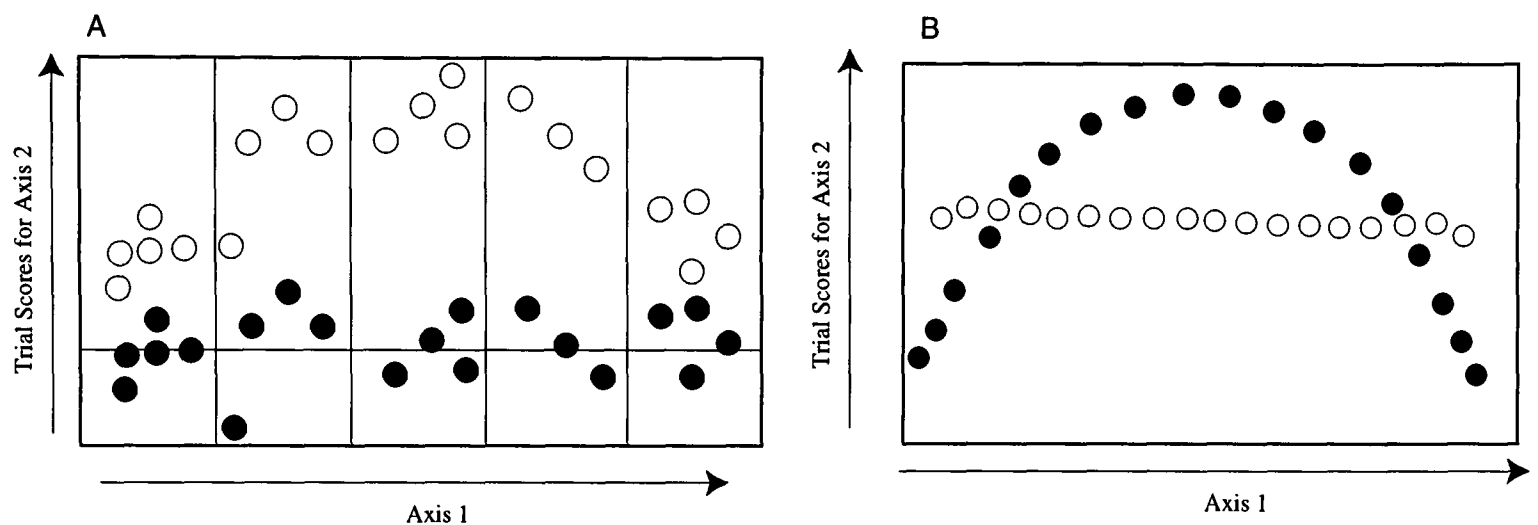


Figure 3.11: Figure A displays a simplified schematic diagram, showing the method of detrending [after Hill & Gauch, 1980]. The open circles indicate scores before detrending; the black circles are the sample sites after detrending. These are obtained by subtracting, within each of the five segments, the mean trial scores of the second axis within each segment. [Hill & Gauch, 1980; Jongman *et al.*, 1987]. Figure B displays a simplified representation of the result of detrending (after Hill & Gauch [1980]).

However, the use of DCA is not always an attractive option. Wartenberg *et al.* [1987] argue that there is no empirical justification for the method, since the DCA model is not consistent with the structure of the data. In addition, there is no theoretical justification for the method, since the DCA model is, as Hill & Gauch [1980] point out, an *ad hoc* adjustment of CA. In relation to the 'arch effect', the position of points on the first axis are not changed, and all DCA does is flatten the arch on the original plot. They continue, 'this deception does not enhance our understanding of the data or help identify the cause of the observed distortion'. Many workers, including Wartenberg *et al.* [1987] and Minchen [1987] have pointed out that DCA may result in loss of ecological information if some of the arch represents real environmental patterns in the original data. For example, Minchen [1987] noted on the basis of an extensive simulation study, that DCA flattened out some of the variation associated with one of the natural underlying gradients. He ascribed this loss of information to an instability in detrending.

Dargie [1986] noted that a certain amount of distortion in CA ordination is attributable to changes in the richness of the variables being investigated along gradients and axes in addition to the arch effect. DCA does not necessarily correct for this. He concluded that the ecological literature has emphasised beta diversity (between-habitat diversity) as a significant source of distortion, but richness of the variables is probably also important because they change systematically along most successional and environmental gradients. Finally, the segmentation process of detrending forces the variables

(*species*) into discrete parcels which are given equal weighting. This procedure is unacceptable because it probably imposes structure on the data where none existed before.

It is apparent, that DCA does not solve the problem of the arch effect and in fact, DCA may add more confusion. To assess whether DCA would be more beneficial than CA in assessing the variability in the data a three-step approach was conducted for the present study. Firstly, the identity of the *species* which created the arch effect were determined. Secondly they were removed, and finally, the pattern of sample scores from CA and DCA were compared. In the first case, the *species* which created the arch were recognised as significantly different from the main body of data. This therefore suggests that they represent specific environmental conditions and, thus, the arch shape reflects a real pattern in the data set that should not be ignored. Secondly, the removal of the influential data does improve the spread of the data, as illustrated in Section 3.7, However, the major underlying trends were very similar. Hence, it appears that the CA axis 2 is environmentally meaningful, (*i.e.*, the real trends have not been overprinted by the mathematical artefact). Finally, data processed using CA and DCA were compared. The results from the DCA sample scores are shown in Figure 3.12. The DCA plot clearly increases the dispersion of the data points and spreads the points more evenly across the plot. It is likely, however, that this relatively even distribution is an artefact of the segmentation process which gives equal weighting to the different segments. It is apparent from the raw data set in Appendix D that some *species* are either very rare or very abundant, and should not be given the same weighting. In addition, the same underlying trends were identified on axis 2 from both CA and DCA.

In light of the above discussion, it is concluded that the extra processing of the data using DCA does not improve the quality or reliability of the results and in some instances, DCA may remove real patterns from the data. It should be noted, however, that the interpretation of the CA-arch affected data was conducted with caution to ensure that the trends were environmentally significant and not a mathematical artefact.

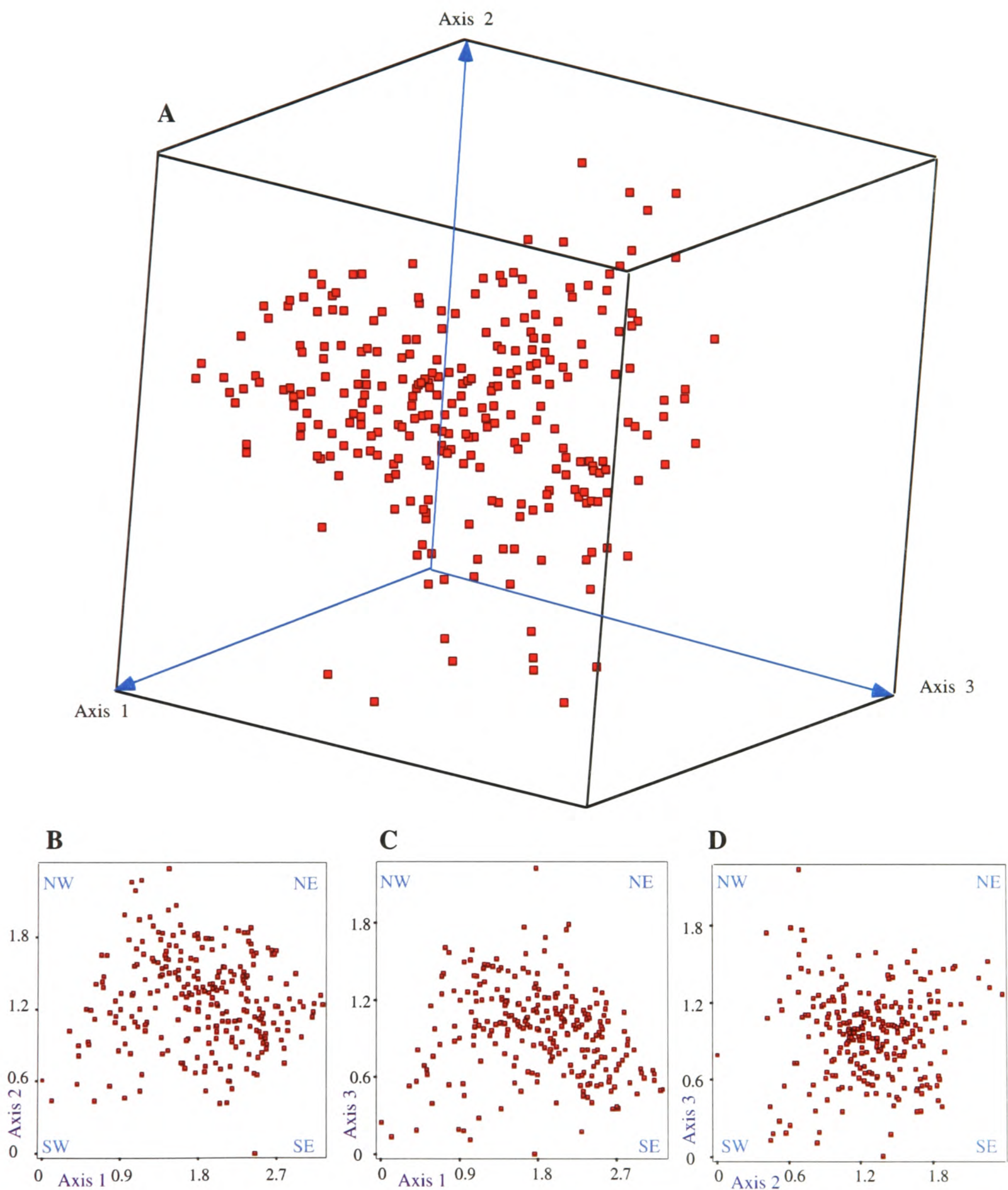


Figure 3.12: Figure A displays the three-dimensional Detrended Correspondence Analysis ordination plot of sample scores for all the samples investigated within this study, with scaling-option one applied. Figure B shows the scatter of points on axes 1 v 2. Figure C shows the plane of axes 1 v 3 and Figure D shows the plane of axes 2 v 3.

3.5.3 Interpretation of CA sample scores

The amount of variability explained by each axis in Figure 3.13 is given by the eigenvalues, which are 0.34, 0.18 and 0.14 for axes 1, 2 and 3 respectively. Thus, in Figure 3.13B, axis 1 v 2 is the most important plot in explaining the total variation within the dataset. The scatter of points in plot B reveals a strong trend from the NW quadrant to the SE quadrant. The remainder of points occur in an array towards the NE quadrant. In Figure 3.13C, axis 1 v 3 is the second most important plot and shows that the majority of points plot around the centre of the diagram with two zones extending towards the SE and NW quadrants. Figure 3.13D illustrates the plane of axis 2 v 3. The arrangement of points occur in a cross-like structure, *i.e.*, the majority of points cluster around the core of the diagram thinning towards the outer margins of the cross formed by the axes.

In Figure 3.13B, several points in the NE quadrant are clearly separated from the main cluster, implying that the former are very different in composition to the samples which form the NW-SE ‘stringer’. It is very likely that these outliers represent some extreme environmental/rare condition. In the current status, it is very difficult to determine subjectively whether the central population comprises distinct associations. It is possible, however, to surmise that the composition of the ‘end members’ of the stringer (*i.e.*, those in the NW and SE) are quite different and the points in between probably comprise intermediate composition between these end members. This proposal is supported by the findings displayed in Table 3.1 which highlighted the existence of samples comprising both SOM and discrete fragments and samples dominated by one of the *major* categories. Thus, it is probable that the underlying controls which cause the associations of the *species* in the samples that form the ‘end members’ of the stringer are quite different, in comparison to those which lie in between. The spatial distribution in Figures 3.13C and D is quite different. The spread of data points is more even than Figure 3.13B implying that different information in terms of the associations of organic matter has been extracted by axis 2 and 3, as expected. The overall scatter of data in all of the plots in Figure 3.13 supports the suggestion mentioned in Chapter 1: that acid-insoluble assemblages are not distinct groups, but instead comprise a great diversity of individual components whose associations form a natural continuum.

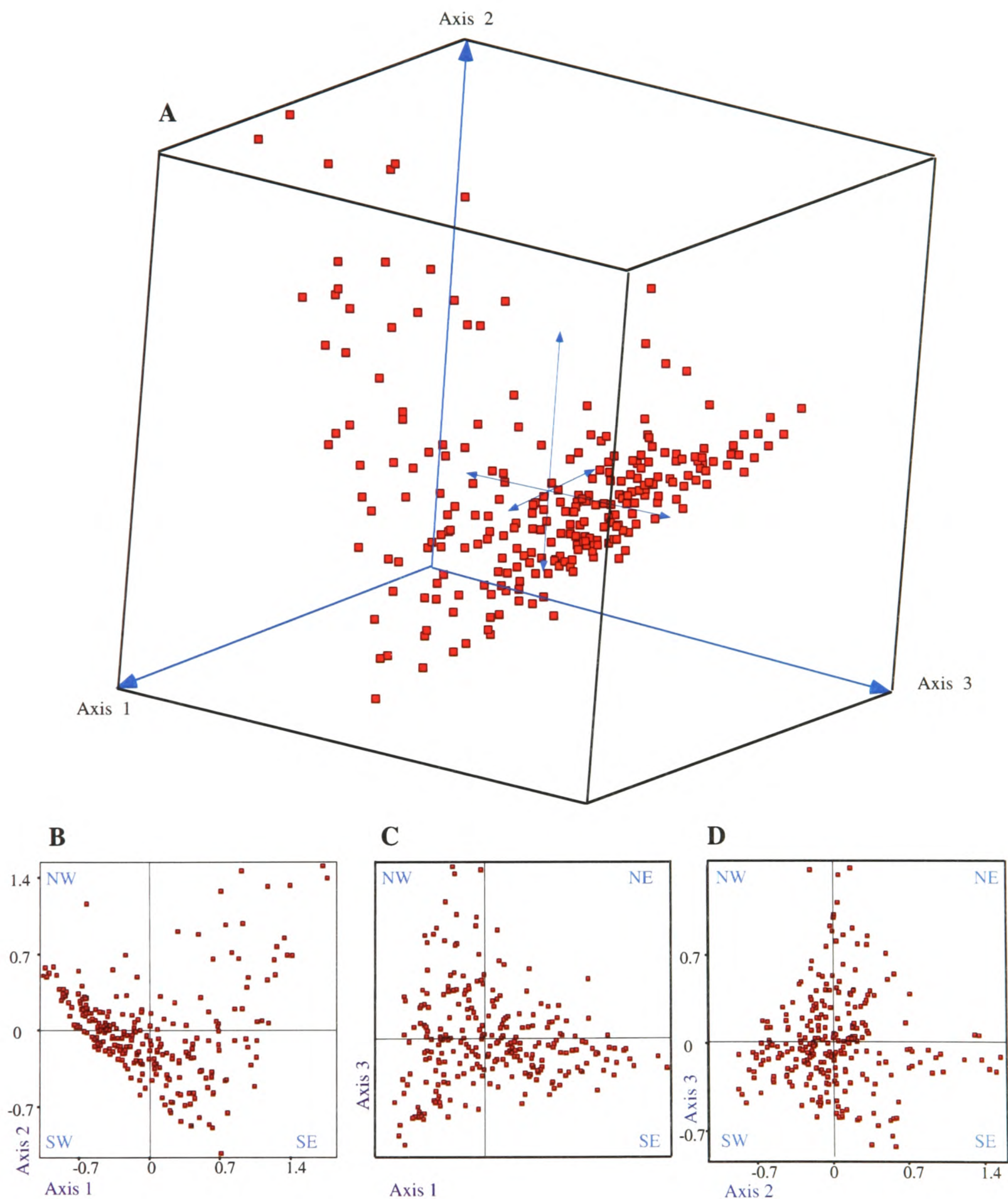


Figure 3.13: Figure A displays the three-dimensional Correspondence Analysis ordination plot of sample scores for all the samples investigated within this study, with scaling-option one applied. Figure B shows the scatter of points on axes 1 v 2. Figure C shows the plane of axes 1 v 3 and Figure D shows the plane of axes 2 v 3. Eigenvalues for axes 1, 2 and 3 are 0.34, 0.18 and 0.14 respectively.

3.5.4 *Species* (organic matter) associations

Species ordination plots were produced to highlight qualitatively the complex relationships between the different particulate organic-matter components. Figure 3.14 displays the *species* score data for all of the samples investigated in this study. The *species* data includes all 46 particulate organic matter categories contained in Appendix D, and the index of absolute organic-matter content per gram of sediment. The latter was included because Lewis [1995] reported that this was an important parameter in determining the environment of deposition. As expected, Figure 3.14 displays a relatively similar scatter of points to Figure 3.13A, with a central cluster of points. The outliers, however, form relatively discrete packages. These are obviously divorced from the central population implying that these *species*, especially those on the edge of the diagram, are rare and/or rarely observed in association with the *species* which occupy the central cluster. Jongman *et al.* [1987] suggested that variables which plot on the edge of diagrams are very rare, either because they are associated with extreme (environmental) conditions or because their few occurrences, by chance, occur in sites associated with extreme conditions. In contrast, the limited separation of points, observed in the central cluster, indicates that these *species* are either often observed in association with each other and/or the outliers have reduced the spread of data in the central cluster.

The central cluster comprises: all palynomorphs, except *Classopollis* pollen and tasmanitids; index of organic matter per gram of sediment; transparent-yellow, fluorescent, fibrous and non-fibrous SOM; black-bladed, fluorescent, cellular fragments, and a selection of vita-fragments (*i.e.*, fragments which display clear botanical features). Many of the vita-fragments occupy the outer margins of the central cluster. Both fluorescent, fibrous, yellow-brown and brown-black SOM plot just above the upper part of the central cluster. The latter lie below the package of fluorescent, brown and black, equidimensional and bladed, non-vita, discrete fragments. A small discrete cluster of vascular bundles and yellow-brown, fluorescent, non-fibrous SOM is recognised to the left of the population of fluorescent, non-vita, discrete fragments.

Towards the front of the plot two discrete populations are recognised. The group on the left-hand side of the plot predominantly consists of non-vita, brown-equidimensional and -bladed, non-fluorescent, cellular and non-cellular, discrete fragments. Black-equidimensional and -bladed, non-fluorescent, non-cellular non-vita fragments are also present within this group. The cluster towards

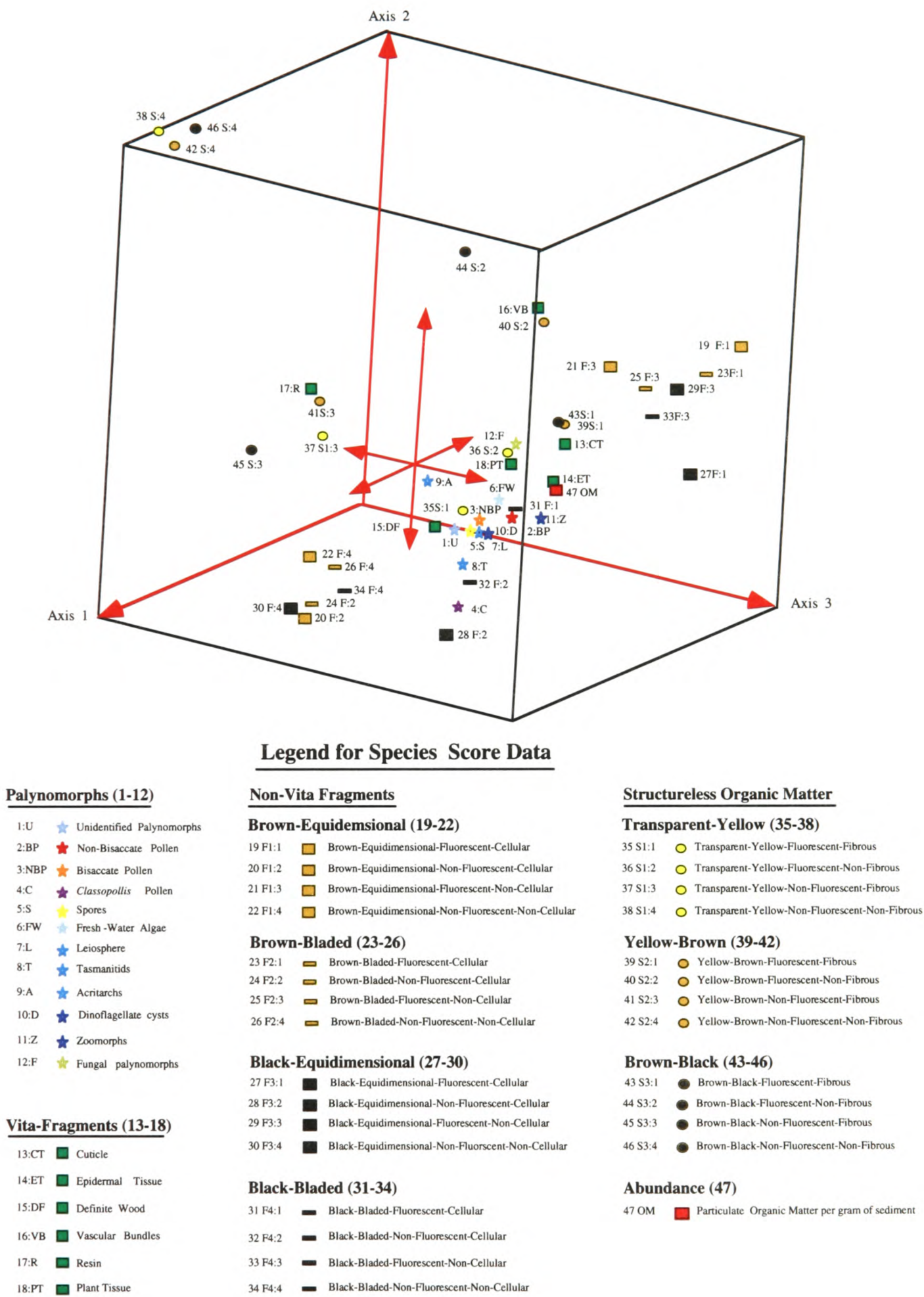


Figure 3.14: Three-dimensional Correspondence Analysis ordination plot of *species* scores with scaling-option one applied. This includes all the *species* described in Appendix D and the index of particulate organic matter per gram of sediment as illustrated in the legend beneath the plot. A number of discrete populations of *species* are evident endorsing the visual identification, which was made during the collection of count data.

the right of the diagram comprises black-equidimensional and -bladed, non-fluorescent, cellular, non-vita fragments, *Classopollis* pollen and tasmanitids.

The remaining groups occur in the upper part of the plot and mainly comprise non-fluorescent, fibrous and non-fibrous SOM. The only exception is the component resin which plots in the bundle of transparent-yellow and yellow-brown, non-fluorescent, fibrous SOM. The spatial distribution of the *species* is generally analogous to the groups recognised using the conventional method, *i.e.*, SOM and the majority of non-vita fragments form separate entities.

3.5.5 Distribution of particulate organic matter in the samples

An appreciation of particulate organic matter composition of the samples was obtained by:

- superimposing the sample and *species* ordination plots upon each other. Sample points which lie close to a *species* point are likely to contain a high abundance of that *species*, and the expected abundance or probability of occurrence of a *species* decreases with distance from its position in the plot. It is therefore possible to make inferences about the *species* composition of the samples.
- employing a single-linkage filter (minimum or nearest neighbour) to the *species* score data. Single linkage, a sorting strategy which is often used in taxonomic research [Kent & Coker, 1992], searches for the nearest individuals. In this study, the 1st, 2nd and 3rd closest neighbours were determined using MACspin. This is a graphical statistical package which permits the user to rotate three-dimensional figures in real time. Rotation of the three-dimensional figure with the filter applied permitted the identification of the first three nearest neighbours. To provide an overview of the findings, only the first closest neighbours are displayed.

In addition to examining the scatter of points in three-dimensions, the association between samples and *species* was investigated using two-dimensional plots of Axes 1 v 2, Axes 1 v 3, and Axes 2 v 3. The results of which are displayed in Figures 3.16 to 3.18. A list of the groups and associations determined by the nearest neighbour filter are included in Table 3.4. These results were used to assist in the determination of *species* and sample associations, gain an understanding of the underlying controls and establish the different assemblages outlined in Section 3.11.

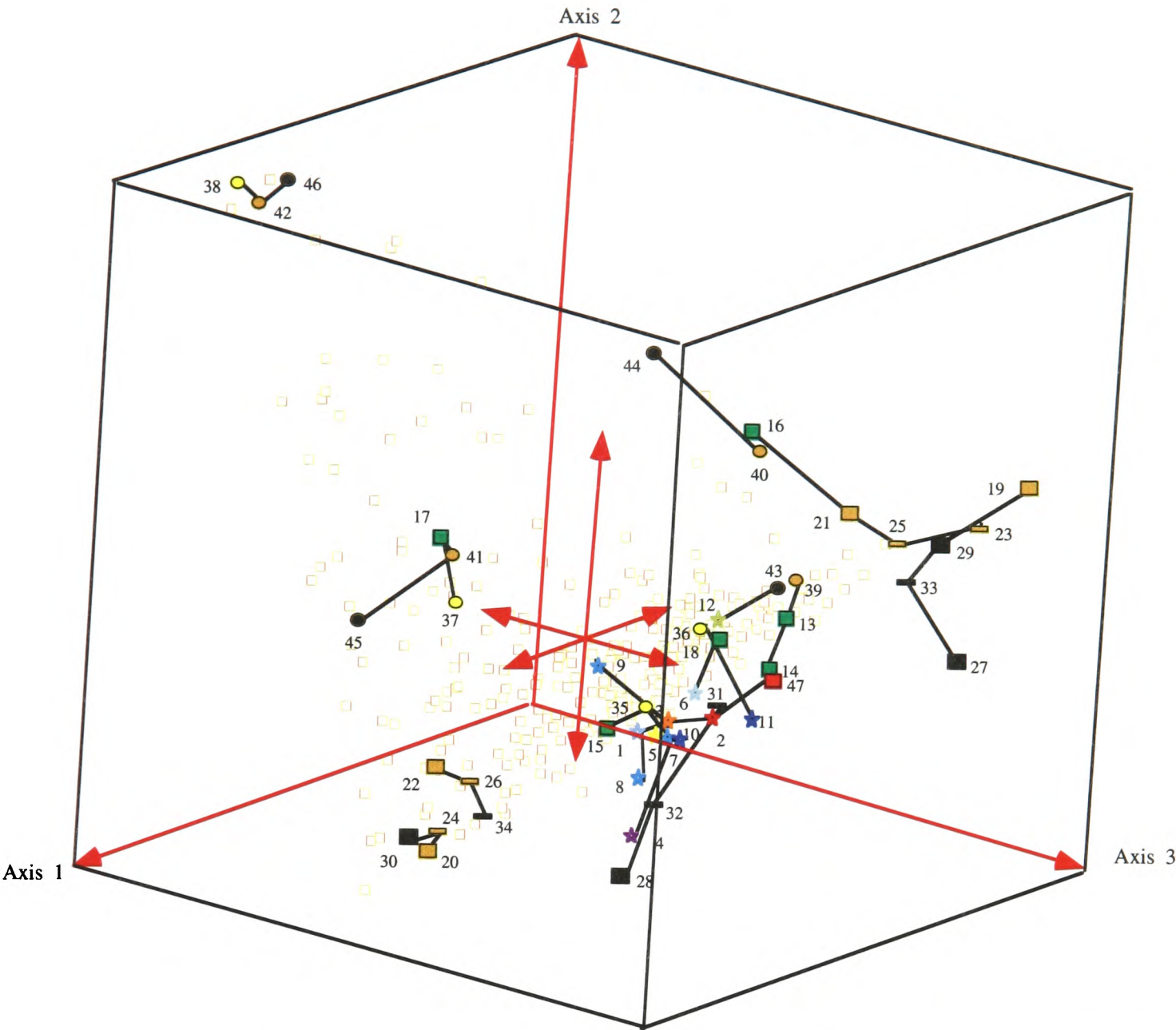


Figure 3.15: Three-dimensional plot of Correspondence Analysis ordination results of sample and *species* score data for all samples after the nearest neighbour filter were applied to *species* score results. Scaling-option one was applied. Sample points are displayed as open orange boxes. The lines between two individual *species* points link their closest partner. A list of the various associations determined by the single-linkage filter are included in Table 3.4

Interpretation

SOM is the most common fraction recorded in the samples investigated, as noted in Table 3.1. Examination of Figure 3.15 to Figure 3.18 reveals that transparent-black, non-fluorescent, and dark-coloured, fluorescent SOM plot as separate entities in the outer margins of the figures, which only contain limited numbers of sample points. In contrast, fluorescent SOM, in particular pale-coloured fibrous and non-fibrous SOM, plot within the main central cluster of sample points. This suggests that fluorescent, pale-coloured SOM is the most abundant fraction recorded in this investigation, which concurs with the raw data contained in Appendix D. This proposal is also supported by the occurrence of category 47, the index of particulate organic matter per gram of sediment in the main central cluster.

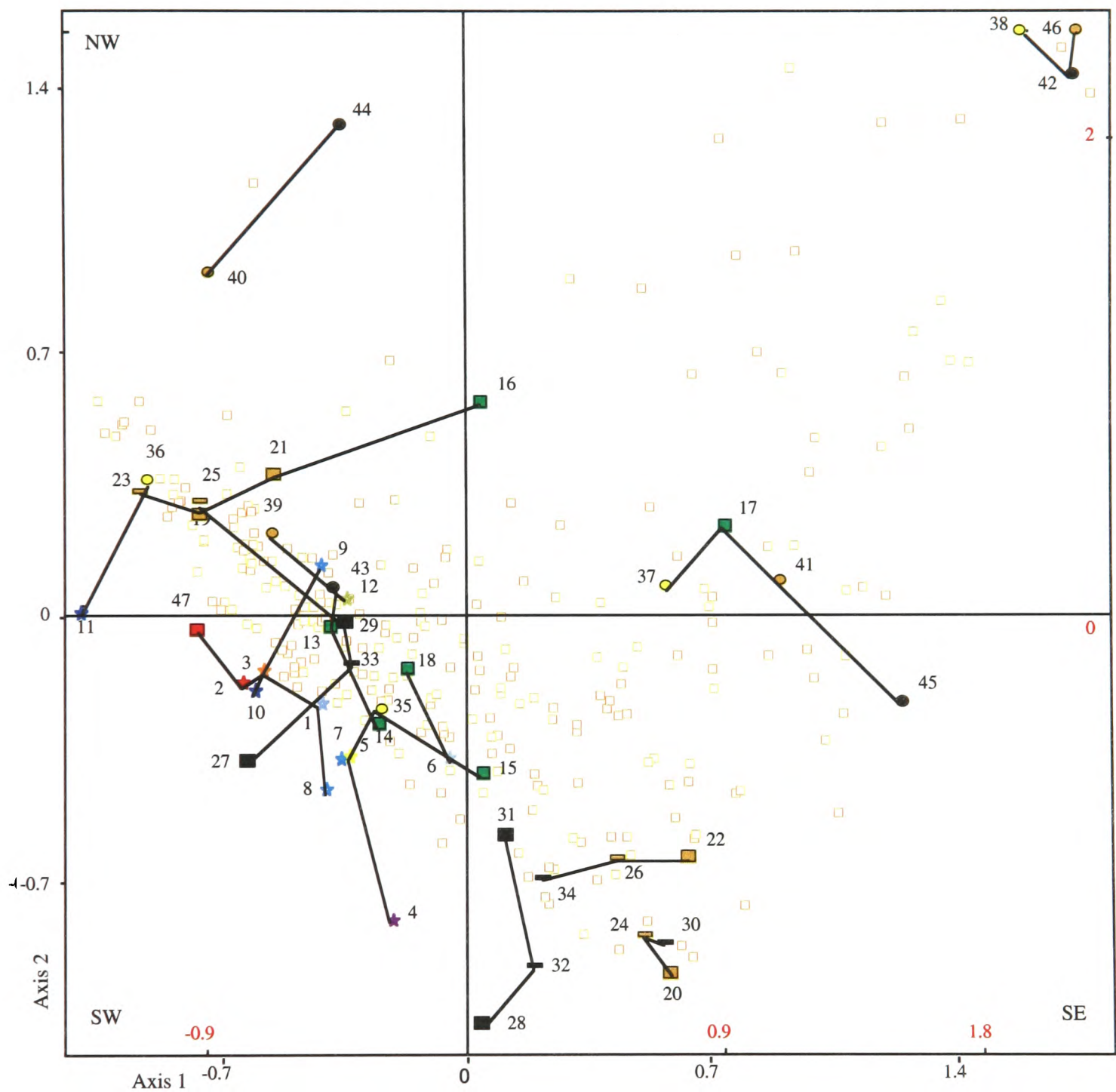


Figure 3.16: Axes 1 v 2 plot of Correspondence Analysis ordination results of sample and *species* score data for all samples after the nearest neighbour filter were applied to *species* score results. Scaling-option one was applied. Sample points are displayed as open orange boxes. The lines between two individual *species* points link their closest partner. A list of the various associations are included in Table 3.4. The *species* score axes values are shown in red. The sample score axes values are displayed in black.

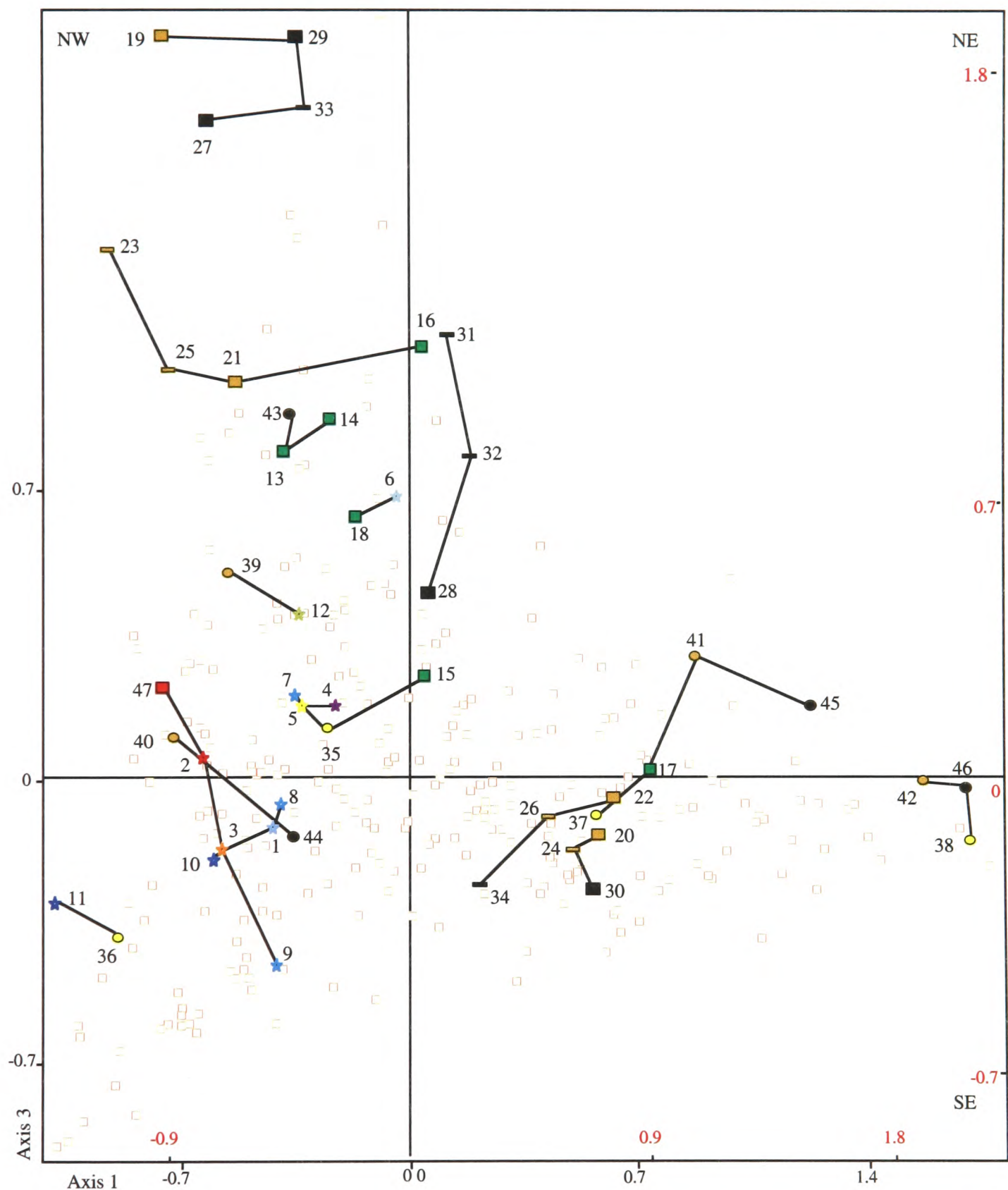


Figure 3.17: Axes 1 v 3 plot of Correspondence Analysis ordination of *species* and sample score data for all samples after nearest neighbour filter has been applied. Scaling-option one was applied. Sample points are displayed as open orange boxes. The lines between two individual *species* points link their closest partner. A list of the various associations are included in Table 3.4. The *species* score axes values are shown in red. The sample score axes values are displayed in black.

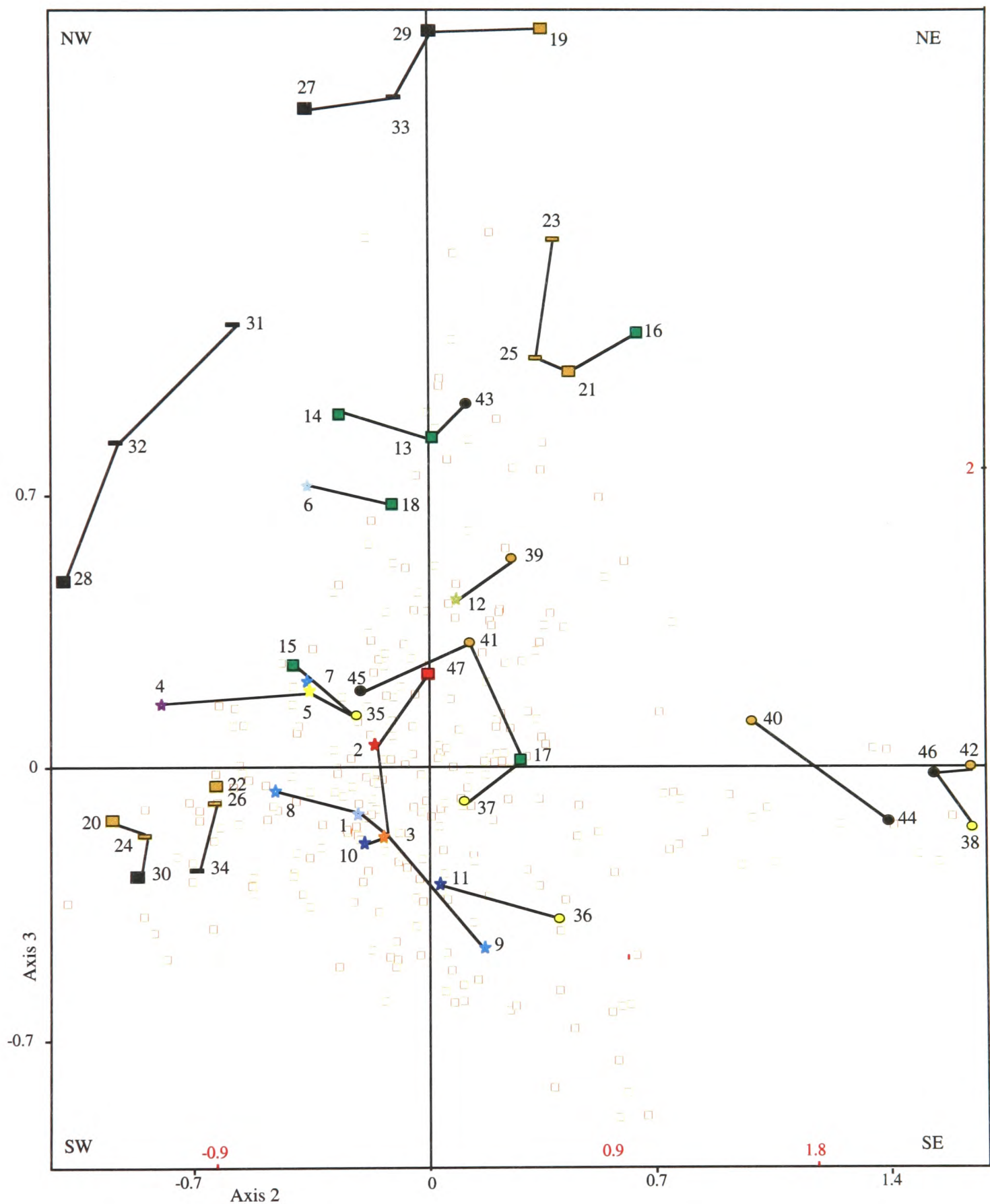


Figure 3.18: Axes 2 v 3 plot of Correspondence Analysis ordination of *species* and sample score data for all samples after nearest neighbour filter has been applied. Scaling-option one was applied. Sample points are displayed as open orange boxes. The lines between two individual *species* points link their closest partner. A list of the various associations are included in Table 3.4. The *species* score axes values are shown in red. The sample score axes values are displayed in black.

Dark, non-fluorescent SOM is indicative of a lower preservation status, which is usually associated with more oxic environments, increased transportation and/or bioturbation. By contrast, well-preserved, fluorescent SOM is usually associated with limited transportation and anaerobic conditions where degradation is limited. Thus, the higher proportions of pale, fluorescent, fibrous and non-fibrous SOM indicate that the majority of sediments investigated in this study accumulated relatively close to the source of this organic matter, in low-energy environments where dysoxic or at least temporarily anoxic conditions prevailed. The clear separation of fluorescent and non-fluorescent SOM strongly suggests that the redox status of the host sediments and/or extent of exposure to high-energy conditions were influential on the nature of the organic matter.

The source of pale, fluorescent, fibrous and non-fibrous SOM has been questioned by many workers. Whitaker [1984] suggested that this material represented bacterial biomass that only developed under certain conditions. In contrast, many workers including Rogers [1979]; Boulter & Riddick [1986]; Venkatachala [1981] and Van der Zwan [1990] suggested that the primary source of the former material is very variable, ranging from autochthonous planktonic organic matter, benthic microbial mat material to plant matter. Figures 3.17 and 3.18 show that transparent-yellow, fluorescent, fibrous SOM plots closer to non-saline palynomorphs than saline palynomorphs, whilst transparent-yellow, fluorescent, non-fibrous SOM plots near to saline/marine palynomorphs. It is important to note that the raw data shows that transparent-yellow, fluorescent, non-fibrous SOM occurs in both marine and terrestrial settings. These associations suggest that transparent-yellow, fluorescent, fibrous SOM is more likely to be terrestrially derived, whilst transparent-yellow, fluorescent, non-fibrous SOM may be derived from either the terrestrial or marine realm *i.e.*, it is bio-degraded terrestrial or bio-degraded aqueous organic matter. Thus, dominance of transparent-yellow, fluorescent, fibrous SOM is indicative of a terrestrial or quasi-marine setting where the sediments accumulated in dysoxic or temporarily anoxic conditions, especially in areas removed from significant influence of fluvial activities. Transparent-yellow, fluorescent, non-fibrous SOM is, however, typical of either; 1) sediments which accumulated in dysoxic and temporarily anoxic marine conditions, especially in areas removed from significant influence of terrestrial input (*i.e.*, during high sea levels or in a distal setting), or 2) dysoxic and temporarily anoxic sediments deposited in close proximity to the source of the material *e.g.*, peat deposits and lake margins where post-depositional chemical modification is more dominant than pre-depositional degradation and post-depositional removal. However, before addressing the controls which influence post-depositional decay it is important to note that those plants/organisms living

in close proximity to a depositional environment or a clastic pathway that leads into that site are more likely to contribute to the organic matter debris than those organisms living some distance from the area of accumulation [Spicer, 1981].

Although the real system is complex, three relatively distinctive consecutive phases have been identified during the breakdown of particulate organic matter under experimental conditions [Valiela, 1984; Benner *et al.*, 1991]. Valiela *et al.* [1985] referred to these three as the leaching, decomposer and refractory phases. The leaching phase is the first change to occur following death or senescence of the organism, and results from autolysis. The decomposer phase takes place following bacterial colonization of the detritus over 0.75-2 years [Benner *et al.*, 1991]. The most important control on the rate of degradation during this phase is the rate of dissolved organic matter release which is dependent on the fermenting bacteria. The rates of degradation during both the leaching and decomposer phases are strongly influenced by temperature and dissolved oxygen content and are greatest under warm and oxic conditions [Tarutis, 1992]. Degradation during the decomposer phase may be significantly stimulated by bioturbation [Andersen & Kristensen, 1992]. The development of the microbial flora during the decomposer phase is typically associated with an increase in oxygen demands during the leaching phase [de la Cruz & Gabriel, 1974]. The rate of post-depositional chemical modification is also effected by the level of water saturation. The highest levels of preservation are often associated with prolonged water-saturation environments and/or continuously dry conditions where the decay process is inhibited [Hedges *et al.*, 1988]. The decay process is most rapid when the organic matter is exposed to the atmosphere and periodically made wet, as damp but well oxygenated conditions are conducive to growth of fungi [Hedges *et al.*, 1988].

The final refractory phase represents the slow breakdown of the least digestable organic matter. The rate of decay during this phase does not appear to show any significant correlation with temperature, nitrogen supply, or detritus feeders [Valiela *et al.*, 1985]. Although even very slow reactions are significant when viewed in the context of the geological time-scale, degradation, at least indicated by a reduction in TOC values, apparently becomes negligible below the top 0.5-1.0 m of the sediment column [Bralower & Thierstein, 1984]. The similarity of the average TOC values of ancient and modern muds at 1-2 m below the surface also suggests that any organic matter that reaches these depths is likely to be permanently buried [Berner, 1982].

Thus, the decay process is most rapid in wet, warm and well-oxygenated conditions. Hence, terrestrial or quasi-marine sediments (deposited in warm settings) exposed to alternate flooding and drying and/or changes in the water table, *e.g.*, 'well-drained' lake margins, terrestrial/brackish floodplains and coastal plains have a lower preservation potential than 'poorly-drained' or sub-aqueous sediments, and probably contain more non-fluorescent, dark-coloured SOM. Galloway [1989] noted that in marginal marine to non-marine sediments, sea-level fluctuations are recorded by cyclic shifts of the shoreline. A landward or seaward shift of the shoreline influences the respective increase or decrease of the water-table and related deterioration or improvement of drainage or rivers [Posamentier & Vail, 1988]. Thus, variations in the relative abundance of pale/dark, fluorescent/non-fluorescent SOM may provide an indication of changes in the palaeotemperature through time, or an indication of the water-saturation levels in the sediments, and in some instances may provide insight to sea-level fluctuations.

Most of the non-vita fragments in Figure 3.16 lie above and below the main central cluster, in the NW and SE quadrants, as clear entities. Sample points plot both in association with these discrete clusters and in the area between the central cluster and discrete clusters of non-vita fragments. This pattern is also evident in Figures 3.17 and 3.18. This distribution suggests that non-vita fragments co-exist with transparent-yellow, fluorescent SOM, vita fragments and palynomorphs, as well as being the most dominant organic matter component of some samples. This is also evident from Table 3.1. Tyson [1995] mentioned in his evaluation of organic matter from a marine setting that high abundances of mixed discrete fragments was evidence of one or a combination of: deposition in close proximity to, or redeposition from fluvio-deltaic source(s) of terrestrial organic matter (which would dilute other components) and/or accumulation in oxidizing environments in which other components have selectively destroyed. Whitaker [1984], Van der Zwan [1990] and Steffen & Gorin [1993] suggested that the abundance and nature of the discrete fragments (allochthonous) fraction is mainly controlled by hydrodynamical processes.

Examination of the two discrete groups of non-vita fragments reveals that the upper group which lies in the NW quadrant of Figure 3.16 comprises fluorescent non-vita fragments, whilst the lower groups in the SE consist of predominantly non-fluorescent non-vita fragments. No previous worker has identified a difference between these categories. This pattern may be caused by variations in the primary source and/or differences in the decay pathway. The nearest-neighbour filter recognised three

Communities	Species
1	20  Brown-Equidimensional, Non-Fluorescent, Cellular Fragments 30  Black-Equidimensional, Non-Fluorescent, Non-Cellular Fragments 24  Brown-Bladed, Non-Fluorescent, Cellular Fragments
2	34  Black-Bladed, Non-Fluorescent, Non-Cellular Fragments 26  Brown-Bladed, Non-Fluorescent, Non-Cellular Fragmentsb 22  Brown-Equidimensional, Non-Fluorescent, Non-Cellular Fragments
3	31  Black-Bladed, Fluorescent, Cellular Fragments 32  Black-Bladed, Non-Fluorescent, Cellular Fragments 28  Black-Equidimensional, Non-Fluorescent, Cellular Fragments
4	4  <i>Classopollis</i> Pollen 5  Spores 35  Transparent-Yellow, Fluorescent, Fibrous SOM 15  Definite Wood 7  Leiosphere
5	6  Fresh Water Algae 18  Plant Tissue
6	8  Tasmanitids 1  Unidentified Palynomorphs 3  Non-Bisaccate Pollen 2  Bisaccate Pollen 47  Index of Particulate Organic matter per gram of sediment 10  Dinoflagellate Cysts 9  Arcitarchs
7	14  Epidermal Tissue 13  Cuticle 43  Brown-Black, Fluorescent, Fibrous SOM
8	27  Black-Equidimensional, Fluorescent, Cellular Fragments 33  Black-Bladed, Fluorescent, Non-Cellular Fragments 29  Black-Equidimensional, Fluorescent Non-Cellular Fragments 19  Brown-Equidimensional, Fluorescent, Cellular Fragments
9	12  Fungal Palynomorphs 39  Yellow-Brown, Fluorescent, Fibrous SOM
10	11  Zoomorphs 36  Transparent-Yellow, Fluorescent, Non-Fibrous SOM
11	23  Brown-Bladed, Fluorescent, Fibrous Fragments 25  Brown-Bladed, Fluorescent, Non-Cellular Fragments 21  Brown-Equidimensional, Fluorescent, Non-Cellular Fragments 16  Vascular Bundles
12	37  Transparent-Yellow, Non-Fluorescent, Fibrous SOM 17  Resins 41  Yellow-Brown, Non-Fluorescent, Fibrous SOM 45  Brown-Black, Non-Fluorescent, Fibrous SOM
13	44  Brown-Black, Fluorescent, Non-Fibrous SOM 40  Yellow-Brown, Fluorescent, Non-Fibrous SOM
14	42  Yellow-Brown, Non-Fluorescent, Non-Fibrous SOM 38  Transparent-Yellow, Non-Fluorescent, Non-Fibrous SOM 46  Brown-Black, Non-Fluorescent, Non-Fibrous SOM

Table 3.4: Different associations determined from nearest neighbour filter method. The single-linkage cluster filter objectively distinguished 14 different associations. It is, however, very important to note that only the closest neighbour in three dimensions was displayed and listed.

separate associations, 1, 2 and 3, which are listed in Table 3.4, within the discrete population of fragments, that occupy the SW quadrant of Figure 3.16. They comprises non-vita, non-fluorescent fragments, except for *species* 31 which is fluorescent. Lewis [1995] noted that the non-fluorescent, black fragments are probably charcoal. It is important to note that Tyson [1993] considered black discrete particles to be a result of oxidation of translucent 'woody' material (which Lewis [1995] suggested was equivalent to non-fluorescent, brown fragments) during prolonged transport or post-depositional alteration. However, in 1995 Tyson suggested that a large preponderance of black fragments was typical of an arid environment. The association of black and brown fragments in close affinity to each other, and in some cases with undegraded SOM, suggests that these fragments were probably not oxidised through post-depositional alteration. In addition, it is important to note that although not displayed, these samples do not contain reworked sporomorphs. Unless there is clear evidence of reworking and variations due to differences in susceptibility to degradation it is acceptable to consider that these non-fluorescent black fragments are in fact charcoal, produced by local wild-fires.

The next closest association, identified by the nearest-neighbour method, includes *Classopollis* pollen, spores, leiospheres, transparent-yellow, fluorescent, fibrous SOM and definite wood. The second closest neighbour to *Classopollis* pollen, which plots just outside the main central cluster is *species* 28: black-equidimensional, non-fluorescent, cellular fragments, of association 3. Although *Classopollis* pollen is commonly abundant in fine-grained sediments, its occurrence in large numbers may at least be as much a reflection of the adaptability and proliferation of the parent plants (family Cheirolepidiaceae which are thermophilic conifers) to a warm, seasonally dry to semi-arid climate [Vakhrameev, 1982, 1991] or saline setting as to sedimentary conditions (see Appendix C for discussion upon 1) the relationship between *Classopollis* pollen and the Cheirolepidiaceae parent plants and 2) occurrence and possible depositional environments). Vakhrameev [1981] also stated that *Classopollis* pollen abundance decreases towards the poles. Values of 1-10%, (of the sporomorph population) apparently indicate temperate conditions, 20-50% warm subtropical conditions and 60-90% semi-arid to arid climatic conditions. Thus, increases are believed to indicate increased aridity or increased seasonality [Vakhrameev, 1981]. The close association of *Classopollis* pollen and black, non-fluorescent, cellular fragments, which are probably charcoal, suggests that this relationship may be climatically developed and/or a result of preferential deposition. The latter scenario may be true according to Tyson [1995] who indicated that concentration of simple pollen is usually due to their buoyancy/hydrodynamic equivalence. However, many workers, including Batten [1975]; Sladen &

Batten [1984] and Tyson [1984] who investigated Jurassic and Cretaceous strata respectively, indicate that *Classopollis* pollen is largely independent of facies and seems to indicate long-term floral and climatic trends. At this juncture it is not possible to decipher whether this association is a response to climatic, geographical or depositional controls.

3.5.6 Synopsis

CA of the *species* and score data, and the nearest-neighbour filter permits the identification of *species* associations, the composition and distribution of organic matter found within the sediments investigated, and in some instances permits the recognition of the primary source of the organic matter. Additionally, CA facilitates the identification of possible casual relationships between *species* associations and processes. For example, the clear separation of fluorescent and non-fluorescent material suggests that the redox status is important. The decay process is most rapid in wet, warm and well-oxygenated conditions. Thus, in the non-marine/quasi-marine settings, the rate of degradation is affected by the palaeotemperature and water-saturation levels, (*i.e.*, whether these sediments were ‘well-drained’ or ‘poorly-drained’). The latter control is particular influential in coastal floodplains where the water-table can fluctuate in response to sea-level changes [Posamentier & Vail, 1988]. Decay processes are more rapid in sediments exposed to alternate flooding and drying and/or fluctuations in the water-table.

The concentration of fragments in some samples indicates that energy levels, proximity to fluvial sources and production rates may also be influential. This is affected by the source, physio-chemical composition, rate of supply and distance of transport of the organic matter supplied to each site and degree of disturbance; *i.e.*, resistant fragments are likely to be abundant when the rate of supply, transportation, degradation and degree of disturbance are high. Moreover, co-occurrence of black-equidimensional, non-fluorescent fragments (charcoal) and *Classopollis* pollen implies that preferential deposition or climatic variations are significant controls. Finally, the spatial distribution of the sample points supports the hypothesis that the data set is relatively homogeneous, but most of the key characters used to define the conventionally defined assemblage groups are at least to some extent spatially distinct.

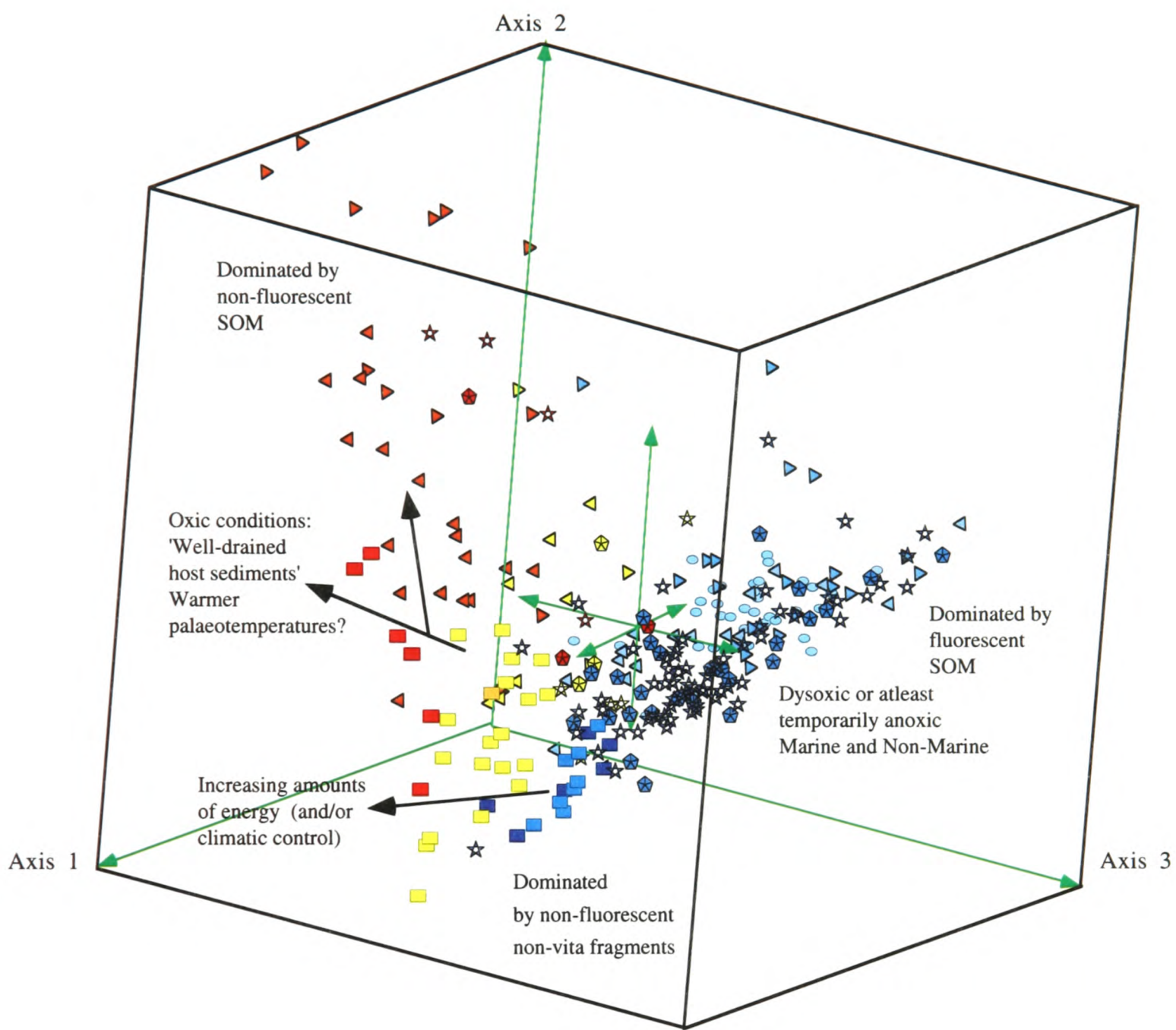
3.6 Validation of Assemblage Groups

To evaluate, visually and quantitatively, the conventionally defined assemblage groups, the CA sample scores were colour coded according to their assemblage groups and fluorescent subgroups as illustrated in Figures 3.19 to 3.22. Details of the assemblage groups are contained in Appendix E.1.

Figure 3.19 reveals that even though the changes are transitional, the majority of assemblage groups identified purely using the method of Batten [1973], especially the fluorescent subgroups, can be distinguished in the CA sample-score configurations. It is apparent from these figures that assemblage groups E and F are very distinctive, whilst the strongly-fluorescent sub-groups of assemblage groups D and G are more difficult to decipher objectively.

The most distinctive feature of Figures 3.20 and 3.21 is the difference between the 'fluorescent' subgroups, which vary from 'strongly-fluorescent' to 'intermediate', to 'weakly-fluorescent' along axis 1 which has an eigenvalue of 0.34. This marked trend suggests that the preservational status of the host sediments is the most dominant influence on the nature of the organic matter in the samples investigated in this thesis. However, detailed examination of Figure 3.20 discloses that there is a transitional change within the strongly fluorescent subgroup. The end-members, A and E/F, are dominated by delicate, well-preserved SOM and resistant fragments, respectively. The former assemblage is usually typical of dysoxic or temporarily anoxic sediments which accumulated in relatively close proximity to the source of organic matter, usually in areas away from fluvio-deltaic activities. Assemblages E and F are dominated by discrete, non-vita fragments. This is generally indicative either of deposition in close proximity to fluvio-deltaic source(s), or oxidizing environments, or of hydrodynamical sorting. Increased exposure to attrition during transportation and/or bioturbation will lead to the removal or oxidation of the more fragile SOM. Thus, this pattern implies there is a relationship between preservation of material and energy levels.

Samples assigned to assemblage groups D and G plot in a rather non-discrete fashion. The key character used to define assemblage groups D and G are the relative abundances of total sporomorphs and dinoflagellate respectively. Although, palynomorphs are important ecological indicators, as discussed in Chapter 2, the only palynomorph category to form a distinctive entity in Figure 3.15 was *Classopollis* pollen. This is probably because the contribution of the remaining palynomorphs is,



Assemblage Groups	Assemblage Subgroups		
	Strongly-Fluorescent SOM	Moderately-Fluorescent SOM	Weakly-Fluorescent SOM
Group Assemblage A: Abundant transparent-yellow, fluorescent, non-fibrous SOM	○		
Group Assemblage B: Abundant total SOM; <very-common total fragments, and < frequent palynomorphs	▶	▶	▶
Group Assemblage C: > Common fragments; SOM < total fragments, and < frequent palynomorphs	◀	◀	◀
Group Assemblage D: Palynomorphs > occasional; total SOM > total discrete fragments	☆	☆	☆
Group Assemblage E: Total fragments > total SOM, and palynomorphs < frequent	■	■	■
Group Assemblage F : Total fragments > total SOM, and palynomorphs > occasional	■	■	
Group Assemblage G: Dinoflagellate cysts > rare.	☆	☆	☆

Figure 3.19: Interpreted three-dimensional Correspondence Analysis plot of sample scores with Assemblage Groups superimposed on the dataset. Scaling-option one was applied. This plot enables the differences between fluorescent subgroups and non-fluorescent fragments to be deciphered.

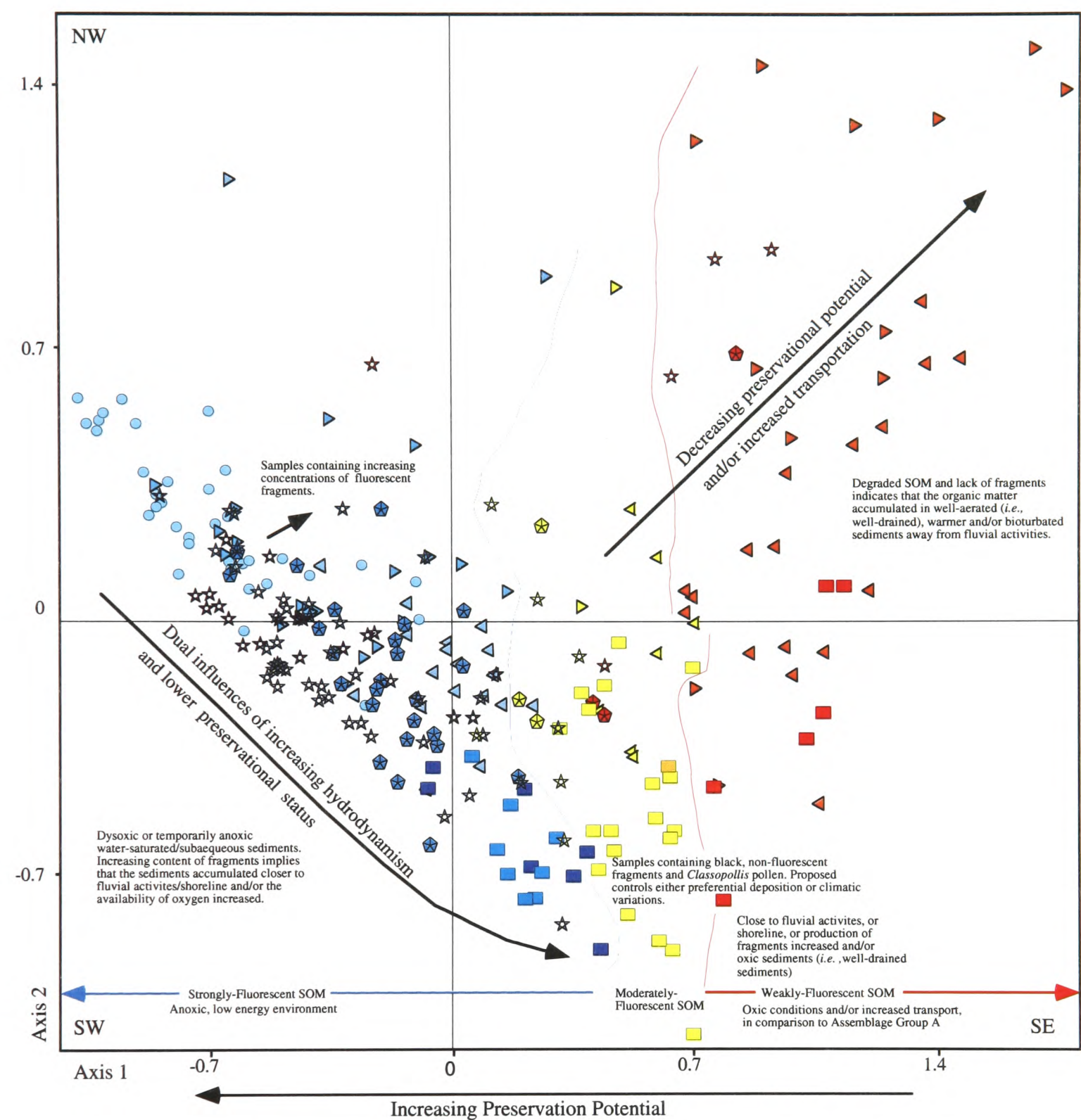
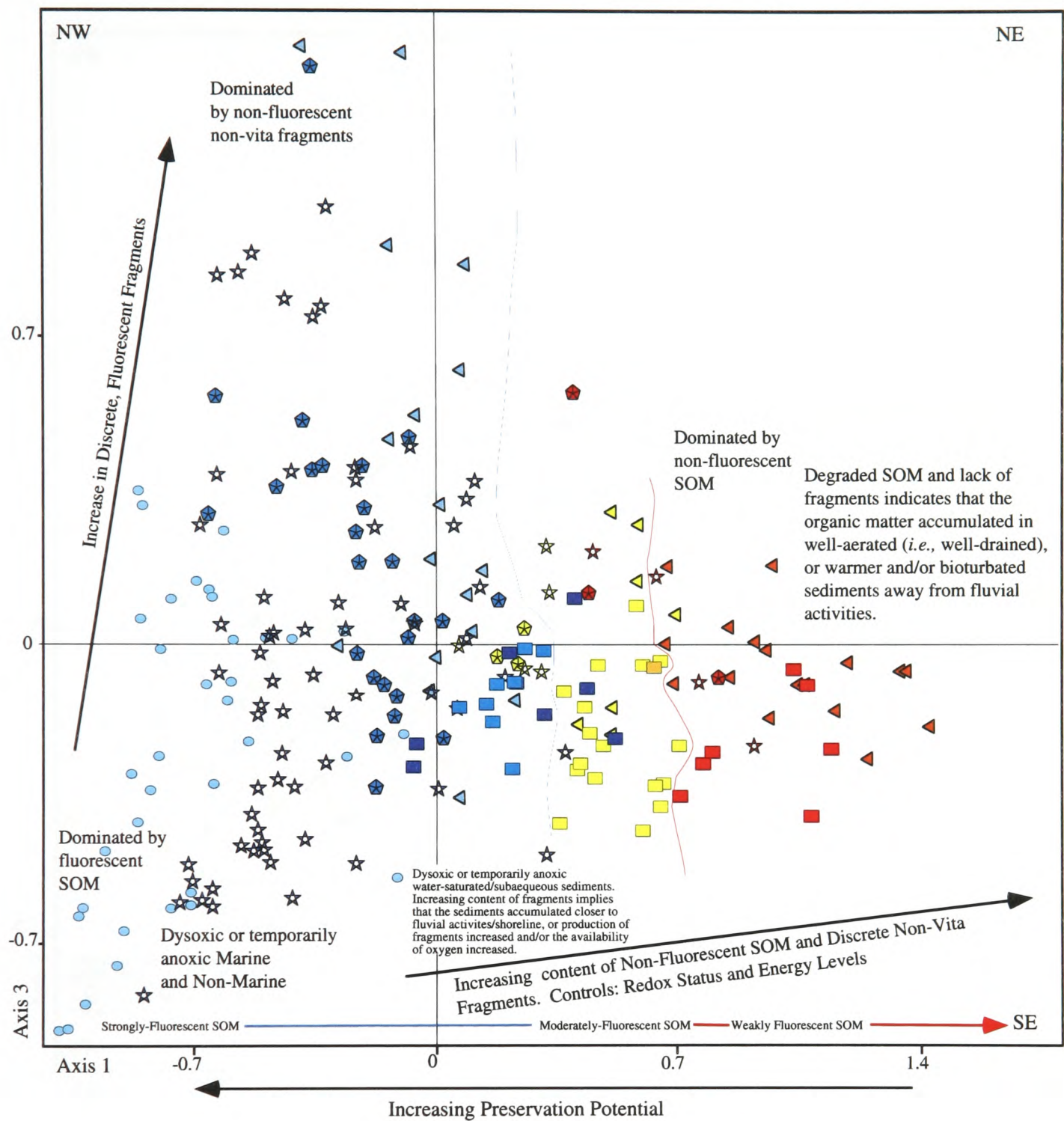
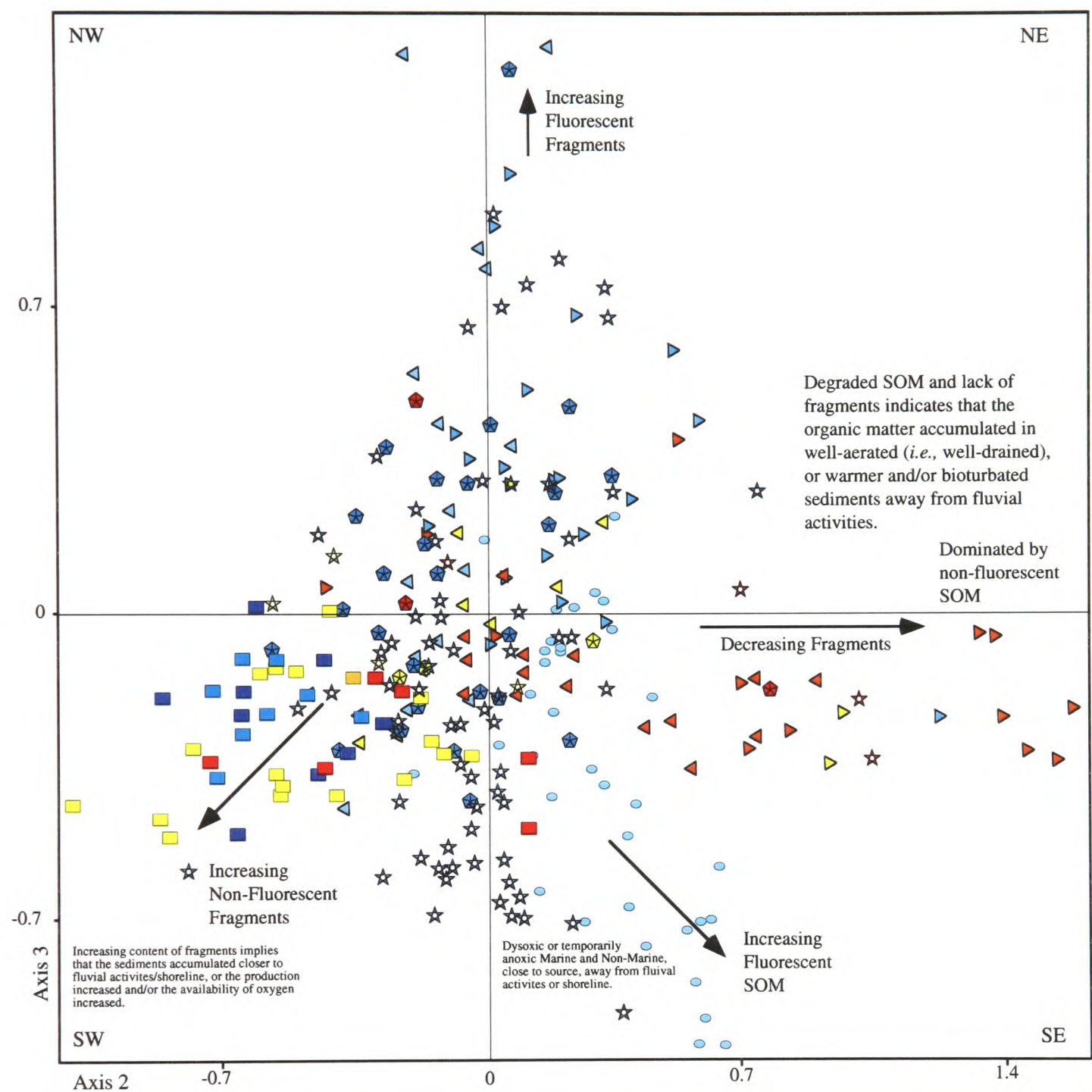


Figure 3.20: Interpreted Axes 1 v 2 Correspondence Analysis plot of sample scores with Assemblage Groups superimposed on the dataset. Scaling-option one was applied. This plot shows that the change from strongly-fluorescent to weakly-fluorescent dominates Axis 1. This plot also enables the underlying trends revealed in Figure 3.13B to be elucidated. The strong trend from the NW quadrant to the SE quadrant shows a change from assemblages dominated by delicate well-preserved material to assemblages dominated by resistant fragments.



Assemblage Groups	Assemblage Subgroups	Strongly-Fluorescent SOM	Moderately-Fluorescent SOM	Weakly-Fluorescent SOM
Group Assemblage A: Abundant transparent-yellow, fluorescent, non-fibrous SOM		●		
Group Assemblage B: Abundant total SOM; <very-common total fragments, and < frequent palynomorphs		▶	▶	▶
Group Assemblage C: > Common fragments; SOM < total fragments, and < frequent palynomorphs		◀	◀	◀
Group Assemblage D: Palynomorphs > occasional; total SOM > total discrete fragments		◆	◆	◆
Group Assemblage E: Total fragments > total SOM, and palynomorphs < frequent		■	■	■
Group Assemblage F: Total fragments > total SOM, and palynomorphs > occasional		■	■	
Group Assemblage G: Dinoflagellate cysts > rare.		★	★	★

Figure 3.21: Interpreted Axes 1 v 3 Correspondence Analysis plot of sample scores with Assemblage Groups superimposed on the dataset. Scaling-option one was applied.



Assemblage Groups	Assemblage Subgroups		
	Strongly-Fluorescent SOM	Moderately-Fluorescent SOM	Weakly-Fluorescent SOM
Group Assemblage A: Abundant transparent-yellow, fluorescent, non-fibrous SOM	●		
Group Assemblage B: Abundant total SOM; <very-common total fragments, and < frequent palynomorphs	▶	▶	▶
Group Assemblage C: > Common fragments; SOM < total fragments, and < frequent palynomorphs	◀	◀	◀
Group Assemblage D: Palynomorphs > occasional; total SOM > total discrete fragments	◆	◆	◆
Group Assemblage E: Total fragments > total SOM, and palynomorphs < frequent	■	■	■
Group Assemblage F: Total fragments > total SOM, and palynomorphs > occasional	■	■	
Group Assemblage G: Dinoflagellate cysts > rare.	☆	☆	☆

Figure 3.22: Interpreted Axes 2 v 3 Correspondence Analysis plot of sample scores with Assemblage Groups superimposed on the dataset. Scaling-option one was applied

in mathematically terms, minor. Variations in the more abundant components are probably more significant mathematically, and hence have a greater influence on the outcome of the CA analysis.

Axis 2, with an eigenvalue of 0.18, shows no structure in terms of the fluorescent subgroups. The pattern discloses a change from assemblage group F and E (non-fluorescent discrete fragment dominated), at the origin, through assemblage groups A-D and G. Non-fluorescent sub-assemblage group B does not plot within this group. Instead, this sub-group occurs as a discrete entity in the uppermost part of axis 2. Thus, the end members of axis 2 are assemblage groups E and sub-assemblage group B which are fragment-dominated and non-fluorescent SOM-dominated (degraded) respectively. Some samples assigned to assemblage group E contain an association of black, non-fluorescent, non-vita fragments and *Classopollis* pollen which may have developed in response to climatic and/or depositional variations. Sub-assemblage group B is typical of well-drained sediments and/or an increase in the palaeotemperature and is primarily observed in host samples collected from the Saltwick Formation, the lower-most non-marine unit of the Ravenscar Group. Assemblage group E is more typical of host sediments from the uppermost non-marine units, in particular the Gristhorpe Member. Thus, it is highly probable that this pattern is a result of variations in the depositional setting through time. This is discussed in Section 3.8.

Axis 3 records a change from assemblage group A (fluorescent SOM), through assemblage groups E, F and D, and sub-assemblage groups B and C (mainly non-fluorescent and intermediate) to fluorescent sub-groups B and D. Samples ascribed to assemblage group G are scattered throughout the plot. The underlying mechanism which could result in such a pattern remains enigmatic at present. It could be due to changes in one or more variations in primary material, proximity to source, hydrodynamics, redox status and/or temporal changes.

Inspection of the host sediments of assemblage A reveals the presence of some atypical environments of deposition. Over 60 % of the samples from the Brent core are assigned to assemblage group A. The key component of group A is fluorescent SOM which is generally associated with low-energy, anoxic conditions. The Brent samples are, however, from a wide variety of environmental settings, including shoreface environments and river channel sandstones which are generally high-energy deposits. The Cleveland Basin samples which are assigned to assemblage group A are more typical because the host sediments are usually plant beds. The Brent Group clearly contains higher levels

of pale-coloured SOM, thus it is not prudent to compare the Brent and Cleveland Basin using abundance data. As the number of *species* counted for each sample is greater than the number of samples examined from the Brent Group these data cannot be analysed independently by CA. It is possible, however, to compare the results from the Cleveland Basin and Brent Group using ratios and changes in stratigraphic trends, the results of which are discussed in Chapter 4. The effect of the Brent Group samples on the overall configuration is addressed in the next section.

3.6.1 Synopsis

The primary underlying control on the organic matter investigated in the present study is the redox potential of the host sediments. The redox potential also appears to be inherently related to the amount of attrition/bioturbation that the organic matter has been exposed to, rate of production, fluctuations in the level of the water-table, palaeotemperature and susceptibility of the organic matter to degradation. Changes along the second axis reflect the stratigraphical position of the sample which may be related to changes in the depositional setting through time. Finally, the majority of the different assemblage groups and sub-groups are recognisable as discrete, but transitional, packages on axis 1 plots.

3.7 Outliers

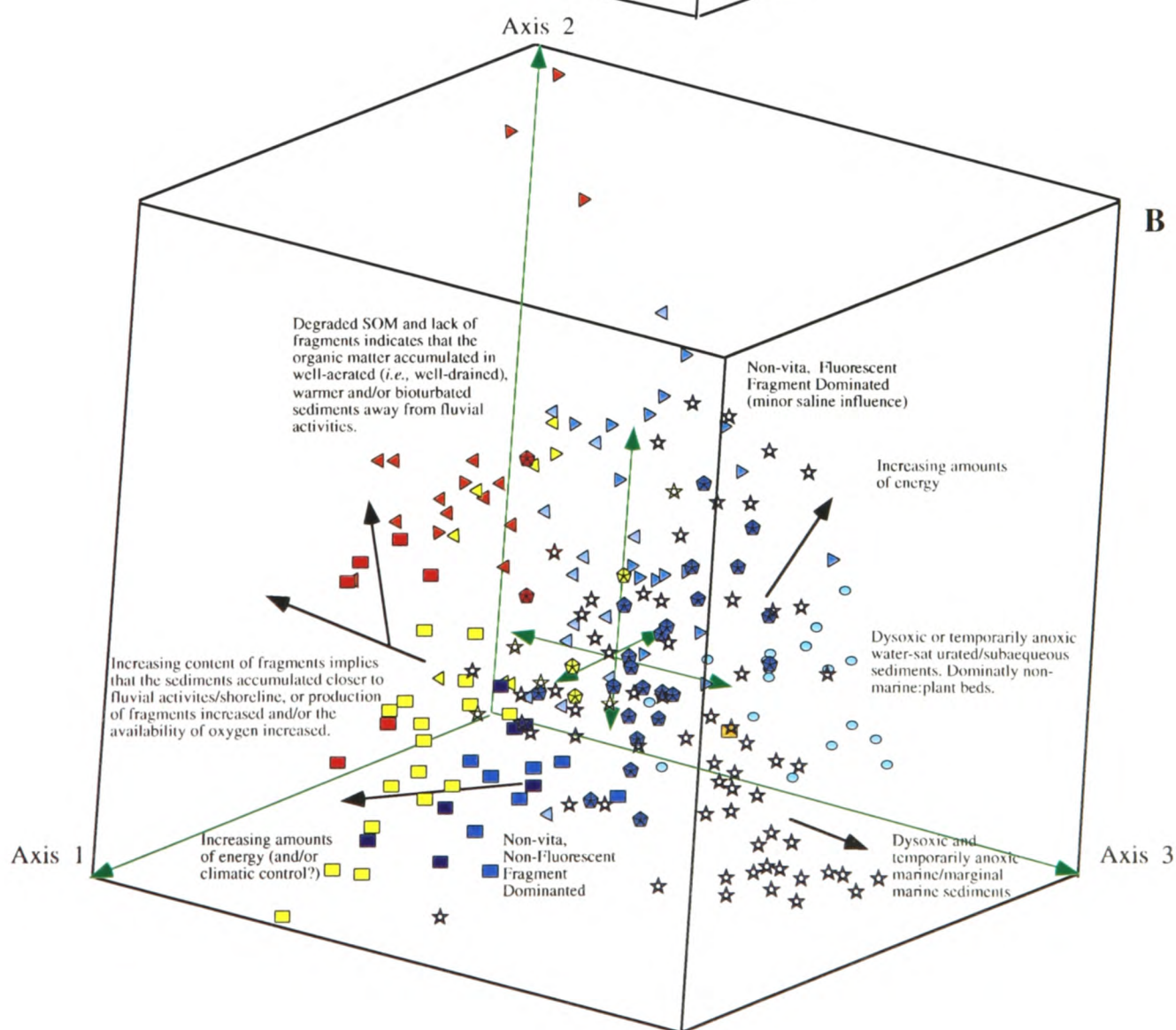
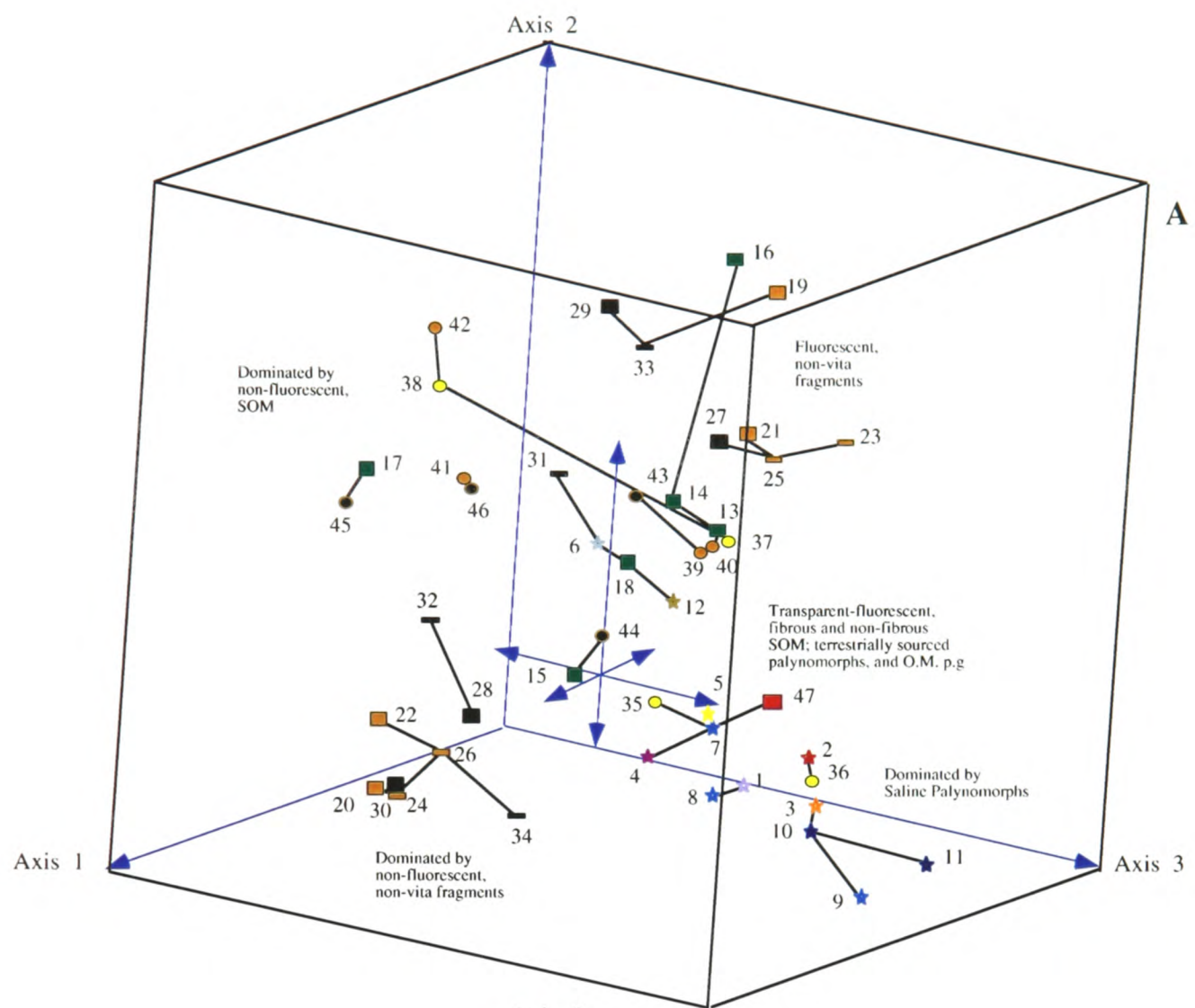
It is apparent from the analysis of the whole data set that a number of outliers exist, *i.e.*, samples which are very different from the others in the data set in terms of their *species* composition. Outliers will affect an ordination regardless of which technique is applied [Kent & Coker, 1992]. Thus, when ordination is performed, the resulting ordination plot shows the outlying sample(s) at one extreme, since the majority of the samples are all much more similar to each other than the outlying samples. The solution is to remove the offending samples or *species* and re-analyse the data. This has the effect of spreading out the remaining samples and displaying the similarity among them much more clearly. It is important to note that removal of samples does not mean that they can be conveniently disregarded; they represent particular environmental and/or taphonomic conditions.

To improve the spread of the data in this study and focus upon the samples from the main study area, the Cleveland Basin, the data were re-analysed removing the Brent Group samples and the Cleveland Basin outliers. Twenty samples from the Cleveland Basin which occupied the upper part

of Figure 3.20 were identified as outliers. Samples 5, 7, 9, 14, 18, 24, 31, 33, 34, 35, 38, 47, 51, 57, 69, 97, 158, 169, 171 and 197 were removed from the statistical analysis. The majority are from the Saltwick Formation of the Ravenscar Group.

Figure 3.23: Interpreted three-dimensional CA plot of *species* and samples scores respectively from the Cleveland Basin after outliers and Brent Group data were removed prior to analysis. Scaling-option one is applied. Plot A displays the *species* scores. Plot B shows the sample scores which have been colour coded according to their fluorescent subgroups. The same legends depicted in Figure 3.14 and Figure 3.19 are used for the *species* and samples respectively. Plots A and B shows very similar patterns to Figures 3.14 and 3.19 respectively. However, the broader spread of data permits the recognition of marine and non-marine categories. Oxidic conditions are mainly found in non-marine and shallow-marine nearshore environments suggesting these were well-drained. In contrast, the dysoxic or temporarily anoxic samples are probably from poorly-drained sediments.

Figure 3.24: Interpreted Axes 1 v 2 plot of *species* and samples scores respectively from the Cleveland Basin after outliers and Brent Group data were removed prior to analysis. Scaling-option one is applied. Plot A displays the *species* scores. Plot B shows the sample scores which have been colour coded according to their fluorescent subgroups. The same legends depicted in Figure 3.14 and Figure 3.19 are used for the *species* and samples respectively. Plots A and B show very similar patterns to Figures 3.16 and 3.20 respectively. However, the broader spread of data permits the recognition of marine and non-marine categories. Oxidic conditions are mainly found in non-marine sediments suggesting these were well-drained or nearshore marine environments. In contrast, the anoxic samples are probably from poorly drained terrestrial sediments or oxygen-depleted waters.



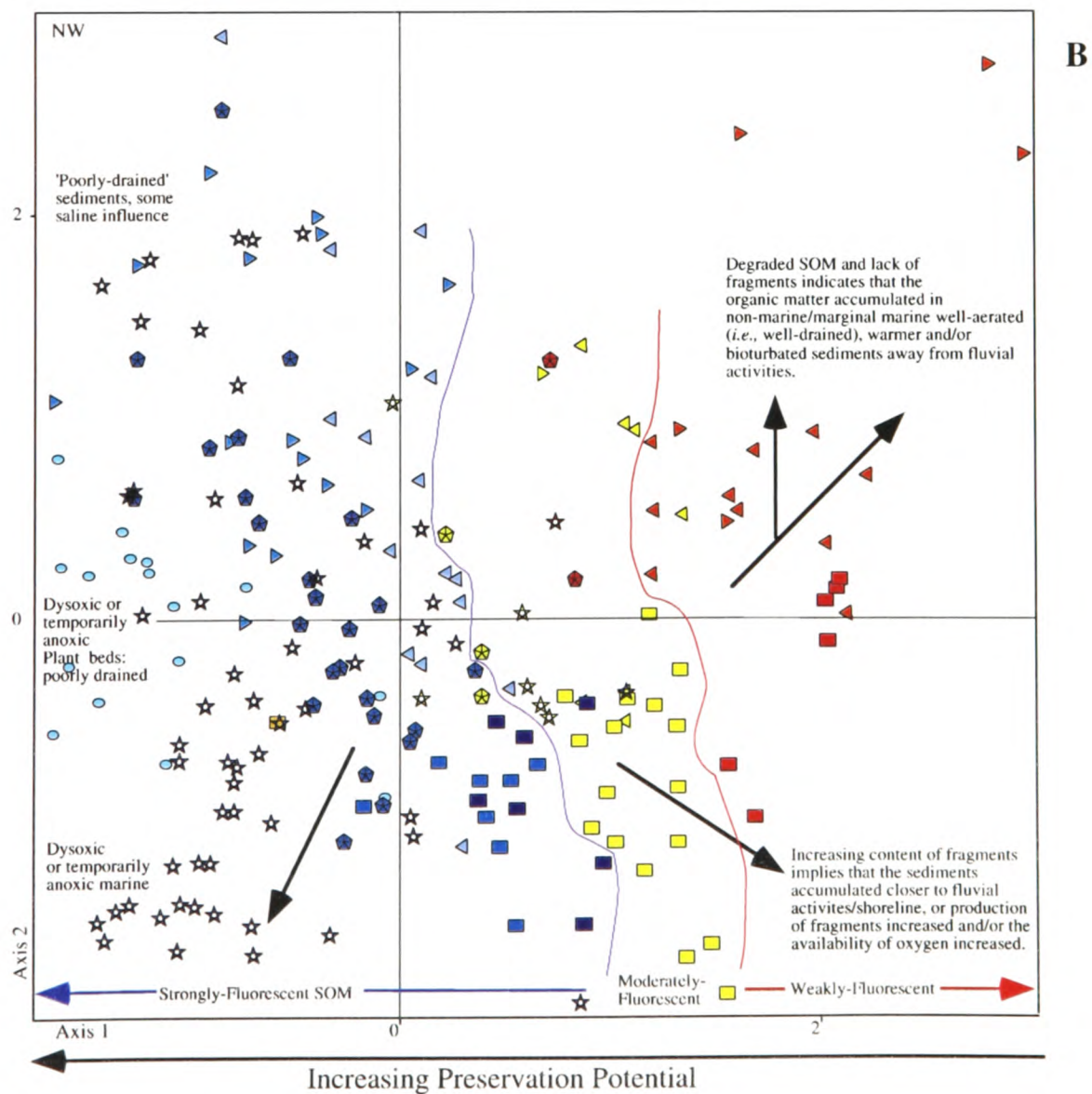
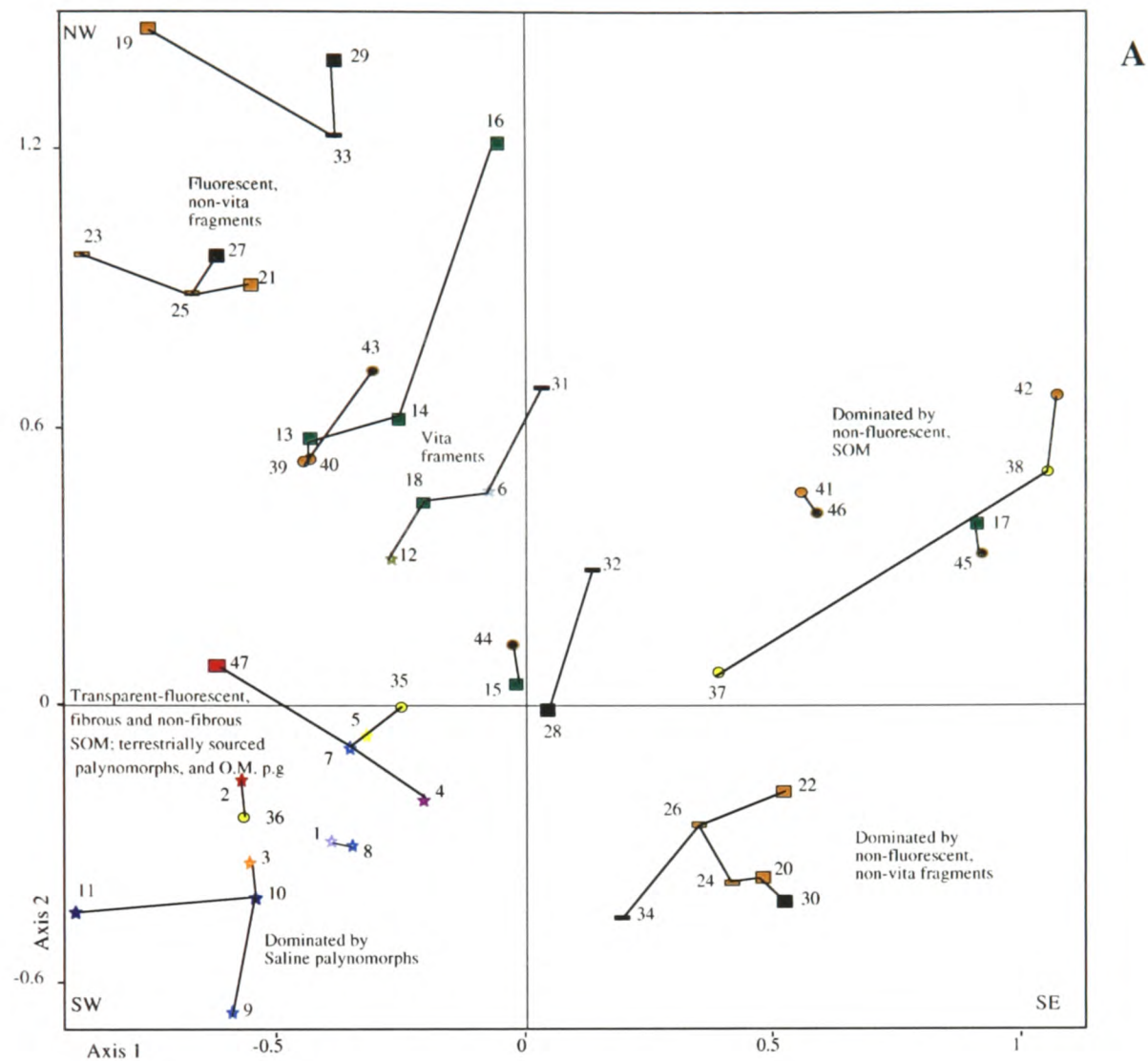
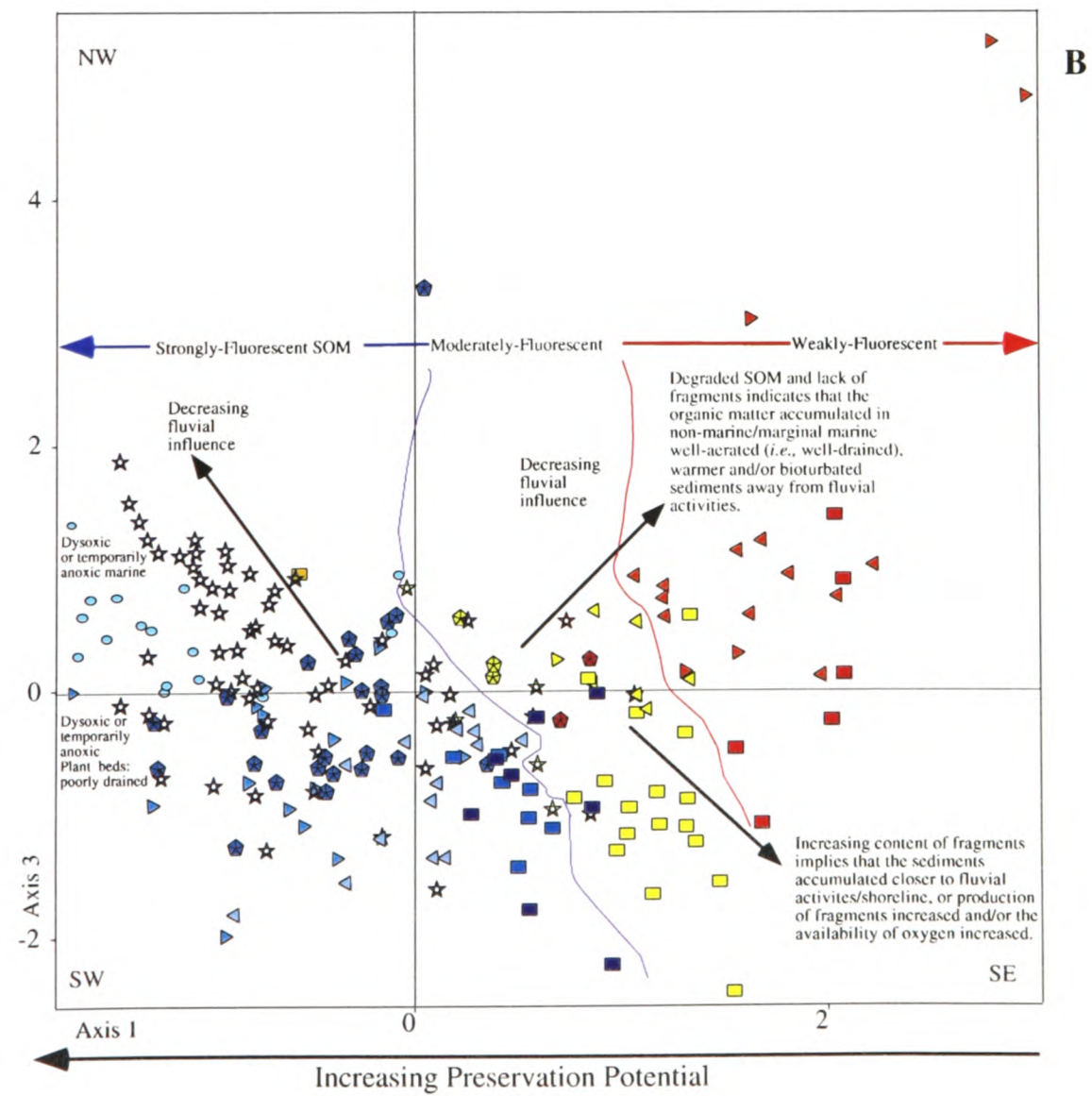
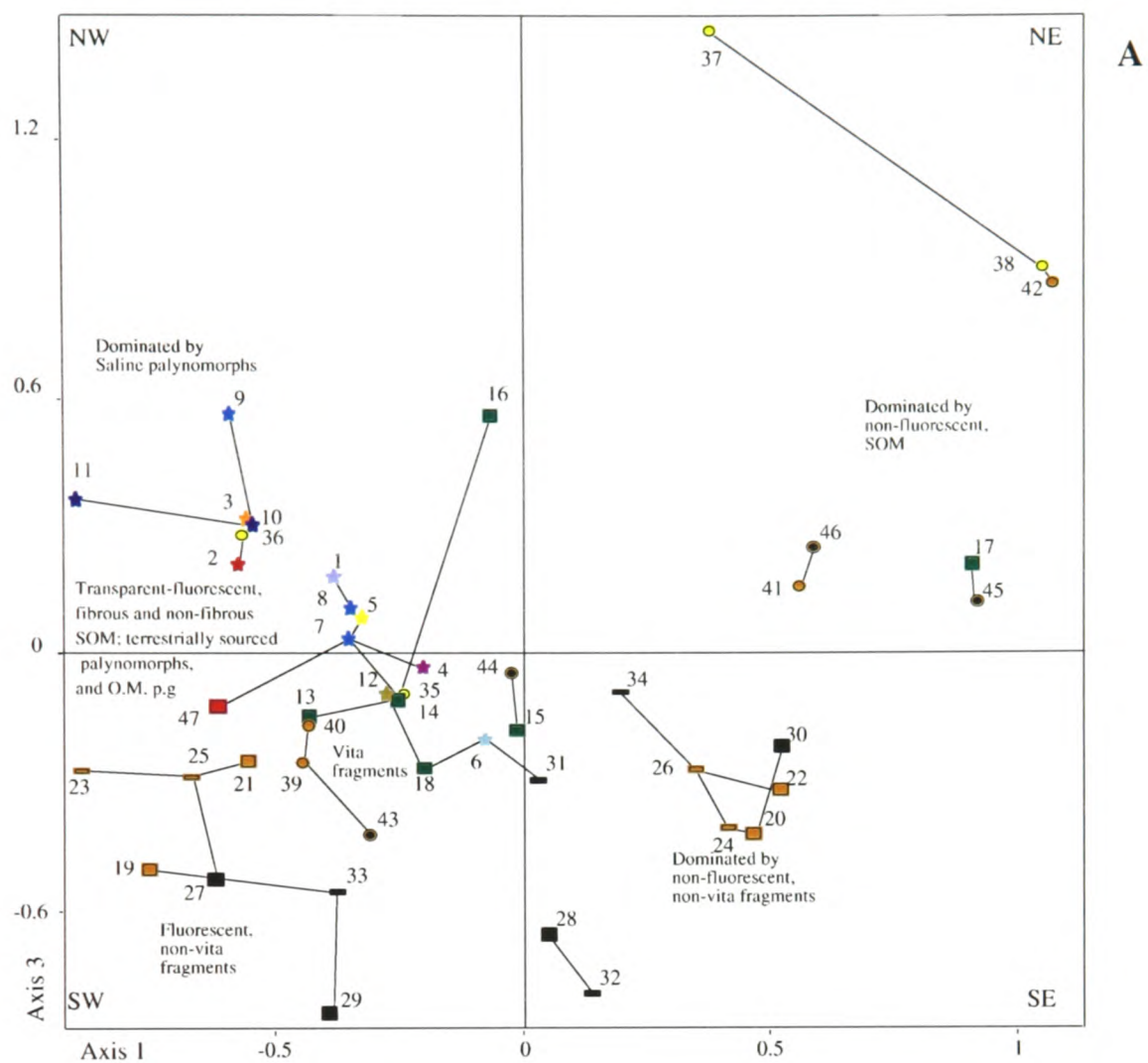
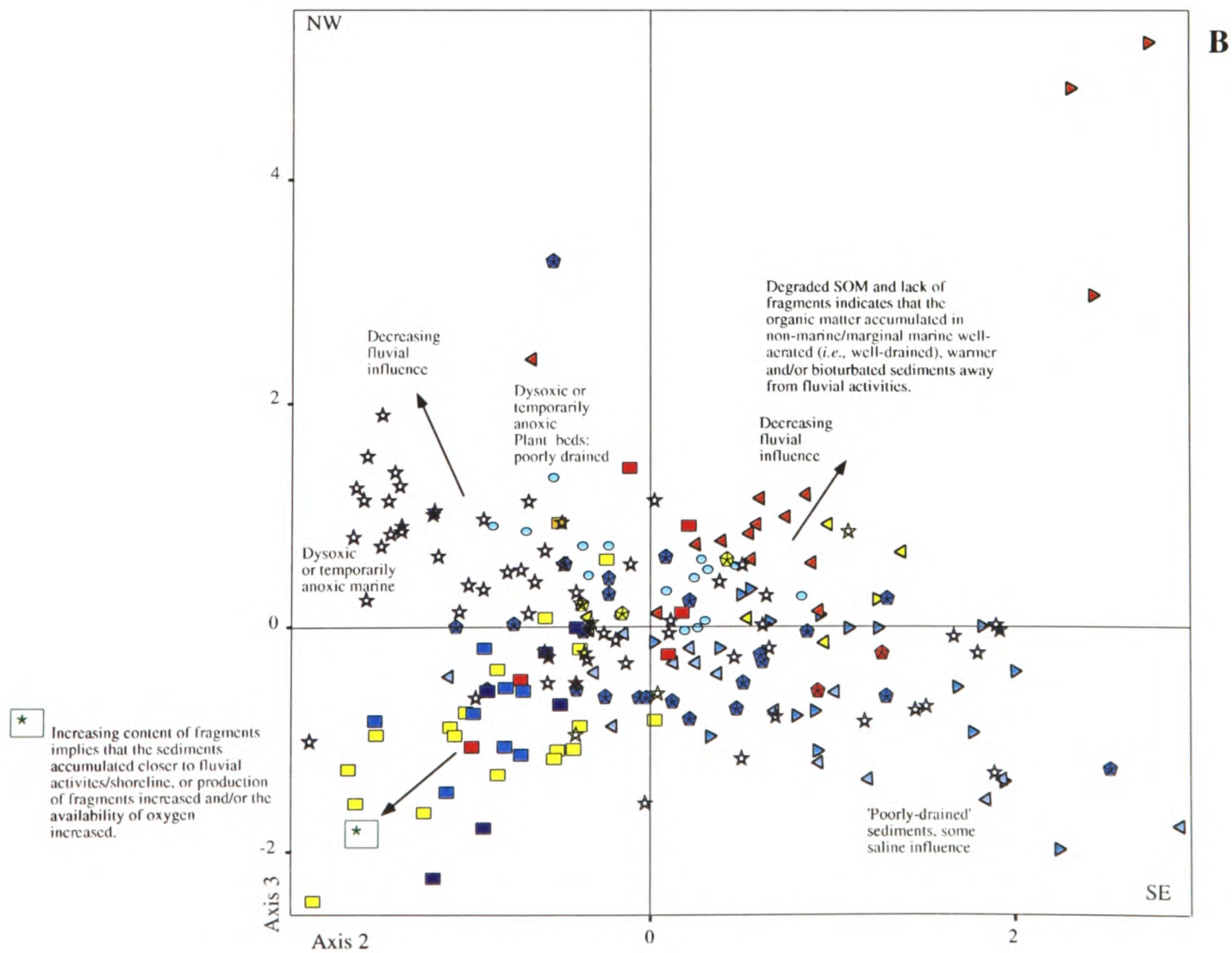
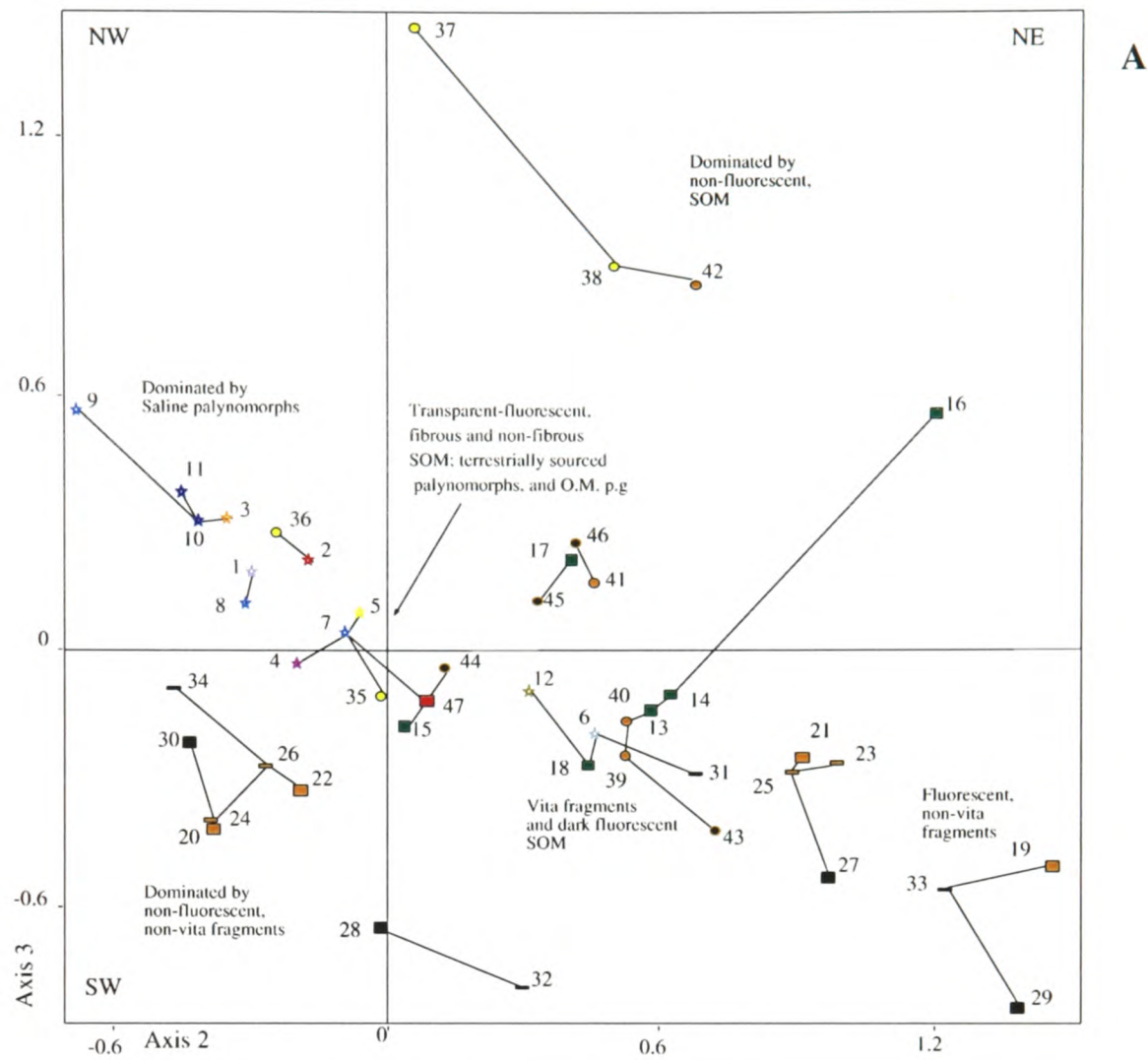


Figure 3.25: Interpreted Axes 1 v 3 plot of *species* and samples scores respectively from the Cleveland Basin after outliers and Brent Group data were removed prior to analysis. Scaling-option one is applied. Plot A displays the *species* scores. Plot B shows the sample scores which have been colour coded according to their fluorescent subgroups. The same legends depicted in Figure 3.14 and Figure 3.19 are used for the *species* and samples respectively. Plots A and B show very similar patterns to Figures 3.17 and 3.21 respectively.

Figure 3.26: Interpreted Axes 2 v 3 plot of *species* and samples scores respectively from the Cleveland Basin after outliers and Brent Group data were removed prior to analysis. Scaling-option one is applied. Plot A displays the *species* scores. Plot B shows the sample scores which have been colour coded according to their fluorescent subgroups. The same keys depicted are used for the *species* and assemblage plots. Plots A and B shows very similar patterns to Figures 3.18 and 3.22 respectively.





Figures 3.23 to 3.26A and B display the *species* and samples scores respectively. The sample points in plot B were categorised according to their respective assemblage group defined by the conventional method. Primary examination discloses that all the plots are very similar to their counterparts shown previously, except the arch effect is no longer present. The most significant difference is the broader spread of the data points which permits the recognition of the marine and non-marine categories, *i.e.*, samples from assemblage group G are clearly distinct.

Axis one in Figure 3.24 displays the same change from fluorescent to non-fluorescent SOM as Figure 3.20. Moreover, the transitional change recognised within the fluorescent subgroups in Figure 3.20, is also evident, though slightly different. In Figure 3.24B, the transitional change is much sharper showing a change from assemblage group A and G (only SOM dominated samples assigned to this group) to assemblage groups E and F. Thus, it is apparent that two inherently linked controls are accounted for by axis one: redox status and extent and duration of transportation. Preservation potential is the principal control and amount of exposure to attrition is the more subordinate control. These major controls are exactly the same as the controls determined from Figure 3.20.

A relatively similar pattern to that shown in the previous plots is recognised on Axis two. A change from Assemblage groups E and F, (and G) through various assemblages to the end member of non-fluorescent, assemblage group B, in the upper most corner of the NE quadrant is observed. Finally, the similarity between these diagrams which do not show the arch effect, and Figures 3.19 to 3.22, supports the use of CA instead of DCA.

3.8 Controls

The previous sections have clarified the role of some of the processes which influence the development of particular associations of organic matter. However, it is important to realise that controls on palynomorphs and palynodebris distribution are very complex. Organic matter may be subjected to a variety of processes both during and after the functional life of the source organism [Gastaldo & Huc, 1994]. To extend the appreciation of the mechanisms governing the genesis of the organic matter associations recognised in the present study, subsections 3.8.1 and 3.8.3 assess the relationship between the spatial distribution of the sample scores and the stratigraphic position and grain-size respectively. Subsection 3.8.5 evaluates the relationship between ‘environmental variables’ of the host sediment and the distribution of *species* and samples.

3.8.1 Stratigraphic distribution

All samples from the Cleveland Basin, except those from the Cloughton Formation, were separated into their respective formations. Samples from the Cloughton Formation were grouped and divided into the following stratigraphic units: the Sycharham and Gristhorpe Member, and the Millepore Bed and Yons Nab Beds of the Lebberton Member. This separation was recognised because a large number of samples were collected from the Cloughton Formation, in comparison to other formations, and it became apparent, during the course of the present study, that the organic matter from this formation showed some intriguing trends. Samples collected from the lateral extent of the Gristhorpe Plant Bed were not included because this is an evaluation of the stratigraphic (temporal) distribution. Although the removal of the outliers improves the spread of the central cluster, all the data were included because the outliers clearly represent specific environmental/taphonomic conditions. In addition, the majority of the outliers are from the lower part of the Ravenscar Group.

Interpretation

Figure 3.27 shows the spatial orientation of the different stratigraphic groups. Visual examination of the non-marine units (*e.g.*, Saltwick and Scalby Formations, and Sycharham and Gristhorpe Members) highlights the presence of some clear differences. The samples from the Saltwick Formation, displayed in Figure 3.27A, occupy the centre and left-hand side of the plot. This configuration suggests that the Saltwick Formation comprises both ‘well-drained’ sediments containing degraded SOM, (this could be caused by warmer conditions, bioturbation, increased transportation and/or fluctuations in

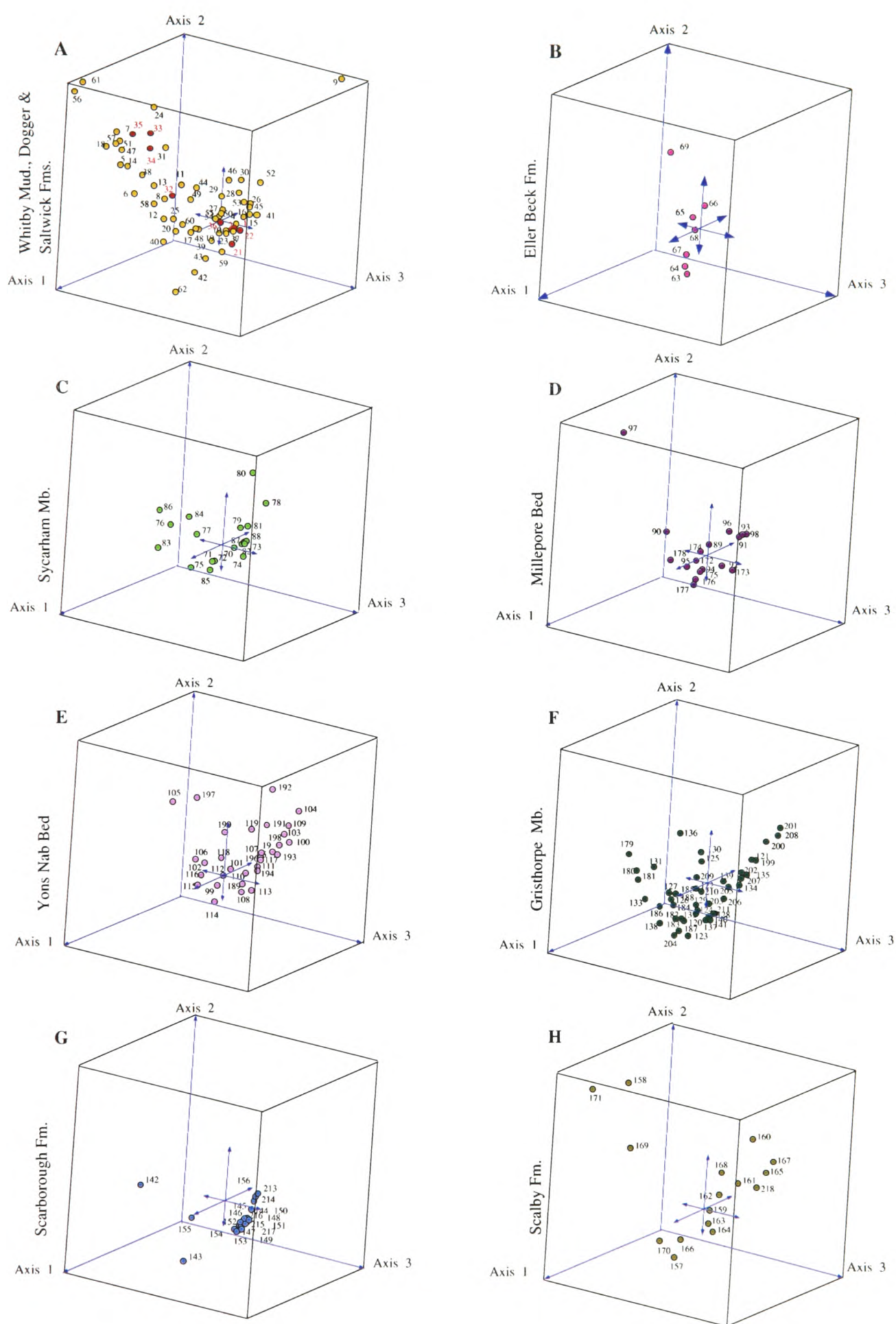


Figure 3.27: Three-dimensional CA ordination plots for Cleveland Basin data. The different plots show the configuration of samples from: A) Whitby Mudstone and Dogger Formations shown in red, and Saltwick Formation in yellow; B) represents samples from the Eller Beck Formation; C) displays the data from the Sycarham Member, Cloughton Formation; D) portrays the samples from the Millepore Bed, Cloughton Formation; E) represents the sample scores from the Yons Nab Beds, Cloughton Formation; F) shows the sample scores from the Gristhorpe Member, Cloughton Formation (samples from the lateral examination of the Gristhorpe plant bed are not displayed); G) displays the sample scores from the Scarborough Formation, and H from the Scalby Formation.

the water-table) and 'poorly drained' comprising well-preserved SOM (which may be caused by cooler, wetter conditions and/or deposition close to source in low-energy anoxic/dysoxic sediments). Thus, a broad range of conditions typified the deposition of the Saltwick Formation. Samples from the Gristhorpe Member, in comparison, occupy the right-hand side and base of Figure 3.27F. This pattern indicates that the Gristhorpe Member contains well-preserved SOM, resistant non-fluorescent fragments and some *Classopollis* pollen. The higher levels of undegraded SOM in the Gristhorpe Member imply that the rate of degradation was lower and/or transportation to the site of deposition was less than the Saltwick Formation. The influx of *Classopollis* pollen may have resulted from either preferential deposition or an increase in palaeotemperature/seasonality. The increase in fragments, (carbonised fragments) in the Gristhorpe Member may be due to a higher production rate resulting from an increase in the amount of wild-fires. This issue is addressed in Chapter 4. The Sycarham Member, shown in Figure 3.27C, which represents the lower part of the Cloughton Formation, is intermediate between the Saltwick and the Gristhorpe plot. Figure 3.27H shows the configuration of samples for the Scalby Formation. These are scattered throughout the diagram indicating that the organic matter was generated and accumulated under a broad range of conditions. The change in the non-marine units from the Saltwick Formation to the Gristhorpe Member indicates that variations in *species* associations occurred through time. This temporal pattern may be due to climatic, geographic and/or depositional variations. For example variations in the level of the water-table could result in the presence of both degraded and non-degraded SOM observed in the Saltwick Formation. Changes in the water-table may be caused by a number of factors, *e.g.*, sea-level fluctuations, local elevation changes, and/or variations in the amount of rainfall. It is important, however, to note that variations in the depositional conditions may reflect the prevailing climatic conditions.

The marine units do not show any clear temporal change. Samples from the Scarborough Formation, displayed in Figure 3.27G, plot in a cluster which indicates that they are very similar, *e.g.*, well-preserved SOM and $\geq$ very-occasional dinoflagellate cysts. This suggests that the organic matter accumulated close to source under dysoxic or temporarily anoxic conditions [Tyson, 1995]. Only three samples plot as separate entities from the main cluster. Their location in the plot implies that there were deposited close to terrestrial sources and/or the prevailing conditions were oxic. The Eller Beck Formation, the Millepore and Yons Nab Beds of the Lebberston Member shown in Figure 3.27B, D and E respectively, all contain fragments which indicates that the host sediments accumulated either close to the shoreline or near fluvial environments and/or where oxic conditions prevailed.

The mean and standard deviation of the index of organic-matter content is depicted for each unit in Table 3.5. Contrary to most studies that use TOC values, the organic-matter content is higher in the non-marine than marine. This is probably because many of the samples, investigated in the present study, were collected from plant beds or units which were visibly rich in organic matter. Many samples were, however, collected from units which are believed to be organically poor, for example, crevasse splays. The presence of organically rich and poor samples in the non-marine units is reflected in the standard deviations, displayed in Table 3.5, which are greater in the non-marine than marine units.

Stratigraphic Unit		Mean	Standard deviation
Scalby Formation		0.48	0.51
Scarborough Formation		0.69	0.67
Cloughton Fm.	Gristhorpe Member	0.99	1.45
	Yons Nab Beds	0.70	0.67
	Millepore Beds	0.50	0.59
	Sycarham Member	1.25	2.13
Eller Beck Formation		0.53	0.59
Saltwick Formation		1.06	1.85
Dogger Formation		0.18	0.12
Whitby Mudstone Fm.		0.88	0.06
Cleveland Basin *		0.83	1.35
Shell		1.36	1.25

Table 3.5: Mean and Standard deviation of organic matter per gram of sediment for each Stratigraphic unit. * All data from the Cleveland Basin are included in this calculation

The Saltwick Formation, Sycarham Member and Gristhorpe Member all comprise relatively similar amounts of organic-matter content per gram of sediment. The Sycarham Member contains the most organic matter, probably because it comprises more drifted plant remains than any other level of the Ravenscar Group. The Sycarham Member has the highest standard deviation, followed by the Saltwick Formation and Gristhorpe Member respectively. This range probably reflects either the nature of the depositional environments, as mentioned above, and/or variations in productivity. The Scalby Formation contains the lowest mean and standard deviation of the non-marine units. This may reflect change, either singular or in combination, in the climate (which will effect production rates), the geographical setting and/or the depositional environments.

It is important to note that Demaison & Moore [1980] reported that even if productivity rates are high, this does not necessarily lead to a high preservation rate. The preservation potential of organic matter is subject to many constraints, as highlighted earlier, and these constraints may overprint the true variations in the rate of production. However, Sladen & Batten [1984] and Powell *et al.* [1990] suggested that a scarcity of land-plant detritus in non-marine and marine settings respectively, sometimes correlate with an arid or semi-arid climate. This could, therefore, indicate that the low levels of index of organic-matter content in the Scalby Formation, in comparison to the other non-marine units was caused by a change from a humid to drier climate. Variations in the climate may also be gleaned from changes in particular associations of different types of organic matter. The decay process is most rapid in moist, warm and well-oxygenated conditions. Thus, the prevalence of both degraded and undegraded SOM in the Saltwick Formation may reflect relative changes in the palaeotemperature, level of the water-table (which may be related to changes in the sea-level/rainfall), amount of transportation to the depositional site and/or bioturbation during the deposition of this formation.

3.8.2 Synopsis

There is clearly a change through time in the nature of the organic matter *species* from the Ravenscar Group and these changes may be geographically, depositional or climatically controlled. Even if the changes are due to variations in the depositional setting, they may reflect the prevailing climatic conditions.

3.8.3 Relationship to grain-size

Many of the earlier workers, including Muir [1964] and Hughes & Moody-Stuart [1967] recognised a relationship between grain-size and organic matter. Muir [1964] studied the relationship between sporomorphs and lithology in the Middle Jurassic of the Cleveland Basin. She observed that spores were consistently present as small percentages in marine sediments, especially siltstones, whilst most thin-walled pollen showed the highest percentages in non-marine, fine-grained sediments. Hughes & Moody-Stuart [1967] indicated that *Classopollis* pollen and small ($\leq 50 \text{ } \mu\text{m}$) thin-walled inaperturate pollen, increased with decreasing sediment grain-size in the Cretaceous 'fluvial-lacustrine' Wealden Group. Tyson [1984] suggested, however, that the relative abundance of *Classopollis* pollen in the Callovian Deep Sea Drilling Project palynomorph assemblages is largely independent of facies and indicates long-term floral and climatic trends. This, therefore, suggests that the concentration or

absence of certain *species* of organic matter are not simply related to grain-size.

The more recent direction has been to suggest that in reality grain-size is only one of a combination of inter-related factors. For example Lewis [1995] mentioned that grain-size is generally a function of the depositional environment, so changes between organic matter and grain-size cannot be viewed as a simple one-to-one relationship. More recently, Batten [1996] suggested that the coarser the grain-size of the sediment (fluvial setting), the greater the water depth, the more oxygenated the bottom, and hence, the longer the organic matter is exposed to degradation processes, the less chance of preservation. The corollary of this is that preservation may be enhanced if deposition takes place in shallow-water (fluvial-lacustrine/interdistributary bay setting), where the sediment is mainly argillaceous, and the sediment-water interface and some of the overlying water column are depleted in oxygen (dysoxic-anoxic). Batten [1996] also noted that fine particulate organic detritus is normally winnowed from medium sands and coarser sediments or destroyed by abrasion.

To evaluate the relationship between grain-size and organic matter, the host sediments for each sample from the Cleveland Basin were classified into one of the following grain-size categories: clay, mud, silt, very-fine-grained, fine-grained and medium-grained. These groups were then superimposed on the sample scores as illustrated in Figure 3.28. Occasionally samples contained two types of grain-size; for example silt and very-fine-grained. These were identified and grouped into intermediate categories as shown in Figure 3.28.

Figure 3.28 displays a clear difference between the end members clay and medium-grained sand host sediments. The majority of the organic matter samples from clay sediments plot in a tight cluster in the mid to upper right-hand side of Figure 3.28A. This area usually represents organic-rich samples from dysoxic-anoxic, low-energy conditions (slack-water). Organic matter samples from medium-grained host sediments, in comparison, are scattered throughout Figure 3.28F. The main concentration lies in the middle and left side of the plot. This area of the plot typically contains samples which have a lower organic-matter content and *species* of organic matter which are related to environments which were partially oxic and/or exposed to higher energy conditions than those in the right side of the plots. This pattern appears to concur with the Batten [1996] conclusions which were outlined above. It should be noted, however, that the grain-size/lithofacies may be also related to the prevailing climatic conditions. Climate has an important influence on the architecture of sediments, through its direct

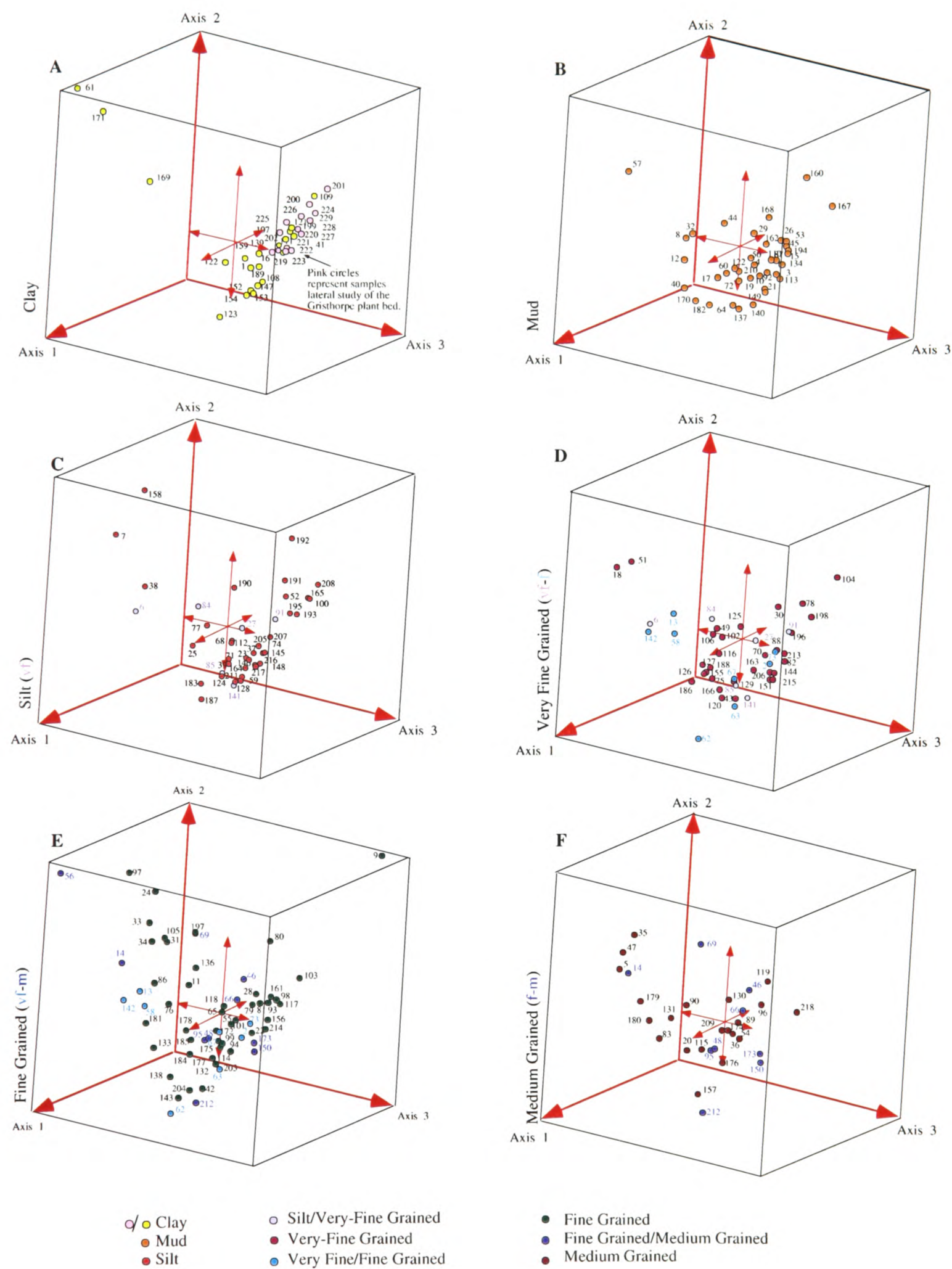


Figure 3.28: Three-dimensional plots of Correspondence Analysis Ordination sample scores separated into grain-size categories. Diagram A shows the spatial distribution of clay samples. Diagram B represents mud. Diagrams C-F represent silt to medium grained sandstone respectively. These diagrams also show the spatial arrangement of samples which have a grain-size between two major categories e.g., silt to very-fine sandstone.

effect on the type of erosion and indirectly through the amount of vegetative cover. The grain-sizes in between the end-members (clay and medium-grained host sediments) are transitional. The change from a tight cluster to a broad spread appears to occur between siltstone and very-fine-grained host sediments.

The average and standard deviation index of organic matter per gram for each grain-size category was also calculated, the results of which are highlighted in Table 3.6. The host sediments clay and mud are clearly richer in organic-matter content than the coarser-grained material. This pattern finds support from a number of workers, including Durand [1980]; Tyson [1995] and Batten [1996] who reported the same style of change with grain-size.

Grain-Size	Mean	Standard Deviation
Clay	1.98	2.83
Mud	1.09	1.17
Silt	1.73	1.19
Very-Fine-Grained	0.94	1.69
Fine-Grained	0.37	0.50
Medium-Grained	0.27	0.43

Table 3.6: Mean and standard deviation of index of organic matter content for each grain-size category.

The standard deviations in Table 3.6 show some intriguing trends. The clay category displays the highest standard deviation. This suggests that both organic-rich and -poor samples occur in this class. The presence of organically poor clays is atypical. This, therefore indicates that either the preservation rate, accumulation and/or production rate was very low for these host sediments. The former may have been caused by higher rates of decay (which may result from fluctuations in the level of the water-table, and/or an increase in the palaeotemperature, transportation or bioturbation). Low accumulation rates may indicate that the host sediments did not occur in the main clastic pathways. Low rates of organic production, as mentioned earlier, may be indicative of arid or semi-arid environments.

3.8.4 Synopsis

It is clear that there is a relationship between grain-size and index of organic matter per gram of sediment. It appears, however, that these trends are related to variations in the rate of decay, production and/or transportation, which are related to different environments of deposition. Variations in the latter may be a function of the prevailing climatic regime. Thus, grain-size is not a direct control on the nature or content of the organic matter.

3.8.5 Environmental Variables: Canonical Correspondence Analysis

Although indirect ordination (CA) of the count data has provided a useful insight into the structure and causal relationships it does not permit the dual analysis of *species* (organic matter)-environmental relationships. Moreover, the underlying controls are subjectively assigned in CA. ter Braak [1986, 1988] developed Canonical Correspondence Analysis (CCA), a direct ordination package, to solve this problem. CCA is an extension of CA in which environmental data are incorporated into the ordination. CCA permits the qualification of environmental data and samples/*species* simultaneously. Thus, the technique of CCA aims to select the linear combinations of environmental variables that best explain the variations in the organic-matter composition of the samples on each ordination axis, in addition to exploring the variability in the data set, *i.e.*, the environmental data are used directly to organize the information. This result is achieved by use of multiple regression that, during the ordination process, regresses the environmental variables onto either the individual *species* or samples as so desired. Thus, the ordination diagrams display the pattern of variation in *species* composition and the main relations between samples, and each of the environmental variables. Comparison of the CA output with the CCA output can be used to test the validity and significance of the patterns, (*i.e.*, repeatability).

Method

To investigate the associations between *species* of organic matter and 'environmental variables', two separate matrices were employed. The same data matrix of abundance of organic-matter categories used in CA (Cleveland Basin data) was employed and a second matrix of 'environmental variables' or 'describers' was assembled for the Cleveland Basin. This included data from the lithological descriptions, examination of each sedimentary sample, the stratigraphic position and lithofacies category of each sample. The environmental data matrix was designed to record whether a specific environ-

mental variable was present or absent [after Lewis, 1995]. The categories used in this study differ from those of Lewis [1995] because they were designed to reflect the specific nature of the sediments investigated herein. The environmental variables recognised as potentially important on the basis of previous analysis and published literature, were subdivided into six classes: 1) general environmental elements, 2) visible organic matter, 3) colour of organic matter, 4) grain-size, 5) lithofacies and 6) stratigraphic position. These classes were separated further, as highlighted in Table 3.7. The data matrix was created by exhaustively coding the presence/absence of each environmental category, except colour of organic matter and lithology, for each sample in binary form (0/1). In a number of cases, more than one subclass was present in the categories ‘colour of organic matter’ and ‘lithology’. For example, 70 % of the visible organic matter was dull-brown and 30% was shiny-black, thus values of 0.7 and 0.3 were assigned to these categories respectively.

Environmental Variables											
General		Visible O.M.		O.M. Colour		Grain Size		Lithofacies		Stratigraphic Unit	
◆ 1	Roots	◆ 7	Rich	◆ 11	Brown Dull	◆ 15	Clay	◆ 21	Alluvial	◆ 25	Whitby Mudstone
◆ 2	Burrows	◆ 8	Average	◆ 12	Black Dull	◆ 16	Mud	◆ 22	Estuarine	◆ 26	Dogger Formation
◆ 3	Flora	◆ 9	Low	◆ 13	Black Shiny	◆ 17	Silt	◆ 23	Lagoonal	◆ 27	Saltwick Formation
◆ 4	Fauna	◆ 10	Absent			◆ 18	Vf grained	◆ 24	Marine	◆ 28	Eller Beck Formation
◆ 5	Plant Frag.					◆ 19	F grained			◆ 29	Sycarham Member
◆ 6	Wood					◆ 20	M grained			◆ 30	Millepore Bed
◆ 14	Iron. Nods.									◆ 31	Yons Nab Bed
										◆ 32	Gristhorpe Member
										◆ 33	Scarborough Formation
										◆ 34	Scalby Formation

Table 3.7: Different categories scored for environmental matrix.

Plots

The method of displaying the CCA output which incorporates environmental data into the analysis and constrains the spread of *species* or samples according to the influence of each environmental variable on them is by ‘Biplot’. The plots comprise either *species* (of organic matter) or samples points as in CA. The environmental variables are usually shown as arrows. These arrows, which are overlain on the *species* or sample plots, explain, as far as possible, the spread of the *species* or sample data in terms of environmental factors [Lewis, 1995].

There are a number of important features related to the interpretation of the environmental variables. This account is compiled from ter Braak [1986, 1988]; Kent & Coker [1992] and Lewis [1995]. The fundamental attributes of the environmental arrows are their directions, angles between the environmental vector and axes, and their relative lengths. Each arrow points in the direction of maximum change of that environmental variable across the diagram. The length of each arrow is proportional to the rate of change of that particular environmental variable in the direction it points. Furthermore, the length of each arrow reflects how much the *species*/sample distributions differ along that environmental variable [ter Braak, 1986]. The *species*/sample endpoints that plot close to, or beyond, the tip of an environmental vector are strongly correlated with that environmental variable. Those *species*/samples which lie at the opposite end of the vector are negatively correlated with that environmental variable. The longer the environmental vector, the greater the correlation between the environmental variable and the ordination axes [ter Braak, 1987]. The angles between the arrows reflect the intercorrelations between the variables. The angle between an arrow and each axis is a representation of its degree of correlation with the axis. Hence, environmental variables with long vectors which are parallel or sub-parallel to an axis influence the spread of the *species*/samples displayed in the ordination diagram to a greater extent than environmental variables with short arrows and a large angle between the vector and axis. This is an important feature of CCA because it overcomes the subjective nature with which environmental controls are often added to ordination axes in CA.

Monte Carlo Test

Prior to interpreting the CCA output, a Monte Carlo test, which is incorporated into the CANOCO program, was performed on the data set to evaluate the significance of the correlation. The result after 99 random permutations of the sample numbers in the environmental data was 0.01, *i.e.*, the significance is 99.9%.

Interpretation

Firstly, it is important to note that the configurations observed in the CA plots, and hence underlying trends, are also evident in the CCA plots. For example, Figure 3.30 displays the CCA sample scores of axes 1 v 2 (scaling-option two applied), colour coded to represent the conventionally defined assemblages. The change observed in the CA axes 1 v 2 plots, from strongly fluorescent to weakly fluorescent is clearly present. Figure 3.29 displays the CCA *species* scores of axes 1 v 2

when constrained by the environmental variables with scaling one applied. The legend for the different environmental variables and *species* of organic matter are displayed in Table 3.7 and Table 3.8 respectively.

Legend for Species Score Data		
Palynomorphs (1-12)	Non-Vita Fragments	Structureless Organic Matter
1 ★ Unidentified Palynomorphs	Brown-Equidimensional (19-22)	Transparent-Yellow (35-38)
2 ★ Non-Bisaccate Pollen	19 ■ Brown-Equidimensional-Fluorescent-Cellular	35 ● Transparent-Yellow-Fluorescent-Fibrous
3 ★ Bisaccate Pollen	20 ■ Brown-Equidimensional-Non-Fluorescent-Cellular	36 ● Transparent-Yellow-Fluorescent-Non-Fibrous
4 ★ <i>Classopollis</i> Pollen	21 ■ Brown-Equidimensional-Fluorescent-Non-Cellular	37 ● Transparent-Yellow-Non-Fluorescent-Fibrous
5 ★ Spores	22 ■ Brown-Equidimensional-Non-Fluorescent-Non-Cellular	38 ● Transparent-Yellow-Non-Fluorescent-Non-Fibrous
6 ★ Fresh-Water Algae	Brown-Bladed (23-26)	Yellow-Brown (39-42)
7 ★ Leiosphere	23 ■ Brown-Bladed-Fluorescent-Cellular	39 ● Yellow-Brown-Fluorescent-Fibrous
8 ★ Tasmanitids	24 ■ Brown-Bladed-Non-Fluorescent-Cellular	40 ● Yellow-Brown-Fluorescent-Non-Fibrous
9 ★ Acritarchs	25 ■ Brown-Bladed-Fluorescent-Non-Cellular	41 ● Yellow-Brown-Non-Fluorescent-Fibrous
10 ★ Dinoflagellate cysts	26 ■ Brown-Bladed-Non-Fluorescent-Non-Cellular	42 ● Yellow-Brown-Non-Fluorescent-Non-Fibrous
11 ★ Zoomorphs	Black-Equidimensional (27-30)	Brown-Black (43-46)
12 ★ Fungal palynomorphs	27 ■ Black-Equidimensional-Fluorescent-Cellular	43 ● Brown-Black-Fluorescent-Fibrous
Vita-Fragments (13-18)	28 ■ Black-Equidimensional-Non-Fluorescent-Cellular	44 ● Brown-Black-Fluorescent-Non-Fibrous
13 ■ Cuticle	29 ■ Black-Equidimensional-Fluorescent-Non-Cellular	45 ● Brown-Black-Non-Fluorescent-Fibrous
14 ■ Epidermal Tissue	30 ■ Black-Equidimensional-Non-Fluorescent-Non-Cellular	46 ● Brown-Black-Non-Fluorescent-Non-Fibrous
15 ■ Definite Wood	Black-Bladed (31-34)	Abundance (47)
16 ■ Vascular Bundles	31 ■ Black-Bladed-Fluorescent-Cellular	47 ■ Particulate Organic Matter per gram of sediment
17 ■ Resin	32 ■ Black-Bladed-Non-Fluorescent-Cellular	
18 ■ Plant Tissue	33 ■ Black-Bladed-Fluorescent-Non-Cellular	
	34 ■ Black-Bladed-Non-Fluorescent-Non-Cellular	

Table 3.8: Legend for the *species* organic matter categories

As axis 1 is much more significant than axis 2, any environmental vectors that are strongly correlated with this axis are likely to be very important. Figure 3.29 reveals that the environmental vectors ‘clay’ and the ‘Saltwick Formation’ are the longest of all the ‘environmental’ vectors which closely correlate with axis one. They are the most influential vectors. As ‘clay’ is the longest, it is the most important. It is interesting to note that ‘clay’ and ‘Saltwick’ are negatively correlated. This difference is probably due to the fact that the host sediments from the Saltwick Formation were rarely clay. ‘Medium-grained sand’ and ‘fine-grained sand’ ‘environmental’ vectors are respectively, the third and fourth longest environmental vectors which correlate with axis 1 and therefore have great significance in the ordination. The latter plot in positive side of the ordination plot near the environmental vector for the Saltwick Formation. The grain-size variables are strung out along axis one and plot from left to right in order of decreasing grain-size. Hence samples that plot on the negative side of axis one are more likely to be composed predominantly of clay-sized grains, for example the Gristhorpe Member, whilst those on the positive side are likely to be composed of coarser grained particles.

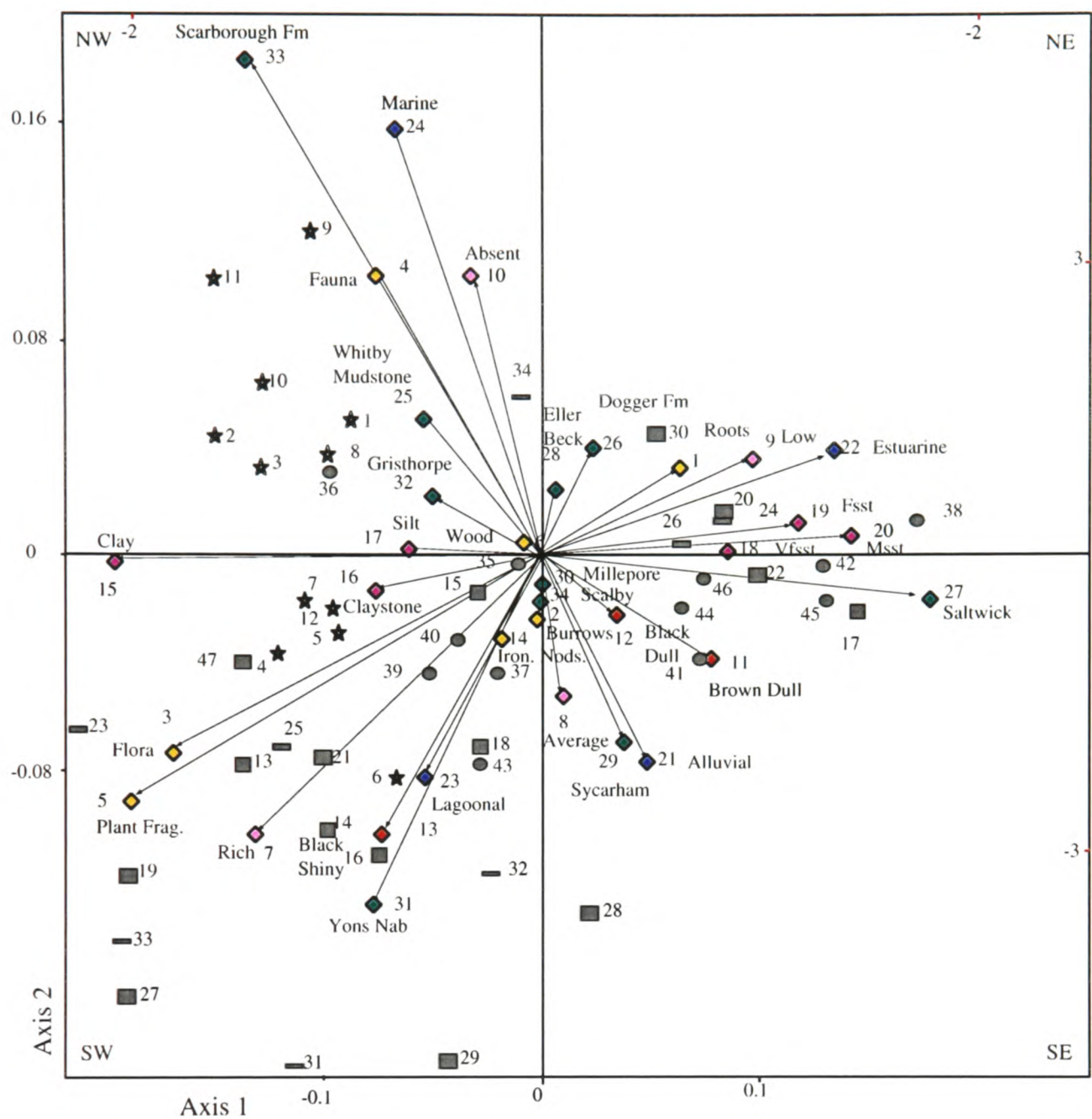
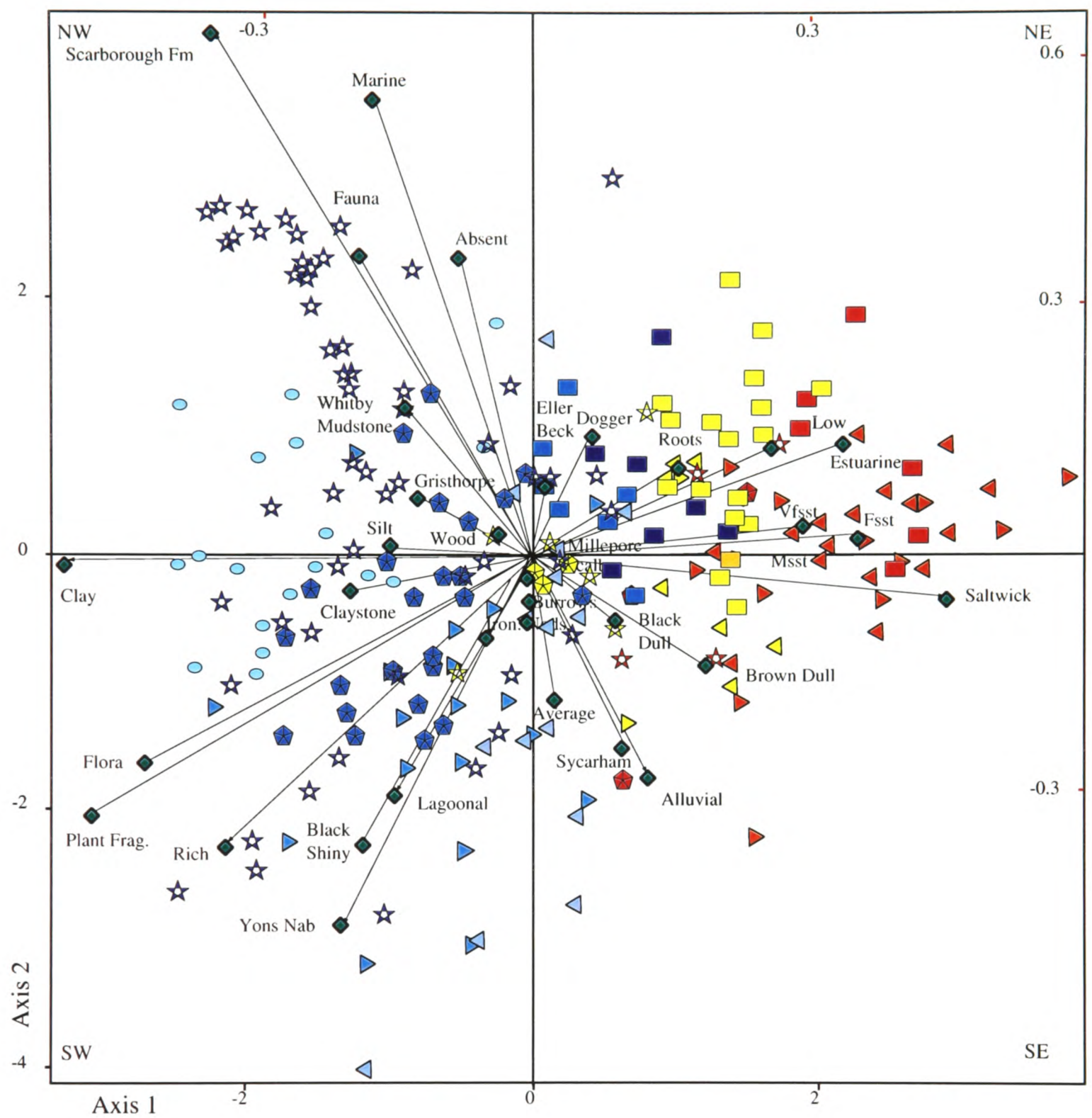


Figure 3.29: Axis 1 v 2 plot of Canonical Correspondence Analysis Ordination of *species* scores and environmental variables. Scaling-option one was applied. The axes values shown in black correspond to the environmental vector scores. The axes values depicted in red correspond to the *species* scores.

The trend of the Scarborough Formation vector suggests that it correlates equally with axes 1 and 2. The fauna environmental variable plots in line with the Scarborough Formation vector, indicating a strong correlation between these two environmental variables, as expected. In the SW quadrant the environmental vectors, 'flora', 'plant fragments', 'rich' (in visible organic matter), 'Yons Nab' and 'black shiny' all plot in close association. This implies that samples rich in organic matter are likely to contain flecks of 'black shiny' organic matter and plant fragments, and most of these are found in the Yons Nab Member. The remaining environmental variables are generally unimportant, as indicated by their short vectors.



Assemblage Groups	Assemblage Subgroups	Strongly-Fluorescent	Intermediate-Fluorescence	Weakly-Fluorescent
Group Assemblage A: Abundant transparent-yellow, fluorescent, non-fibrous SOM				
Group Assemblage B: Abundant total SOM; <very-common total fragments, and < frequent palynomorphs				
Group Assemblage C: > Common fragments; SOM < total fragments, and < frequent palynomorphs				
Group Assemblage D: Palynomorphs > occasional; total SOM > total discrete fragments				
Group Assemblage E: Total fragments > total SOM, and palynomorphs < frequent				
Group Assemblage F: Total fragments > total SOM, and palynomorphs > occasional				
Group Assemblage G: Dinoflagellate cysts > rare.				

Figure 3.30: Axis 1 v 2 plot of Canonical Correspondence Analysis Ordination of sample scores and environmental variables. Scaling-option two was applied. The axes values shown in black correspond to the environmental vector scores. The axes values depicted in red correspond to the sample scores.

Comparison of Figure 3.29 and Figure 3.30 shows the species of organic matter which are more commonly found in the different conventionally defined assemblage types, and which environmental vectors influence the development of particular associations. For example in the NW quadrant, which is dominated by 'marine' environmental variables, dinoflagellate cysts, zoomorphs and acritarchs are recognised. Moving towards the SW quadrant, *species* and environmental variables associated with 'plant beds' are identified, for example, well-preserved SOM, the index of organic matter, and 'clay' and 'mud'. This pattern supports the findings of the grain-size analysis which generally found that the host sediments of samples containing the most organic matter were clay to very-fine-grained. In the positive side of the plot non-fluorescent fragments are associated with coarser grained sediments. This pattern therefore indicates that the preservation of fine, fragile organic material is primarily related to decay rate and transportation. This, therefore, supports the interpretations based on the CA plots.

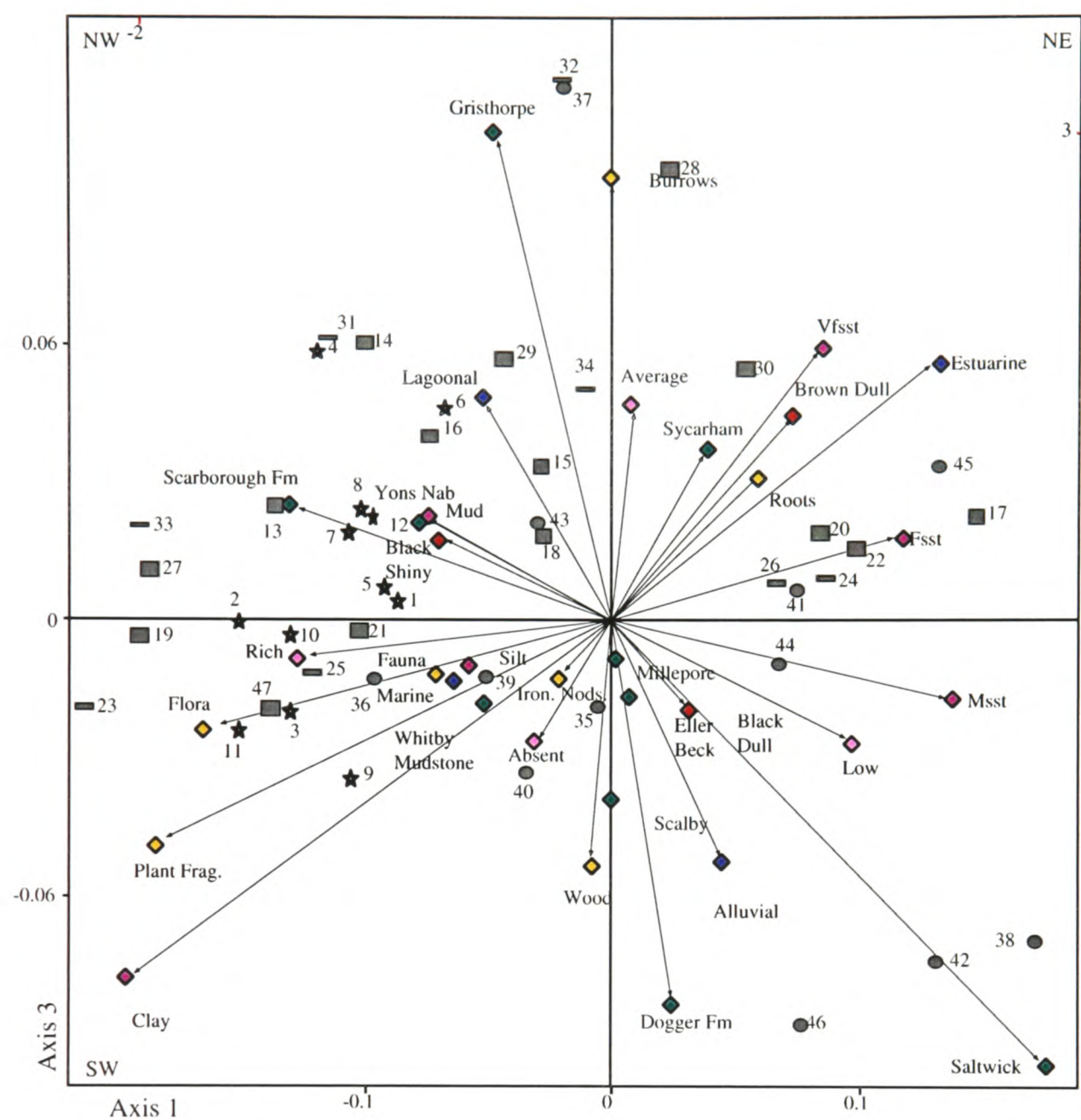
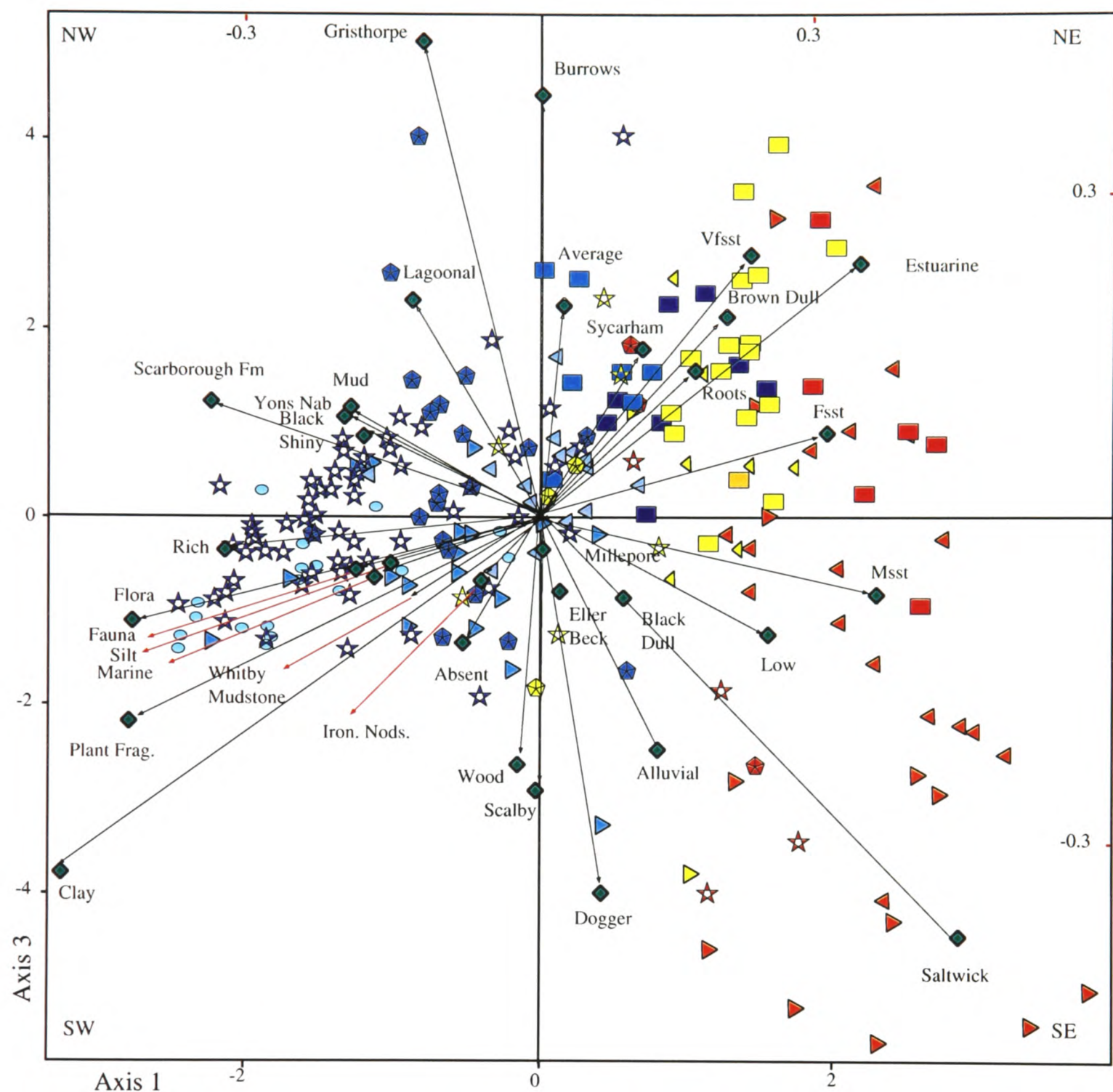


Figure 3.31: Axis 1 v 3 plot of Canonical Correspondence Analysis Ordination of *species* scores and environmental variables. Scaling-option one was applied. The arrows represent the environmental variables. The axes values shown in black correspond to the environmental vector scores. The axes values depicted in red correspond to the *species* scores.

Figures 3.31 and 3.32 display the CCA *species* and samples scores respectively, the configuration of which has been constrained by the environmental vectors, depicted as arrows. These plots show that the environmental vectors ‘burrows’ and ‘Gristhorpe Member’ strongly correlate with the positive side of axis 3. The environmental vectors ‘wood’ and ‘Dogger Formation’ correlate with the negative part of axis 3. This, therefore, lends support to the CA based interpretations that the conditions prevailing during the Gristhorpe Member and Dogger Formation were different. In addition, the environmental vector ‘Saltwick Formation’ lies in the opposite quadrant to the Gristhorpe Member indicating that they are also negatively correlated. This difference was also evident in the analysis of the stratigraphic arrangement of the CA sample scores in subsection 3.8.1.



Assemblage Groups	Assemblage Subgroups			Strongly-Fluorescent	Moderately-Fluorescent	Weakly-Fluorescent
Group Assemblage A: Abundant transparent-yellow, fluorescent, non-fibrous SOM				○		
Group Assemblage B: Abundant total SOM; <very-common total fragments, and < frequent palynomorphs				▴	▴	▴
Group Assemblage C: > Common fragments; SOM < total fragments, and < frequent palynomorphs				▴	▴	▴
Group Assemblage D: Palynomorphs > occasional; total SOM > total discrete fragments				▴	▴	▴
Group Assemblage E: Total fragments > total SOM, and palynomorphs < frequent				▴	▴	▴
Group Assemblage F: Total fragments > total SOM, and palynomorphs > occasional				▴	▴	▴
Group Assemblage G: Dinoflagellate cysts > rare.				☆	☆	☆

Figure 3.32: Axis 1 v 3 plot of Canonical Correspondence Analysis Ordination of sample scores and environmental variables. Scaling-option two was applied. The axes values shown in black correspond to the environmental vector scores. The axes values depicted in red correspond to the sample scores.

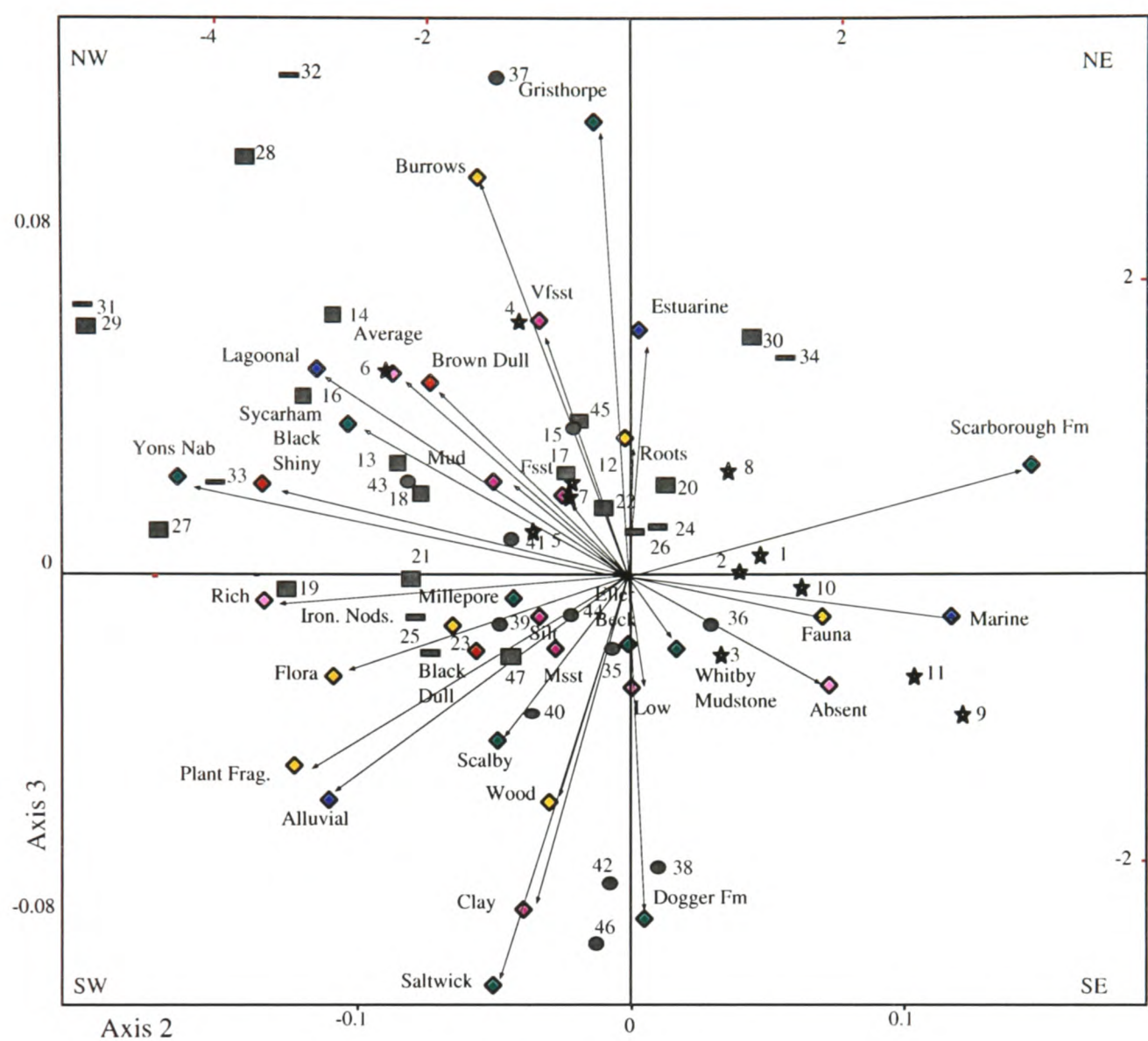
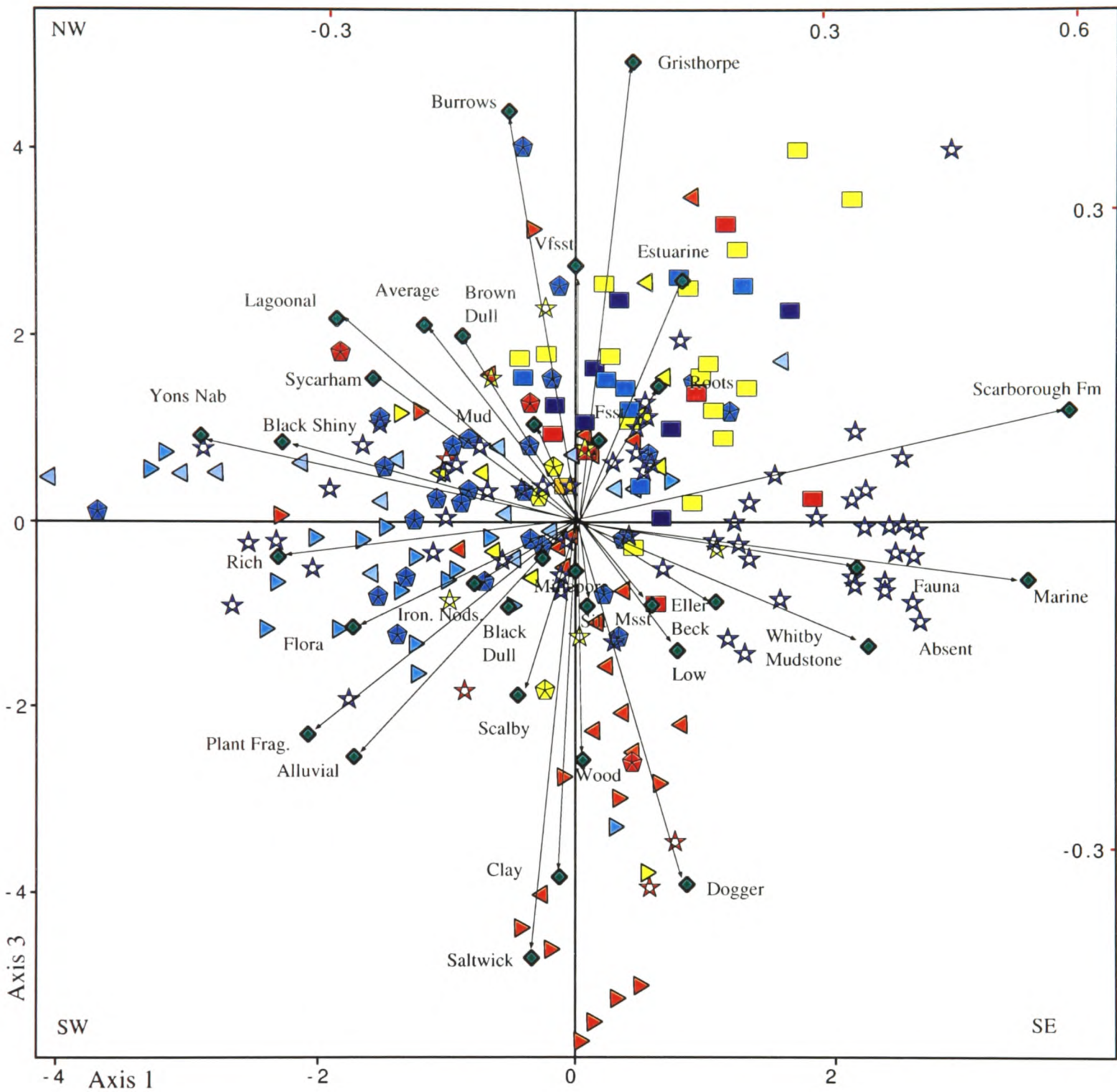


Figure 3.33: Axis 2 v 3 plot of Canonical Correspondence Analysis Ordination of sample scores and environmental variables. Scaling-option two was applied.

Figures 3.33 and 3.34 show the CCA *species* and sample scores respectively with environmental vectors superimposed. An interesting point is the association of the fluorescent fragments with the environmental descriptors ‘lagoonal’, ‘Yons Nab’ and ‘Sycarham Member’. It is believed that the production of this material may have increased during this period and/or the decay pathway was more conducive to the preservation of this type of organic matter.



Assemblage Groups	Assemblage Subgroups			Strongly-Fluorescent	Moderately-Fluorescent	Weakly-Fluorescent
Group Assemblage A: Abundant transparent-yellow, fluorescent, non-fibrous SOM				○		
Group Assemblage B: Abundant total SOM; <very-common total fragments, and < frequent palynomorphs				▶	▶	▶
Group Assemblage C: > Common fragments; SOM < total fragments, and < frequent palynomorphs				◀	◀	◀
Group Assemblage D: Palynomorphs > occasional; total SOM > total discrete fragments				⬢	⬢	⬢
Group Assemblage E: Total fragments > total SOM, and palynomorphs < frequent				■	■	■
Group Assemblage F: Total fragments > total SOM, and palynomorphs > occasional				■	■	
Group Assemblage G: Dinoflagellate cysts > rare.				★	★	★

Figure 3.34: Axis 2 v 3 plot of Canonical Correspondence Analysis Ordination of sample scores and environmental variables. Scaling-option two was applied.

3.8.6 Synopsis

The CCA plots clearly correspond to their CA counterparts. It is evident that axis 1 displays the same trend. Thus, preservation (dysoxic-oxic gradient) and transportation (energy-levels) are the most influential factors governing palynofacies composition. It is also apparent that there is a clear difference between the nature of organic matter recorded in the Gristhorpe Member and Saltwick Formation.

3.9 Range of organic matter within particular lithofacies

Batten [1996] stated that the value of palynofacies analysis to palaeoenvironmental interpretation is now widely recognised, on the basis of the number of papers published within the last few years that have this as their primary aim. Many workers have, however, questioned the reliability of palynofacies as a tool for environmental reconstruction. This uncertainty probably lies within the history of the subject, whereby a specific association of organic matter was assigned to a particular lithofacies type. For example, Whitaker [1984] stated that distributary channels, (regime of high-energy channel sand bodies) were characterised by sparse total kerogen, which was dominantly inertinite. He also stated that crevasse splays, which deposited organic matter into low-energy bays/lagoons, are poorly sorted in the proximal setting and inertinite dominated with some vitrinite, miospores and cuticle. In contrast, the organic matter associated with the distal setting is well-sorted, comprising vitrinite and structured sapropels.

To test the predictive qualities of palynofacies as an indicator of the environment of deposition some of the CA sample scores (from the Cleveland Basin) were categorised using an independent lithofacies scheme which was developed using sedimentological and ichnological information. This approach was designed to avoid introducing subjective bias into the investigation. Morgans [1997] developed a scheme to interpret and classify the diverse lithologies found in the Ravenscar Group of Yorkshire. A summary of her sedimentary facies scheme and distinguishing criteria are displayed in Figure E.2. Her scheme comprises four major lithofacies types; Alluvial, Estuarine, Lagoonal and Marine. Each category contains further subdivisions. For a more comprehensive account the reader is referred to Morgans [1997]. The samples which are used are from sections which have been lithologically logged by Morgans [1997], namely the Dogger and Saltwick Formation exposed

at High Hawsker, the Eller Beck Formation, the Gristhorpe Member and the Scarborough Formation. The categories defined by Morgans [1997] are displayed in Figures 3.1 to 3.3. The different lithofacies groups were used to colour code the CA sample score results as shown in Figure 3.35.

Interpretation

Figure 3.35A displays the configuration of the 'alluvial' samples. This category encompasses a very broad range of environments from channel-facies associations, which include the coarsest sediments to fine-grained 'well- and poorly drained' floodplain deposits, within the Ravenscar Group. There does not appear to be any clear separation of the different alluvial lithofacies and it is apparent that samples defined as 'well-drained' plot in areas of the diagram which represent poorly drained samples, for example, samples 134, 206 and 207. Although, there is no clear relationship between alluvial lithofacies and organic matter, it is evident that the nature of the organic matter can add an extra dimension to the interpretation of the environment of deposition. For example, it may be possible to elucidate whether fine-grained 'well- and poorly-drained' floodplain deposits accumulated in low-energy/high-energy and/or dysoxic/oxic conditions.

Figure 3.35B contains samples ascribed to lagoonal and estuarine lithofacies. The different categories do appear to form relatively distinctive clusters. Examination of the location of the different classes of lithofacies, however, reveals that a large percentage of the samples defined as 'high-energy interdistributary bay deposits' are dominated by well-preserved SOM and subordinate fluorescent non-vita fragments. This indicates that these samples probably accumulated in relatively low-energy environments, where dysoxic to temporarily anoxic conditions prevailed. Samples defined as littoral sands plot towards the left side of Figure 3.35B, indicating that they accumulated under high-energy, oxic conditions, as expected.

Figure 3.35C contains samples assigned to marine lithofacies. Investigation of the arrangement shows that there is no clear relationship between the majority of the lithofacies categories and organic matter. The samples defined as accumulating in 'siliclastic embayments' and 'tidal sand belts' do, however, plot towards the left and lower part of the plot which is associated with oxic or partially oxic, high-energy conditions, as expected.

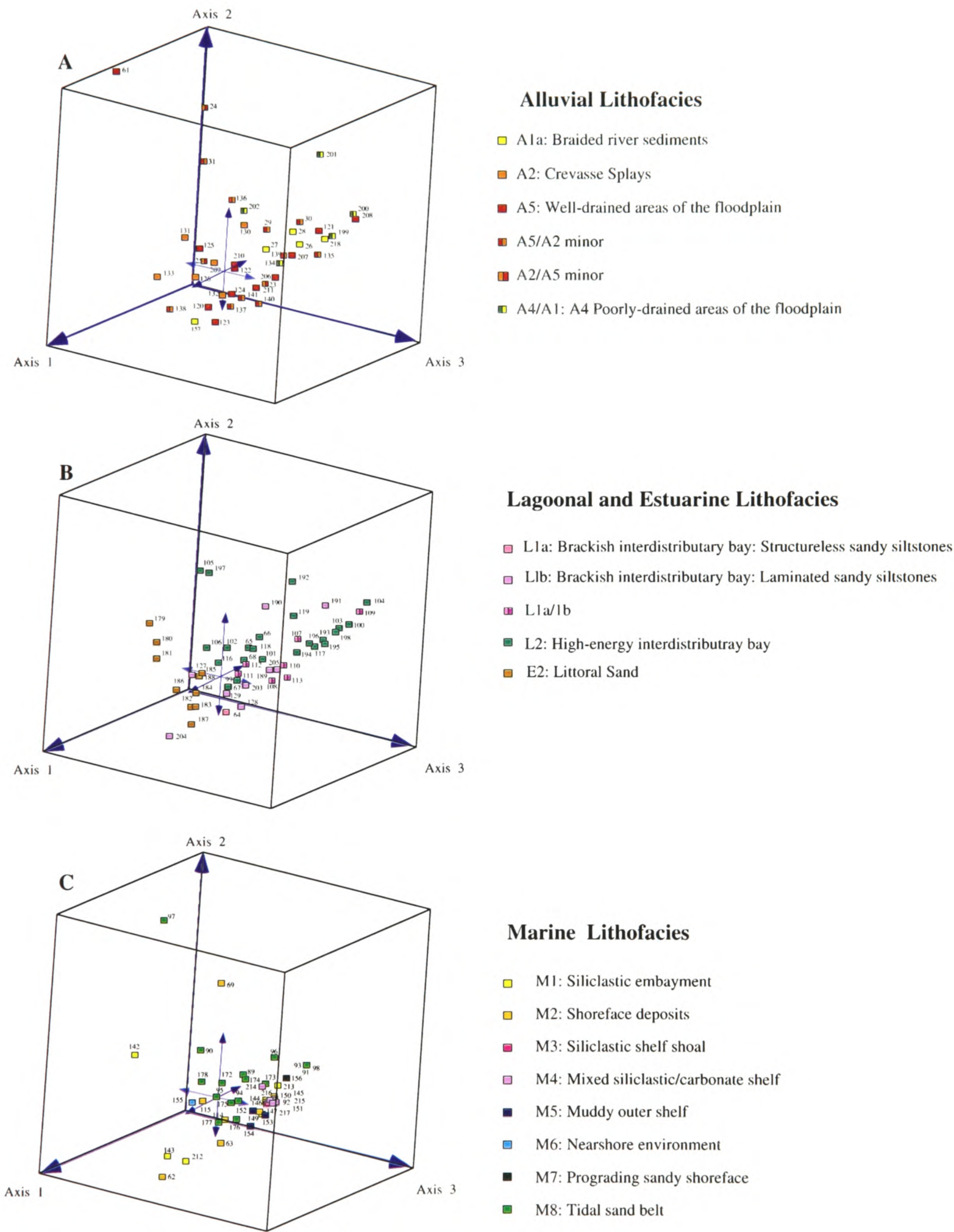


Figure 3.35: Three-dimensional plots of Correspondence Analysis Ordination sample scores separated into lithofacies categories *sensu* Morgans (1997). Diagram A shows the spatial distribution of alluvial samples. Diagram B represents lagoonal and estuarine lithofacies and diagram C shows the marine lithofacies samples. Note only those samples classified by Morgans [1997] are used in these plots.

3.9.1 Synopsis

It is clear that in some instances different lithofacies may display the same 'kerogen' and, conversely, the same lithofacies may reveal different 'kerogen' associations which supports the proposal of Gastaldo [1996]. It is evident, however, that nature of the organic matter displayed by samples from coarser host sediments can be associated with their lithofacies, for example 'littoral sands'. In addition, it is apparent that the nature of the organic matter adds an extra dimension to the interpretation of sediments, especially fine-grained host sediments. It is important to note that the interpretation of the nature of the organic matter should be undertaken in conjunction with other environmental information, *i.e.*, sedimentary information.

3.10 Implications of Results

The principal aims of this chapter were to gain a quantitative appreciation of the underlying controls and test the reliability of palynofacies as an environmental indicator. The multivariate statistical analysis has clearly highlighted that the organic matter, investigated in this study, forms a continuum. Detailed examination of the *species* (organic-matter) associations and superimposition of the conventionally defined assemblages on the sample scores revealed the underlying controls. The primary control is redox potential which is linked to energy-levels (degree of transportation and disturbance associated) with the environment of deposition. It is also evident that the nature of the organic matter varied through time and this may reflect climatic changes.

It is clear that organic matter is not a precise indicator of lithofacies. However, in the case of deltaic sediments, it may be very useful because the nature of the organic matter provides extra information about environmental elements *i.e.*, water-saturation, palaeotemperature, productivity, bioturbation and/or amount of transportation. In addition, the statistical analysis has permitted temporal trends to be elucidated. It is important to note that the results from the organic matter need to be integrated with sedimentological data and each specific case evaluated in relation to the underlying controls.

The majority of the assemblage groups defined by the conventional method were identifiable as separate parcels in the statistical output. The assemblage groups D and G were, however, scattered

in a less discrete fashion. Assemblage group D overlapped with B and C, whilst assemblage group G only separated into discrete clusters when the outliers had been removed. The overlap between B, C and D exists because samples in assemblage group D were classified using sporomorphs. The latter are minor in mathematical terms; thus the more abundant, or more obvious, components were stressed statistically at the expense of 'sporomorphs' which are ecologically useful. Therefore, as neither the statistical nor conventional method is perfect, the results from both methods, including the appreciation of the underlying controls, were integrated and used to define the assemblage-types employed in the palaeoenvironmental analysis. A summary of these assemblages is described in Section 3.11.

3.11 Assemblage Groups

Integration of the results from the conventional and statistical analysis permitted 19 nineteen assemblage groups to be identified: 1-19. These were separated and the different groups may be distinguished by the letter following the assemblage group number, for example, Assemblage Group 2B. The latter groups were further subdivided into major (five or more samples) or minor (4 samples or less) assemblage-types. In one case the assemblage-type was divided into sub-assemblage-types. Although the minor assemblage-types are often transitional between major assemblage-types, they are recognised as individual assemblage-types for two reasons: 1) to enable a high-resolution study, and 2) for future comparison with other palynofacies investigations. A synopsis of the assemblage groups, key characters and typical interpretation is provided in Table 3.9 and Table 3.10. A complete description of the different assemblages is contained in Appendix E.

The first 12 assemblage groups contain absent or rare dinoflagellate cysts and the remaining seven contain greater than or equal to 'very-occasional' dinoflagellate cysts. The order of description of the different groups is designed to reflect the change from well-preserved organic matter to poorly preserved organic matter, *i.e.*, the change from low-energy, anoxic conditions to high-energy, oxic conditions as this was recognised as the most important feature from the statistical analysis. The same order of descriptions also applies to the description of assemblage-types within each group.

	Assemblage Group (AG)	Key Character(s)	Typical Interpretation
Less than very-occasional dinoflagellate cysts	AG 1	Abundant Transparent-Yellow, Fluorescent, Non-Fibrous SOM	Anoxic-dysoxic, very limited comminution, close to source. Host sediments water-saturated.
	AG 1A	Abundant Transparent-Yellow, Fluorescent, Non-Fibrous SOM	Anoxic-dysoxic, close to source, very limited comminution, (i.e., limited bioturbation and/or water circulation). Host sediments water-saturated. Minor decrease in anoxia
	AG 1B	Abundant Transparent-Yellow, Fluorescent, Non-Fibrous SOM & Brown-Equidimensional Fragments	
	AG 1C	Abundant Transparent-Yellow, Fluorescent, Non-Fibrous SOM and	
	AG 2	Fluorescent SOM	Anoxic/dysoxic to oxic, limited comminution, close to source.
	AG 2A	Transparent-Yellow, Fluorescent, Fibrous and Non-Fibrous SOM	Anoxic and or atleast temporarily dysoxic, very limited comminution, close to source (but slightly less than AG1), and not subject to fluvial influences. Limited water circulation, and/or burrowing. Host sediment water-saturated. Oxic and or atleast temporarily oxic, close to source (but slightly less than AG2A), and not subject to fluvial influences. More water circulation, and/or burrowing than AG2A. Host sediment aerated.
	AG 2B	Transparent-Yellow, Fluorescent, Fibrous and Non-Fibrous and Yellow-Brown, Fluorescent, Fibrous SOM	
	AG 2C	Transparent-Yellow, Fluorescent, Non-Fibrous, Yellow-Brown, Fluorescent, Fibrous and Brown-Black, Fluorescent, Fibrous SOM	
	AG 2C	Brown-Black, Fluorescent, Fibrous SOM	
	AG 3	Fluorescent and Non-Fluorescent SOM	Partially anoxic to oxic, limited comminution, relatively close to source. Host sediments wet.
	AG 3A	Transparent-Yellow, Fluorescent and Non-Fluorescent, Non-Fibrous SOM	Partially anoxic, limited comminution, relatively close to source. Host sediments wet. Oxic, limited comminution, relatively close to source. Host sediments well-aerated
	AG 3B	Brown-Black, Non-Fluorescent, Fibrous and Transparent-Yellow, Fluorescent, Non-Fibrous SOM	
	AG 4	Non-Fluorescent SOM	Partial oxic-oxic, limited comminution, relatively close to source. Host sediments well-aerated.
	AG 4A	Transparent-Yellow, Non-Fluorescent, Non-Fibrous and Transparent-Yellow, Non-Fluorescent, Non-Fibrous SOM	Partially oxic, limited comminution, relatively close to source (but slightly less than AG3) and limited fluvial influences. Oxic, limited comminution, relatively close to source (but slightly less than AG3) and limited fluvial influences.
	AG 4B	Transparent-Yellow, Non-Fluorescent, Non-Fibrous and Brown-Black, Non-Fluorescent, Non-Fibrous SOM	
	AG 4C	Brown-Black, Non-Fluorescent and Fluorescent SOM, Transparent-Yellow and Yellow-Brown, Non-Fluorescent, Non-Fibrous SOM	
	AG 4D	Brown-Black, Non-Fluorescent, Fibrous SOM	
	AG 5	Fluorescent SOM and Non-Vita Fragments	Anoxic/dysoxic to oxic, close to fluvial activities.
	AG 5A	Transparent-Yellow, Fluorescent, Fibrous SOM and Non-Vita Fragments	Well-preserved SOM from local source and fragments from fluvial activities. Therefore, this association is probably a result of mixing of two or more sources: Anoxic/dysoxic sediments near to fluvial activities (i.e., poorly-drained). Poorly-preserved SOM from local source and/or fluvial input. Fragments from fluvial activities. Oxic sediments (i.e., well-drained) near to fluvial activities.
	AG 5B	Transparent-Yellow and Yellow-Brown, Fluorescent, Non-Fibrous SOM and Non-Vita Fragments	
	AG 5C	Transparent-Yellow and Brown-Black, Fluorescent, Non-Fibrous SOM and Non-Vita Fragments	
	AG 5D	Transparent-Yellow, Yellow-Brown, Brown-Black SOM and Non-Vita Fragments	
	AG 5E	Brown-Black, Fluorescent, Fibrous SOM and Non-Vita Fragments	
	AG 6	Fluorescent SOM, Non-Vita Fragments and Sporomorphs	Anoxic/dysoxic, close to floral source and/or fluvial activities.
	AG 6A	Transparent-Yellow, Fluorescent, Non-Fibrous SOM, Equidimensional, Non-Fluorescent, Non-Cellular Fragments	Well-preserved SOM from local source and fragments from fluvial activities. Sporomorphs either from local floral source or present through hydrodynamically equivalence. Therefore, this association is probably a result of mixing of two or more sources: Anoxic/dysoxic sediments near to fluvial activities (i.e. poorly-drained).
	AG 6B	Transparent-Yellow, Fluorescent, Non-Fibrous SOM, Equidimensional and Bladed, Non-Fluorescent, Non-Cellular Fragments	
	AG 7	Fluorescent and Non-Fluorescent SOM, and Non-Vita Fragments	Partially anoxic, close to fluvial sources.
	AG 7A	Transparent-Yellow, Non-Fluorescent, Non-Fibrous SOM and Non-Vita Fragments	Well- and poorly-preserved SOM either from local source, or transported by fluvial activities, or sediments partially oxic. Fragments from fluvial activities.
	AG 7B	Transparent-Yellow, Non-Fluorescent, Non-Fibrous SOM, Yellow-Brown Fluorescent, Fibrous SOM and Black-Equidimensional, Non-Fluorescent, Non-Cellular Non-Vita Fragments	

Table 3.9: Summary of Assemblage Groups AG1-AG7. More detailed descriptions of the different assemblage groups are contained in Appendix E

	Assemblage Group (AG)	Key Character(s)	Typical Interpretation
Less than very-occasional dinoflagellate cysts	AG 8	Non-Fluorescent SOM and Fragments	Oxic, close to fluvial activities.
	AG 8A	Transparent-Yellow, Non-Fluorescent, Non-Fibrous SOM and Non-Vita Fragments	Poorly-preserved SOM: well-aerated sediments and/or > fluvial input. ↓ Increasing degradation and/or transportation
	AG 8B	Transparent-Yellow, Non-Fluorescent and Fluorescent Non-Fibrous SOM & Brown-Black, Non-Fluorescent, Non-Fibrous SOM and Non-Vita Fragments	
	AG 8C	Brown-Black, Non-Fluorescent, Non-Fibrous SOM and Non-Vita Fragments	
	AG 9	Non-Vita Fragments and Fluorescent SOM	Very close to fluvial sources. Anoxic-dysoxic Host sediments water-saturated.
	AG 9A	Non-Vita Fragments and Fluorescent SOM	
	AG 10	Non-Vita Fragments, Fluorescent and Non-Fluorescent SOM	Very close to fluvial sources. Partial anoxic Host sediments wet.
	AG 10A	Non-Vita Fragments, Fluorescent and Non-Fluorescent SOM	
	AG 11	Non-Vita Fragments and Non-Fluorescent SOM	Very close to fluvial sources. Oxic. Host sediments well-aerated.
	AG 11A	Transparent-Yellow, Non-Fluorescent, Non-Fibrous and Transparent-Yellow,Non-Fluorescent, Non-Fibrous SOM	
	AG 12	Non-Vita Fragments and Sporomorphs	Very close to fluvial sources. Oxic. Host sediments well-aerated.
	AG 12A	Non-Vita Fragments, Sporomorphs and Fluorescent SOM	
	AG 12B	Non-Vita Fragments, Sporomorphs, Fluorescent SOM and Non-Fluorescent SOM	
Greater than or equal to than very occasional dinoflagellate cysts	AG 13	Transparent-Yellow, Fluorescent SOM and > Rare Dinoflagellate Cysts	Anoxic-dysoxic, very limited comminution, close to source. Subaqueous sediments. Saline
	AG 13A	Transparent-Yellow, Fluorescent, Non-Fibrous and Fibrous SOM and Occasional Dinoflagellate Cysts	
	AG 13B	Transparent-Yellow, Fluorescent, Non-Fibrous SOM and Occasional Dinoflagellate Cysts	
	AG 14	Transparent-Yellow, Fluorescent, Non-Fibrous and Yellow-Brown, Fluorescent, Fibrous SOM	Dysoxic, to temporarily anoxic limited comminution, close to source. Subaqueous sediments. Saline
	AG 15	Transparent-Yellow, Fluorescent, Non-Fibrous Yellow-Brown and Brown-Black Fluorescent SOM	Partially anoxic, limited comminution, less close to source than AG14 . Subaqueous sediments. Saline
	AG 16	Transparent-Yellow, Fluorescent and Non-Fluorescent SOM	Partially oxic, limited comminution, close to source. Host sediments partially aerated. Saline
	AG 17	Transparent-Yellow, Non-Fibrous, Fluorescent SOM and Non-Vita Fragments	Anoxic-dysoxic, close to fluvial input or shoreline. Subaqueous sediments. Saline
	AG 18	Transparent-Yellow, Fluorescent SOM, Non-Vita Fragments and Sporomorphs	Anoxic-dysoxic, close to fluvial input or shoreline. Host sediments water-saturated. Saline
	AG 19	Non-Vita Fragments and Dinoflagellate Cysts	Oxic, close to fluvial input or shoreline. Host sediments aerated. Saline.

Table 3.10: Summary of Assemblage Groups AG8-AG19. More detailed descriptions of the different assemblage groups are contained in Appendix E

3.12 Conclusions

Previous publications have only described qualitatively the controls which influence the form of organic matter in a sedimentary succession. The use of multivariate statistical analysis, using CA and CCA of the relationships between environmental variables and the sample and *species* data, has not only permitted the quantitative assignment of controls but also improved the quality and reliability of the interpretation. The similar configuration between the CA and CCA output supported the allocation of the underlying controls assigned to the CA output. It is evident that preservation is the primary control. Redox potential also appears to be linked to energy-levels (*e.g.*, degree of transportation and disturbance which the particulate organic matter has been subjected to). It is also apparent that there is a change in the association of organic-matter components through time, especially between the Saltwick Formation and the Gristhorpe Member. In addition, the nature of the organic matter in the Scalby Formation indicates that this may have accumulated under drier conditions than the Gristhorpe Member. Moreover, important conclusions regarding the source of transparent-yellow, fluorescent, fibrous and non-fibrous SOM have been made, *i.e.*, that transparent-yellow, fluorescent, fibrous SOM is more likely to be terrestrially derived, whilst transparent-yellow, fluorescent, non-fibrous SOM may be derived from either the terrestrial or marine realm *i.e.*, it is bio-degraded terrestrial or bio-degraded aqueous organic matter. Finally the spatial distribution of the sample points supports the hypothesis that the data set is relatively homogeneous, but most of the key characters used to define the conventionally defined assemblage groups are at least to some extent spatially distinct.

Multivariate statistics analysis should not be used as the only method to define assemblage groups, as the more abundant, or more obvious, components are stressed at the expense of those that are close to being statistically insignificant but are nevertheless geological important. Thus, information gleaned from both the multivariate statistical and conventional analysis was used to define 19 different assemblage groups.

Chapter 4

Temporal and Spatial Environmental Change in Aalenian to Bathonian

4.1 Introduction

It is important to use as many lines of evidence as possible in the determination of palaeoenvironmental changes. Although conventional sedimentology allows the recognition of sandy environments in a deltaic setting, palynofacies studies have provided significant insights into the true nature of the intervening shales, while also adding an extra dimension to the interpretation of the sands [Fisher & Hancock, 1985]. This is principally because the processes of delta building is extremely sensitive to small changes in the environment [Barrell, 1912]. For example, alterations in the nature of sediment and organic matter available, in the movements of the water into which the material is dropped, or movements either of the sea floor or the neighbouring land [Black, 1934b], weathering and vegetation cover, which are a function of the prevailing climate, are all capable of altering profoundly the structure of any delta. Thus, in the present study, the findings from Chapter 3 have been integrated with the stratigraphic and sedimentological information gleaned from fieldwork and previous work by Morgans [1997] to provide comprehensive palaeoenvironmental interpretations. This chapter describes the various palaeoenvironmental changes beginning with the Dogger and Saltwick Formations and continuing up the succession. In each section a general overview is provided followed by a more detailed description of the sedimentology and organic matter of the sections examined. The findings from the different units are drawn together and compared with a coeval section from the Brent Group in section Section 4.7.

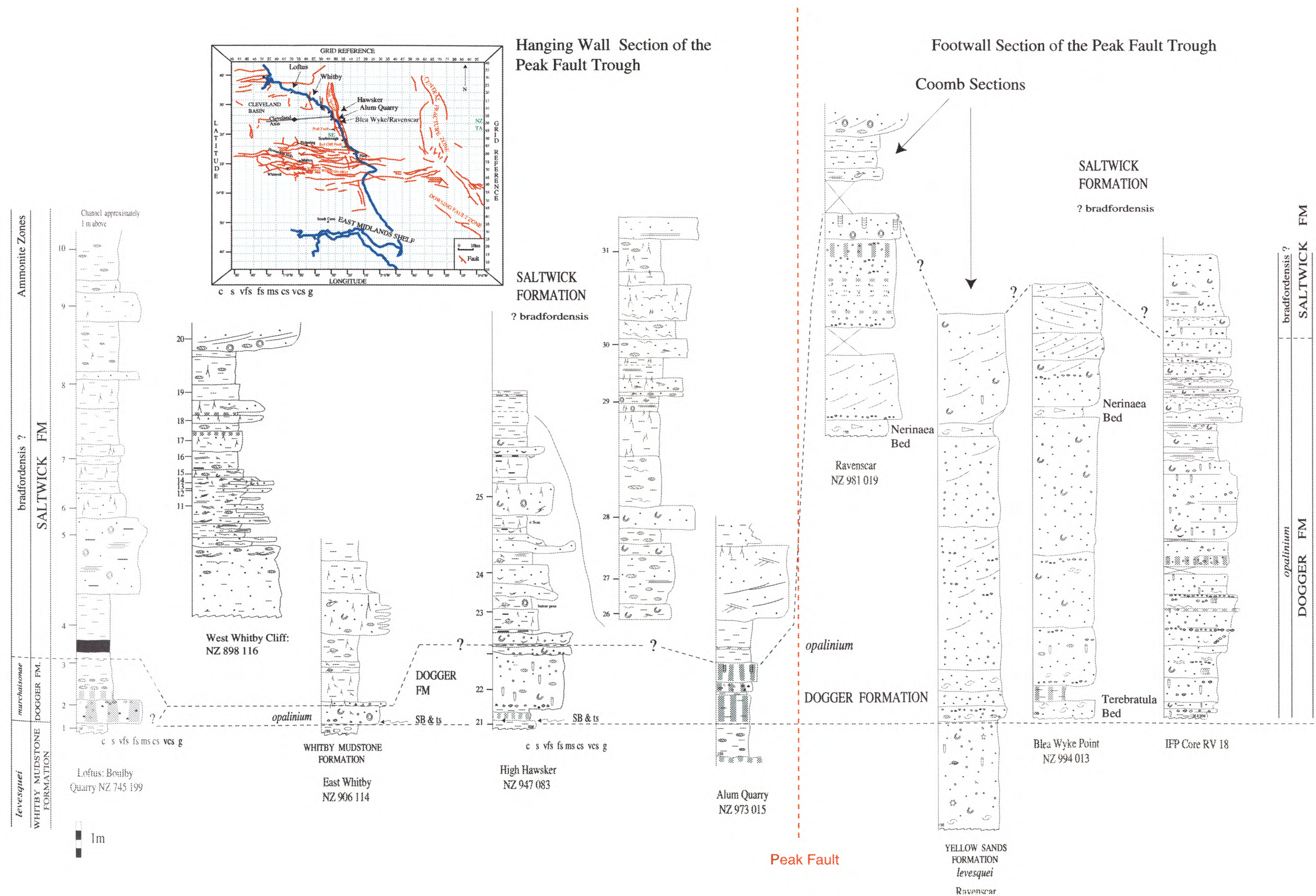
4.2 Dogger and Saltwick Formations

Nine sections encompassing the heterolithic variations of the Dogger Formation and lowermost 10 metres of the Saltwick Formation which outcrop along the North Yorkshire Coast between Boulby and Blea Wyke point were examined in the present study. These are illustrated in Figure 4.1. The section exposed at West Whitby is included in Figure 4.1, even though the Dogger Formation is not exposed at this locality. The Dogger Formation is, however, considered to lie 2-3 metres below the basal sandstone described in Figure 4.1 (pers. comm. Alexander, 1996). In addition, the Dogger Formation is exposed to the east of Whitby and has been recorded in boreholes to the west of the town [Hemingway *et al.*, 1963]. The exposure of the Saltwick Formation at Blea Wyke Point is described in subsection 4.2.6. One additional description was made from the IFP borehole RV18, which was drilled in the Ravenscar area. New sedimentary descriptions are provided for six of the localities; Boulby (Loftus Quarry), West and East Whitby, Alum Quarry, Ravenscar and Blea Wyke Point (Saltwick Formation only). The lithological descriptions of the Dogger and Saltwick Formations exposed at High Hawsker and the Dogger Formation exposed at Blea Wyke Point were guided by Morgans [1997] and Hesselbo (1995, unpublished) respectively. The nature of organic matter was examined using samples from Boulby, West Whitby, High Hawsker and Blea Wyke Point. These results are discussed in subsections 4.2.3 to 4.2.6.

4.2.1 Dogger Formation

Black [1934b] identified two topographical belts which had a profound influence upon the distribution and character of the Dogger Formation. In the central and eastern part of the basin, the gently folded Lias was cut down to a remarkably level plain, whereas the early Aalenian landscape in the west comprised a surface which was indented by a series of valleys carved deeply into the shales of the Upper Lias. The Dogger Formation spans a considerable amount of time, from the *opalinum* Zone [Cope *et al.*, 1980b; Kent, 1980; Riding, 1984] to the *murchisonae* Zone, making it very difficult to constrain

Figure 4.1: From right to left. New sedimentary description of the Dogger Formation and basal 10 metres of the Saltwick Formation exposed in Boulby Quarry, NZ 745 199; new sedimentary description of Saltwick Formation, West Whitby, NZ 898 116; new sedimentary description of Dogger and Saltwick Formations, East Whitby, NZ 906 114; Dogger and Saltwick Formations, High Hawsker, NZ 947 083 [after Morgans, 1997]; new sedimentary description of Dogger and Saltwick Formations, Alum Quarry, NZ 973 015; new sedimentary description of Dogger and Saltwick Formations, Ravenscar NZ 981 019 and NZ 9815 0185; Dogger Formation, Blea Wyke Point, NZ 994 013, (after Hesselbo, 1995, unpublished) and Dogger Formation, IFP Core 18 (Ross and Morgans, 1996, unpublished). Numbers beside lithological descriptions refer to sample points. No horizontal scale is implied.



and interpret the contemporaneity of the complex pattern of lithofacies in the Dogger Formation. The formation can, however, be divided into parts on the basis of their ammonites. *Opalinum*-Zone deposits are confined to central and eastern parts of the basin, whereas younger, *murchisonae*-Zone deposits are recognised in the north and west of the basin.

The lowermost *opalinum*-Zone deposits can be segregated into two contrasting facies as mentioned by Morgans [1997]. This distinction is most obvious between the Dogger Formation which lies within the downthrow side of the Peak Fault Trough and that which lies in the upthrow section of the Peak Fault Trough, as illustrated in Figure 4.1. The succession exposed on the foreshore at Blea Wyke Point, within the trough, consists of sandstone and a sandy, sideritic, berthierine-rich oolite forming a 12 m thick unit. Within this unit, two fossil-rich beds are recognised: the highly fossiliferous *Nerinaea* Bed with *N. cingenda*, bivalves and corals near the top and the *Terebratula* Bed near the base with *Lobothyris trilineata*, gastropods, corals and abundant phosphatic pebbles which represent reworking of the underlying Toarcian sediments. In comparison, at Alum Quarry and East Whitby, (outside the Peak Fault Trough), the Dogger Formation is condensed (only 50 cm at East Whitby), poor in fossils and is represented by ferruginous sandy-mudstones containing abundant phosphatized pebbles of Lower Jurassic shale.

Even within the Peak Fault Trough the character of this formation is different. Four sections were examined in the downthrow side of the Peak Fault. Near the Peak Fault, above the part of the cliff known as the Coomb, two sections were measured. As noted by Rastall & Hemingway [1941] and shown in Figure 4.1, in the exposures of the Dogger Formation nearest the Peak Fault the distinctive *Terebratula* bed seen at Blea Wyke Point is absent. These beds are also missing in the IFP core RV18. The *Terebratula* Bed may be represented in part by a fossiliferous pebble bed. The *Nerinaea* bed is represented in all sections described in this thesis, except the IFP core RV18. Rastall & Hemingway [1941] noted that this bed was entirely unrepresented in the first 50 yards east of the fault. It would therefore appear that the *Nerinaea* and *Terebratula* Beds so prominent near Blea Wyke Point thin out and are probably lenticular in form. Due to the absence of the two fossil-beds, in some of the sections, and the paucity of diagnostic fossils, the correlation of this succession is principally based on lithology.

The uppermost portion of the Dogger Formation is restricted to the western and northern parts of the basin, where *opalinum*-Zone deposits are missing and the unit rests directly on the Alum shales. The formation consists of a conglomerate, limestone and ironstone succession, which occupies the deepest parts of the palaeovalleys [Black, 1934b]. These are overlain by shales yielding *murchisonae* Zone ammonites, above which lies a sequence of mudstone, siltstone and sandstone.

The disparity in thickness, lithology and age of the Dogger Formation in the Cleveland Basin highlights the variability which developed in response to a number of factors including accommodation space and sediment supply. For example, the expanded and condensed nature of the unit in the down-throw and upthrow side of the Peak Fault Trough highlights deposition by infilling of the lows (*e.g.*, Ravenscar) and erosion and reworking on structural highs (*i.e.*, Alum Quarry) respectively.

4.2.2 Saltwick Formation

This formation marks the commencement of deltaic deposition in the Middle Jurassic. Exposures of the lower part of the Saltwick Formation can be found along the coast between Boulby and Blea Wyke Point. The contact with the underlying Dogger Formation is either gradational or abrupt. Muir [1964] observed marine palynomorphs and Black [1934a] found the leaf *Pachypteris papillosa* which Harris [1964] suggested grew in a salty setting either on mud flats or on the margins of tidal channels. This indicates that the beds were deposited in brackish water. Knox [1973] and Livera & Leeder [1981] stated that a tidal influence upon deposition was, however, restricted to north and west of the Cleveland Basin, as rapid delta progradation from the northeast, which is represented by channel sandstones, limited marine influences in north east of the Cleveland basin. Eschard [1989] mentioned, however, that the local occurrence of wavy bedding and cross-stratification in the Ravenscar area indicate that deposition at this locality was occasionally influenced by tidal processes.

Identification of the level of maximum flooding influence in the Saltwick Formation is hampered by poor exposure in the field. However, as noted by Morgans [1997] and shown in Appendix F, the basal beds, which comprise littoral sheet sands separated by a mudstone, contain marine trace fossils, including *Skolithos* and *Rhizocorallium*. Within the mudstone there is a cemented surface which Morgans [1997] interpreted as the maximum flooding surface. Overlying this surface is the approximately 45m thick regressive phase [Morgans, 1997]. Livera & Leeder [1981] identified a vertical transition in the Saltwick Formation from major bedload channels near the base to argillaceous,



Figure 4.3: View of the Saltwick and Eller Beck Formation exposed in the North Cliff of Hayburn Wyke.

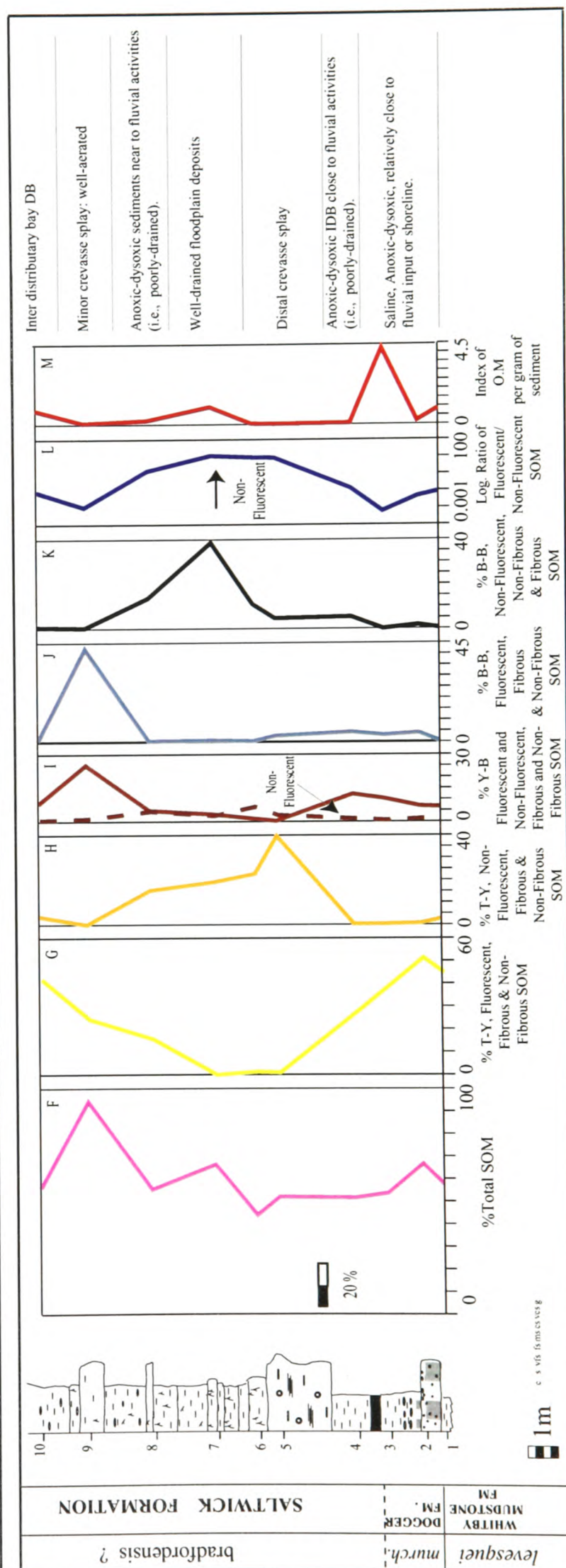
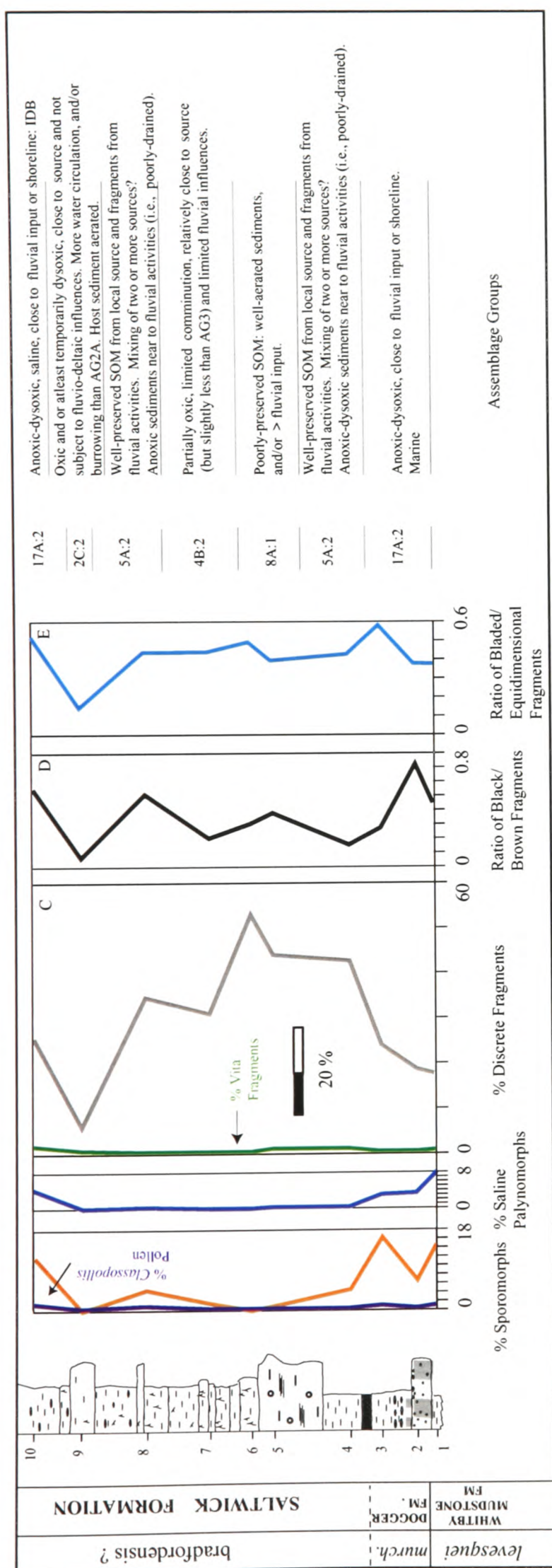
overbank deposits in which isolated meandering channel bodies occur as shown in Figure 4.3. These changes are considered to reflect gradual abandonment of the delta lobe, as a consequence of a slow rise in relative sea level and subsidence of the area due to sediment consolidation. At the top of the Saltwick Formation distal saline swamps became established prior to the deposition of the shallow marine Eller Beck Formation.

4.2.3 Boulby

Figure 4.4 depicts the section exposed at Boulby, which includes the Dogger Formation and lowermost 10 metres of the Saltwick Formation, and provides an overview of the changes in selected organic-matter categories. The lower part of the section at Boulby comprises a condensed sideritic ironstone which is overlain by fossiliferous (*murchisonae*-Zone) ferruginous shales [Black, 1934b]. These shales pass upwards into unfossiliferous sideritic shales which merge gradually into the overlying grey carbonaceous silts with plant remains. Black [1934b] commented that it is very difficult to separate the (*murchisonae*-Zone) shales from the oldest 'deltaic' beds. Variations in the organic matter, however, provides some insight. The occurrence of very-occasional saline palynomorphs, (includes tasmanitids, leiospheres, acritarchs, dinoflagellate cysts and zoomorphs) in sample 3, shown in column B, and rare relative abundance of saline palynomorphs in sample 4 enables the change from saline (marine) to terrestrial dominated to be determined. The sharp increase in discrete fragments, shown in column C, above sample 3 also suggests that these sediments accumulated closer to fluvial input (*i.e.*, terrestrial) than the samples below. The gradual passage from the (*murchisonae* Zone) shales into the overlying sideritic shales, and from saline to non-saline palynomorphs indicates that there was no extensive break in sedimentation in this area. Variations recorded in the saline palynomorphs and *Classopollis* pollen are very similar. This indicates that either these types of palynomorphs acted in a similar manner, taphonomically, or that the parent plants grew in a saline setting.

Variations in the character and abundance of the different types of SOM, shown in columns F to L, and discrete fragments indicate that the oldest deltaic sediments (sample 4) accumulated in low-energy, water-saturated, dysoxic-anoxic conditions which were occasionally subject to the influence of fluvial activities. Evidence of the latter is also gleaned from the presence of a laterally accreted sandstone, which overlies the poorly drained flood-plain deposits. This sandstone body is interpreted

Figure 4.4: New sedimentary description of the Dogger and Saltwick Formations exposed at Boulby Quarry, NZ 745 199. Upper diagram contains columns A to E and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in discrete fragments and vita fragments. Columns D and E illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. The lower diagram shows columns F to M. These contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM; transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM and yellow-brown, non-fluorescent, fibrous and non-fibrous SOM (dashed line); brown-black, fluorescent, fibrous and non-fibrous SOM; brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.



as a distal crevasse-splay deposit. The sediments immediately above contain poorly preserved SOM inferring that they were well-aerated, *i.e.*, well-drained. Above, the presence of well-preserved SOM indicates a return to water-saturated sediments, either in the form of a shallow lake or wetlands. The uppermost sample comprises saline palynomorphs, well-preserved SOM and non-vita fragments indicating that sedimentation occurred in a brackish interdistributary bay close to fluvial influences.

4.2.4 West Whitby

The complex alluvial sandstone body of the Saltwick Formation exposed in the cliffs west of Whitby comprises a large number of channel storeys stacked in a complex vertical and lateral pattern [Alexander & Gawthorpe, 1993]. These sediments were deposited on the hanging-wall side of the N-S trending Whitby Fault which influenced the nature of sedimentation in this area. The Saltwick Formation, at West Whitby, is laterally variable in character over its outcrop area, as illustrated in Figure 4.5; some sections are dominated by multistorey channel sandstone bodies, while other areas preserve isolated and fine-grained sediments [Alexander & Gawthorpe, 1993]. In the present investigation samples were primarily collected from the fine-grained sediments because these generally yield more organic matter. The section which was examined primarily comprises stacked fine-grained palaeosols and pedogenically altered sheet sandstones, as illustrated in Figure 4.6 and 4.7. Selected characteristics of the organic matter are also depicted in Figure 4.7.

The lower part of the section, examined in this study, contains intercalations of sands and silt as shown in Figure 4.6. The occurrence of wave- and current-ripple lamination, planar lamination and desiccation cracks in these sediments indicates that they accumulated under waning flow conditions and were occasionally sub-aerially exposed. The dominance of poorly preserved SOM and discrete fragments highlights that these sediments were well-drained and accumulated close to the clastic pathway. The upper part of the heterolithic sands and silts and majority of the overlying silts record evidence of plant colonization. This suggests that the channels did not occupy the area and significant channel incision prevented regular flooding of the overbank adjacent to the channels, and sedimentation rates outside the channels were low. It is believed that the presence of well-preserved SOM and, in some cases, discrete fragments shows, however, that the flood-plains were occasionally subject to flooding and fluctuations in the water-table. The well-preserved SOM either collected in shallow water lakes or water-saturated wetlands on the coastal plain. The latter deposits probably formed in topographic lows where the water-table intersected the flood-plain surface, *e.g.*, abandoned channels



Figure 4.5: View of the Saltwick Formation exposed at West Cliff, Whitby.

and/or depressions associated with the Whitby Fault. The poorly preserved SOM, in comparison, accumulated in well-drained flood-plain deposits. Thus, the different assemblage groups show that the extent of exposure to fluvial influences varied as did the water-saturation level of the sediments.

The sedimentological data also reveal no evidence of direct marine influence on the deposition of these sediments which supports the proposal by Knox [1973] and Livera & Leeder [1981] who suggested that a tidal influence upon deposition was restricted to north and west of the Cleveland Basin. There is, however, a minor brackish element in some of the organic-matter samples.

4.2.5 High Hawsker

This section at High Hawsker is quite similar to the West Whitby outcrop, except in that the exposed Dogger Formation is condensed. The outcrop at High Hawsker comprises channel sandstone bodies and sections of fine-grained sediments. The latter represent flood-plain deposits in the form of minor crevasse splays and palaeosols. Two sections were lithologically described [after Morgans, 1997]. The first section illustrated in Figure 4.8 is laterally equivalent to a large multistorey channel to the south. The second section describes the sediments which have infilled an abandoned channel. The

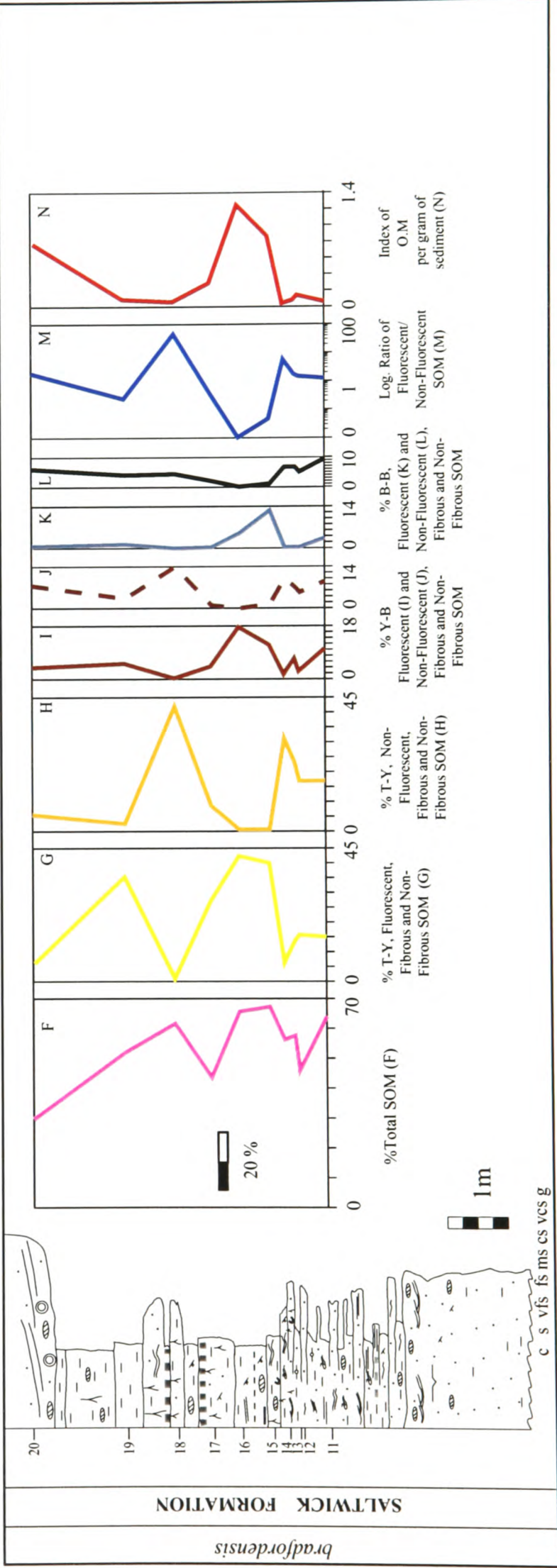
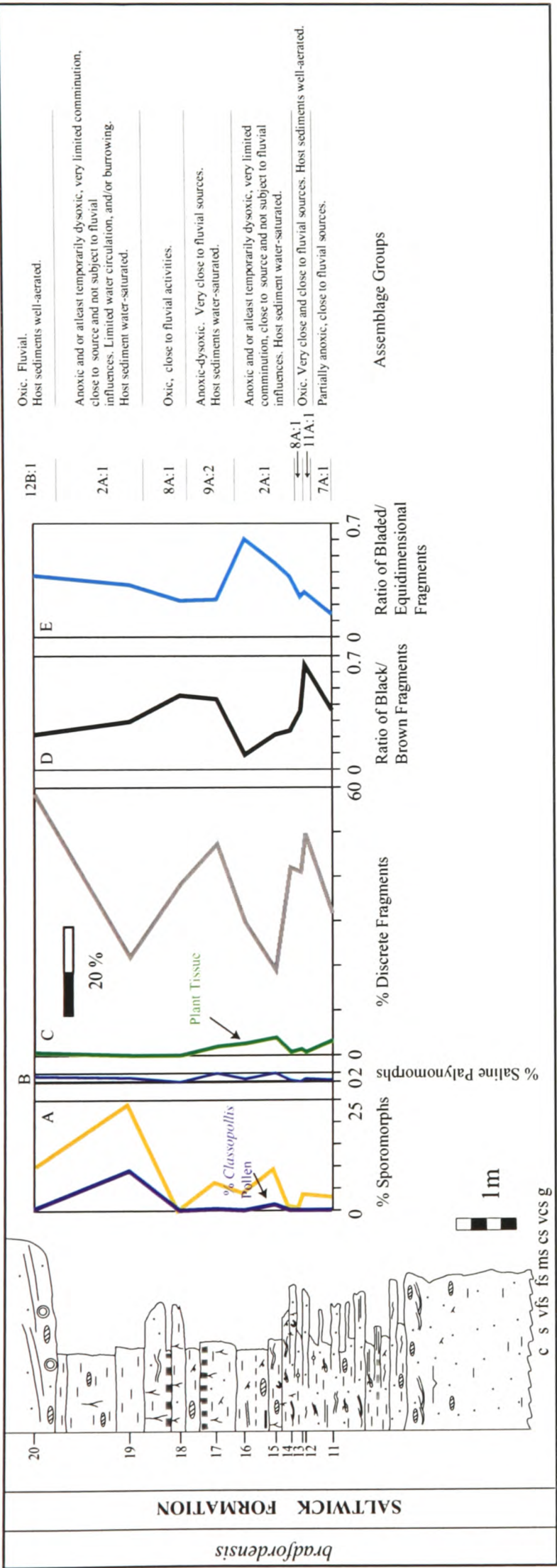


Figure 4.6: View of the section logged at West Cliff, Whitby. The stacked fine-grained palaeosols and pedogenically altered sheet sandstones occur in the lower part of the photograph.

relationship between these two section is illustrated in Figure 4.1.

The Dogger Formation at High Hawsker is represented by a mere two metres. The organic matter is indicative of deposition close to source in a low-energy setting. It is believed that the organic matter accumulated during a quiescent period of clastic input. The first sample from the deltaic Saltwick Formation is from a rooted unit. The presence of saline microflora and non-vita fragments indicates that deposition occurred in a medium-energy, brackish interdistributary bay close to a clastic pathway. The similar pattern of percentage change recorded in both saline palynomorphs and *Classopollis*

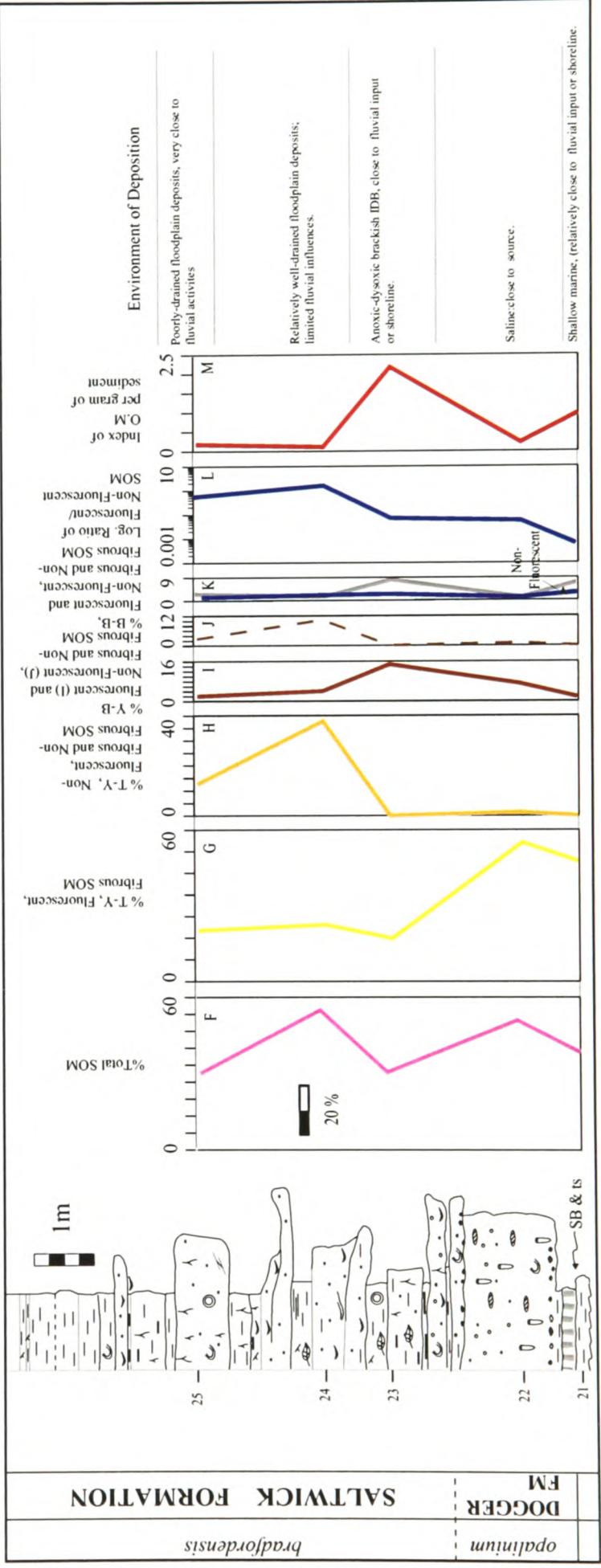
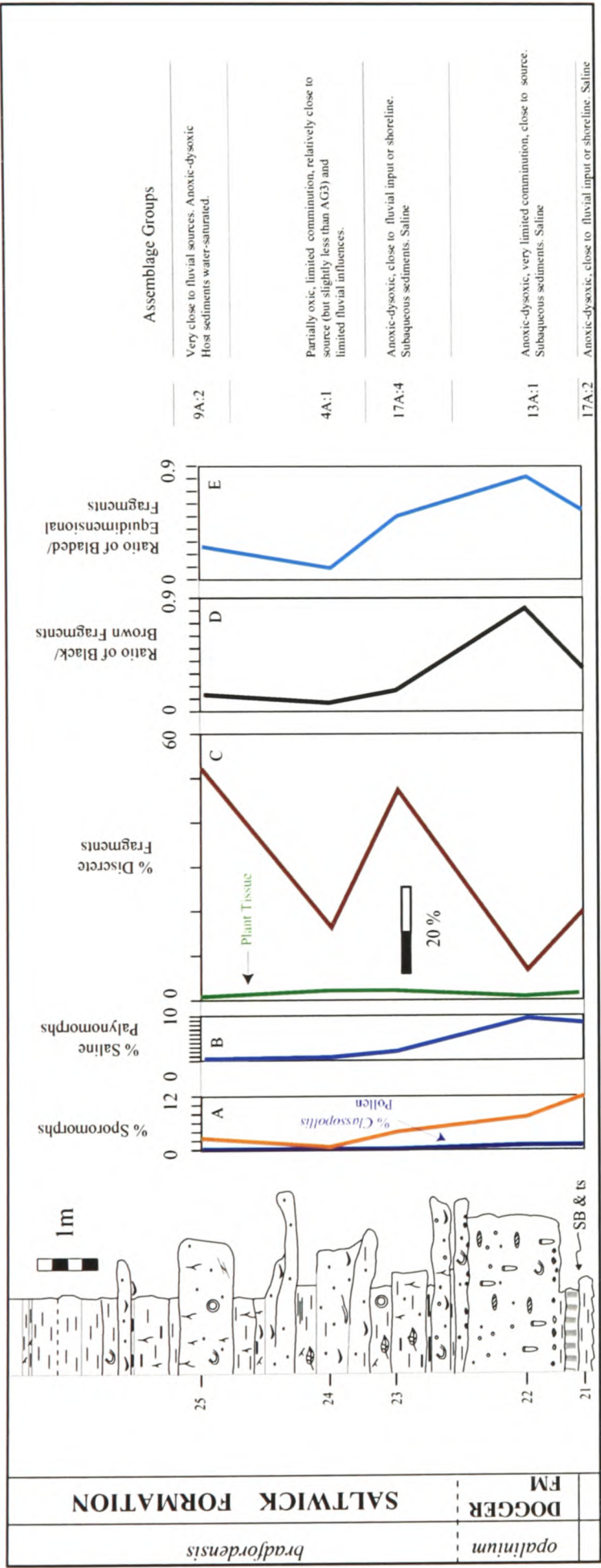
Figure 4.7: New sedimentary description of the Saltwick Formation exposed at West Cliff, Whitby, NZ 947 083. The Dogger Formation lies 2-3 metres below the basal sandstone (pers. comm. Alexander, 1996). In addition, the Dogger Formation is exposed to the east of Whitby and has been recorded in boreholes to the west of the town [Hemingway *et al.*, 1963]. Upper diagram contains columns A to E and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in discrete fragments and vita fragments. Columns D and E illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. The lower diagram shows columns F to N. These contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM; transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM; yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fluorescent, fibrous and non-fibrous SOM; brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.

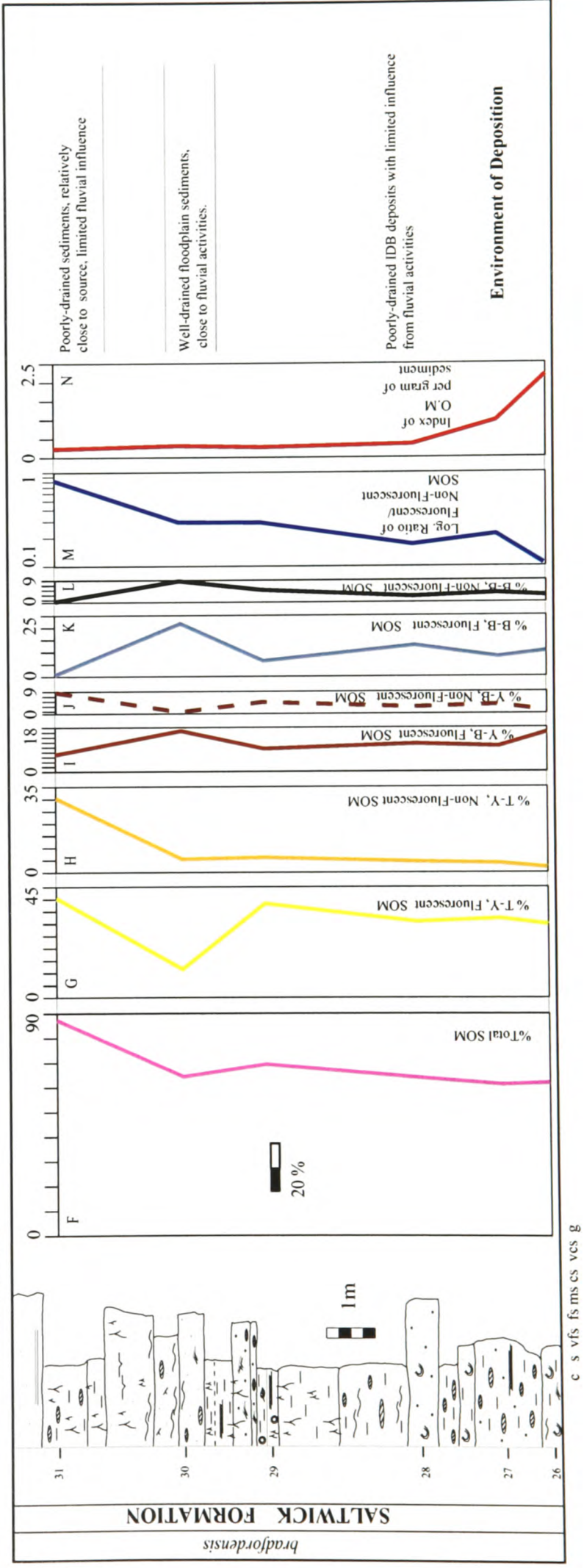
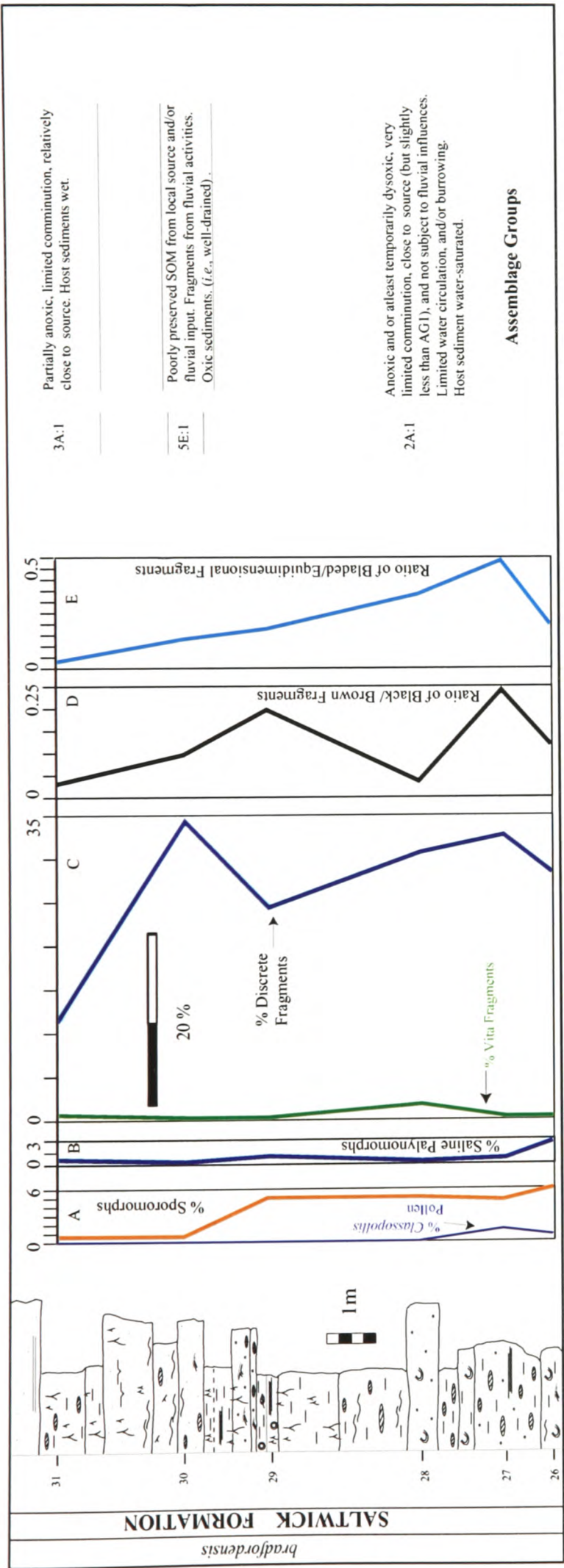


pollen is either a result of preferential deposition or an indication that the parent plants grew in a saline setting. The presence of saline microflora suggests that the extent of tidal influences, which Eschard [1989] identified in the Ravenscar area, extended further north than Knox [1973] and Livera & Leeder [1981] proposed. Variations in SOM and discrete fragments which are similar to that observed in the West Whitby and Boulby sections, are recognised in High Hawsker samples as illustrated in figures 4.8 and 4.9. Thus, this area was subject to fluctuations in the water-table and influences of fluvial activities.

Figure 4.8: Sedimentary description of the Dogger and Saltwick Formations, High Hawsker NZ 947 083 [after Morgans, 1997]. Upper diagram shows columns A to E and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in discrete fragments and vita fragments. Columns D and E illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. The lower diagram shows columns F to M. These contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM; transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM; yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fluorescent, fibrous and non-fibrous SOM (grey line) and brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.

Figure 4.9: Continued sedimentary description of the Dogger and Saltwick Formations, High Hawsker, NZ 947 083 [after Morgans, 1997]. Upper diagram shows columns A to E and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in discrete fragments and vita fragments. Columns D and E illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. The lower diagram shows columns F to N. These contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM; transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM; yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fluorescent, fibrous and non-fibrous SOM; brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.

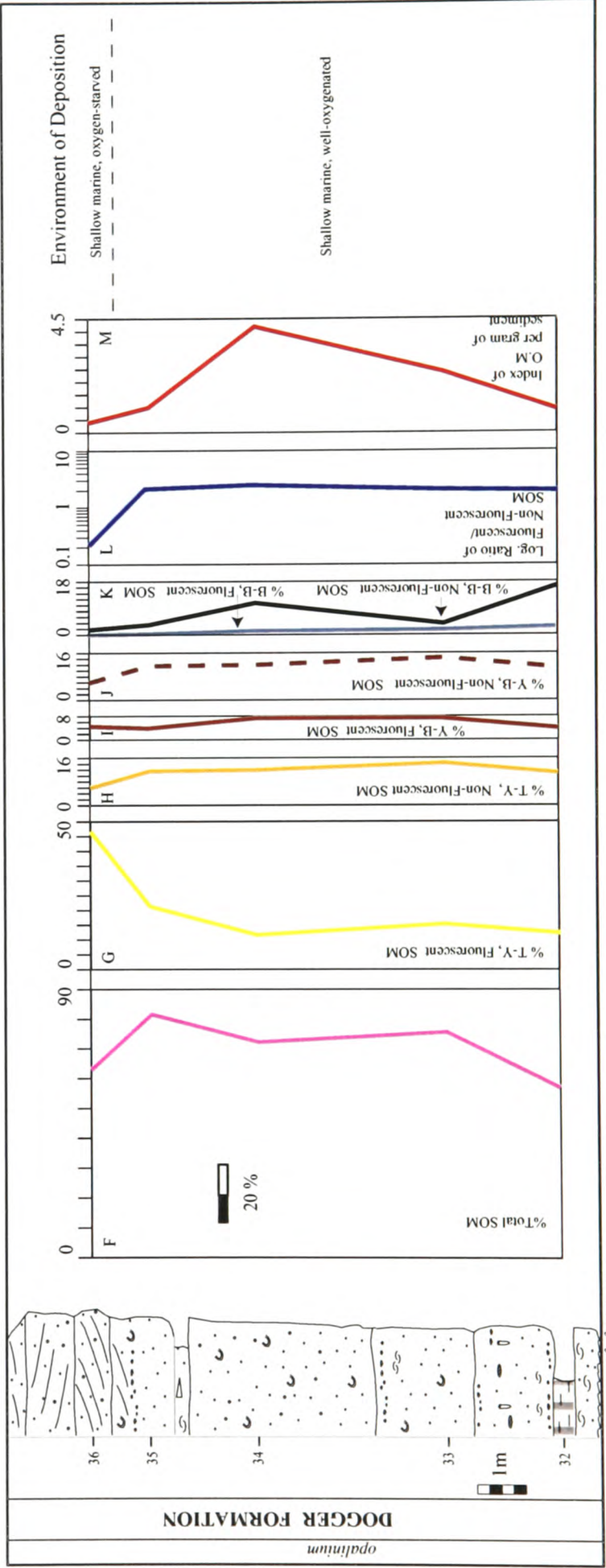
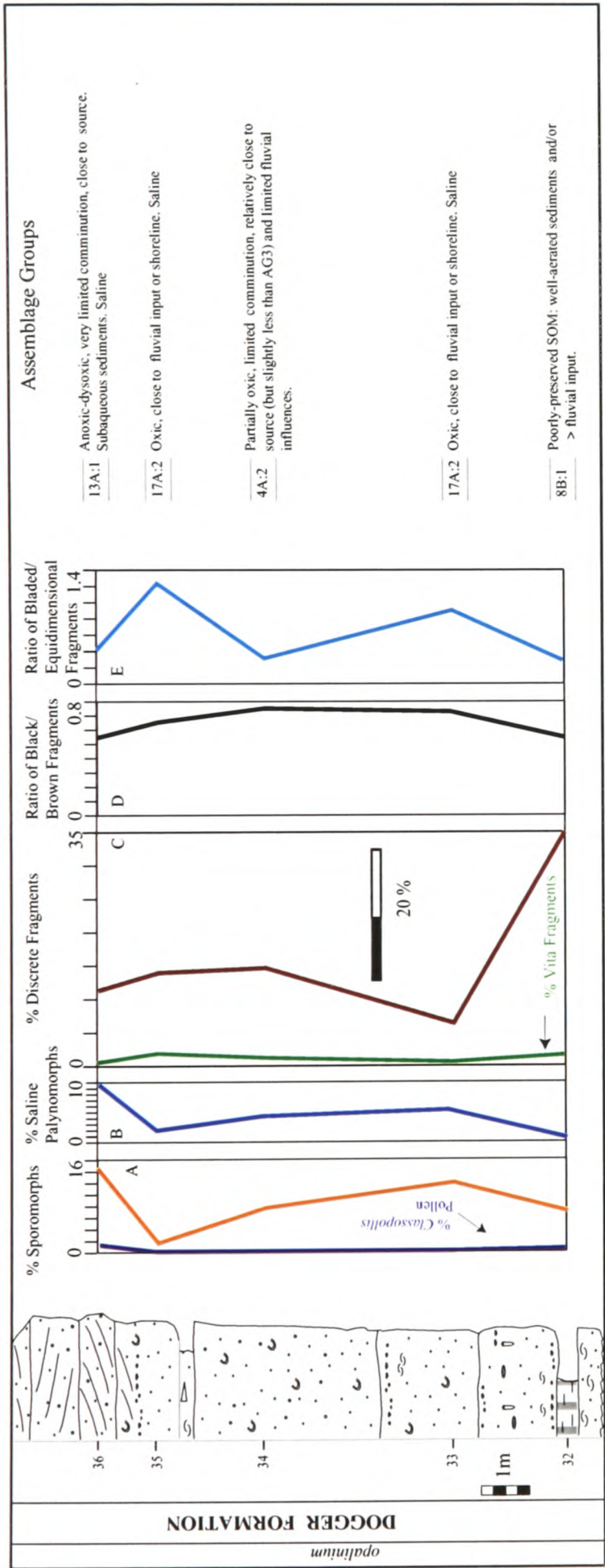




4.2.6 Blea Wyke Point

The Dogger Formation exposed on the foreshore at Blea Wyke is shown in Figure 4.10. The assemblages of organic matter are overwhelmingly dominated by terrestrially derived material. The saline palynomorphs comprise on average 4-6 %. The maximum is 10 %. The saline palynomorphs comprise dinoflagellate cysts, acritarchs, tasmantids, leiospheres and zoomorphs. Of these, dinoflagellate cysts are the most significant. It is interesting to note that *Classopollis* pollen increases in uppermost sample, in conjunction with an increase in saline palynomorphs. This indicates that either the parent plants grew in a saline environment or taphonomic processes have overprinted the primary signal. The nature of the SOM and non-vita fragments indicates that the environment was oxic and close to terrestrial input, and thus a well-oxygenated sea is envisaged. This conclusion concurs with Hemingway [1974], who commented that the macropalaeontological and sedimentological evidence points to deposition in a well-oxygenated shallow sea. Once again, the variations detected in saline palynomorphs and *Classopollis* pollen are very similar. This is either a result of preferential deposition or an indication that the parent plants grew in a saline setting.

Figure 4.10: Sedimentary description of the Dogger Formation, Blea Wyke Point, NZ 947 083 (after Hesselbo, unpublished). Upper diagram shows columns A to E and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in discrete fragments and vita fragments. Columns D and E illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. The lower diagram shows columns F to M. These contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM; transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM; yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fluorescent, fibrous and non-fibrous SOM (grey line) and brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.

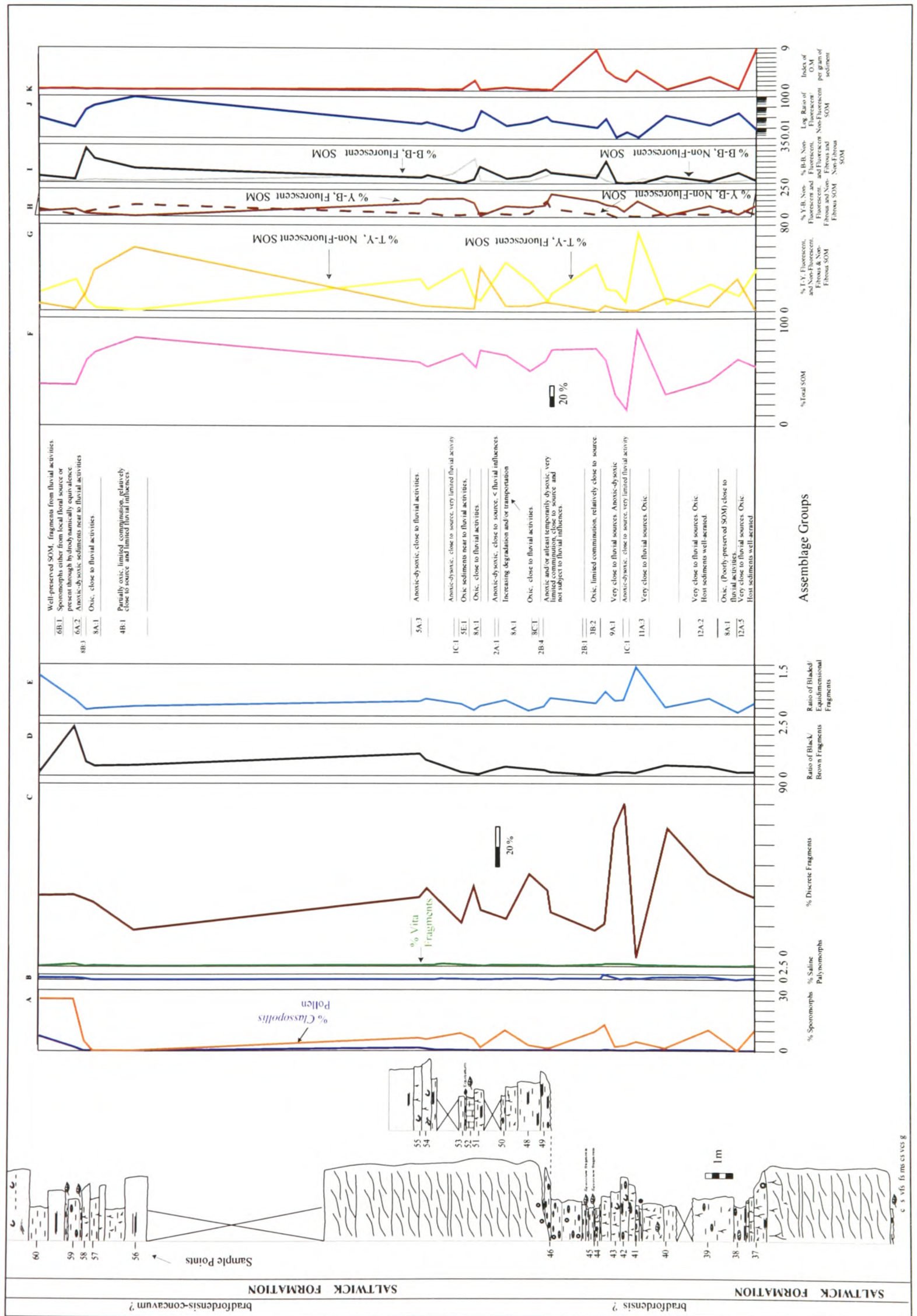


Saltwick Formation

The vertical transition recognised by Livera & Leeder [1981] from major bedload channels near the base to argillaceous overbank deposits in which isolated mixed loaded channels occur is evident in the sedimentary description displayed in Figure 4.11. The organic matter in the lower part of the succession records fluctuations in the water-table and influence of fluvial activities. It is apparent that the content of organic matter per gram of sediment is clearly higher in the lower part of the section than the upper portion. This suggests that the sediments in the lower part were poorly drained, or the production rate of organic matter was higher and/or the palaeotemperature was lower, in comparison to the upper portion of the Saltwick Formation.

There is also a decline in the relative abundance of fragments towards the upper part of the succession examined, which reflects the decreasing influence of fluvial activities which concurs with Livera & Leeder [1981]. There is, however, a general increase in the content of black non-vita fragments (column D), in comparison to brown non-vita fragments up section. According to Tyson [1995], an increase in the abundance of black fragments may be due to one or more of the following factors; a) extensive transportation, either in duration and/or distance (*i.e.*, distal depositional environment (basinal and shelf sediments during high sea level with limited input of fresh (unaltered) discrete fragments), b) oxidising environment where the fragments are small and predominantly equidimensional, (usually typical of sandy sub-aerial sediments), c) local reworking from sediments of high maturation level, d) charcoal following wildfires, or e) an arid environment. Morgans [1997] noted that the upper part of the Saltwick Formation contained plant macrofossils (ferns) which displayed evidence of burning. Thus, it is possible that these fragments are charcoal and are a result of an increase in the production of black fragments, *i.e.*, an increase in wildfires. The limited extent of this phenomenon and absence of data from coeval sediments, however, makes it very difficult to conclusively determine whether the material is localised or basin wide (*i.e.*, climatic).

Figure 4.11: New sedimentary description of the Saltwick Formation, Blea Wyke (NZ 947 083). Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in discrete fragments and vita fragments. Columns D and E illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. Columns F to K contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM and transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM and yellow-brown, non-fluorescent, fibrous and non-fibrous SOM (dashed line); brown-black, fluorescent, fibrous and non-fibrous SOM (grey line) and brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.



4.2.7 Synopsis

The character of the Dogger Formation varies considerably across the basin, in response to variable relief on the underlying surface, and hence the amount of accommodation space and sediment supply. Both gradational (*e.g.*, Boulby) and abrupt (*e.g.*, High Hawsker) contacts between the Saltwick Formation and underlying Dogger Formation are recognised. Variations in the saline palynomorphs, yielded from the lower portion of the Saltwick Formation, pick out minor marine ingressions within the delta plain, as far north as Boulby, and as far north-east as High Hawsker. Thus, it is believed that the Saltwick Formation was probably deposited on a coastal-plain where the amount of marine influence on alluvial deposition varied in both space and time leading to the development of local brackish, lagoonal or embayment conditions. The concomittant change in both saline palynomorphs and *Classopollis* pollen, in three separate sections, indicates that the parent plants grew in a saline environment. Fluctuations in the relative abundance of well- and poorly preserved SOM indicate that the coastal plain had a low relief with large areas of saturated soil, shallow water-table lakes with local levees, alluvial ridges and tectonic highs which produced sufficient relief to allow the development of well-drained soils. It is also possible to infer that the sediments examined in the upper part of the Saltwick were well drained, in comparison, to the lower portion due to a fall in the water-table and/or an increase in the palaeotemperature. During the deposition of the Saltwick Formation it is thought that the drainage pattern in the Cleveland Basin would have undergone repeated minor changes by channel migration, avulsion and river capture which resulted in the different amounts of fragments and different types of SOM recorded within the organic matter samples.

4.3 Iron Scar: uppermost Saltwick Formation, Eller Beck Formation and basal part of the Sycharham Member

Marine waters subsequently flooded across the low-lying delta plain [Knox, 1973] to form a basin-wide shallow sea that was no deeper than seven metres in which the thin (4.5-8 metres thick) Eller Beck Formation was deposited. The most complete exposure of this regionally extensive unit is found at Iron Scar (TA 004 970). This section was examined by Morgans [1997] and her lithological description was used as a guide in the field.

The lithological description and results of the organic matter investigation are displayed in Figure 4.12 and Figure 4.13. The lithological description shows that the Eller Beck Formation overlies a mud-silt unit of the Saltwick Formation which contains limited root foundations in the base. The sample examined from this unit is organically very poor, almost barren, with a high frequency of degraded SOM and low frequency of very-small sized non-vita fragments. This association indicates low-energy oxygenated conditions away from fluvial activities. Although not recorded in the count data, acritarchs were identified in this sample inferring that the sediments accumulated in a brackish/marginal marine low-energy environment.

The Eller Beck Formation may be divided into two parts: a lower unit of shales and subsidiary ironstones, and an upper unit of sandstone [Hemingway, 1974]. The basal units of the Eller Beck Formation contain an intensely bioturbated, (*e.g.*, *Diplocraterion*, *Thalassinoides* and *Rhizocorallium* which penetrate the surface of transgression), locally berthierine-rich oolitic sideritic ironstone which yields a diverse fauna including the bivalves *Gervillia*, *Liostrea* and some gastropods [Knox, 1973]. The character of the intensely bioturbated siderite-rich bed suggests that it was deposited during a period of reduced sedimentation, when faunal abundance and diversity reached a peak across the basin producing a diverse trace-fossil assemblage. The resulting firmground, which is well exposed at Iron Scar, in comparison to the IFP core RV 18, is interpreted as the maximum flooding surface [Morgans, 1997]. The amount of saline palynomorphs is higher in the bioturbated unit than the overlying shale. The contact between the overlying thick shale and ironstone bed is sharp. Knox [1973] inferred that the genesis of ironstone was initially halted by the sedimentation of clay material in suspension, in contrast to increased terrigenous input [Knox, 1973]. The reduction in non-vita fragments and increased frequency of SOM (*i.e.*, limited terrigenous input) lends support to the proposal of Knox

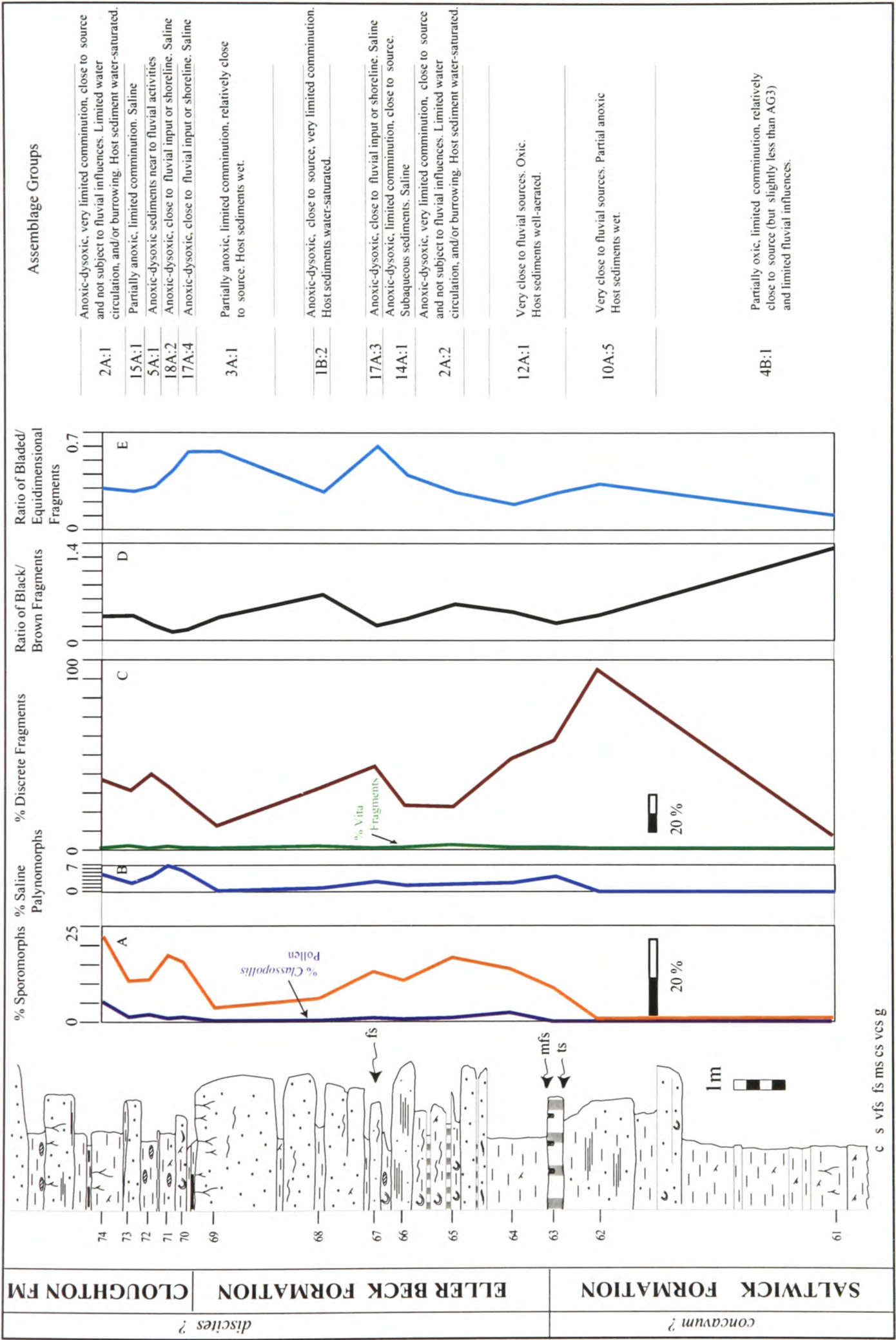


Figure 4.12: Sedimentary description of the Saltwick Formation, Eller Beck Formation and the basal 3-4 metres of the Sycharham Member, Hayburn Wyke-Iron Scar (NZ 9675 0155-9680 0185) [after Morgans, 1997]. This diagram shows columns A to E and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in discrete fragments and vita fragments. Columns D and E illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively.

[1973].

The higher parts of the Eller Beck Formation coarsen upwards as a result of progradation into bioturbated wave-generated sandstones [Knox, 1973]. This trend commences with lenticular and flaser-bedded sands with interbedded silty laminae which contain lower levels of faunal abundance and bioturbation. Both facies exhibit saline palynomorphs, relatively well-preserved SOM and a range of non-vita fragments. As observed in older deposits, examined in this investigation, an increase in *Classopollis* pollen is mirrored by an increase in saline palynomorphs. Well-developed roots penetrate the top of the Eller Beck Formation and here there is an increase in transparent-yellow, non-fluorescent SOM probably related to sub-aerial exposure.

The overlying Sycarham Member of the Cloughton Formation is also exposed at Iron Scar, however only the lowermost 3-4 m are exposed. A complete lithological description of this member is shown in Figure 4.14 and the upper part of the Sycarham Member is discussed in Section 4.4. The first sample from the Sycarham Member is clearly very rich in organic matter (column L, Figure 4.13). The whole decaying mass of organic matter would produced intensely anaerobic water. All of the samples in the lower beds, some of which contain roots, are indicative of deposition in a low-energy brackish setting, which was close to the shoreline/fluvial activities.

4.3.1 Synopsis

During the initial transgression there was a change from brackish silts and muds to the overlying bioturbated unit which was oxic. The units above are primarily anaerobic with varying amounts of discrete fragments which reflect the amount of terrestrial input. The lower beds of the Sycarham Member were probably deposited in an anoxic-dysoxic, brackish coastal marsh.

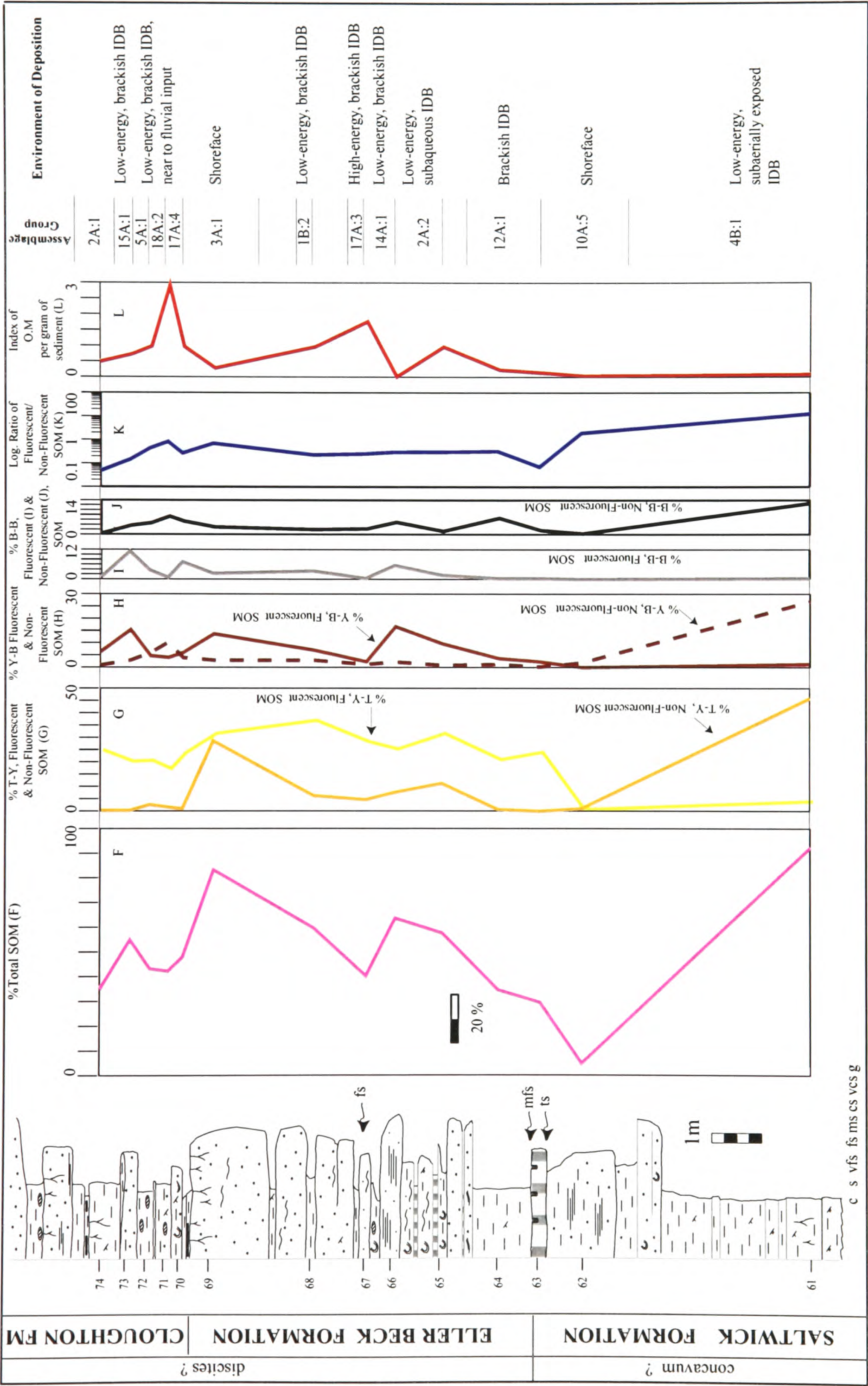


Figure 4.13: New Sedimentary description of the Saltwick Formation, Eller Beck Formation and the basal 3-4 metres of the Sycarham Member, Hayburn Wyke-Iron Scar (NZ 9675 0155-9680 0185). This diagram shows columns F to M. These contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM; transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM; yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fluorescent, fibrous and non-fibrous SOM; brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.

4.4 Cloughton Formation

The sedimentology and organic matter from three sections of the Cloughton Formation were examined: 1) Cloughton Wyke, 2) Northern Yons Nab, and 3) Osgodby Nab as shown in the inset map in Figure 4.14. The first section, exposed at Cloughton Wyke (TA 026 956-020 951), was deposited within the Peak Trough that was active at various stages during the Middle Jurassic. The two remaining sections crop out approximately 15km to the south in Cayton Bay. The section at Yons Nab, south Cayton Bay lies just to the east of the trough and the thinnest section at Osgodby Nab, north Cayton Bay, lies just within the Peak Fault Trough. The location and relationship between these three sections and the IFP RV18 core is illustrated in Figure 4.14. The main sediment supply was north–south, although the section at Yons Nab, outside the fault trough, probably contains material sourced from the west.

Previous workers have, on the basis of the macrofauna, separated the Cloughton Formation into a 50-metre-thick, lower deltaic Sycharham Member, the Lebberston Member, a shallow-marine unit, and the Gristhorpe Member which is interpreted as the deposit of a vegetated delta plain. The Sycharham Member is relatively poorly exposed. The sediments consist of very-pale grey shales, commonly penetrated by roots, interbedded with dark-grey organic-rich shales. Many of the shales contain evidence of bioturbation. Thin laterally accreted sandstones which are commonly rooted, and cross-bedded channel sandstones are also present. The Lebberston Member is a heterolithic, poorly fossiliferous, bioturbated unit which Livera & Leeder [1981] interpreted as beach deposits and lagoonal sediments. In the south-east of the basin the lower part of the Lebberston Member is traditionally divided into the lower calcareous Millepore Bed, and an upper siliclastic-rich unit, termed the Yons Nab Beds, which have been described as the transgressive and regressive phases of the Lebberston Member respectively. The Millepore Bed, from Yons Nab northwards, show a continuing facies change in the widely separated exposures from calcareous facies to more arenaceous, ferruginous facies. At Yons Nab, the Millepore Beds is represented by cross-bedded oolite [Bate, 1959] and is overlain by 5.5 m of marine sandstones and shales which represent the Yons Nab Beds. These contain a rich shallow-water lamellibranch fauna as well as plentiful ostracods and plant remains [Bate, 1959]. The Millepore Oolite is well developed at Osgodby Nab, the northern headland of Cayton Bay, but here it is overlain by deltaic sandstones and not by the Yons Nab Beds. This sandstone probably represents a contemporaneous deltaic distributary [Bate, 1959]. At Cloughton Wyke, seven miles to the north, the Millepore

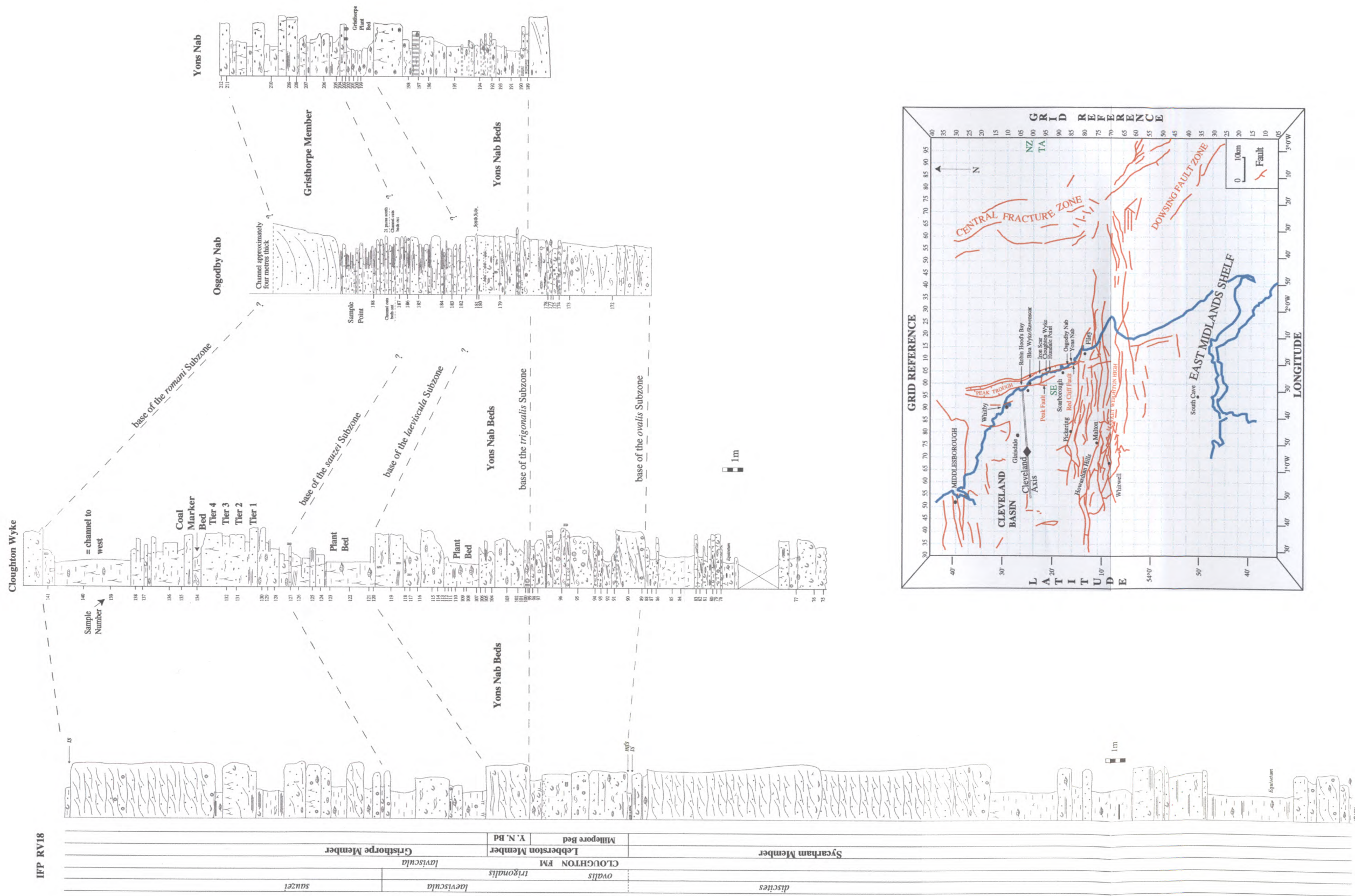


Figure 4.14: Lithological description and correlation of the sections of Cloughton Formation examined in this thesis. From left to right: IFP core RV18, (Ross and Morgans, 1996, unpublished); Cloughton Wyke (TA 026 956-020 951) [after Morgans, 1997]; Osgodby Nab (TA 064 854), [after Morgans, 1997] and Yons Nab (TA 081 843) [after Morgans, 1997]. Location of the sections is shown in the inset map. No horizontal scale is implied. Numbers beside lithological description correspond to sample numbers.

Beds are overlain by 6.75 m of arenaceous shale and sandstone containing marine fossils. This upper marine horizon, equivalent to the Yons Nab Beds, can be seen to pass laterally into a typical deltaic sandstone only a few hundred yards from the section. Towards the north, these beds thin and it becomes difficult to differentiate between Yons Nab Beds and the overlying Gristhorpe Member in the Ravenscar area, *e.g.*, IFP core RV18.

Delta-top conditions resumed with the deposition of the Gristhorpe Member, which is up to 20 metres thick. A regime of marsh flats and shifting river channels resulted in the deposition of a succession of crevasse-splay sandstones, intercalated with plant-bearing mudstones and siltstones. The lower part comprises dark shales with thin coal stringers suggesting that they were formed by drifted plant input into standing water. These beds are overlain by a series of stacked laterally accreted sandstones interpreted as crevasse-splay deposits. This stratigraphic change is shown in Figures 4.15 and 4.16 for Cloughton Wyke and Yons Nab, Cayton Bay respectively. In both the Yons Nab and Cloughton Wyke sections saline palynomorphs are evident in the majority of samples, shown in Figures 4.17 and 4.18. This indicates that the saline influence was more extensive in both the non-marine members of the Cloughton Formation, in comparison to the Saltwick Formation. Marine influence is also evident in the sediments, in the form of bioturbation *e.g.*, *Diplocraterion* and *Teichichnus* burrows. One bioturbated horizon, in the lower part of the Gristhorpe Member, is recognized in all sections except Osgodby Nab. The associated increase in saline palynomorphs shown in Figures 4.17 and 4.18 indicate that this is a basin-wide phenomenon, suggesting that it resulted from a minor rise in relative sea level rather than delta-lobe switching.

A number of other important features in the nature of different components of organic matter occur in the Cloughton Formation. There is an increase in the relative abundance of vita fragments shown in column C, Figures 4.17 and 4.18, in the Lebberston Member and lower-mid Gristhorpe Member of the Cloughton Formation, in comparison to other parts of the succession. Either the depositional environment has become more suitable for the preservation of this material (which contains recognizable botanical tissue *e.g.*, cuticle) or the original tissues were thicker and hence more resistant to decay. This change may be the result of one or more of the following processes; taphonomic sorting, change in the local depositional environment, which may be a function of climatic change and/or a response to a climatic change. It is interesting to note that the quantitative evaluation of the Middle Jurassic Cleveland Basin macrofloral distribution conducted by Morgans [1997] shows that xeromorphic



Figure 4.15: View of the basal section of the Gristhorpe Member exposed at Cloughton Wyke (TA 026 956-020 951). The lower part comprises dark shales with thin coal stringers suggesting that they were formed by drifted plant input into standing water. These beds are overlain by a series of stacked laterally-accreted sandstones interpreted as crevasse splay deposits. The basin-wide bioturbated unit lies within the dark band of beds below the crevasse splays. This photograph is courtesy of Helen Morgans. Rucksack towards the base of the photograph shows the approximate scale.

genera, exhibiting xeromorphic characteristics, which include thick-walled mesophyll cells, occur in the Lebberston Member. Morgans [1997] interpreted the abundance of xeromorphic genera in the Lebberston Member as a result of taphonomic sorting. The presence, however of more vita fragments in both the Lebberston Member and lower part of the Gristhorpe Member, in a wide range of different lithofacies and both aerobic and anaerobic conditions indicates that this pattern is not a result of taphonomic sorting. It is important to note that plants growing in areas of increased salinity, *e.g.*, mangroves, have adaptations to reduce water loss and prevent excessive salt uptake, termed halophytic features, which can be very similar in nature to xeromorphic characters formed in arid environments. On the basis of the saline influence on deltaic deposition, mentioned above, it is thought that a large percentage of the flora contained halophytic features. Thus, it is believed that the deltaic conditions during this period may have been very similar to the modern day Ganges-Brahmaputra delta: large area of swamp penetrated by channels carrying as much saline water as fluvial discharge [Elliot, 1978]. The saline influx would account for the ubiquitous saline microflora as well as for occasional bioturbated horizons.



Figure 4.16: View of the basal section of the Gristhorpe Member exposed at Yons Nab (TA 081 843). The lower part comprises dark shales with thin coal stringers suggesting that they were formed by drifted plant input into standing water. This photograph is courtesy of Helen Morgans. Author for scale.

The range of the index of organic matter, shown in column K, Figure 4.19 from Cloughton Wyke echoes the lithofacies type with plant beds being very rich in organic matter compared with sediments of the basal bioturbated sand ridges and crevasse splays, as expected. Total relative percentage abundance of SOM (column F) does not, however, reflect the lithofacies, for example, the lower part of the Gristhorpe plant bed, ‘coal marker’ bed and prograding sand ridges, in the Yons Nab Member all contain similar amounts. It is only when the different colour and fluorescent SOM sub-categories, in columns G-J, are examined that more valuable information is obtained. These columns highlight that the plant beds contain more fluorescent, lighter SOM than non-fluorescent, dark SOM. This association is indicative of a low-energy reducing environment which are the best conditions for the preservation of organic matter. Darker, non-fluorescent material is associated with high-energy, bioturbated oxic environments. The crevasse-splays sediments and prograding sands and burrowed units show high levels of dark, non-fluorescent material, as expected. Clearly a range of oxic and reducing conditions existed within the Cloughton Wyke sequences. This pattern is also evident in the section at Yons Nab illustrated in Figure 4.20.

Towards the top of the section at Cloughton Wyke and Yons Nab there is a general increase in the ratio of black/brown non-vita fragments, column D and E respectively, *i.e.*, the amount of black

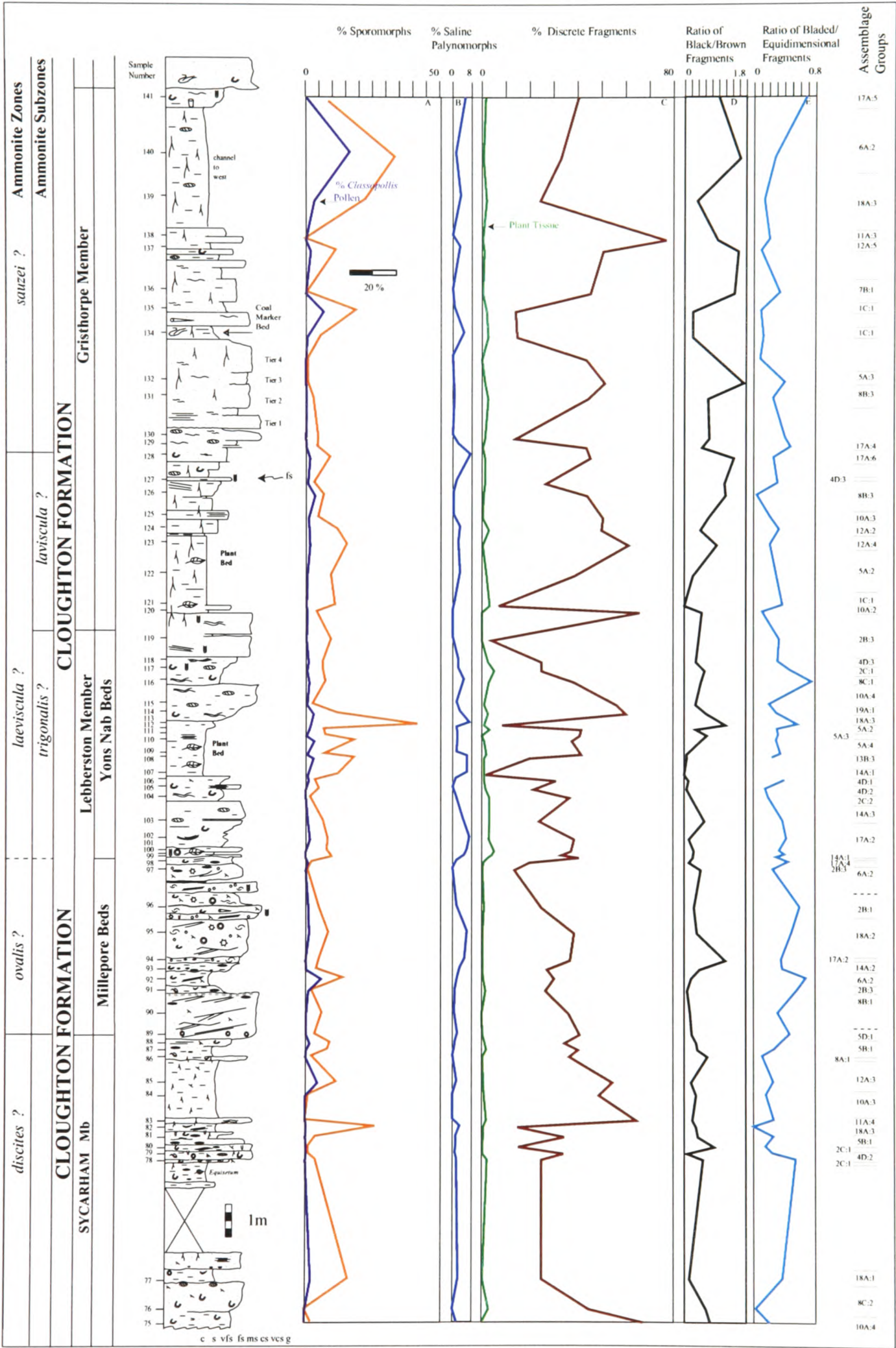


Figure 4.17: Sedimentary description of the upper Sycarham Member to base of the Scarborough Formation, Cloughton Wyke [after Morgans, 1997]. This diagram shows columns A to E and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in discrete fragments and vita fragments. Columns D and E illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. Details of the different assemblage types are contained in Appendix F.

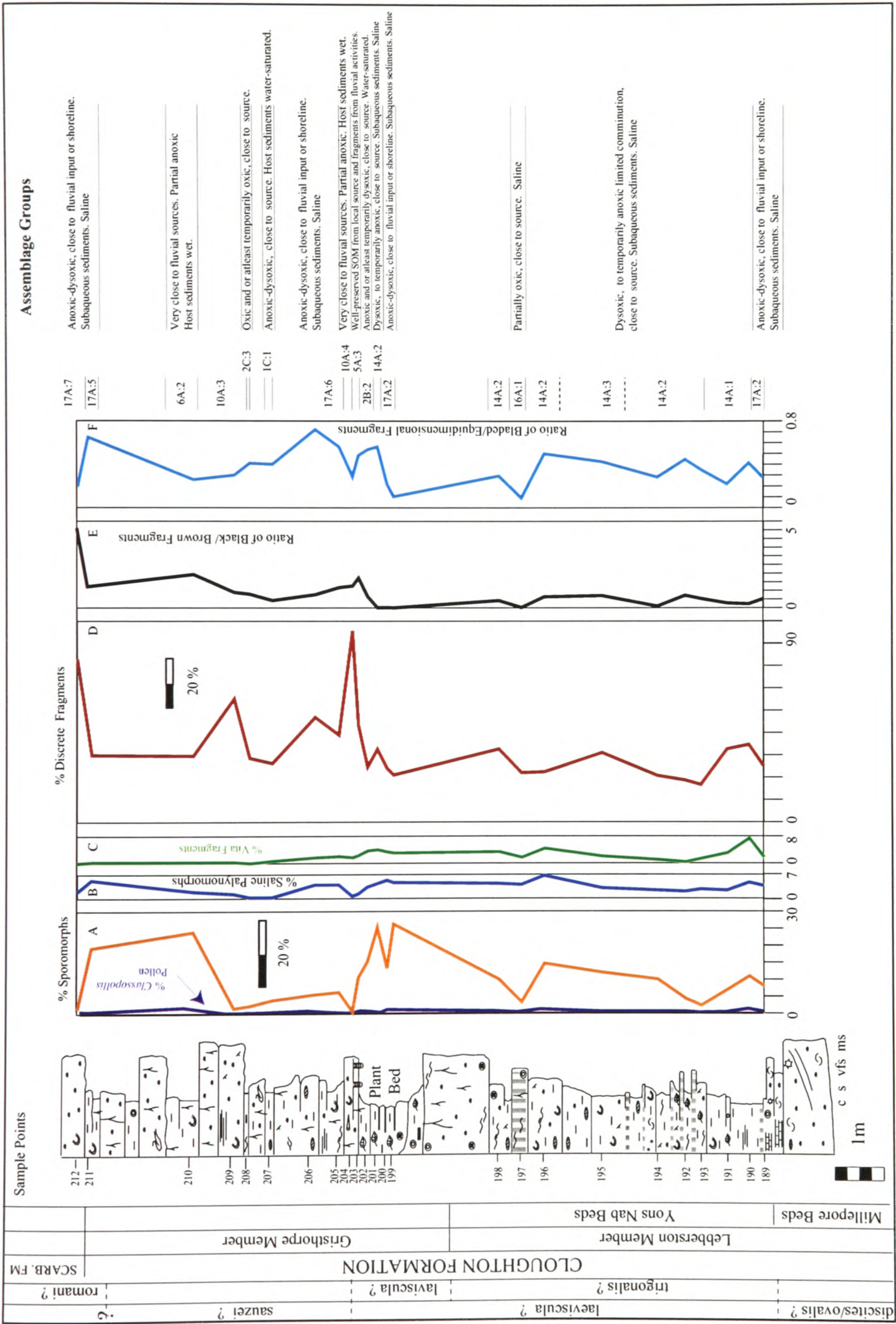


Figure 4.18: Sedimentary description of the upper Millepore Bed, Leberston Member to base of the Scarborough Formation, Yons Nab [after Morgans, 1997]. This diagram shows columns A to F and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change vita fragments. Column D depicts relative percentage change in discrete fragments and Columns E and F illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively.

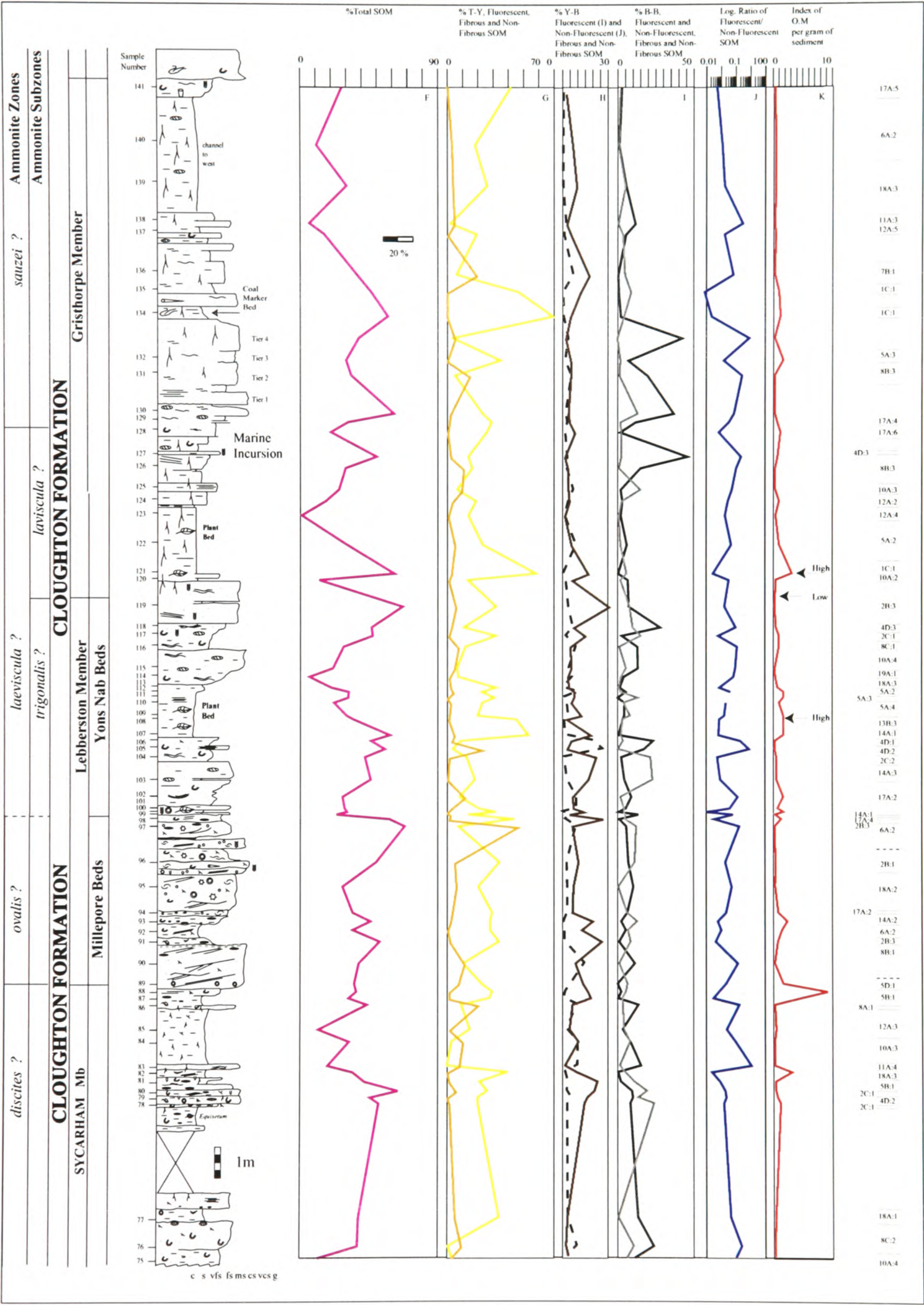


Figure 4.19: Sedimentary description of the upper Sycarham Member to base of the Scarborough Formation, Cloughton Wyke [after Morgans, 1997]. This diagram shows columns F to K. These contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM and transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM and yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fluorescent, fibrous and non-fibrous SOM and brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.

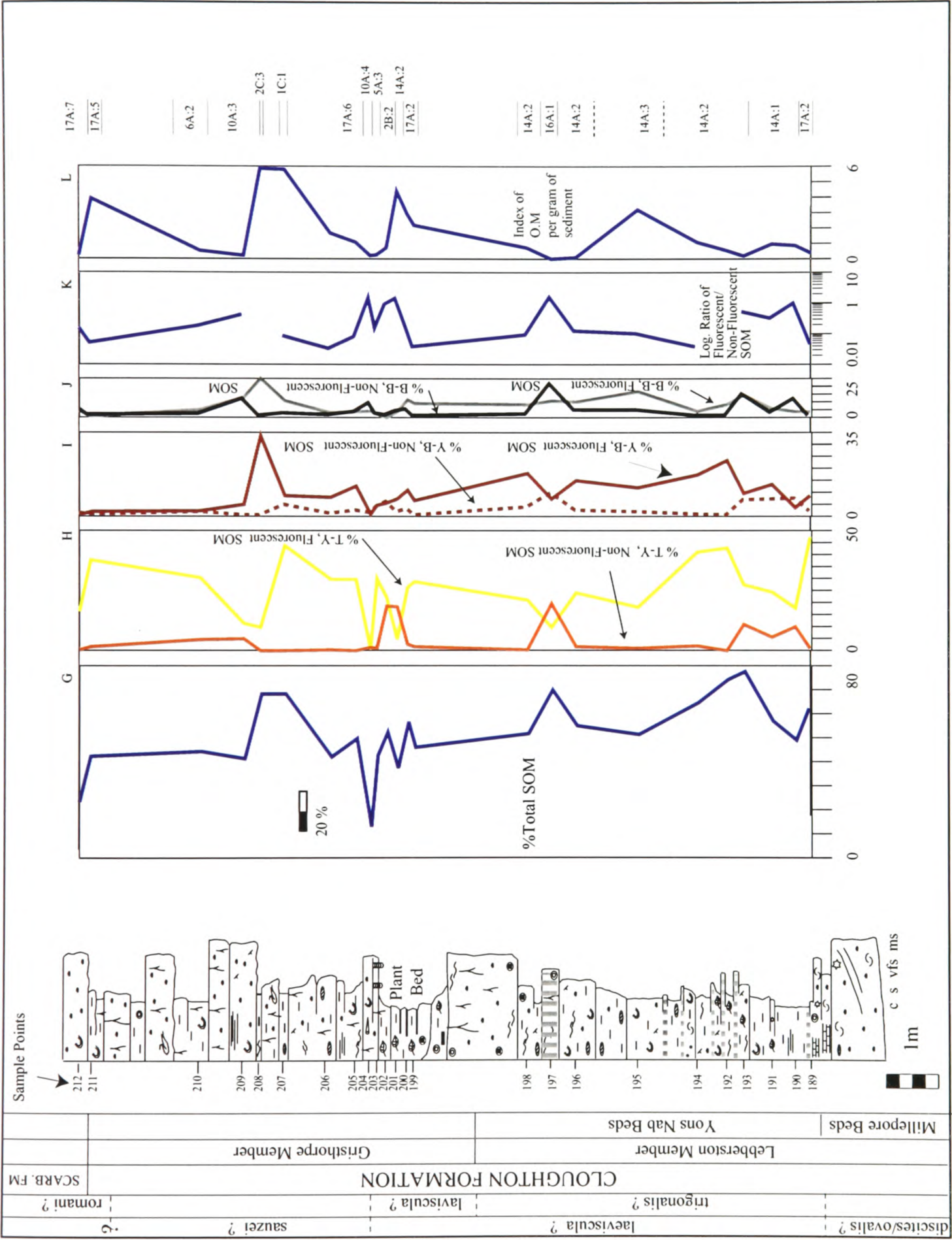


Figure 4.20: Sedimentary description of the upper Millepore Bed, Leberston Member, to base of the Scarborough Formation, Yons Nab [after Morgans, 1997]. This diagram shows columns G to L. These contain relative percentage change in total SOM; transparent-yellow, fibrous and non-fibrous SOM and transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fibrous and non-fibrous SOM and yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fibrous, fibrous and non-fibrous SOM and brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of

(carbonised) fragments increases. This increase, as mentioned earlier may be due to a number of different factors. Thus, it is prudent to assess whether this change, through time, is a taphonomic artefact or a genuine manifestation of environmental/climatic variation. The similar trend in the black/brown ratio in both sections, which were probably sourced from different parts of the basin, and in a wide range of lithologies, strongly suggests that this trend is basin wide, and hence probably climatic, *i.e.*, this could indicate that there is an increase in the amount of wildfires up-section and hence may be due to a climatic change.

There is, however, some debate concerning the formation of carbonised (fusinized debris) particles. There is no doubt that they can be produced by the burning of wood and some workers favouring the action of fire upon woody material as being the only cause [Cope, 1981]. A number of workers, including Schopf [1975] and Beck *et al.* [1982] have, however, questioned the fire-related origin of particular occurrences of charcoal. Schopf [1975] claimed that some form of biological process, for example oxidative decay at an early stage, could produce fusain without pyrolysis. MacKowsky [1968] stated that in drier swamps or swamps with fluctuating water the upper oxidative layer may extend downwards with subsequent conversion of the humic debris to inertinite. Fisher and Hancock [in Scott & Collinson, 1978] supported this theory and referred to the presence of inertinitised rootlets in position of growth in the Ravenscar Group.

This alternative to wildfire as the fusain-forming mechanism was sought by the above authors as they considered wildfires in coal-swamps as totally implausible. However, Chaloner [1994] pointed out that this argument has been weakened by the importance of fires in the Everglades, USA and Borneo. It is, therefore, clear that fires are not just restricted to dry areas, even in generally humid areas widely regarded as improbable sites for wildfires, ignition can occur after drought. In addition, Cohen & Spackman [1977] who conducted a survey of modern peat-swamps concluded that 'no evidence is found to support the hypothesis that fusinite in coal can be derived from any process other than fire'. It is also evident that the black fragments, identified in this study, occur in both oxic and anaerobic host sediments. This, therefore suggests that the black fragments recorded in this study are not the result of a post-depositional alteration.

Over the years, a number of criteria have been set to distinguish between fusain formed by pyrolysis and various forms of wood affected by different degrees of diagenesis. Fine anatomical details of

pits and wall thickenings are preserved in charred, woody tissues, but the original components of the cell wall (middle lamella, primary wall and secondary wall) lose their intrinsic identity on pyrolysis [McGinnes *et al.*, 1974; Cope & Chaloner, 1980]. Cope & Chaloner [1980] also stated that this apparent homogenisation of the wall takes place above 300 °C and is observed in all charcoals over a wide range of geological ages. Cope [1981] examined the inertinised rootlets of Fisher [1980] under SEM and found that they revealed little in the way of anatomical detail and the morphology was generally structureless. To assess whether the black fragments in the present study were indeed charcoal and not the result of post-depositional alteration a number were selected at random for examination under reflected light and SEM. The majority of black fragments displayed the appropriate characters as illustrated in Figures 4.21 and 4.22 of a black fragment that shows fine anatomical features under SEM.

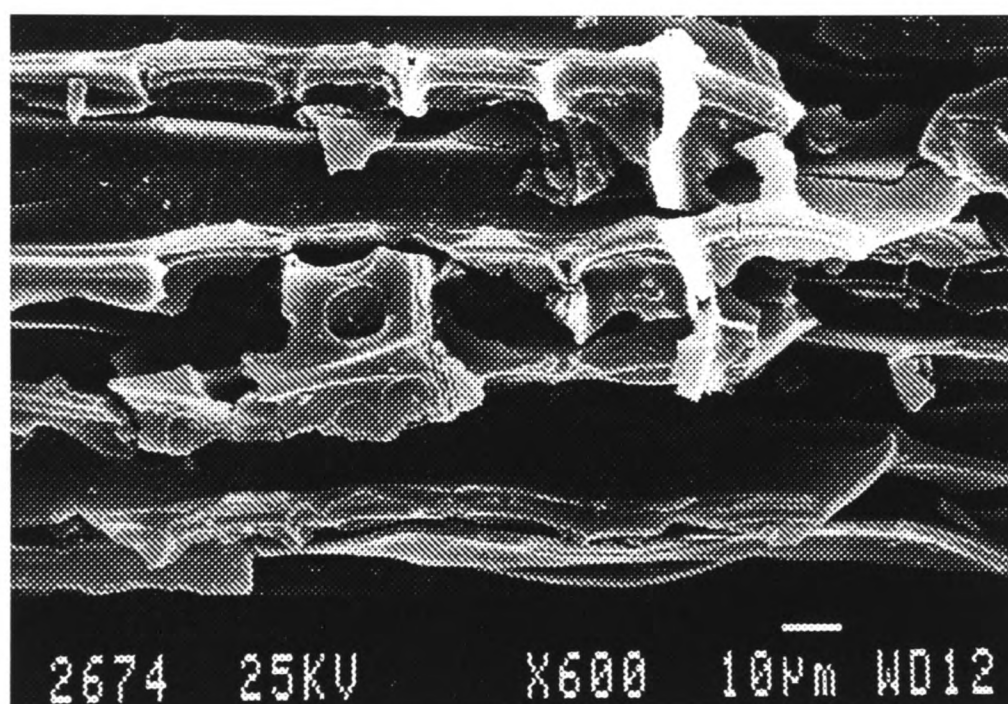


Figure 4.21: Adjacent cell walls are apparently fused together with the elimination of the middle lamella zone, an anatomical feature which is characteristic of burnt wood [McGinnes *et al.*, 1974].

Thus, the flux in black fragments towards the top of the Gristhorpe Member was probably caused by an increase in fire. Moreover, Harris [1958, 1981] argued that the nature of the charcoal in the Mesozoic rocks points inescapably to a fire origin. Further supporting evidence comes from Skolnick [1958]. He proposed that the preservation of fusain-rich beds requires rapid burial away from heavy currents and/or incorporation in a marine system. Clearly such environments were available in the lower and middle part of the Cloughton Formation and in the Saltwick Formation. However, as observed earlier, brown fragments dominate these sections, except for a few isolated peaks in the Saltwick Formation. A source is evidently required so the change observed is related to an increase

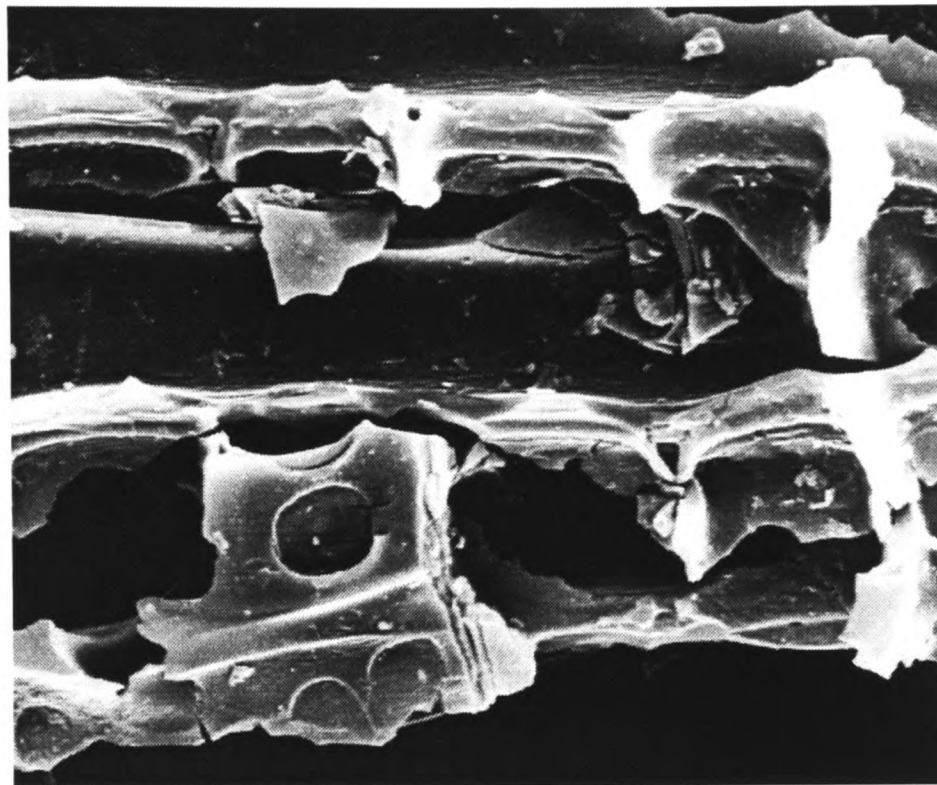


Figure 4.22: Detailed view of the fine anatomical features, shown in Figure 4.21.

in production. Hence, the occurrence/extent of fires increased during the deposition of the upper part of the Cloughton Formation in response to a climatic change in the early Bajocian.

In contrast, to the older deposits in the Middle Jurassic, Cleveland Basin, the variations in *Classopollis* pollen, in the upper part of the Cloughton Formation are distinct from changes in saline palynomorphs. This suggests that the parent plant that was the source of the *Classopollis* pollen did not grow in a saline setting. This proposal is supported by the work of Harris [1979], who noted that *P. maculosum* (see Appendix C for details regarding the relation between *Classopollis* pollen and *P. maculosum*) clearly grew near to river channels and *Equisetum* swamps.

Another point of note is the manifestation of the *Classopollis* pollen acme in the early Bajocian (*sauzei* Zone) in the Cloughton Wyke section, Figure 4.17. This acme occurs during the influx of black non-vita fragments. Recently, Ziaja & Wcislo-Luranc [1999] mentioned that fire caused the opening of the covering flap of tissue and shedding of the seeds of *Hirmeriella*. Additionally, several North Sea workers, including Helland-Hansen *et al.* [1992] and Bray *et al.* [1995] have suggested that increases in *Classopollis* pollen in the early Bajocian of the Middle Jurassic Brent Group were caused by an increase in the palaeotemperature. In the thinnest section exposed at Osgodby Nab, Figure 4.23 it is possible to detect the first evidence of an increase in *Classopollis* pollen and increase in the ratio of black to brown fragments. Hence, this concomitant increase in black fragments and

Classopollis pollen would suggest that the climate became warmer and/or more seasonal, and the amount of wildfires was greater in the Bajocian, in comparison to the Aalenian.

4.4.1 Synopsis

Each section and individual members vary in thickness. This range implies that the palaeogeography, and hence accommodation space and sediment supply changed during the deposition of these predominately fluvio-deltaic sediments. The lithofacies- and taphonomic-independent nature of the black fragment distribution and its similar trend in time-equivalent sections, which were probably sourced from different parts of the basin, strongly suggest that this increase was a basin wide event. This indicates that conditions altered throughout the basin in the upper part of the Cloughton Formation. The flux in black fragments was probably caused by an increase in number/extent of fires. Hence, it is proposed that fires became more prevalent during the deposition of the upper part of the Cloughton Formation in response to a climatic change beginning in the early Bajocian. The co-occurrence of the *Classopollis* pollen peak, during this period, further supports the existence of a change in the palaeoclimate. Thus, it is proposed that the early Bajocian was warmer/more arid than the preceding Aalenian, which is earlier than the previous palynological [Boulter & Windle, 1993], stable isotope [Hendry, 1997] and palaeobotanical investigations [Morgans *et al.*, 1999].

4.5 Scarborough Formation

The nature of the overlying Scarborough Formation, (*sauzei-humphriesianum* Zones), the only fully marine unit recognised in the Aalenian-Bathonian, was determined from three sections; 1) IFP core RV18, 2) Cloughton Wyke to Hundale Point and 3) Yons Nab which are illustrated in Figure 4.24. This formation shows marked variations in thickness reaching a maximum of 32 metres at Ravenscar [Fox-Strangways, 1892]. South of Hundale Point the thickness decreases rapidly; the comparable succession at Yons Nab (TA 085 842) is represented by a mere four metres. The Scarborough Formation at Ravenscar and Hundale Point shows a broad two-fold division into a lower unit dominated by sandstone and an upper interval dominated by calcareous mudstone and siltstone. The formation at Hundale Point was divided into seven members by Parsons [1977] and Gowland & Riding [1991] and comprises calcareous sandstone, sandy limestone, siltstone and calcareous mudstone, containing sideritic ironstones and nodules in bedded horizons. This broad range of lithologies reflects a

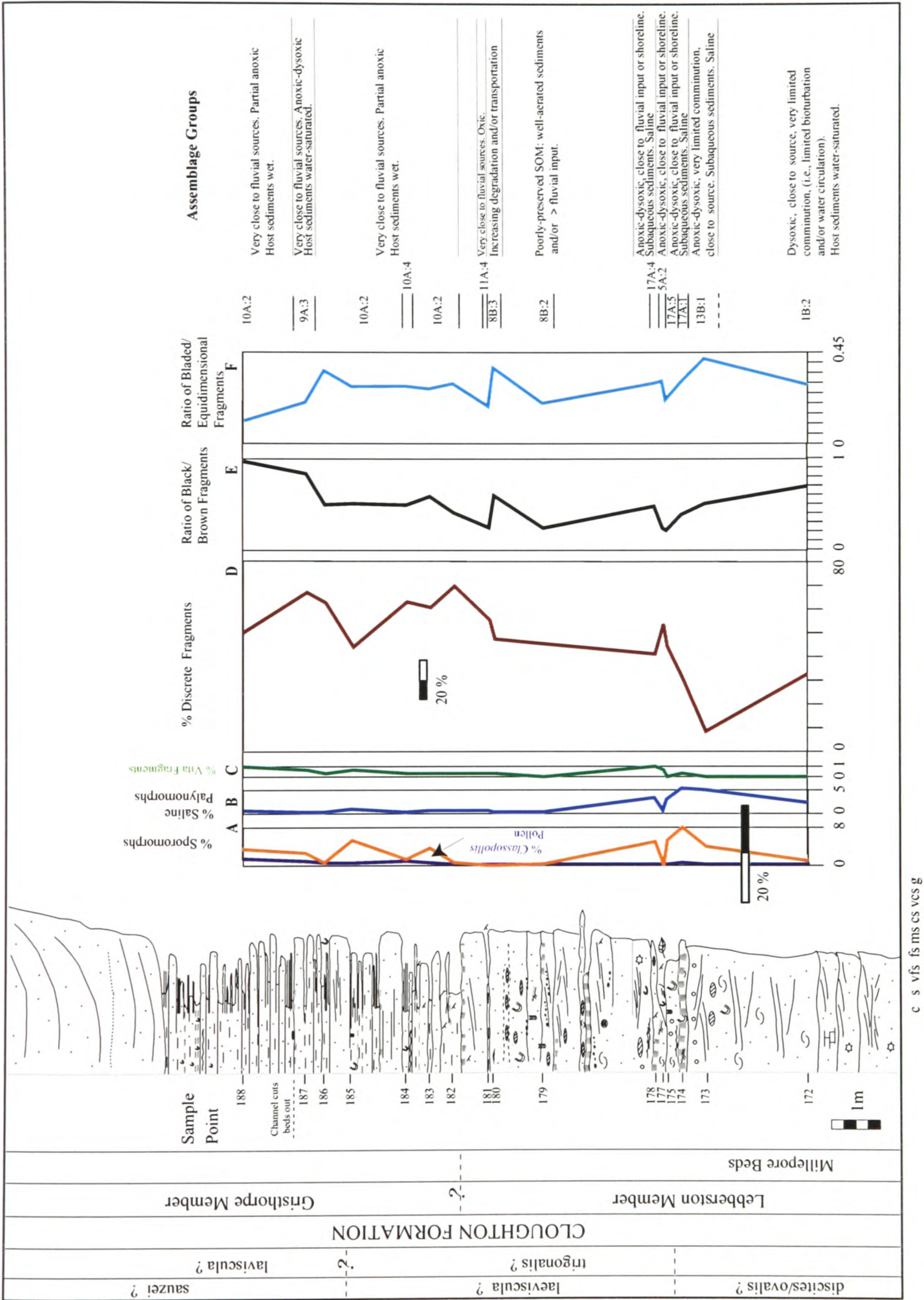


Figure 4.23: Sedimentary description of the Millepore Bed, Leberston Member and Gristhorpe Member, Osgodby Nab [after Morgans, 1997]. This diagram shows columns A to E and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in vita fragments. Column D illustrates relative change in discrete fragments. Columns E and F illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. The relative changes in SOM categories and index of organic matter are

range of environments that include brackish sandy embayment, nearshore sandy and muddy shelf, and offshore mud-dominated shelf [Gowland & Riding, 1991]. The nature of the organic matter in the formation was examined from both Hundale Point and Yons Nab.

It is clear that SOM dominates the insoluble organic matter in the succession at Hundale Point. According to Van der Zwan [1990] the abundance of SOM is characteristic of stagnant bottom conditions, *i.e.*, anoxic-dysoxic. Discrete fragments are typically low in abundance, in comparison to the non-marine units. The basal beds of the Scarborough Formation (Helwarth Beck Member), contain the highest levels of discrete fragments and lowest amounts of saline elements recorded in the Scarborough Formation at Cloughton Wyke. The association indicates that these beds accumulated in a brackish bay and/or brackish lagoon, in comparison to the beds above which were probably deposited in more distal settings.

The increase in black (carbonised) non-vita fragments illustrated in column D, Figure 4.24, recognised in the upper part of the Cloughton Formation (Gristhorpe Member) continues up into the mid-Scarborough Formation. The corresponding relative change in bladed/equidimensional fragments depicted in column E, Figure 4.24, shows that the distribution becomes approximately bimodal. Cope [1981] noted that the mechanical disintegration of charcoal fragments leads to the production of small splinter-like clasts. Lewis suggested that the black-bladed category was equivalent to Whitaker [1984]'s bladed shaped palynomaceral-4 that Whitaker considered to be extremely buoyant and could be transported over long distances. The equidimensional black fragments are approximately synonymous with palynomacerals 1 and 2 and thus Lewis [1995] interpreted them as having low buoyancy. It is clear that the ratio of equidimensional to bladed fragments increases up section after the deposition of the Helwarth Beck Member. A similar pattern, of high levels of black-bladed fragments is observed in the Yons Nab section in Figure 4.27. This indicates that the sediments with high concentrations of bladed discrete fragments were deposited in a more distal setting and are probably charcoal fragments.

4.5.1 Synopsis

The sedimentological and palynofacies data indicate the confinement of the deep water deposits to the upper part of the sequence. Generally these assemblages are indicative of anoxic-dysoxic conditions which were not significantly influenced by terrestrial input.

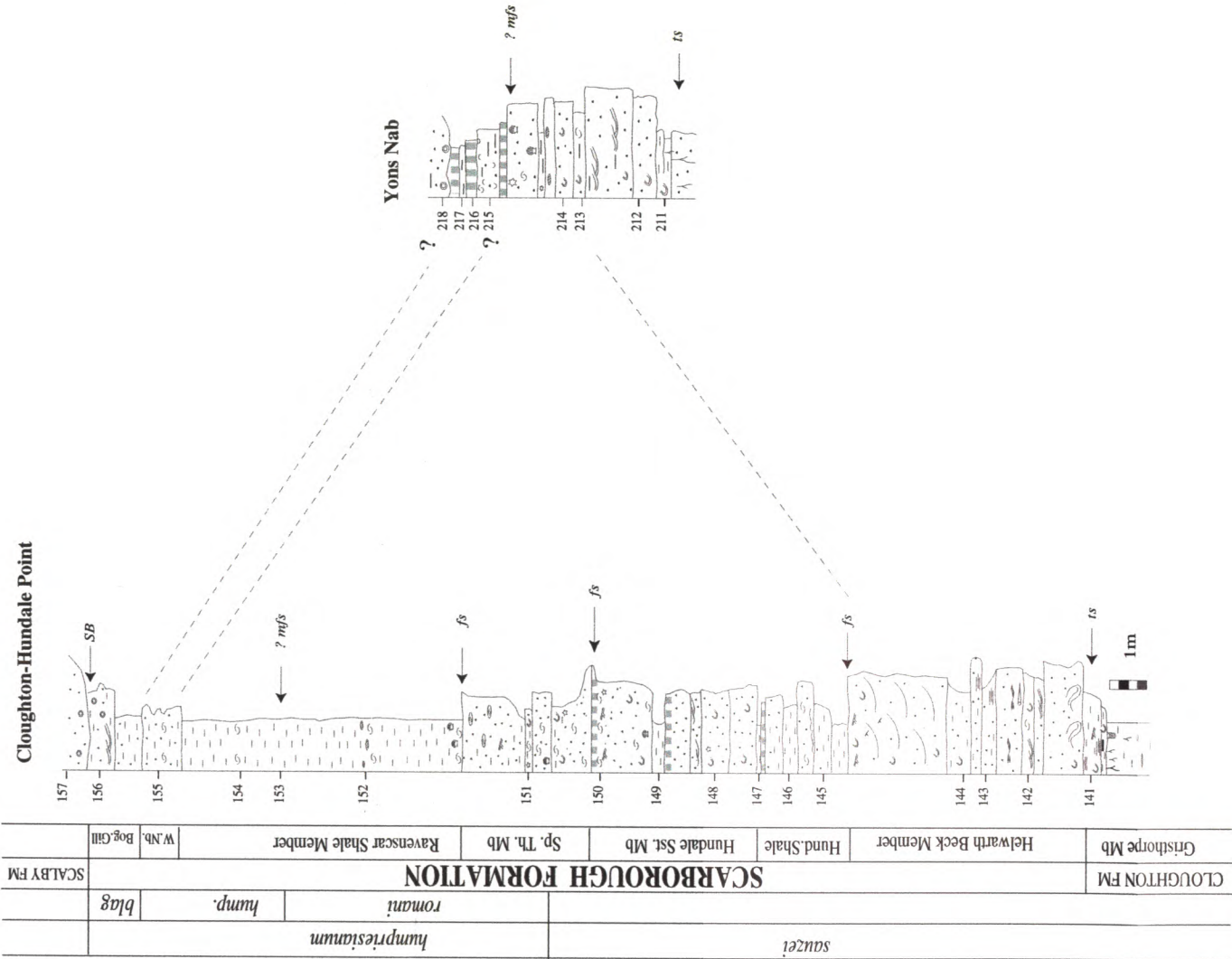
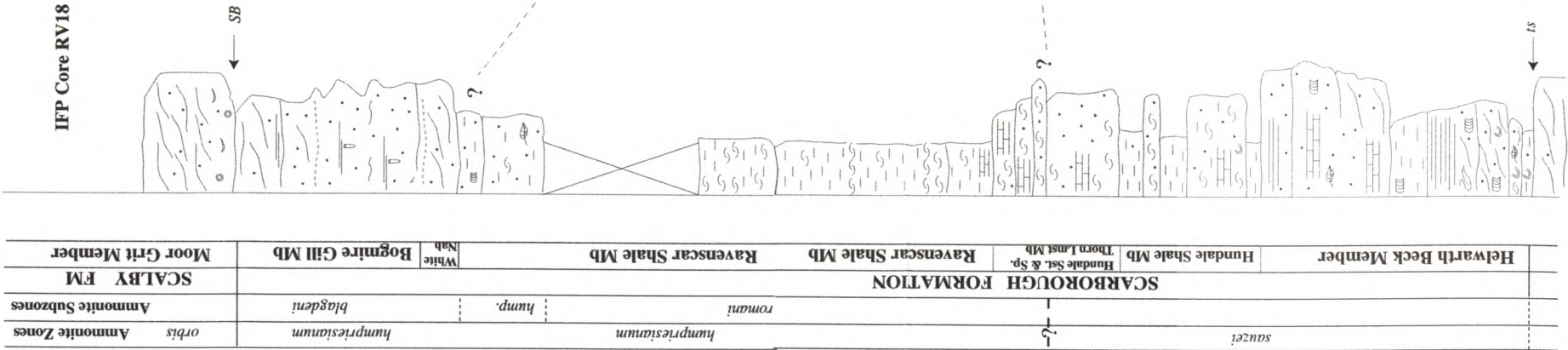


Figure 4.24: Sedimentary description of Scarborough Formation. From left to right: IFP core RV18 (Ross and Morgans, 1996 unpublished), Hundale Point [after Morgans, 1997] and Yons Nab [after Morgans, 1997]. No horizontal scale is implied. Numbers beside description correspond to sample numbers.

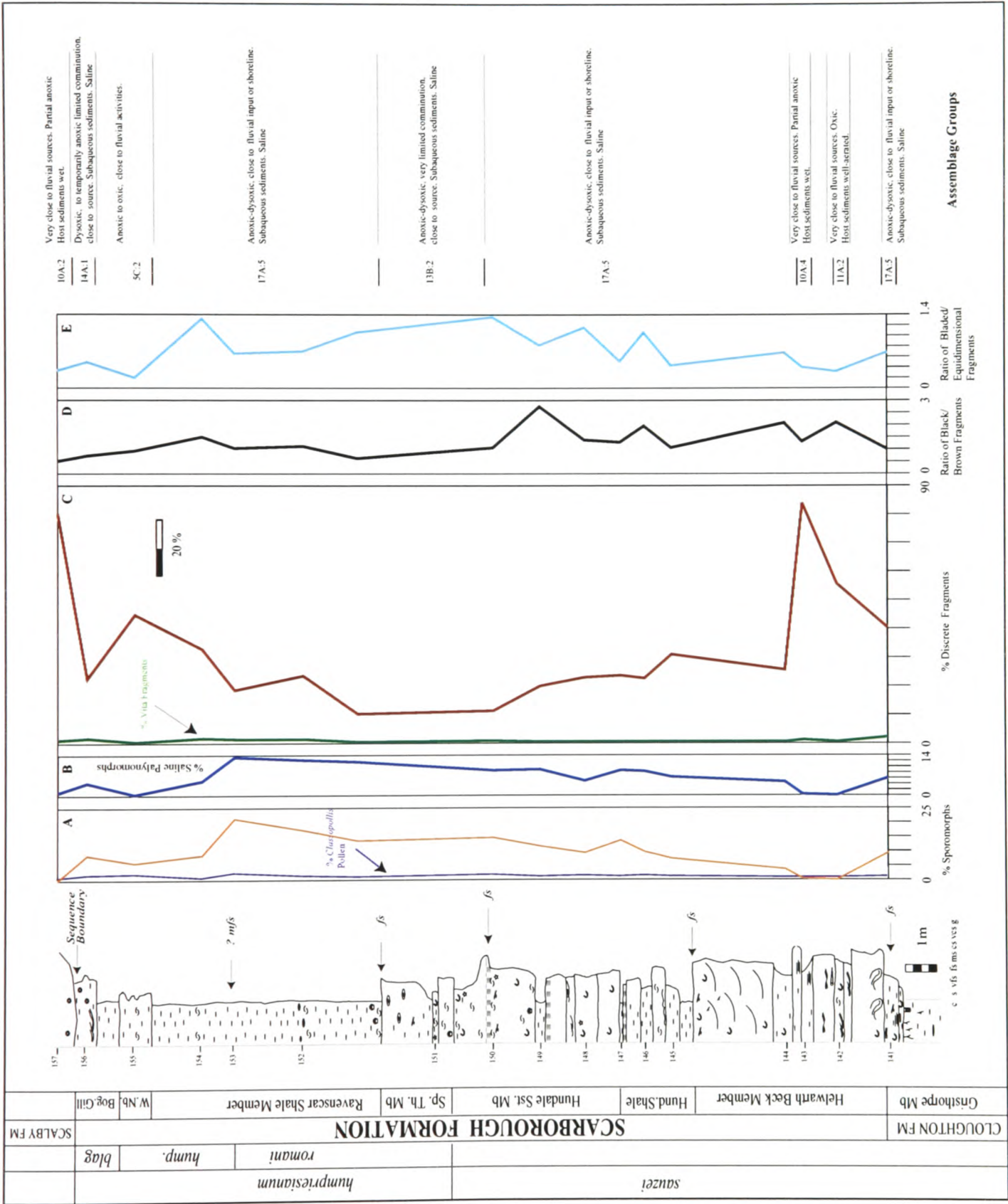


Figure 4.25: Sedimentary description of the Scarborough Formation, Hundale Point [after Morgans, 1997]. This diagram shows columns A to E and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in vita fragments. Column D illustrates relative change in discrete fragments. Columns E and F illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively.

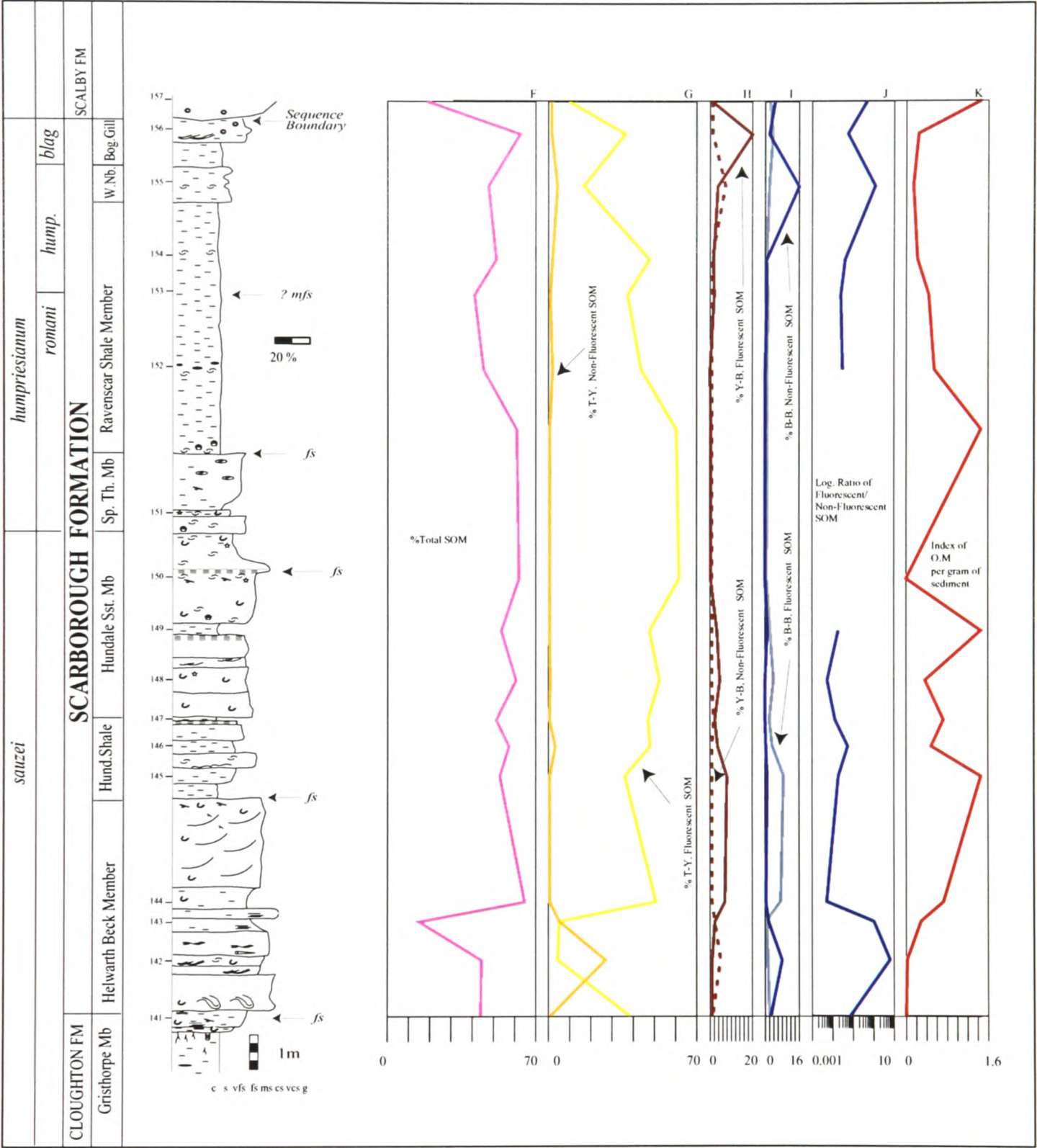
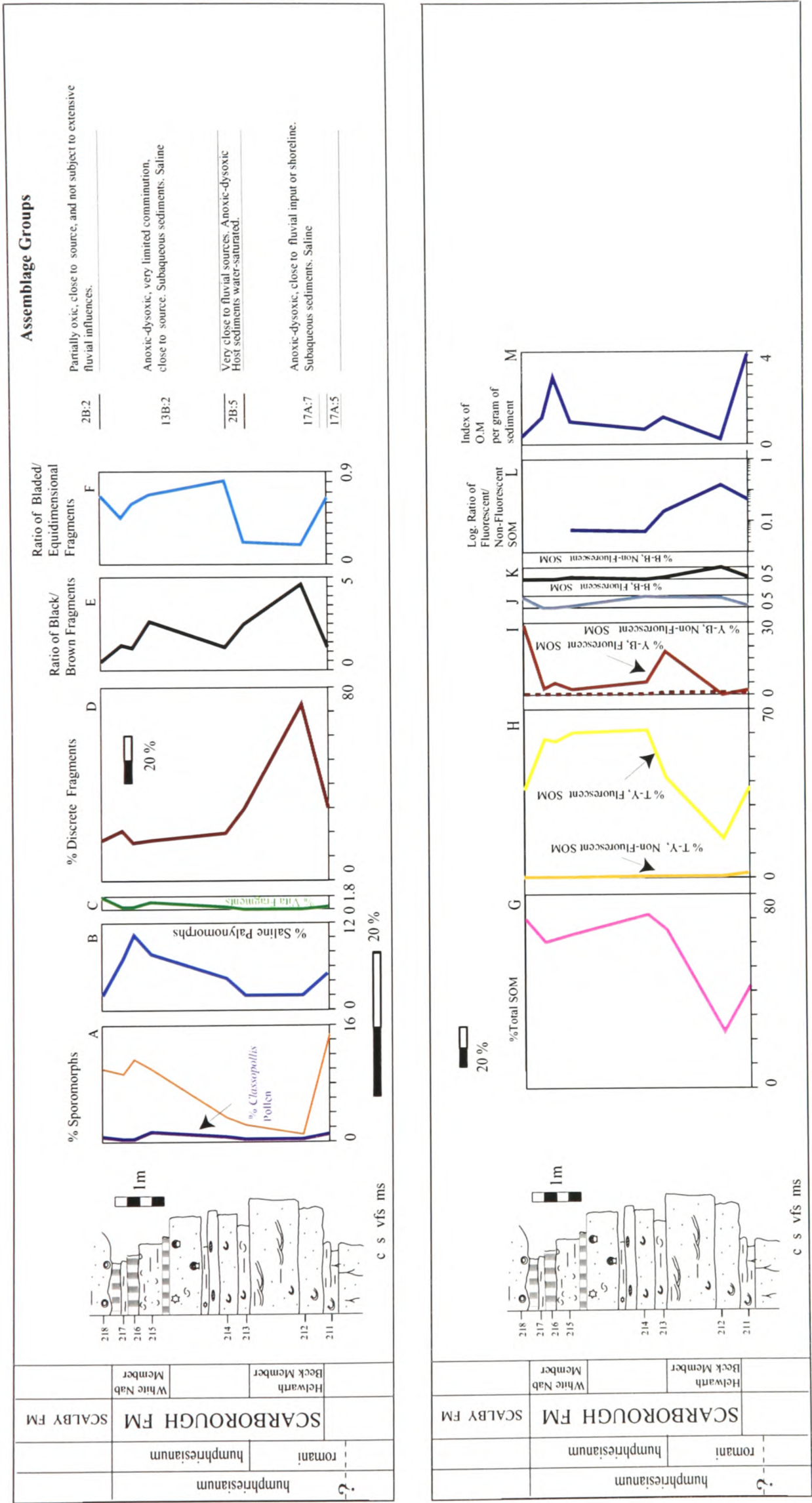


Figure 4.26: Sedimentary description of the Scarborough Formation, Hundale Point [after Morgans, 1997]. This diagram shows columns F to K. These contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM; transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM; yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fluorescent, fibrous and non-fibrous SOM and brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.



4.6 Scalby Formation

Three sections were examined in the present study, 1) IFP RV16, 2) Burniston Steps and 3) Scalby Ness. The paralic sediments of the Scalby Formation were divided into two members by Nami & Leeder [1978]: a lower unit of predominately cross-bedded sandstone, termed the Moor Grit Member, and an upper unit dominated by planar bedded siltstones and mudstones, with plant debris and interbedded, laterally extensive channel sandstones, which contain rare dinosaur footprints, namely the Long Nab Member [Leeder & Nami, 1979]. In this study, the main collection site was in the Long Nab Member, which contains evidence of bioturbation.

The organic matter which was examined from Burniston Steps and Scalby Ness was very sparse as illustrated column L, Figures 4.29 and 4.28 respectively in concordance with Riding & Wright [1989]. This suggests that either productivity or preservation potential was low, in comparison to the preceding formations. Hence, the sediments were either well drained, or the palaeotemperature was higher, (*i.e.*, the climate was more arid/seasonal). The generally sparse palynofloras are dominated by terrestrially-derived spores and pollen. Saline elements are rare, the most abundant record occurring in sample 164, Figure 4.29. The overall pattern of the organic matter and sedimentological characteristics of the Long Nab Member, the shales and sandstones which contain burrows and some saline elements, plant debris and in situ roots are interpreted as swamps and brackish interdistributary bay deposits.

Even though the sampling resolution is less than other sections investigated, it is apparent that the ratio of black to brown fragments is much lower than the upper part of the Gristhorpe Member and Scarborough Formation. There are only isolated peaks. This at first appears to contradict field evidence, as the Scalby Plant Bed and the base of the coarse channel sandstones are known to contain an abundance of charcoaled macroscopic plant debris. However, the occurrence of the macroscopic material is limited and it should not be presumed that the remainder of the Scalby Formation contains abundant charcoaled matter. Cope [1993] suggested that the wildfires which produced the charcoaled debris were more likely to have occurred during times of periodic drought. Indeed, Cope [1993] observed cell wall 'checking' which is a feature of desiccation in some of the charcoal from the Scalby channel sandstone which supports the theory of desiccation. He also commented that charcoaled debris would have been removed from the burnt area by run-off process, perhaps by flood

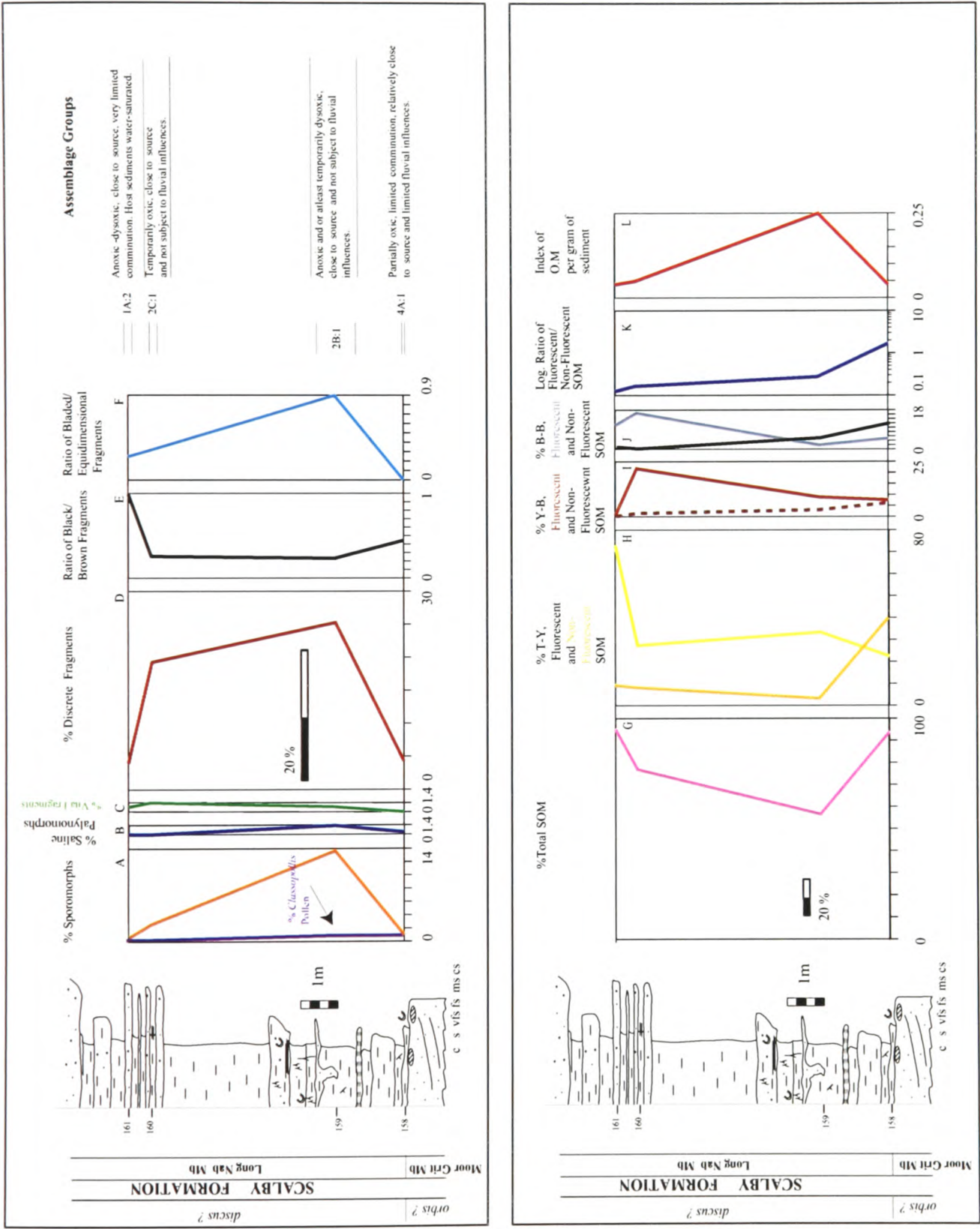


Figure 4.28: Sedimentary description of the Scalby Formation, Burniston Wyke [after Morgans, 1997]. The upper diagram shows columns A to F and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline palynomorphs. Column C shows relative percentage change in vita fragments. Column D illustrates relative change in discrete fragments. Columns E and F illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. The lower diagram shows columns G to L. These contain relative percentage change in total SOM; transparent-yellow, fibrous and non-fibrous SOM; transparent-yellow, non-fibrous SOM; transparent-yellow, non-fibrous SOM; yellow-brown, fibrous and non-fibrous SOM; yellow-brown, fibrous and non-fibrous SOM; brown-black, fibrous and non-fibrous SOM; brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.

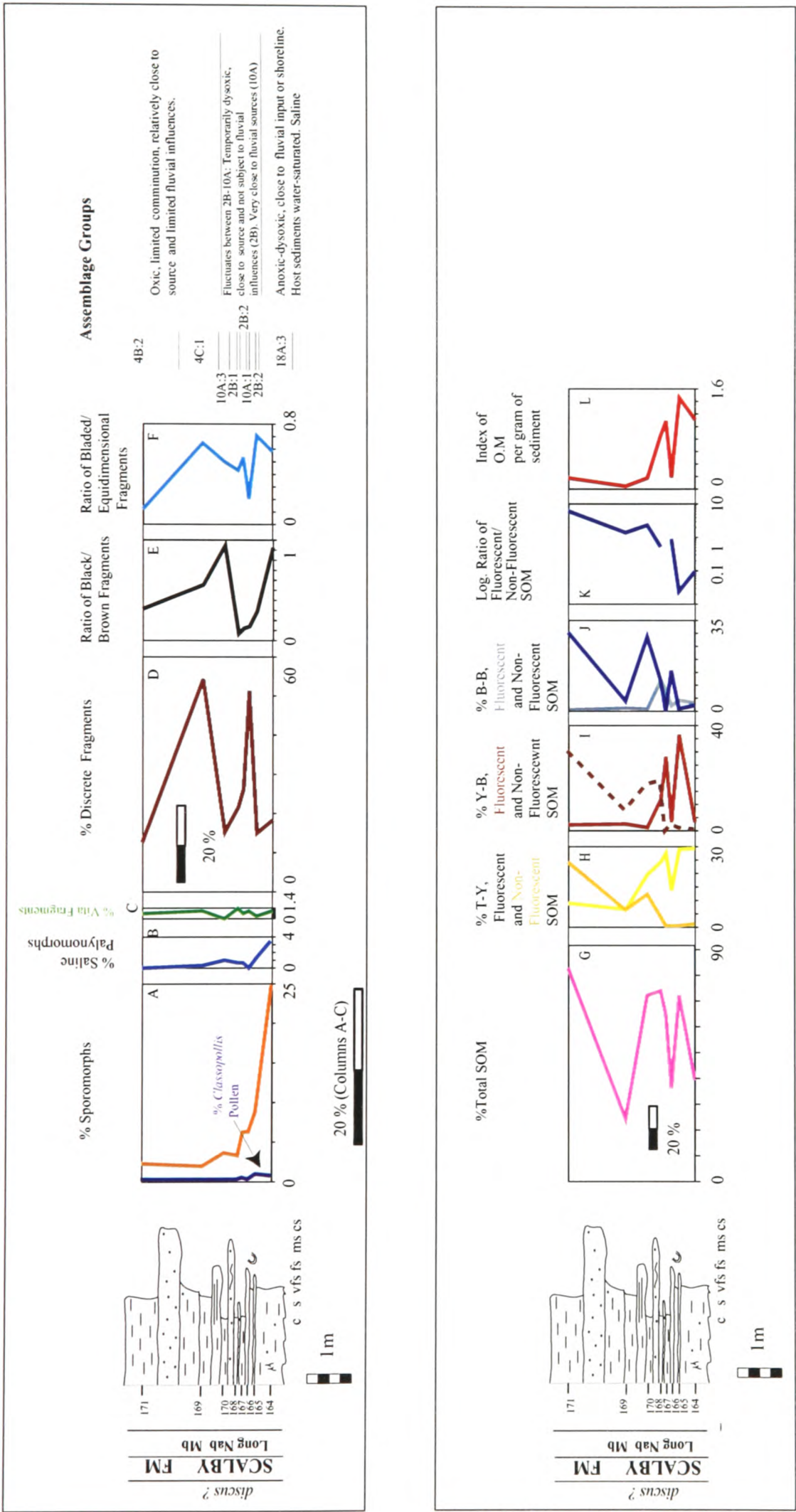


Figure 4.29: Sedimentary description of the Long Nab Member, Scalby Ness. The upper diagram shows columns A to F and list of the Assemblage groups. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in saline paly. fragments. Column C shows relative percentage change in vita fragments. Column D illustrates relative change in discrete fragments. Columns E and F illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. The lower diagram shows columns G to L. These contain relative percentage change in total SOM; transparent-yellow, fluorescent, fibrous and non-fibrous SOM; transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM; yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fluorescent, fibrous and non-fibrous SOM; brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.

waters related to wet periods following the droughts. In any event, unwaterlogged charcoal would have entered the delta distributary channel as part of its flotation load. However, a significant proportion of the charcoal would have become waterlogged and then transported as part of the traction load and thus eventually have been sedimented as a component of the channel sandstones. The dominance of charcoal in the sandstones is therefore not solely a question of its enhanced preservation potential but of sedimentological processes acting to differentiate the transport mechanism and depositional behaviour of the available plant debris.

It is also interesting to note that Cope [1993] stated that it is apparent that the more shaly floodplain facies within the Scalby Formation preserve a different flora to the charcoallified fraction found in the coarser, more sandy channel facies. The flora from the former beds is characterised by an abundance of cycadophytes and ginkgophytes with poor representation of conifers, whilst the converse is the case for the charcoallified flora which is dominated by conifers with only rare occurrences of cycadophytes and ginkgophytes. These changes may reflect the 'Neves effect'. Chaloner & Muir [1968] also recognised a similar pattern in the palynomorph assemblages. . They demonstrated that probable conifer pollen was most abundant and the dominant pollen in the sandstones, whereas in shales and coals fern spores were the most abundant type. The abundance patterns showing a facies differentiation in both macrofossil and microfossil plant assemblages may be explained in terms of a complex relationship between spatial differentiation of the original vegetation, depositional processes and fossilization process.

4.6.1 Synopsis

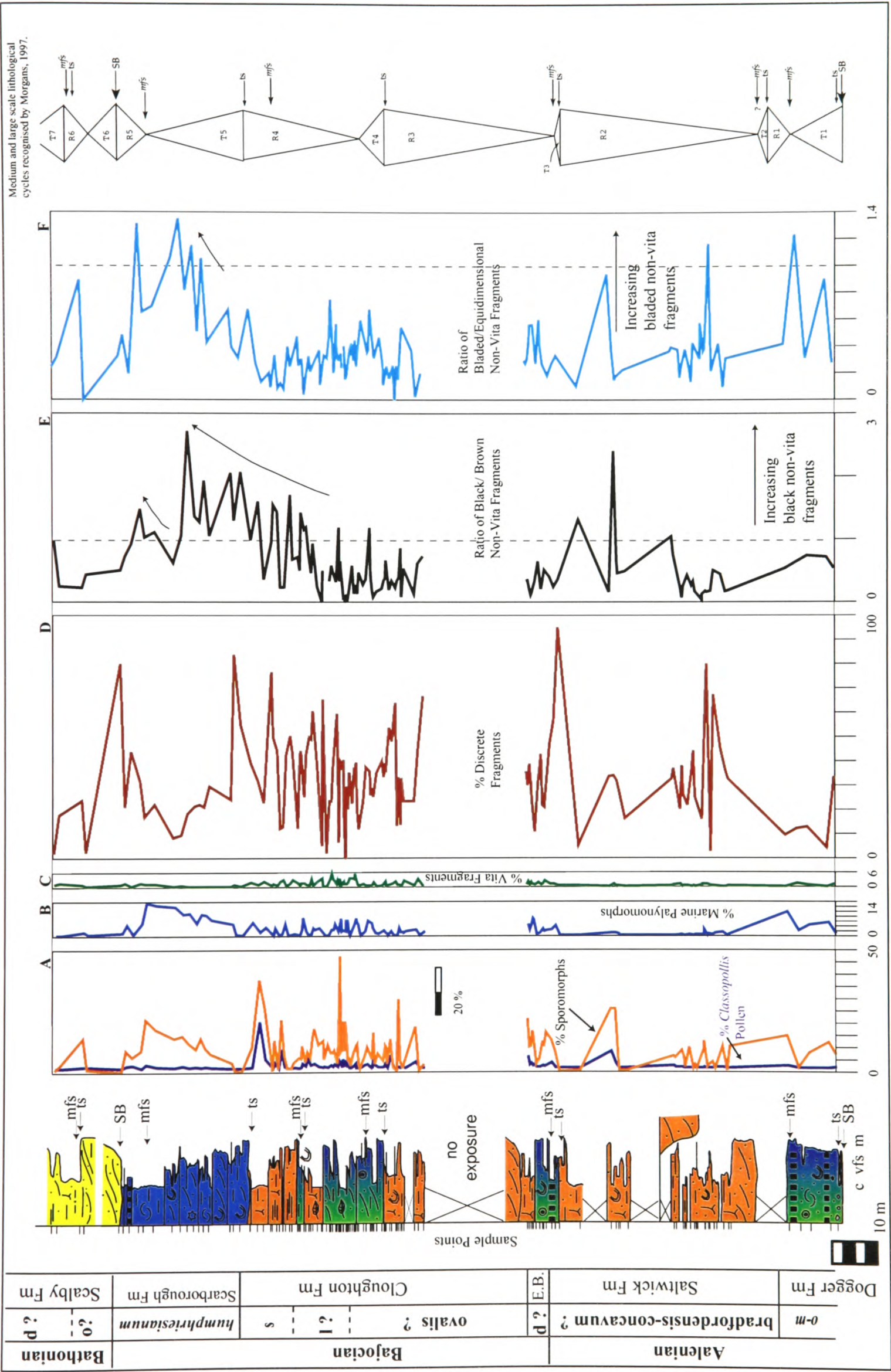
The Scalby Formation appears to have been a period which was subject to droughts and floods, (*i.e.*, seasonal). The overall pattern of the organic matter and sedimentological characteristics of the Long Nab Member are interpreted as swamps and brackish interdistributary bay deposits.

4.7 Aalenian to Bathonian

It is apparent that the pattern of deposition, as mentioned by Alexander [1992] is complicated by spatial and temporal variations in the amount of saline influence. These variations range from major changes in shore-line position resulting in the alternating deposition of non-marine and marine formations to minor shore-line movements [Alexander, 1992]. The fluctuating extent of saline influences was probably a result of the interplay of numerous factors including sedimentation rate, local tectonic activity, eustatic variations and climatic changes. The extent of these changes on architecture of the sediments may be viewed in Figure 4.30 and Figure 4.31 which both contain a composite lithological description of the Aalenian to Bathonian, Middle Jurassic of the Cleveland Basin. This description is compiled from outcrop exposed between Blea Wyke (NZ 994 013) and Burniston Bay (TA 007 899). As some sections of the Middle Jurassic are not exposed the IFP cores, RV18 and RV 16, (details of which are contained in Appendix F) were used to constrain the position of the various sections. In addition, the different sequence stratigraphic cycles recognised by Morgans [1997] are included. She divided the Middle Jurassic (Aalenian to Bathonian) into two large-scale ('second order') lithological cycles, with durations of approximately 3-10 m.a., and a further six-medium scale cycles of relative sea-level. The medium-scale cycles, which are highly asymmetrical, are illustrated in Figure 4.30. The sequence boundaries defining the second-order cycles were determined by Morgans [1997] on the basis of erosional unconformities or sedimentary facies successions indicative of reduced accommodation space in proximal areas. They are identified in the *aalensis* Subzone of the *levesquei* Zone (uppermost Toarcian), and spanning the *subfurcatum* to *morrisi* Zones (late Bajocian to early to mid-Bathonian). At this second-order level, Morgans [1997] recognised a maximum-flooding surface within the *humphriesianum* Subzone of the *humphriesianum* Zone on the basis of evidence for sediment starvation and a restricted faunal component.

Figures 4.30 and 4.31 also provide an overview of the relative percentage changes and ratios for particular organic-matter categories. The extent of the temporal variations of saline influences on

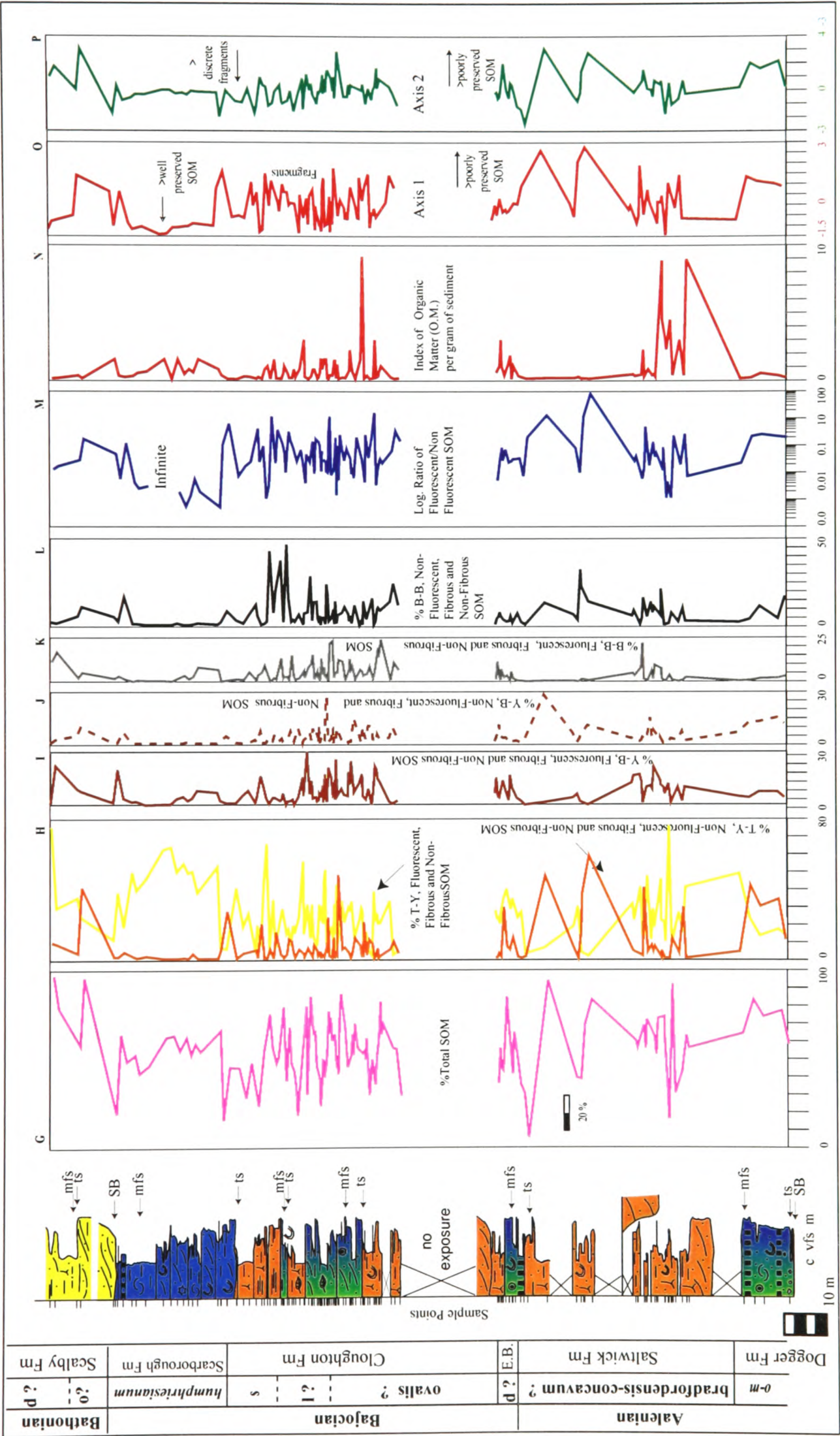
Figure 4.30: Composite lithological description of Aalenian to Bathonian of the Cleveland Basin. Description based on outcrop exposed between Blea Wyke Point (NZ 994 013) and Burniston Bay (TA 007 899). IFP cores, RV18 and RV16, details of which are contained in Appendix F were used to constrain the position of some of the sections. Column A shows relative percentage change in sporomorphs and *Classopollis* pollen. Column B depicts relative percentage change in marine palynomorphs. Column C shows and vita fragments. Column D shows the relative percentage change in discrete fragments. Column E and F illustrate ratio of black/brown, non-vita fragments and ratio of equidimensional/bladed, non-vita fragments respectively. The medium and large-scale lithological cycles recognised by Morgans [1997] are also illustrated.



the alluvial environment may also be observed (Figure 4.30, column B). This illustrates the relative percentage change in saline palynomorphs. The peak of saline palynomorphs permits the identification of the second-order maximum-flooding surface within the *humphriesianum* Subzone of the *humphriesianum* Zone. In the older sediments the changes in saline palynomorphs are concomitant with variations in *Classopollis* pollen. In contrast, sediments collected from the younger Grithorpe Member, do not display the same pattern. This suggests that the earlier parent plants occupied saline setting whilst the younger parent plants grew close to fresh water. The low amounts of discrete fragments, shown in column D, Figure 4.30 and very high occurrence of transparent-yellow, fluorescent, non-fibrous SOM, illustrated in column G, Figure 4.31, yielded from Scarborough Formation samples, indicate that the material collected away from fluvial influences (*i.e.*, distal) in an anoxic-dysoxic setting. The dominance of well-preserved SOM is also apparent in column O, Figure 4.31. This displays the eigen values of axis one from the canonical analysis. As shown the majority of samples have eigen values which reflect the dominance of well-preserved SOM. It is also apparent that the upper part of the Saltwick Formation and part of the Scalby Formation contains a concentration of samples which contain poorly preserved SOM which may have been caused by an increase in palaeotemperature or lowering of the water-table. Poor exposure of these formations, however, hinders determination of whether this is a localised pattern or due to a basin-wide environmental change.

The sedimentological description also reveals that the contact between the Scarborough Formation and underlying Cloughton Formation is relatively sharp. There is, however, no evidence for a significant hiatus. The basal beds of the Scarborough Formation overlie root-bearing sediments which yielded saline palynomorphs (leisospheres and occasional acritarchs and dinoflagellates). This association represents deposition in a brackish lagoons which is very similar to the overlying Helwarth Beck Member. Thus, it reflects the establishment of a more open interdistributary bay, rather than any dramatic transgressive regime.

Figure 4.31: Composite lithological description of Aalenian to Bathonian of the Cleveland Basin. Description based on outcrop exposed between Blea Wyke Point (NZ 994 013) and Burniston Bay (TA 007 899). IFP cores, RV18 and RV16, details of which are contained in Appendix F were used to constrain the position of some of the sections. Columns G to N contain total relative percentage change in SOM abundance; transparent-yellow, fluorescent, fibrous and non-fibrous SOM and transparent-yellow, non-fluorescent, fibrous and non-fibrous SOM; yellow-brown, fluorescent, fibrous and non-fibrous SOM; yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; brown-black, fluorescent, fibrous and non-fibrous SOM; brown-black, non-fluorescent, fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively. Columns O and P illustrate the correspondence analysis sample scores for axes 1 and 2 respectively.



The increase in black (carbonised) non-vita fragments (*i.e.*, fragments without any clear botanical affinity), in the upper part of the Cloughton Formation (Gristhorpe Member) to mid-Scarborough Formation, in comparison to the Saltwick Formation and Sycarham Member, is clearly evident as illustrated in column E, Figure 4.30. Isolated peaks do, as mentioned earlier, occur within these units, especially in the upper part of the Saltwick Formation.

Examination of the results from the Brent Group core also reveal a similar increase in the abundance of black fragments. Column A, Figure 4.32 depicts the abundance of *Classopollis* pollen. The acme of *Classopollis* pollen occurs at the beginning of the increase in black non-vita fragments. According to Helland-Hansen *et al.* [1992] an increase in *Classopollis* pollen occurs in the early Bajocian in the Brent Group. This, as mentioned earlier, is believed to be a response to an increase in the palaeotemperature.

Cope [1993] commented that the abundance of charcoalfied material in the Brent Group was comparable in preservation and facies distribution to that in the Middle Jurassic of the Cleveland Basin. He also stated that there is a significant amount of evidence that wildfire was a significant component in the Jurassic land ecosystem from a large number of widely separate occurrence throughout north-west Europe and the North Atlantic area. Hence, this concomitant increase in black fragments, in both the non-marine and marine setting and in the Cleveland Basin and the Brent Group, and acme of *Classopollis* pollen would suggest that the climate became warmer and/or more seasonal, and the amount of wildfires was greater in the Bajocian, in comparison to the Aalenian.

4.8 Conclusions

Stratigraphic plots of the distribution of organic matter and sedimentology clearly enable changes in the palaeoenvironment to be documented. Each section and individual members vary in thickness. This range implies that the palaeogeography, and hence accommodation space and sediment supply changed during the deposition of these predominately fluvio-deltaic sediments. For example, the character of the Dogger Formation varies considerably across the basin, in response to variable relief on the underlying surface. The expanded and condensed nature of the unit in the downthrow and upthrow side of the Peak Fault Trough highlights deposition by infilling of the lows (*e.g.*, Ravenscar) and erosion and reworking on structural highs (*i.e.*, Alum Quarry) respectively.

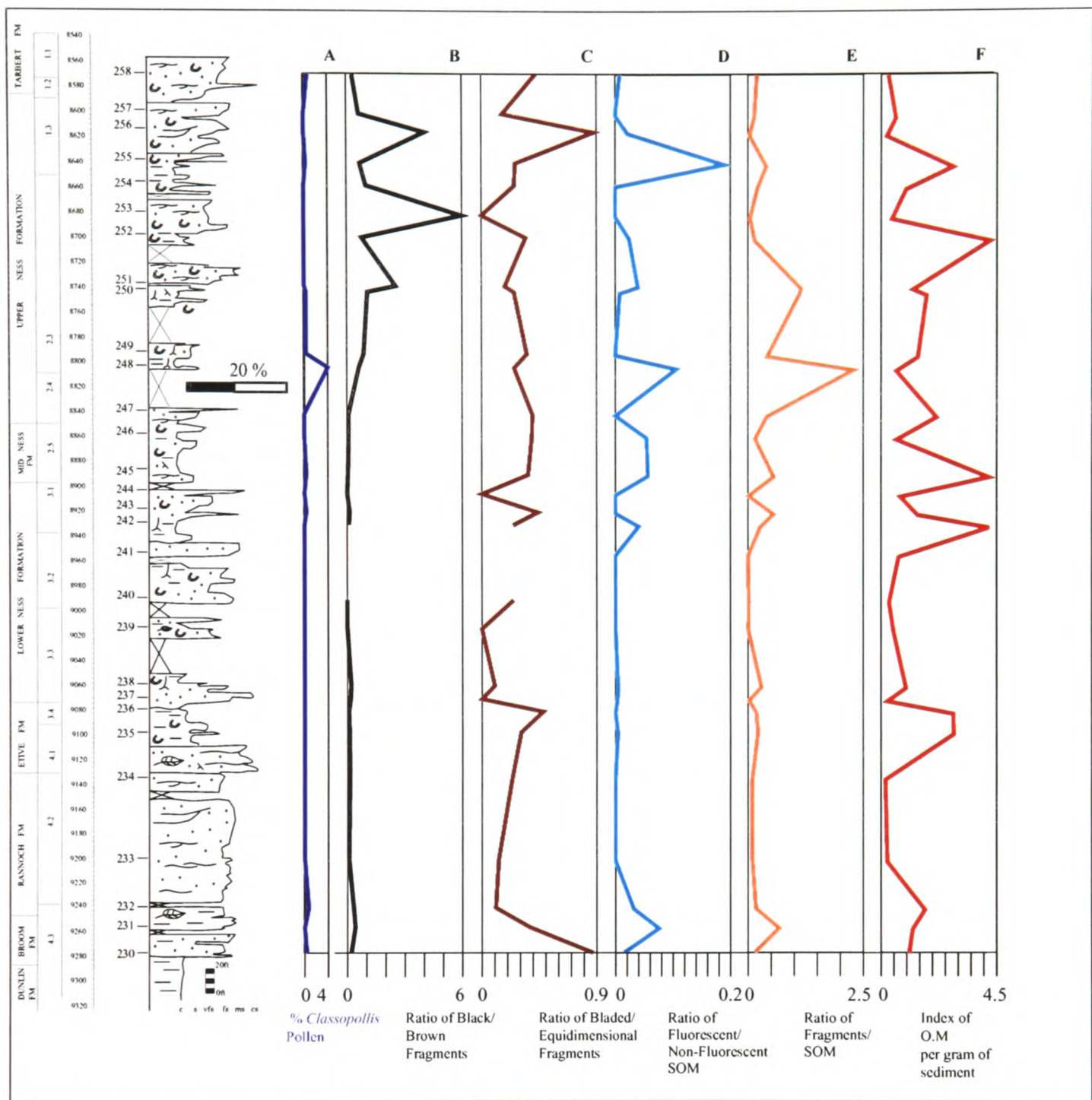


Figure 4.32: Summary lithological description of 211/29-3 (after Ichron [1996]). Particular categories and ratios of organic matter are also depicted. A more detailed lithological description is contained in Appendix F.

Variations in saline palynomorphs permits the presence of brackish horizons within the delta plain sequences to be determined, and it is apparent that the saline characteristics were an important influence on the form and nature of the sediments and organic matter. For example, saline palynomorphs yielded from the lower portion of the Saltwick Formation pick out minor marine incursions within the delta plain, as far north as Boulby, and as far north-east as High Hawsker. Thus, it is believed that the Saltwick Formation was probably deposited on a coastal plain where the amount of marine influence on alluvial deposition varied in both space and time leading to the development of local brackish, lagoonal or embayment conditions.

Fluctuations in the relative abundance of well- and poorly preserved SOM indicate that the sediments were deposited in coastal-plain/flood-plain which had a low relief with large areas of saturated soil, shallow water-table lakes with locally levees, alluvial ridges and tectonic highs which produced sufficient relief to allow the development of well-drained soils. During the deposition of the Ravenscar Group it is thought that the drainage pattern in the Cleveland basin would have undergone repeated minor changes by channel migration, avulsion and river capture which resulted in the different amounts of fragments and different types of SOM recorded within the organic matter samples.

The lithofacies- and taphonomic-independent nature of the black fragment distribution and its similar trend in time-equivalent sections, which were probably sourced from different parts of the basin strongly suggest that this increase was a basin wide event. This indicates that conditions altered throughout the basin in the upper part of the Cloughton Formation. The flux in black fragments was probably caused by an increase in fire. Hence, it is proposed that fires became more prevalent up-section in response to a climatic change beginning in the early Bajocian. The co-occurrence of the *Classopollis* pollen peak, during this period, further supports the existence of a change in the palaeoclimate. Thus, it is proposed that the early Bajocian was warmer/more arid than the preceding Aalenian, which is earlier than the previous palynological [Boulter & Windle, 1993], stable isotope [Hendry, 1997] and palaeobotanical investigations [Morgans *et al.*, 1999].

Chapter 5

Conclusions

The integration of palynofacies analysis, and sedimentological and ichnological information has facilitated a detailed assessment of the paleoenvironmental setting of the Middle Jurassic of the Cleveland Basin, both spatially and temporally. Before the appraisal of the palaeoenvironmental changes could be conducted it was, however, necessary to address the fundamental issues which have recently led a number of workers to question the utility of palynofacies analysis, as a tool for environmental reconstruction. These include variations in the preparation and counting techniques, the use of subjective and vague terminology used to classify organic matter, existence of numerous classification schemes and problems associated with analysing large data sets. More importantly, a number of investigators have demonstrated that different settings may yield the same organic-matter and conversely the same setting may reveal different organic-matter patterns. This situation arose because of the limited understanding about the way in which palynofacies assemblages, in particular the palynodebris, changes between different settings, and the complex controls that govern the development of assemblages. No published work has made any quantitative distinction between major and minor influences. This is clearly a paradoxical situation, given that the 'palynolithofacies' technique relies on the belief that specific lithofacies contain distinctive assemblages and that these must be governed by factors associated with that environment.

To address these problems a systematic approach was devised. The first step was to conduct a critique of the plethora of classification schemes that are available. Following this appraisal the scheme devised by Lewis [1995] was modified to create a robust hierarchical classification scheme, based on designated procedures. Where possible, Lewis's criteria and categories were maintained, with some

restructuring, to maximise the amount of detail obtained, expedite the application of the classification scheme, and permit integration and comparison with other investigations. The alterations resulted in the generation of a hierarchical scheme with increasing detail and different modes of microscope illumination being incorporated at each successive phase. This permits the operator to expand the categories if desired whilst allowing comparison with other schemes.

The second step was to gain an appreciation of the underlying controls on the genesis of different organic-matter associations and test the reliability of palynofacies analysis using multivariate statistical techniques. This investigation showed that the organic matter investigated in this study, does not form discrete groups but instead comprises a great diversity of individual components whose associations form a natural continuum. The quantitative examination of the organic matter associations and superimposition of the conventionally defined assemblages on the sample scores from the CA analysis revealed the underlying controls. The primary control was identified as preservation potential which is affected by redox status, and to a lesser extent by the degree and duration of transportation and disturbance to which the organic matter has been subjected. The secondary influence, in this investigation, was documented as the change in the nature of organic matter through time, and this may reflect climatic changes. In addition, this analysis revealed that the majority of the assemblage groups defined by the conventional method were identifiable as separate parcels in the statistical output. A number of conventionally defined groups did not, however, form discrete packages, primarily because these were defined using palynomorphs. These are minor in mathematical terms, thus the more abundant, or more obvious, components were stressed statistically at the expense of palynomorphs.

Comparison of the statistical output with stratigraphic position, grain size and 'environmental descriptors' of the host sediment (*e.g.*, presence of macroscopic floral remains and burrowing) extended the understanding of the underlying controls. The latter investigation was carried out using Canonical Correspondence Analysis (CCA), a direct ordination technique. The similarity between the CA and CCA output supports the identification of the subjectively assigned underlying controls on the basis of the CA output. Additionally, the Monte Carlo test which was performed prior to the CCA analysis illustrated that the data set was highly significant. Finally, comparison of the CA statistical output with an independently established lithofacies scheme revealed that organic matter is not a precise indicator of lithofacies. However, in the case of deltaic sediments, palynofacies proved to be very useful because the nature of the organic matter provided extra information about the degradation process,

and hence the water-saturation, palaeotemperature, productivity, and/or amount of transportation

The final step, after gaining an appreciation of the underlying controls was to group the different associations of organic matter into assemblage groups. As neither the conventional approach and multivariate statistics analysis were perfect, the results from both were integrated and used to define the 19 assemblage groups employed in the palaeoenvironmental analysis.

Stratigraphic plots of the distribution of organic matter and sedimentology enabled changes in the palaeoenvironment to be documented. Variations in the palynofacies assemblages through the Aalenian to Bathonian, UK reflect changes in the redox status, proximity to source, salinity and hydrodynamics. In addition, variations in the thickness and lithofacies of each section and individual members were recognised. This range implies that the palaeogeography, and hence accommodation space, sediment supply and drainage pattern changed during the deposition of these predominately fluvio-deltaic sediments.

An increase in the abundance of black fragments (charcoal) and *Classopollis* pollen, an indicator of increased intensity of warmth and/or seasonally dry periods, was detected in the early Bajocian, in comparison to the Aalenian. The abundance of charcoal in the early-middle Bajocian indicates that the delta catchment areas were subject to episodic wildfire events, probably comparable with those observed in the coastal swamps of Florida. As the event is both stratigraphically restricted and wide spread, it may represent partly a brief evolutionary development in the flora related to climatic and/or other palaeoenvironmental effects, (*e.g.*, precursor to the climatic changes recorded in the Late Jurassic). The recognition of widespread charcoal throughout the Bajocian Jurassic record, at least for the UK area raises an interesting question concerning palaeoenvironmental reconstruction. Uncontrolled wildfire in the geological past could have had a considerable impact on the evolution and development of vegetation types and stratigraphic architecture.

There is potential for a number of projects. One possible direction would be a detailed assessment of the palynoflora, *e.g.* similar to the study conducted by Abbink [1998]. Another project could be a examination of the black fragments under a reflected light unit which would permit the temperature of burning to be determined, and examination under the SEM to permit identification of the generic level and potential species type of the charcoal. These results could be incorporated into a stable-isotope

study on the black fragments and/or *Classopollis* pollen. The aim of this would be at the production of a genus-level carbon-isotope curve initially for the Middle Jurassic of the UK. In addition, determination of the temperature of burning for the black fragments may provide some insight into possible extent of fractionation. This research would produce isotopic data from a predominantly terrestrial sequence and may enable high-resolution chemostratigraphic correlation between fully marine, paralic and terrestrial settings.

Bibliography

- ABBINK, O.A. 1998. *Palynological investigations in the Jurassic of the North Sea region*. Ph.D. thesis, Laboratory of Palaeobotany and Palynology, Utrecht.
- ALEXANDER, J. 1986. Idealised flow model to predict alluvial sandstone body distribution in the Middle Jurassic Yorkshire Basin. *Marine Petroleum Geology*, **3**, 298–305.
- ALEXANDER, J. 1992. A discussion of alluvial sandstone body characteristics related to variations in marine influence, Middle Jurassic of the Cleveland Basin, UK, and the implications for analogous Brent Group strata in the North Sea Basin. In: MORTON, A.C., HAZELDINE, R.S, GILES, M.R., & BROWN, S. (eds), *Geology of the Brent Group*. Geological Society Special Publication.
- ALEXANDER, J., & GAWTHORPE, R.L. 1993. The complex nature of a Jurassic multistorey, alluvial sandstone body, Whitby, North Yorkshire. In: NORTH, C.P., & PROSSER, D.J. (eds), *Characterization of Fluvial and Aeolian Reservoirs*, vol. 73. Geological Society Special Publication, London.
- ANDERSEN, F.O., & KRISTENSEN, E. 1992. The importance of benthic macrofauna in decomposition of microalgae in a coastal marine sediment. *Limnology and Oceanography*, **37**, 1392–1403.
- ARKELL, W.J. 1933. *The Jurassic System in Great Britain*. Oxford University Press.
- ASHTON, M. 1975. A new section in the Lincolnshire Limestone of South Humberside and its significance. *Proceedings of the Yorkshire Geological Society*, **40**, 419–429.
- ASHTON, M. 1980. The stratigraphy of the Lincolnshire Limestone Formation (Bajocian) in Lincolnshire and Rutland (Leicestershire). *Proceedings of the Yorkshire Geological Society*, **91**, 201–223.

- BARNARD, P.C., COLLINS, A.G., & COOPER, B.S. 1981. Identification and distribution of Kerogen facies in a source rock horizon - examples from the North Sea Basin. *Pages 271–282 of: BROOKS, J. (ed), Organic Maturation Studies and Fossil Fuel Exploration.* Academic Press, London.
- BARNARD, P.D.W. 1973. Mesozoic floras. *Pages 175–187 of: HUGHES, N.F. (ed), Organisms and Continents through time.* Special Papers in Palaeontology, vol. 12. Palaeonol. Soc. London.
- BARRELL, J. 1912. Criteria for the Recognition of Ancient Delta Deposits. *Bulletin of the Geological Society of America*, **xxiii**, 377–446.
- BATE, R.H. 1959. The Yons Nab Beds of the Middle Jurassic of the Yorkshire Coast. *Proceedings Yorkshire Geological Society*, **32**, 153–164.
- BATE, R.H. 1964. Middle Jurassic Ostracoda from the Millepore Series, Yorkshire. *Bulletin of the British Museum (Natural History), Geology*, **10**, 1–34.
- BATE, R.H. 1965. Middle Jurassic Ostracoda from the Grey Limestone Series. *Bulletin of the British Museum (Natural History), Geology*, **11**, 73–134.
- BATE, R.H. 1967. Stratigraphy and palaeogeography of the Yorkshire Oolites and their relationships with the Lincolnshire Limestone. *Bulletin of the British Museum (Natural History), Geology*, **14**, 111–141.
- BATTEN, D.J. 1973. Use of palynologic assemblage-types in Wealden correlation. *Palaeontology*, **16**, 1–40.
- BATTEN, D.J. 1975. Wealdon Palaeoecology from the distribution of plant fossils. *Proceedings of the Geologists' Association*, **85**, 433–458.
- BATTEN, D.J. 1996. 26A: Palynofacies and palaeoenvironmental interpretation. *Pages 1011–1064 of: JANSONIUS, J., & MCGREGOR, D.C. (eds), Palynology: principles and applications*, vol. 3. American Association of Stratigraphic Palynologists Foundation.
- BECK, C.B., COY, K., & SCHMID, R. 1982. Observations on the fine structure of *Callixylon* wood. *American Journal of Botany*, **69**, 54–76.
- BENNER, R., FOGEL, M.L., & SPRAGUE, E.K. 1991. Diagenesis of below-ground biomass of *Spartina alterniflora* in salt-marsh sediments. *Limnology and Oceanography*, **36**, 1358–1374.

- BENNINGHOFF, W.S. 1962. Calculation of pollen and spore density in sediments by addition of exotic pollen in known quantities. *Pollen et Spores*, **4**, 332–333.
- BERNER, R.A. 1982. Burial of organic carbon and pyrite sulfur in the modern ocean: its geochemical and environmental significance. *American Journal of Science*, **282**, 451–473.
- BLACK, M. 1928. 'Washouts' in the Estuarine Series of Yorkshire. *Geological Magazine*, **65**, 301–307.
- BLACK, M. 1929. Drifted plant beds of the Upper Estuarine Series of Yorkshire. *Quaternary Journal of the Geological Society, London*, **85**, 389–437.
- BLACK, M. 1934a. The Middle Jurassic Rocks. *Pages 261–306 of: WILSON, V., BLACK, M., & HEMINGWAY, J.E. (eds), A synopsis of Jurassic Rocks of Yorkshire., vol. 22.*
- BLACK, M. 1934b. Sedimentation of the Aalenian rocks of Yorkshire. *Proceedings of Yorkshire Geological Society*, **22**, 265–279.
- BONNY, A.P. 1972. A method for determining absolute pollen frequencies in lake sediments. *New Phytology*, **71**, 393–403.
- BOSTICK, N.H. 1971. Thermal alteration of clastic organic particles as an indicator of contact and burial metamorphism in sedimentary rocks. *Geoscience and Man*, 83–92.
- BOULTER, M.C. 1994. An approach to a standard terminology for palynodebris. *In: A., TRAVERSE (ed), Sedimentation of Organic Particles.* Cambridge University Press.
- BOULTER, M.C., & RIDDICK, A. 1986. Classification and analysis of palynodebris from the Palaeocene sediments of the Forties Field. *Sedimentology*, **33**, 871–86.
- BOULTER, M.C., & WINDLE, T. 1993. A reconstruction of some Middle Jurassic vegetation in Northern Europe. *Special papers in Palaeontology*, **49**, 125–154.
- BOWEN, J.M. 1975. The Brent Oilfield. *Pages 353–360 of: WOODLAND, A.W. (ed), Petroleum and the Continental Shelf of Northwest Europe.* Applied Science Publishers, London.
- BRADSHAW, M.J., & BATE, R.H. 1982. Lincolnshire borehole proves greater extent of the Scarborough Formation (Jurassic:Bajocian). *Journal of Micropalaeontology*, **1**, 141–147.

- BRADSHAW, M.J., COPE, J.C.W., CRIPPS, D.W., DONOVAN, D.T., HOWARTH, M.K., RAWSON, P.F., WEST, I.M., & WIMBLEDON, W.A. 1992. *Pages 107–129 of: COPE, J.C.W., INGRAM, J.K., & RAWSON, P.F. (eds), Atlas of Palaeogeography and Lithofacies*, vol. 13. Geological Society, London Memoirs.
- BRALOWER, T.J., & THIERSTEIN, H.R. 1984. Low productivity and slow deep-water circulation in Mid-Cretaceous oceans. *Geology*, **12**, 614–618.
- BRASIER, M.D. 1980. *Microfossils*. Allen and Unwin.
- BRASIER, M.D., & BRASIER, C.J. 1978. Littoral and fluviatile facies in the ‘Kelaways Beds’ on the Market Weighton Swell. *Proceedings of the Yorkshire Geological Society*, **41**, 1–20.
- BRAY, A.A., BUTLER, N., KIMBER, R.N., & DRAPER, L. 1995. Evolution of the Brent delta: an overview of patterns and controls. *Pages 97–123 of: OTI, M.N, & POSTMA, G. (eds), Geology of deltas*.
- BROWN, S. 1990. Jurassic. *Pages 219–254 of: GLENNIE, K.W. (ed), Introduction to the Petroleum Geology of the North Sea*. Blackwell Scientific Publications.
- BROWN, S., & THOMSON, A.R. 1987. Patterns in the deposition of the Brent Group (Middle Jurassic) U.K. North Sea. *Pages 899–913 of: BROOKS, J., & GLENNIE, K.W. (eds), Petroleum Geology of North West Europe*. Graham and Trotman, London.
- BRUGMAN, W.A., VAN BERGEN, P.F., & KERP, J.H.F. 1994. A quantitative approach to Triassic palynology: the Lettenkeuper of the Germanic Basin as an example. *In: A., TRAVERSE (ed), Sedimentation of Organic Particles*. Cambridge University Press.
- BUCKMAN, S.S. 1915. A palaeontological classification of the Jurassic rocks of the Whitby district, with a zonal table of Liassic ammonites. *Pages 59–102 of: FOX-STRANGEWAYS, C., & BARROW, G. (eds), The geology of the Country between Whitby and Scarborough*. Memoirs geological Survey of Great Britain.
- BUDDING, M.C., & INGLIN, H.F. 1981. A reservoir geological model of the Brent sands in Southern Cormorant. *Pages 326–334 of: ILLING, L.V., & HOBSON, G.D. (eds), Petroleum Geology of the Continental Shelf of North-West Europe*. Heyden, London.
- BUJAK, J.P., BARSS, M.S., & WILLIAMS, G.L. 1977. Offshore east Canada’s organic type and colour and hydrocarbon potential. *The Oil and Gas Journal*, **75**, 198–201.

- BURGESS, J.D. 1974. Microscopic examination of kerogen (dispersed organic matter) in petroleum exploration. *Geological Society of American Special Paper*, **153**, 19–30.
- CALLOMON, J. H., & CHANDLER, R. B. 1994. Some early Middle Jurassic ammonites of Tethyan affinities from the Aalenian of southern England. *Proceedings of the 3rd Pergola International Symposium: Palaeopelagos Special Publication 1*.
- CALLOMON, J.H., & CHANDLER, R.B. 1990. A review of the ammonite horizons of the Aalenian - Lower Bajocian stages in the Middle Jurassic of Southern England. *Memoire della Carta geologica d'Italia*, **40**, 85–112.
- CANNON, S.J.C., GILES, M.R., WHITAKER, M.F., PLEASE, P.M., & MARTIN, S.V. 1988. A regional reassessment of the Brent Group, U.K. Sector, North Sea. *Pages 126–146 of: MORTON, A.C., HASZELDINE, R.S., GILES, M.R., & BROWN, S. (eds), Geology of the Brent Group. Geological Society Special Publication*, 61.
- CHALONER, W.G. 1994. Fossil charcoal as an indicator of palaeoatmospheric oxygen level. *Journal of the Geological Society, London*, **146**, 171–174.
- CHALONER, W.G., & MUIR, M. 1968. Spores and floras. *In: WESTOLL, D., & MURCHISON, T.S. (eds), Coal and coal-bearing strata*.
- CHU, S.P. 1943. The influence of the mineral composition of the medium on the growth of planktonic algae. Part II. The influence of the concentration of inorganic nitrogen and phosphatic phosphorus. *Marine Geology*, **31**, 110–138.
- COHEN, A. D., & SPACKMAN. 1977. Phytogenic organic sedimentary environments in the Everglades-mangrove complex. Pt II. The origin, description and classification of the peats of southern Florida. *Palaeontographica*, **B167**.
- COMBAZ, A. 1964. Les Palynofacies. *Revue de Micropaleontologie*, **7**, 205–18.
- COMBAZ, A. 1980. Les Kerogens vus au microscope. *Pages 55–111 of: DURNAD, B. (ed), Kerogen, Insoluble Organic Matter from Sedimentary rocks. Editions Technip, Paris*.
- CONTINI, D., ELMI, S., & MOUTERDE, R. 1971. Les zones du Jurassique en France; Aalenien
Translated Title: The Jurassic zones in France; the Aalenian. *Bulletin de la Societe Geologique de France*, **2**, 84–85.

- COPE, J.C.W., DUFF, K.L., PARSONS, C.F., TORRENS, H.S., & WIMBLEDON, W.A. 1980a. *A Correlation of Jurassic Rocks in the British Isles. Part One: Middle and Upper Jurassic*. Special Report of the Geological Society, London, 14.
- COPE, J.C.W., DUFF, K.L., PARSONS, C.F., TORRENS, H.S., & WIMBLEDON, W.A. 1980b. *A Correlation of Jurassic Rocks in the British Isles. Part Two: Middle and Upper Jurassic*. Special Report of the Geological Society, London, 15.
- COPE, M.J. 1981. Products of natural burning as a component of the dispersed organic matter of sedimentary rocks. *Pages 89–109 of: BROOKS, J. (ed), Organic maturation studies and fossil fuel exploration*. Academic Press, London.
- COPE, M.J. 1993. A preliminary study of charcoalfied plant fossils from the Middle Jurassic Scalby Formation of north Yorkshire. *Special Papers in Palaeontology*, **49**, 101–111.
- COPE, M.J., & CHALONER, W.G. 1980. Fossil charcoal as evidence of past atmospheric composition. *Nature*, **283**, 647–649.
- CORRERIA, M. 1974. Diagenesis of sporopollenin and other comparable organic substances: application to hydrocarbon research. *Pages 89–101 of: BROOKS, J., GRANT, P., MUIR, M.D., SHAW, G., & VAN GIZEL, P. (eds), Sporopollenin*. Academic Press, London.
- COUPER, R.A. 1958. British Mesozoic microspores and pollen grains. A systematic and stratigraphic study. *Palaeontographica B*, **103 (4-6)**, 75–179.
- CROSS, A.T., THOMPSON, G.C., & ZAITEFF, J.B. 1966. Source and distribution of palynomorphs in bottom sediments, southern part of Gulf of California. *Marine Geology*, **4**, 467–524.
- DARGIE, T.C.D. 1986. Species richness and distortion in reciprocal averaging and detrending correspondence analysis. *Vegetatio*, **65**, 95–98.
- DAVIES, M.B. 1973. Redeposition of pollen grains in Lake sediments. *Limnology and Oceanography*, **18**, 44–52.
- DAVIS, M.B., & DEEVEY, E.S. 1964. Pollen accumulation rates: estimates from late-glacial sediment of Rogers Lake. *Science*, **145**, 1293–1295.
- DE LA CRUZ, A.A., & GABRIEL, B.C. 1974. Caloric, elemental, and nutritive changes in decomposition *Juncus roemerianus* leaves. *Ecology*, **55**, 882–886.

- DEEGAN, C.E., & SCULL, B.J. 1977. *A standard lithostratigraphic nomenclature for the Central and Northern North Sea*. Tech. rept. Report of the Institute of Geological Sciences 77/25.
- DEMAISON, G.J., & MOORE, G.T. 1980. Anoxic environments and oil source bed genesis. *American Association of Petroleum Geologists, Bulletin*, **64**, 1179–1209.
- DENNISON, C., & FOWLER, R.M. 1980. Palynological identification of facies in a deltaic environment. *Pages 1–22 of: Proceedings of the Meeting on the Sedimentation of North Sea Reservoir Rocks, Geilo 1980*. Norsk Petroleumsforening.
- DETTMAN, M.E. 1963. Upper Mesozoic microfloras from southeastern Australia. *Royal Society Victoria Proc., New Ser.*, **77**, 1–148.
- DIGBY, P.G.N. 1987. *Multivariate Analysis of Ecological Communities*. Chapman and Hall, London.
- DODSON, J.R. 1983. Pollen recovery from organic lake clays; a comparison of two techniques. *Pollen et Spores*, **25**, 131–138.
- DOWNIE, C., HUSSAIN, M.A., & WILLIAMS, G.L. 1971. Dinoflagellate cysts and acritarch associations in the Paleogene of southeast England. *Geoscience and Man*.
- DURAND, B. 1980. *In: DURAND, B. (ed), Kerogen: Insoluble Organic Matter From Sedimentary Rocks*. Editions Technip, Paris.
- EDWARDS, K.J., & GUNSON, A.R. 1978. A procedure for the determination of exotic pollen concentrations with a coulter counter. *Pollen et Spores*, **20**, 303–309.
- ELLIOT, T. 1978. Deltas. *Pages 97–142 of: READING, H.G. (ed), In Sedimentary environment and facies*. Blackwells, Oxford.
- ESCHARD, R. 1989. *Geometrie et dynamique de sequences de depots dans un systeme deltaique (Jurassique moyen), Basin de Cleveland, Angleterre*. Ph.D. thesis, Institut de Geologie de Strasbourg.
- EVITT, W.R. 1963. A discussion and proposals concerning fossil dinoflagellates, hystrichospheres, and acritarchs. I & II. *Proceedings of the National Academy of Sciences, Washington*, **49**, 158–64; 298–302.

- EYNON, G. 1981. Basin development and sedimentation in the Middle Jurassic of the northern north Sea. *Pages 196–204 of: ILLING, L.V., & HOBSON, G.D. (eds), Petroleum geology of the continental shelf of North-Western Europe: Proceedings of the second conference.*
- FALT, L.M., HELLAND, R., WILK JACOBSON, V., & RENSHAW, D. 1989. Correlation of transgressive-regressive depositional sequences in the Middle Jurassic Brent/Viking Group megacycle. *Pages 191–201 of: COLLINSON, J.D. (ed), Correlation in Hydrocarbon Exploration.* Graham and Trotman, London.
- FARLEY, M.B. 1988. Environmental variation, palynofloras, and paleoecological interpretation. *Pages 126–146 of: DIMICHEL, W.A., & WING, S.L. (eds), Methods and Applications of Plant Paleoecology.* Paleontological Society Special Publication, 3.
- FARROW, G.E. 1966. Bathymetric zonation of Jurassic trace fossils from the coast of Yorkshire, England. *Palaeogeography, Palaeoclimatology and Palaeoecology*, **2**, 103–151.
- FENSOME, R.A, GOCHT, H, STOVER, L.E., & WILLIAMS, G.L. 1993. *The Eisenack catalog of fossil dinoflagellates; New series; Volume 2.* E. Schweizerbart'sche Verlagsbuchhandlung. Stuttgart.
- FENTON, J.P.G., RIDING, J.B., & WYATT, R.J. 1994. Palynostratigraphy of the central Middle Jurassic 'White Sands' of central England. *Proceedings of the Geologists' Association*, **105**, 225–230.
- FILATOFF, J. 1975. Jurassic palynology of the Perth Basin, Western Australia. *Palaeontographica B*, **154**, 1–113.
- FISHER, M.J. 1980. Kerogen distribution environments in the Middle Jurassic of Yorkshire, U.K. *Pages 574–580 of: Proceedings of the IV International Palynological Conference, Lucknow, 1976–77, vol. 2.*
- FISHER, M.J., & HANCOCK, N.J. 1985. The Scalby Formation (Middle Jurassic, Ravenscar Group) of Middle Jurassic: reassessment of age and depositional environment. *Proceedings Yorkshire Geological Society*, **45** (4), 293–298.
- FOX-STRANGWAYS, C. 1892. *The Jurassic rocks of Great Britain.* Memoir of the Geological Survey of Great Britain.
- FOX-STRANGWAYS, C., CAMERON, A.G., & BARROW, G. 1896. *The geology of the country around Northallerton and Thirsk.* Memoir of the Geological Survey.

- GALLOWAY, W. E. 1989. Genetic Stratigraphic Sequences in Basin Analysis I: Architecture and Genesis of Flooding Bounded Depositional Units. *American Association of Petroleum Geologists Bulletin*.
- GASTALDO, R.A. 1996. *Palynofacies of Wetland soils in the temperate-subtropical mobile-Tensaw River delta*. Tech. rept. Department of Geology, Auburn University.
- GASTALDO, R.A., & HUC, A.Y. 1994. Sediment facies, depositional environments, and distribution of phytoclasts in the Recent Mahakam River Delta, Kalimantan, Indonesia. *Palaios*, **7**, 574–590.
- GAUCH, H.G. 1982. *Multivariate Analysis in Community Ecology*. Cambridge studies in Ecology. Cambridge University Press.
- GORDON, A.D. 1981. *Classification. Monographs on Applied Probability and Statistics*. Chapman and Hall, London.
- GOWLAND, S., & RIDING, J.B. 1991. Stratigraphy, sedimentology and palaeontology of the Scarborough Formation (Middle Jurassic) of the Hundale Point, North Yorkshire. *Proceedings of the Yorkshire Geological Society*, **48**, 375–392.
- GRAUE, E., HELLAN-HANSEN, W., JOHNSON, J., LOMO, L., & STEEL, R.J. 1987. Advance and retreat of the Brent Delta System. Pages 915–937 of: BROOKS, J., & GLENNIE, K.W. (eds), *Petroleum Geology of North West Europe*. Graham and Trotman, London.
- GRAYSON, J.F. 1981. Microspectrofluorescence and kerogen liquefaction. Pages 343–378 of: BROOKS, J. (ed), *Organic Maturation Studies and Fossil Fuel Exploration*. Academic Press, London.
- GRIMALDI, D., BECK, C.W., & BOON, J.J. 1989. Occurrence, chemical characteristics, and paleontology of the fossil resins from New Jersey. *American Museum Novitates*, **2948**, 25pp.
- GUY, D.J.E. 1971. Palynological investigations in the Middle Jurassic of the Vilhrlmsfalt Boring, Southern Sweden. *The Institutes of Mineralogy, Palaeontology and Quaternary Geology*.
- GUY-OHLSON, D. 1992. *Botryococcus* as an aid to the interpretation of palaeoenvironmental and depositional processes. *Review of Palaeobotany and Palynology*, **71**, 1–15.
- GUY-OHLSON, D., & BOLACH, G.T. 1982. Comparative morphology of the genus *Tasmanities* (Pterospermales, Chlorophyta). *Phycologia*, **31**, 523–536.

- HABIB, D., & DRUGG, W.S. 1987. Palynology of sites 603 and 605, Leg 93, Deep Sea Drilling Project. *Pages 751–775 of: VAN HINTE, J.E., & WISE, S.E. JR. ET AL (eds), Initial Reports of the Deep Sea Drilling Project.* US Government Printing Office, Washington, DC,.
- HAMILTON, G. 1982. Triassic and Jurassic calcareous nannofossils. *Pages 136–167 of: LORD, A.R. (ed), A stratigraphical Index of Calcareous Nannofossils.* British Micropalaeontological Society.
- HANCOCK, N.J., & FISHER, M.J. 1981. Deltas with particular reference to Yorkshire, Middle Jurassic North Sea. *Pages 186–195 of: ILLING, L.V. HOBSON, G.D. (ed), Petroleum Geology of the Continental Shelf of North West Europe.* Heyden, London.
- HARRIS, T.M. 1958. Forest fire in the Mesozoic. *Journal of Ecology*, **46**, 447–453.
- HARRIS, T.M. 1964. *The Yorkshire Jurassic Flora II.* British Museum (Natural History) London.
- HARRIS, T.M. 1979. Coniferales. *Page pp. 165 of: The Yorkshire Jurassic Flora*, vol. V. British Museum (National History).
- HARRIS, T.M. 1981. Burnt ferns from the English Wealden. *Proceedings of the Geologists' Associations*, **92**, 47–58.
- HART, G.F. 1986. Origin and Classification of organic matter in clastic systems. *Palynology*, **10**, 1–23.
- HEDGES, J.L., CLARK, W.A., & COWIE, G.L. 1988. Organic matter sources to the water column and surficial sediments of a marine bay. *Limnology and Oceanography*, **33**, 1116–1136.
- HELLAND-HANSEN, W., STEEL, R., NAKAYAMA, K., & KENDALL, C.G.ST. C. 1989. Review and computer modelling of the Brent Group stratigraphy. *Pages 237–252 of: WHATELY, M.K.G., & PICKERING, K.T. (eds), Deltas: sites and traps for fossil fuels*, vol. 41. Geological Society Special Publication, London.
- HELLAND-HANSEN, W., ASHTON, M, LØMO, L., & STEEL, R. 1992. Advance and retreat of the Brent delta: recent contributions to the depositional model. *Pages 109–128 of: MORTON, A.C., HASZELDINE, R.S., GILES, M.R., & BROWN, S. (eds), Deltas: sites and traps for fossil fuels*, vol. 61. Geological Society Special Publication, London.
- HEMINGWAY, J.E. 1949. A revised terminology and subdivision of the Middle Jurassic rocks of Yorkshire. *Geological Magazine*, **86**, 67–71.

- HEMINGWAY, J.E. 1951. Report on a field meeting for 1949. *Proceedings Yorkshire Geological Society*, **28**, 118–122.
- HEMINGWAY, J.E. 1974. Jurassic. *Pages 161–223 of: RAYNER, D.H., & HEMINGWAY, J.E. (eds), The Geology and Mineral Resources of Yorkshire*. Yorkshire Geological Society.
- HEMINGWAY, J.E., & KNOX, R.W.O'B. 1973. Lithostratigraphic nomenclature of the Middle Jurassic strata of the Yorkshire Basin of north-east England. *Proceedings Yorkshire Geological Society*, **39**, 527–535.
- HEMINGWAY, J.E., & RIDDLER, G.P. 1982. Basin inversion in North Yorkshire. *Transactions of the Institute of Mining and Metallurgy, Section B*, **91**, B175–186.
- HEMINGWAY, J.E., WILSON, V., & WRIGHT, C.W. 1963. *Geology of the Yorkshire Coast. Geological Association Guide, 34*. Benham, Colchester.
- HENDRY, J. 1997. Palaeoenvironmental geochemistry: evidence for Middle Jurassic seasonality from *Isognomom* Bivalves in a Bathonian lagoon. *Page 40 of: British Sedimentological Research Group Abstracts*.
- HESSELBO, S.P., & JENKYN, H. C. 1995. A comparison of the Hettangian to Bajocian successions of Dorset and Yorkshire. *Pages 105–150 of: Field Geology of the British Jurassic*.
- HILL, M.O. 1979. *DECORANA - a FORTRAN Program for Detrended Correspondence Analysis and Reciprocal Averaging*. Cornell University, Department of Ecology and Systematics, Ithaca, New York.
- HILL, M.O., & GAUCH, H.G. 1980. Detrended correspondence analysis, an improved ordination technique. *Vegetatio*, **42**, 47–58.
- HUGHES, N.F., & MOODY-STUART, J.C. 1967. Palynological facies and correlation in the English Wealden. *Review of Palaeobotany and Palynology*, **1**, 259–268.
- ICHRON. 1996. *Graphical descriptions and interpretation of core 211/29-3*. Tech. rept. Shell U.K.
- JONGMAN, R.H.G., TER BRAAK, C.J.G., & VAN TONGEREN Ø.F.R. 1987. *Data Analysis in Community and Landscape Ecology*. Pudoc, Wageningen.
- JORGENSEN, S. 1967. A method of absolute pollen counting. *New Phytology*, **66**, 489–493.

- KENDALL, P.F., & WROOT, H.E. 1924. *The geology of Yorkshire*. Privately printed, Vienna.
- KENT, M., & COKER, P. 1992. *Vegetation Description and Analysis - A practical Approach*. Belhaven Press, London.
- KENT, P.E. 1955. The market Weighton Structure. *Proceedings of the Yorkshire Geological Society*, **30**, part 2(12), 197–227.
- KENT, P.E. 1966. A review of the correlation of the Lincolnshire Limestone. *Leicester Literary and Philosophical Society*, **60**, 57–69.
- KENT, P.E. 1980. Subsidence and uplift in East Yorkshire and Lincolnshire: a double inversion. *Proceedings of Yorkshire Geological Society*, **42**, 505–524.
- KENT, P.E., & BAKER, F.T. 1938. Ammonites from the Lincolnshire Limestone. *Transactions of the Lincolnshire Naturalists Union*, **IX**, 169–170.
- KIRBY, G.A., & SWALLOW, P.W. 1984. Tectonism and sedimentation in the Flamborough Head region of north-east England. *Proceedings Yorkshire Geological Society*, 301–309.
- KNOTT, S.D., BURCHELL, M.T., JOLLEY, E.J., & FRASER, A.J. 1993. Mesozoic to Cenozoic plate reconstructions of the North Atlantic and hydrocarbon plays of the Atlantic margins. *Pages 953–974 of: PARKER, J.R. (ed), Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference*. Geological Society, London.
- KNOX, R.W.O'B. 1973. The Eller Beck Formation (Bajocian) of the Ravenscar Group of NE Yorkshire. *Geological Magazine*, **110**, 511–534.
- KNOX, R.W.O'B. 1984. Lithostratigraphy and depositional history of the late Toarcian sequence at Ravenscar, Yorkshire. *Proceedings Yorkshire Geological Society*, 99–108.
- KOPPELHUS, E.B. 1991. Palynology of the Lower Jurassic Ronne Formation on Bornholm, eastern Denmark. *Bulletin of the Geological Society of Denmark*, **39**, 91–110.
- KOPPELHUS, E.B., & NIELSEN, L.H. 1994. Palynostratigraphy and palaeoenvironments of the Lower to Middle Jurassic Baga Formation of Bornholm, Denmark. *Palynology*, **18**, 139–194.
- KOVACH, W.L. 1988. Multivariate methods of analyzing Paleoecological data. *Pages 72–104 of: DIMICHELE, W.A., & WING, S.L. (eds), Methods and Applications of Plant Paleoecology*, vol. 3. Paleontological Society Special Publication.

- KOVACH, W.L., & BATTEN, D.J. 1994. Association of palynomorphs and palynodebris with depositional environments: quantitative approaches. *Pages 391–408 of: TRAVERSE, A. (ed), Sedimentation of Organic Particles.* Cambridge University Press.
- KRASSILOV, V.A. 1981. Changes in Mesozoic vegetation and extinction of dinosaurs. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **34** (3-4), 207–224.
- LEEDER, M., & GOWLAND, S. 1985. *The Middle Jurassic Sediments of the Yorkshire Coast, North-eastern England. Poroperm Excursion Guide No.1.*
- LEEDER, M.R., & NAMI, M. 1979. Sedimentary models for the non-marine Scalby Formation (Middle Jurassic) evidence for late Bajocian/Bathonian uplift of the Yorkshire Basin. *Proceedings Yorkshire Geological Society*, **42**, 461–482.
- LEWIS, W. 1995. *Upper Cretaceous palynofacies, vegetation and climate of the north slope, Alaska.* Ph.D. thesis, University of Oxford.
- LIVERA, S.E. 1989. Facies associations and sand geometries in the Ness Formation of the Brent Group, Brent field. *Pages 269–286 of: WHATELY, M.K.G., & PICKERING, K.T. (eds), Deltas: sites and traps for fossil fuels*, vol. 41. Geological Society Special Publication, London.
- LIVERA, S.E., & LEEDER, M.R. 1981. The Middle Jurassic Ravenscar Group ('Deltaic Series') of Yorkshire: recent sedimentological studies as demonstrated during a Field Meeting, 2-3 may 1980. *Proceedings of the Geologists' Association*, **92**, 241–250.
- LORENTE, M.A. 1990. Textural characteristics of organic matter in several subenvironments of the Orinoco upper delta. *Geologie en Mijnbouw*, **69**, 263–278.
- LORENTE, M.A., & VAN BERGEN, P.F. 1990. A multilevel approach to organic matter classification. *Stuifmail*, **8**(2), 9–16.
- LOTT, G.K., & HUMPHREYS, B. 1992. The stratigraphy and petrology of Middle Jurassic (Ravenscar Group) sediments in cored boreholes from the north Yorkshire coast. *Proceedings of the Yorkshire Geological Society*, **49** (1), 23–40.
- MACKOWSKY, M.T. 1968. European Carboniferous coalfields and Permian Gondwana coalfields. *In: MURCHISON, & WESTOLL (eds), Coal and coal bearing strata.* Oliver and Boyd, Edinburgh.

- MAHER, L.J. 1972. Nomograms for computing 0.95 confidence limits of pollen data. *Review of Palaeobotany and Palynology*, **13**, 85–93.
- MAHER, L.J. 1981. Statistics for Microfossil concentration measurements employing samples spiked with marker grains. *Review of Palaeobotany and Palynology*, **32**, 153–191.
- MASRAN, T.C., & POCKOCK, S.A.J. 1981. The classification of plant-derived particulate organic matter in sedimentary rocks. *Pages 145–176 of: BROOKS, J. (ed), Organic Maturation Studies and Fossil Fuel Exploration*. Academic Press, London.
- MASTERS, M.J. 1971. The occurrence of *Chytridium marylandicum* on *Botryococcus braunii* in School Bay of the Delta Marsh. *Canadian Journal of Botany*, **49**, 1479–1485.
- MATTHEW, J. 1969. The assessment of a method for the determination of absolute pollen frequencies. *New Phytology*, **68**, 161–166.
- MCGINNES, E.A.JR., SZOPA, P.S., & PHELPS, J.E. 1974. Use of scanning electron microscopy in studies of wood charcoal formation. *Pages 469–476 of: Scanning Electron Microscopy, part II*.
- MILSOM, J., & RAWSON, P.F. 1989. The Peak Trough – a major control on the geology of the North Yorkshire Coast. *Geological Magazine*, **126**, 699–705.
- MINCHEN, P.R. 1987. An evaluation of the relative robustness of techniques for ecological ordination. *Vegetatio*, **69**, 89–107.
- MOORE, P.D, WEBB, J.A., & COLLINSON, M.E. 1991. *Pollen Analysis, 2nd Edition*. Blackwells.
- MORGANS, H.S. 1997. *Early to Middle Jurassic stratigraphic development, vegetation and climate change in north-western Europe*. Ph.D. thesis, University of Oxford.
- MORGANS, H.S., HESSELBO, S.P., & SPICER, R.A. 1999. The seasonal climate of the Early-Middle Jurassic Cleveland Basin, England. *In press: Palaios*.
- MORRIS, P.H. 1989. The Aalenian to Callovian (Middle Jurassic). *Page 593 of: JENKINS, D.G., & MURRAY, J.W. (eds), Stratigraphic atlas of fossil foraminifera*. British Micropalaeontological Society, 2nd Ed.
- MORTON, A.C., HASZELDINE, R.S., GILES, M.R., & BROWN, S. 1992. Introduction. *Pages 1–2 of: MORTON, A.C., HASZELDINE, R.S., GILES, M.R., & BROWN, S. (eds), Geology of the Brent Group*. Geological Society, London.

- MOSIMANN, J.E. 1965. Statistical methods for the pollen analyst: multinomial and negative multinomial techniques. *Pages 636–673 of: KUMMEL, B., & RAUP, D. (eds), Handbook of paleontological techniques.* Freeman, W.H., San Francisco.
- MUIR, M.D.. 1964. *The palaeoecology of the small spores of the Middle Jurassic of Yorkshire.* Ph.D. thesis, University of London.
- MULLER, J. 1959. Palynology of Recent Orinoco Delta and Shelf Sediments: reports of the Orinoco Shelf expedition. *Micropalaeontology*, **5**.
- MUSSARD, J., GÉRARD, J., DUCAZEUX, J., & BÉGOUEN, V. 1994. 'Quantitative palynology': A tool for the recognition of genetic depositional sequences. Application to the Brent Group. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine.*, **18**, 463–474.
- NAMI, M. 1976. An exhumed Jurassic meander belt from Yorkshire. *Geological Magazine*, **113**, 47–52.
- NAMI, M., & LEEDER, M.R. 1978. Changing channel morphology and magnitude in the Scalby Formation (M.Jurassic) of Yorkshire, England. *Pages 431–440 of: MIALL, A.D. (ed), Fluvial Sedimentology.*
- NØHR-HANSEN, H. 1989. Visual and chemical kerogen analyses of the Lower Kimmeridge Clay, Westbury, England. *In: Northwest European Micropalaeontology and Palynology.*
- NORLING, E. 1972. Jurassic stratigraphy and foraminifera of western Scanic, southern Sweden. *Sveriges Geologiske Undersogelse Series Ca*, **47**, 120.
- PARRY, C.C., WHITLEY, P.K.J., & SIMPSON, R.D.H. 1981. Integration of palynological and sedimentological methods in facies analysis of the Brent Formation. *Pages 205–215 of: ILLING, L.V., & HOBSON, G.D. (eds), Petroleum Geology of the Continental Shelf of North West Europe.* Heyden, London.
- PARSONS, C.F. 1974. The Bajocian stratigraphy of eastern England. *Proceedings of the Yorkshire Geological Society*, **40**, 115–116.
- PARSONS, C.F. 1977. A Stratigraphic revision of the Scarborough Formation (Middle Jurassic) of the North-East Yorkshire. *Proceedings of the Yorkshire Geological Society*, **41**, Part 2, No.20, 203–222.

- PARSONS, C.F. 1980. Aalenian and Bajocian Correlation Chart. *In*: COPE, J.C.W., DUFF, K.L., PARSONS, C.F., TORRENS, H.S., WIMBLEDON, W.A., & WRIGHT, J.K. (eds), *A Correlation of Jurassic Rocks in the British Isles. Part Two: Middle and Upper Jurassic*. Special Report of the Geological Society, London, 15.
- PECK, R.M. 1974. A comparison of four absolute pollen preparation techniques. *New Phytology*, **73**, 187–198.
- PENNINGTON, W., & BONNY, A.P. 1970. Absolute pollen diagrams from the British late-glacial. *Nature*, **226**, 871–872.
- PIELOU, E.C. 1975. *Ecological Diversity*.
- POCOCK, S. A. J., VASANTHY, G., & VENKATACHALA, B. S. 1988. Introduction to the study of particulate organic materials and ecological perspectives. *Journal of Palynology*, **23**, 167–88.
- POCOCK, S.A.J. 1970. Palynology of the Jurassic sediments of Western Canada. Part 1: Terrestrial species. *Palaeontographica, Abt.B.*, **130**, 12–72, 73–136.
- POCOCK, S.A.J. 1982. Identification and recording of particulate sedimentary organic matter. *In*: STAPLIN, D.J., DOW, W.G., C.W.D., MILNER, O'CONNER, D.I., POCOCK, S.A.J., VAN GIZEL, P., WELTE, D.H., & YUKLER, M.A. (eds), *How to Assess Maturation and Palaeotemperatures*. Society of Economic palaeontologists and Mineralogists, Short Courses.
- POCOCK, S.A.J., & JANSONIUS, J. 1961. The pollen genus *Classopollis* Pflug, 1953. *Micropaleontology*, **7** (4), 439–449.
- POSAMENTIER, H.W, & VAIL, P.R. 1988. Eustatic controls on clastic deposition II - Sequence and system tract models. *Pages 125–154 of*: WILGUS, C.K., & HASTINGS, B.S. (eds), *Sea-Level Changes. An Integrated Approach*, vol. 42. Soc. Econ. Paleontol.Miner. Spec Pub.
- POWELL, A.J, DODGE, J.D., & LEWIS, J. 1990. Neogene to Pleistocene palynological facies of the Peruvian continental margin upwelling, Leg 112. *In*: SUESS, E., & HUENE, VON (eds), *Proceedings of the Ocean Drilling Project, Scientific Results*. College Station, Texas.
- POWELL, J.H., & RATHBONE, P.A. 1983. The Relationship of the Eller Beck Formation and the supposed Blowgill Member (Middle Jurassic) of the Yorkshire Basin. *Proceedings of the Yorkshire Geological Society*, **44, Part 3**(26), 365–373.

- RASTALL, R.H., & HEMINGWAY, J.E. 1941. The Yorkshire Dogger II. *Geological Magazine*, **78**, 351–170.
- RAWSON, P.F., & WRIGHT, J.K. 1992. *The Yorkshire Coast. With contributions by J.E. Hemingway and F. Whitham*. Vol. Fieldguide No. 34. Geologists' Association, London.
- RICHARDS, P.C. 1990. The early to mid-Jurassic evolution of the north northern North Sea. *Pages 191–205 of: HARDMAN, R.F.P., & BROOKS, J. (eds), Tectonic events responsible for Britain's oil and gas reserves*, vol. 55. Geological Society Special Publication.
- RICHARDS, P.C. 1992. An introduction to the Brent Group: a literature review. *Pages 15–26 of: MORTIN, A.C., HASZELDINE, R.S., GILES, M.R., & BROWN, S. (eds), Geology of the Brent Group*. Geological Society, London.
- RIDING, J.B. 1984. A palynological investigation of Toarcian to early Aalenian strata from the Blea Wyke area, Ravenscar, North Yorkshire. *Proceedings of the Yorkshire Geological Society*, **45**, **Parts 1 & 2**, 109–122.
- RIDING, J.B., & THOMAS, J.E. 1992. Dinoflagellate cyst of the Jurassic system. *Pages xii + 290 of: POWELL, A. J. (ed), A stratigraphic Index of Dinoflagellate Cysts: British Micropalaeontological Society Series*. Chapman and Hall, London.
- RIDING, J.B., & WRIGHT, J.K. 1989. Palynostratigraphy of the Scalby Formation (Middle Jurassic) of the Cleveland basin, north-east Yorkshire. *Proceedings of the Yorkshire Geological Society*, **47**, **Part 4**, 349–354.
- ROGERS, M. A. 1979. Application of organic facies concepts to hydrocarbon source rock evaluation. *Pages 23–30 of: Proceedings of the 10th World Petroleum Congress, Bucharest 1979*. Heyden and Son Ltd., London.
- RONNING, K., & STEEL, R.J. 1987. Depositional sequences within a 'transgressive' reservoir sandstone unit: the Middle Jurassic Tarbet Formation. Hild area, northern North Sea. *Pages 169–176 of: KLEPPE, J. et al (ed), North Sea Oil and Gas Reservoirs*. Graham and Trotman, London.
- RULL, V. 1987. A note on pollen counting in Palaeoecology. *Pollen et Spores*, **29**, (4), 471–480.
- SCHOPF, J.M. 1975. Modes of fossil preservation. *Review of palaeobotany and palynology*, **20**, 27–53.

- SCOTT, A.C., & COLLINSON, M.E. 1978. Organic sedimentary particles: results from scanning electron microscope studies of fragmentary plant material. *In*: WHALLEY, W.B. (ed), *Scanning electron microscopy in the study of sediments*. Ego-Abstracts, Norwich.
- SCOTT, E. 1992. The palaeoenvironments and dynamics of the Rannoch-Etive nearshore and coastal succession. Brent Group, northern North Sea. *In*: A.C., MORTON., HASZELDINE, R.S., GILES, M.R., & BROWN, S. (eds), *Geology of the Brent Group*. Geological Society, London.
- SCULL, B.J., FELIZ, C.J., MCCALED, S.B., & SHAW, W.G. 1966. The inter-discipline approach to palaeoenvironmental interpretations. *Transactions of the Gulf Coast Association of Geological Societies*, **16**, 82–102.
- SENIOR, J.R., & EARLAND-BENNETT, P.M. 1973. The Bajocian Ammonite *Hyperlioceras Rudidiscites* S. Buckman in Eastern England and its significance. *Proceedings of the Yorkshire geological Society*, **Vol. 39, Part. 3, No. 15**, 319–326.
- SKOLNICK, H. 1958. Observations on fusain. *Bulletin of the American Association of Petroleum Geologists*, **42:9**, 2223–2236.
- SLADEN, C.P., & BATTEN, D.J. 1984. Source-area environments of Late Jurassic and Early Cretaceous sediments in Southeast England. *Proceedings of the Geologists' Association, London*, **95**, 149–163.
- SMITH, K., & RITCHIE, J.D. 1993. Jurassic volcanic centres in the Central North Sea. *Pages 519–532 of*: PARKER, J.R. (ed), *Petroleum Geology of Northwest Europe: Proceedings of the 4th conference*, vol. 1. The Geological Society.
- SPICER, R.A. 1981. The sorting and deposition of allochthonous plant material in a modern environment at Silwood Lake, Silwood Park, Berkshire, England. *US Geological Survey Professional Paper*, **1143**, 77p.
- SPICER, R.A. 1988. Quantitative sampling of plant megafossil assemblages. *Pages 29–51 of*: DIMICHELE, W.A., & WING, S.L. (eds), *Methods and Applications of Plant Paleoecology*, vol. 3. Paleontological Society Special Publication.
- STAPLIN, F.L. 1969. Sedimentary organic matter, organic metamorphism, and oil and gas occurrence. *Bulletin of Canadian Petroleum Geology*, **17**, 47–66.

- STAPLIN, F.L., BAILEY, N.J.L., POCOCK, S.A.J., & EVANS, C. 1973. Palynofacies. *Pages 43–52 of: American Association of Petroleum Geologists Symposium, Anaheim.*
- STEFFEN, D., & GORIN, G. 1993. Palynofacies of the upper Tithonian-Berriasian deep-sea carbonates in the Vocontion Trough (SE France). *Bullentin des Centres de Recherches Exploration-Production Elf-Aquitaine*, **17**, 235–247.
- STOCKMARR, J. 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores*.
- STOPES, M.C. 1935. On the petrology of banded bituminous coals. *Fuel*, **14**, 4–13.
- SYLVESTER-BRADLEY, P.C. 1949. Letter to Geological Magazine. *Geological Magazine*, **86(4)**, 263.
- TARUTIS, W.J. JR. 1992. Temperature dependence of rate constants derived from the power model of organic matter decomposition. *Geochimica et Cosmochimica Acta*, **56**, 1378–1390.
- TAYLOR, T.N., & ALVIN, K.L. 1984. Ultrastructure and development of Mesozoic pollen; *Classopollis*. *American Journal of Botany*, **71:4**, 575–587.
- TER BRAAK, C. J. F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology*, **67**, 1167–1179.
- TER BRAAK, C. J. F. 1987. The analysis of vegetation-environment relationships by canonical correspondence analysis. *Vegetatio*, **64**, 69–77.
- TER BRAAK, C. J. F. 1988. *CANOCO - a FORTRAN Program for Canonical Community Ordination by [partial] [Detrended] [Canonical] Correspondence Analysis (Version 2.0.)*. TNO Institute of Applied Computer Science, Wageningen.
- TER BRAAK, C. J. F. 1990. *Update notes: Canoco Version 3.10*. Agricultural Mathematica Group, Wageningen, Netherlands.
- TORRENS, H.S. 1980. Bathonian Correlation Chart. *In: COPE, J.C.W., DUFF, K.L., PARSONS, C.F., TORRENS, H.S., & WIMBLEDON, W.A. (eds), A Correlation of Jurassic Rocks in the British Isles. Part Two: Middle and Upper Jurassic*. Special Report of the Geological Society, London, 15.
- TRALAU, H. 1968. Botanical Investigations in the Fossil Flora of Eriksdal in Fyledalen, Sweden. *The Institutes of Mineralogy, Palaeontology and Quaternary Geology*.

- TRAVERSE, A. 1988. *Palaeopalynology*. Unwin Hyman.
- TRAVERSE, A. 1994. Sedimentation of palynomorphs and palynodebris: an introduction. In: TRAVERSE, A. (ed), *Sedimentation of organic particles*. Cambridge University Press.
- TRAVERSE, A., & GINSBURG, R.N. 1967a. Palynology of the surface sediments of Great Bahama Bank, as related to water movement and sedimentation. *Marine Geology*, **4**, 417–459.
- TRAVERSE, A., & GINSBURG, R.N. 1967b. Pollen and associated Microfossils in the Marine Surface Sediments of the Great Bahama Bank. *Review of Palaeobotany and Palynology*, **3**, 243–254.
- TYSON, R.V. 1984. Palynofacies investigation of Callovian (Middle Jurassic) sediments from DSDP Site 534, Blake-Bahama Basin, western Central Atlantic. *Marine and Petroleum Geology*, **1**, 3–13.
- TYSON, R.V. 1989. Late Jurassic palynofacies trends, Piper and Kimmeridge Clay Formations, UK Onshore and offshore. Pages 135–172 of: BATTEN, D.J., & KEEN, M.C. (eds), *Northwest European Micropalaeontology and Palynology*.
- TYSON, R.V. 1993. Palynofacies. Pages 153–191 of: JENKINS, D.J. (ed), *Applied Micropalaeontology*. Kluwer, Dordrecht.
- TYSON, R.V. 1995. *Sedimentary Organic Matter: Organic facies and palynofacies*. Chapman and Hall.
- TYSON, R.V., & PEARSON, T.H. 1991. Modern and Ancient continental shelf anoxia; and overview. Pages 1–24 of: TYSON, R.V., & PEARSON, T.H. (eds), *Modern and Ancient Continental Shelf Anoxia*, vol. 58. Geological Society Special Publication, London.
- UNDERHILL, J. R., & PARTINGTON, M. A. 1993. Jurassic thermal doming and deflation in the North Sea: implications of the sequence stratigraphic evidence. Pages 337–346 of: PARKER, J.R. (ed), *Petroleum Geology of Northwest Europe: Proceedings of the 4th conference*, vol. 1. The Geological Society.
- VAKHRAMEEV, V.A. 1981. Pollen *Classopollis*: indicator of Jurassic and Cretaceous climates. *The Palaeobotanist*, **28-29**, 301–307.
- VAKHRAMEEV, V.A. 1982. *Classopollis* pollen as an indicator of Jurassic and Cretaceous climates. *International Geology Review*, **24 (10)**, 1190–1195.

- VAKHRAMEEV, V.A. 1991. *Jurassic and Cretaceous floras and climates of the Earth*. Cambridge University Press.
- VALIELA, I. 1984. *Marine Ecological Processes*. Springer-Verlag, New York.
- VALIELA, I., TEAL, J.M., ALLEN, S.D., VAN ETEN, R., GOEHRINGER, D., & VOLKMANN, S. 1985. Decomposition in salt marsh ecosystems: the phases and major factors affecting the disappearance of above-ground organic matter. *Journal of Experimental Marine Biology and Ecology*, **89**, 29–54.
- VAN BERGEN, P.F., JANSSEN, N.M.M., ALFERINK, M., & KERP, J.H.F. 1990. Recognition of organic matter types in standard palynological slides. *Pages 23–37 of: FERMONT, W.J.J., & WEEGINK, J.W. (eds), Proceedings of the International Symposium on Organic Petrology, Zeist January 1990*. Mededelingen Rijks Geologische Dienst, vol. 45.
- VAN DER ZWAN, C.J. 1990. Palynostratigraphy and palynofacies reconstruction of the Upper Jurassic to lowermost Cretaceous of the Draugen Field, offshore mid Norway. *Review of Palaeobotany and Palynology*, **62**, 157–186.
- VAN GIJZEL, P. 1991. A new organic petrologic classification system for organic matter in sedimentary rocks: requirements, criteria, nomenclature. *Pages 14–15 of: LORENTE, M.A., & RAN, E.T.H. (eds), Program of the open workshop on organic matter classification, Amsterdam*. Hugo de Vries-Laboratory, University of Amsterdam.
- VAN KONIJNENBURG-VAN CITTERT, J. A. 1978. Osmundaceous spores *in situ* from the Middle Jurassic Yorkshire, England. *Review of Palaeobotany and Palynology*, **26**, 125–141.
- VAN KONIJNENBURG-VAN CITTERT, J. H. A. 1971. *In situ* gymnosperm pollen from the Middle Jurassic of Yorkshire. *Acta Botanica Neerlandica*, **20**, 1–96.
- VAN KONIJNENBURG-VAN CITTERT, J. H. A. 1987. New data on *Pagiophyllum maculosum* Kendall and its male cone from the Jurassic of North Yorkshire. *Review of Palynology and Palaeobotany*, **51**, 95–105.
- VAN KONIJNENBURG-VAN CITTERT, J. H. A. 1989. Dicksoniaceae spores *in situ* from the Jurassic of Yorkshire, England. *Review of Palaeobotany and Palynology*, **61**, 273–301.
- VAN KONIJNENBURG-VAN CITTERT, J. H. A. 1996. Two Osmundopsis species and their sterile foliage from the Middle Jurassic of Yorkshire. *Palaeontology*, **39** (3), 719–731.

- VAN KONIJNENBURG-VAN CITTERT, J. H. A., & VAN DER BURGH, J. 1996. Review of the Kimmeridgian flora of Sutherland, Scotland, with reference to the ecology and *in situ* pollen and spores. *Proceedings of the Geologists' Associations*, **107**, 97–105.
- VENKATACHALA, B. S. 1981. Differentiation of amorphous matter types in sediments. *Pages 177–200 of: BROOKS, J. (ed), Organic Maturation Studies and Fossil Fuel Exploration.*
- WALL, D., DALE, B., LOHMANN, G.P., & SMITH, W.K. 1977. The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the north and south Atlantic oceans and adjacent seas. *Marine Micropalaeontology*, **2**, 121–200.
- WARTENBERG, D., FERSON, S., & ROHLF, F.J. 1987. Putting things in order: a critique of detrended correspondence analysis. *The American Naturalist*, **129**, 434–448.
- WATERHOUSE, H. K. 1995. High-resolution palynofacies investigation of Kimmeridgian sedimentary cycles. *In: HOUSE, M. R., & GALE, A. S. (eds), Orbital forcing timescales and cyclostratigraphy. Geological Society Special Publication.*
- WHITAKER, M.F. 1984. The usage of palynology in definition of Troll field geology. *In: Reduction of Uncertainties in Innovative Reservoir Geomodelling, 6th Offshore Northern Seas Conference and Exhibition, Stavanger.*
- WHITAKER, M.F., GILES, M.R., & CANNON, S.J.C. 1992. Palynological review of the Brent Group, UK sector, North Sea. *Pages 169–202 of: MORTON, A.C., HASZELDINE, R.S., GILES, M.R., & BROWN, S. (eds), Geology of the Brent Group, vol. 61. Geological Society of London. London, United Kingdom.*
- WHITE, J.M. 1989. Exploration of a practical techniques to estimate the relative abundance of rare palynomorphs using an exotic spike. *Pages 483–486 of: AGTERBERG, F.P., & BONHAM-CARTER, G.F. (eds), Statistical Applications in the Earth Sciences. Geological Survey of Canada.*
- WILLAMS, G. 1992. Palynology as a palaeoenvironmental indicator in the Brent Group, northern North Sea. *Pages 203–212 of: Geological Society Special Publication, No. 61.*
- WILLIAM, L., FOWLER, H.W., & COULSON, J. 1972. *The Shorter Oxford English Dictionary on Historical Perspectives.* Oxford University Press.
- WILLIAMS, D.B., & SARJEANT, W.A.S. 1967. Organic walled microfossils as depth and shoreline indicator. *Marine Geology*, **5**, 389–412.

- WOOLLAM, R., & RIDING, J.B. 1983. Dinoflagellate cyst zonation of the English Jurassic. *Report of the Institute of Geological Sciences*, **83/2**.
- WRIGHT, J.K. 1977. The Cornbrash Formation (Callovian) North Yorkshire and Cleveland. *Proceedings Yorkshire Geological Society*, **41**, 325–346.
- YIELDING, G., BADLEY, M.E., & ROBERTS, A.M. 1992. The structural evolution of the Brent Province. *Pages 27–44 of: MORTIN, A.C., HASZELDINE, R.S., GILES, M.R., & BROWN, S. (eds), Geology of the Brent Group*. Geological Society, London.
- ZIAJA, J, & WCISLO-LURANIEC, E. 1999. *Are the Lower Liassic Plants of Odrowaz (Poland) burnt?*
- ZIEGLER, P.A. 1982. *Geological Atlas of Western and Central Europe*. Shell, The Hague.
- ZIEGLER, P.A., PARRISH, J.M., YAO, J.P, GYLLENHAAL, E.D., ROWLEY, D.B., PARRISH, J.T., NIE, S.Y., BEKKER, A., & HULVER, M.L. 1993. Early Mesozoic phytogeography and climate. *Philosophical Transactions of the Royal Society of London, B*, **341**, 297–305.
- ZIEGLER, P.A., REES, A.M., ROWLEY, D.B., BEKKER, A., LI, QING, & ROWLEY, D.B. 1996. Mesozoic assembly of Asia: constraints from fossil floras, tectonics and palaeomagnetism. *Pages 371–400 of: YIN, A., & HARRISON, M. (eds), The tectonic evolution of Asia*. Cambridge University Press.

Appendix A

Processing Technique

A.1 Processing Technique

As mentioned previously residues were extracted using a modified form of the traditional palynofacies technique, involving hydrochloric and hydrofluoric acid [Moore *et al.*, 1991; Traverse, 1988; Tyson, 1995]. Chemical and physical treatment was kept to a minimum; no oxidation or ultrasonic treatment of the residue was employed, thus reducing the mechanical breakdown of large brittle components, *e.g.*, definite wood. The principal reason for minimising treatment is that there have been reports of damage to organic material when ultrasonic baths are used to disperse clays and break up severely clumped specimens [Dodson, 1983]. The remainder of this section describes the preparation method used in this study. The technique is based on the method successfully employed by Lewis [1995].

- Samples were cleaned with a soft nylon brush and any weathered material discarded. A description of each hand specimen was made, including grain-size, presences or absence of faunal fossils, siderite nodules, macroscopic plant debris, roots and burrowing, and the nature of the visible fragments of organic matter. These sample-specific observations were used to investigate the relationship between organic matter and environmental variables which is documented in Chapter 3.
- Hard samples were crushed using a Fritsch Pulverisette 1, Model 1 (Laboratory jaw crusher). Soft samples were crushed using an anvil and hammer. All elements were cleaned between samples to avoid contamination. The samples were crushed to 0.5 cm².

- To ensure a valid level of *Lycopodium clavatum* spores it was necessary to process only minimum amounts. It is also unnecessarily time consuming to process large quantities. However, to ensure that the quantity processed was representative of the whole sample more material (up to 30 gm) was processed for samples which appeared to be organically poor, whilst 5-10 gm were processed for organically rich samples.
- Weighed samples were placed in 300 ml plastic screw-top bottles into which 100 ml of conc. (37%) hydrochloric acid (HCl) was added to remove any carbonates. The screw-caps were left finger tight at this stage and the samples were observed in case of a violent response. Generally the samples produced very little reaction with the HCl. However, samples which were known to contain a large amount of carbonate were treated with caution and the HCl was added in stages. The screw tops were left loose for a day to permit any gas to escape.
- After standing for 24-48 hours the samples were carefully decanted, ensuring that none of the sample was lost. The samples were then filled with distilled water, gently agitated to wash and left to stand for another 24 hours to let the residue settle. The decanted liquid was checked for particulate organic matter and none was evident. The samples were washed a further six or seven times, each at 24 hours intervals, ensuring that no sample was poured off. This stage was performed to permit the movement of samples from the HCl fume cupboard to another fume cupboard which was suitable for Hydrofluoric acid (HF) and to limit the amount of fluorides forming upon the addition of HF.
- Approximately 50-80 ml of concentrated anal R HF 48 % was added to each sample. This mixture was left to stand for 7-10 days. Samples were gently agitated every 24 hours to disperse the acid among the residue.
- The HF superannuate was poured off into a large beaker containing boric acid crystals (H_3BO_3). This ensured that the HF was partially neutralised before being discarded. The sample residues were washed and decanted a total of 7 times with 24 hours between each washing. The samples were washed until complete neutralisation of the residues was achieved as the sample residue had to be sieved into an ordinary sink because there was no fume cupboard with the required facilities. The relatively large number of rinses subsequent to the acid digestion stage ensured that the concentration of HF remaining in the residue was negligible - effectively nil.
- All of the samples processed in this study were 'spiked' with a known quantity of *Lycopodium clavatum* spores to enable the calculation of absolute weight frequencies: number of particles deposited

per unit weight of sediment [Tyson, 1995]. The spores were supplied in tablet form, each tablet containing several thousand spores held together by sodium bicarbonate and water soluble organics that distinegrated during subsequent processing. The tablets were added to the residues after the first rinse subsequent to HF digestion. Both Lewis [1995] and Waterhouse [1995] considered this to be the optimum time to add the tablets because the organic matter held in the samples should be totally liberated by this time and it is important that the indigenous palynomorphs/palynodebris and *Lycopodium* c. spores behave in a similar way subsequent to this stage so as to avoid introducing bias into the absolute particle abundance. In an effort to maintain a statistically valid ratio between indigenous organic matter and the marker spores relatively large amounts of tablets, up to 20, (approximately 12,542 spores per tablet thus 250,840 spores) were added to each sample. The quantity of marker grains added depended upon the expected particulate density in the host sediment, *e.g.*, more tablets were added to those that appeared organic rich. However, if too many were added, then an inordinate amount of counting time was used in recording the marker grains.

- Prior to the sieving of the sample a small amount of the unsieved residue was collected, for most of the samples, in case examination of the fines was required at a later date. Each sample residue was poured from its plastic bottle into a 5-litre plastic beaker two thirds filled with distilled water to disperse the organic particles through a greater volume of liquid. Small quantities of this mixture and copious amounts of distilled water were gradually poured over a 10 μm nylon sieve clamped into a plastic mesh holder. This ensured, in the majority of cases, that a constant flow of water and fines was maintained at the base of the sieve. If at any stage the sieve became clogged gentle tapping of the mesh holder was sufficient to break the surface tension between the particles and mesh and permit the flow of water to resume. This procedure was continued until the water flowing from the base of the sieve was clear. Although this often proved to be a time consuming technique it was also relatively gentle and limited the potential damaged to the organic particles. Upon completion of this stage the sieved residue was washed into a 250ml Pyrex beaker.
- Approximately 75-100ml of concentrated HCl was added to the residue and then heated on a hot plate in a fume cupboard until the commencement of boiling. This technique was usually sufficient to remove any fluorides which may have formed during the acid digestion stages.
- The residues were resieved following the above technique. As the residue were again sieved in a sink outside of a fume cupboard they were added to a large volume (2-3 litres) of distilled water to ensure dilution of the HCl and minimise the risk of exposure.

- The residue was pipetted into a small plastic vial prior to mounting on slides using the method proposed by Lewis [1995]. Several strew mounts were made for each sample using the following procedure:
 - a) The vial was gently agitated to homogenise the residue.
 - b) In one continuous motion approximately 2-2.5ml of the residue was drawn up into a 5 ml disposable pipette and then squeezed out onto a 22*32 mm thickness 0 (0.08-0.12) cover slip. It was found that if this was done fast enough separation of different sized particles either in the pipette or on the cover slip did not occur. This technique proved very successful and no manual mixing of the residues that might have distorted the even spread of particles on the cover slips was needed. Furthermore, flow lines emanating from the central zone of the cover slip rarely formed. Hence it appears that a random distribution of particles on the cover slip was achieved.
 - c) The cover slips were left to dry in a clean cabinet for a couple of days and then mounted on (1-1.2 mm thick) glass slides using Elvacite 2044. One to two drops of Elvacite were placed on the slide and this was then inverted and held close enough to the cover slip for the Elvacite to make contact and spread. The slide was then flipped over resulting in the gradual settling of the cover slip and even spreading of the Elvacite. The mounted slides were labelled and left for a week to enable the Elvacite to cure.
- Observation and routine counting of the strew mounts was undertaken on a Nikon Optiophot -2 microscope using 10X eyepieces and 20X plan achromat objective in transmitted white light and incident Blue and UV light. The spectrum transmission characteristics of the Blue (B-3A) and UV (UV-2A) incident fluorescences blocks are as follows, respectively:
 - a) Excitation filter 420-490 nm; dichoric mirror 510 nm and barrier filter 520 nm
 - b) Excitation filter 330-380 nm; dichoric mirror 400 nm and barrier filter 420 nm.

The UV excitation allows the observation of blue and green colours and the recording of the complete spectra but produces a relatively weak excitation. The Blue excitation is much more intense but only allows the transmission of fluorescence. The preparations were also inspected under reflected light to assist in differentiating between black fragments, genuine charcoal and pyrite.

A.2 Calculation of Absolute Abundances

The addition of exotic markers to determine absolute pollen abundances was first used by [Benninghoff, 1962]. The technique was modified by Matthew [1969]; Pennington & Bonny [1970] and Bonny [1972], and was appraised by Peck [1974] and Maher [1981]. The most frequently used method of adding exotic markers is to use *Lycopodium* spores. These are supplied in tablets [Stockmarr, 1971] which contain a known quantity of spores, hence avoiding the need to make an exotic marker suspension.

The tablets were supplied by the Department of Quaternary Geology, Lund, Sweden with a data sheet outlining the accuracy of the calculated *Lycopodium* concentration within each tablet. The spore concentration for each tablet was determined with an electronic particle counter: Coulter Counter ZB, tube size 140. 100 samples of five tablets each taken from different places in the batch were prepared by dissolving the tablets in Isoton NaCL solution in 100 ml flasks. 20 counts each of 0.5 ml were made on each sample. The results provided were:

$$X = 62,712$$

$$s = \pm 2081$$

$$V = \pm 3.3\%$$

hence, for tablet, $X = 12,542$

A.2.1 Method

Maher [1981] conducted a very detailed examination of the marker grain technique. The following description is based on his work. During the counting of indigenous particles, to a predetermined total, the *Lycopodium* spores are tallied separately from the main total. The concentration of the indigenous particles within a sample can then be derived from the equation presented by Stockmarr [1971] for calculating the number of particles in a sample.

$$\frac{\text{No. of } Lycopodium \text{ spores added to the sample} \times \text{No. of pollengrains counted on a slide}}{\text{No. of } Lycopodium \text{ spores counted}}$$

Although, not used in this study the absolute abundance of individual categories can be determined by the following equation devised by Maher [1981].

$$\frac{\text{Fossil particle in (X)}}{\text{Fossil particle counted (X)}} = \frac{\text{Lycopodium spores in sample (M)}}{\text{Lycopodium spores counted (n)}}$$

X = any particle type *e.g.*, any category in the sample, any group of particles or the sum of all the categories (the total count).

X = the number of particles of particle type (X) in the total count.

M = the number of *Lycopodium* spores added to the sample.

n = the number of *Lycopodium* spores tallied independently of the total count.

Let $R = X/n$, the ratio of particle type X counted to the *Lycopodium* spores tallied.

Therefore, the number of particles of type X in the sample = RM .

If G is the weight of the sediment sample, the concentration of particle type X in grains/gm = RM/G .

A.3 Index of absolute abundance per gram of sediment

This index was devised, in this investigation, for two reasons; 1) to enable the organic matter content to be envisaged more clearly than if the absolute abundances were presented, and 2) to permit the data to be included in the statistical analysis. The original figure for absolute abundance per gram of sediment is often seven orders of magnitude greater than the relative percentage count data. Thus, its contribution, in mathematical terms is very significant and would obviously impose structure on the data were none existed. The index was calculated by:

- The mean was determined for the organic matter content per gram of sediment.
- The difference between the mean and the organic matter content for each sample was calculated.
- This figure was then divided by the mean to give the index of organic matter.

Thus, any sample containing less than the mean value, will have an index of below 1. Any sample that contains the same amount as the mean will have a value of 1, and a sample which contains more than the average value will have a index of greater than 1.

Appendix B

Scanned Images of Organic Matter

B.1 Introduction

The following section contains scanned images of the organic debris (different types of palynodebris and palynomorphs) observed in the present study. Each figure contains two images. Image A shows the field of view under transmitted white light. Image B displays the same field of view under UV (UV-2A) incident fluorescent light. Unless specified the magnification is 640x.

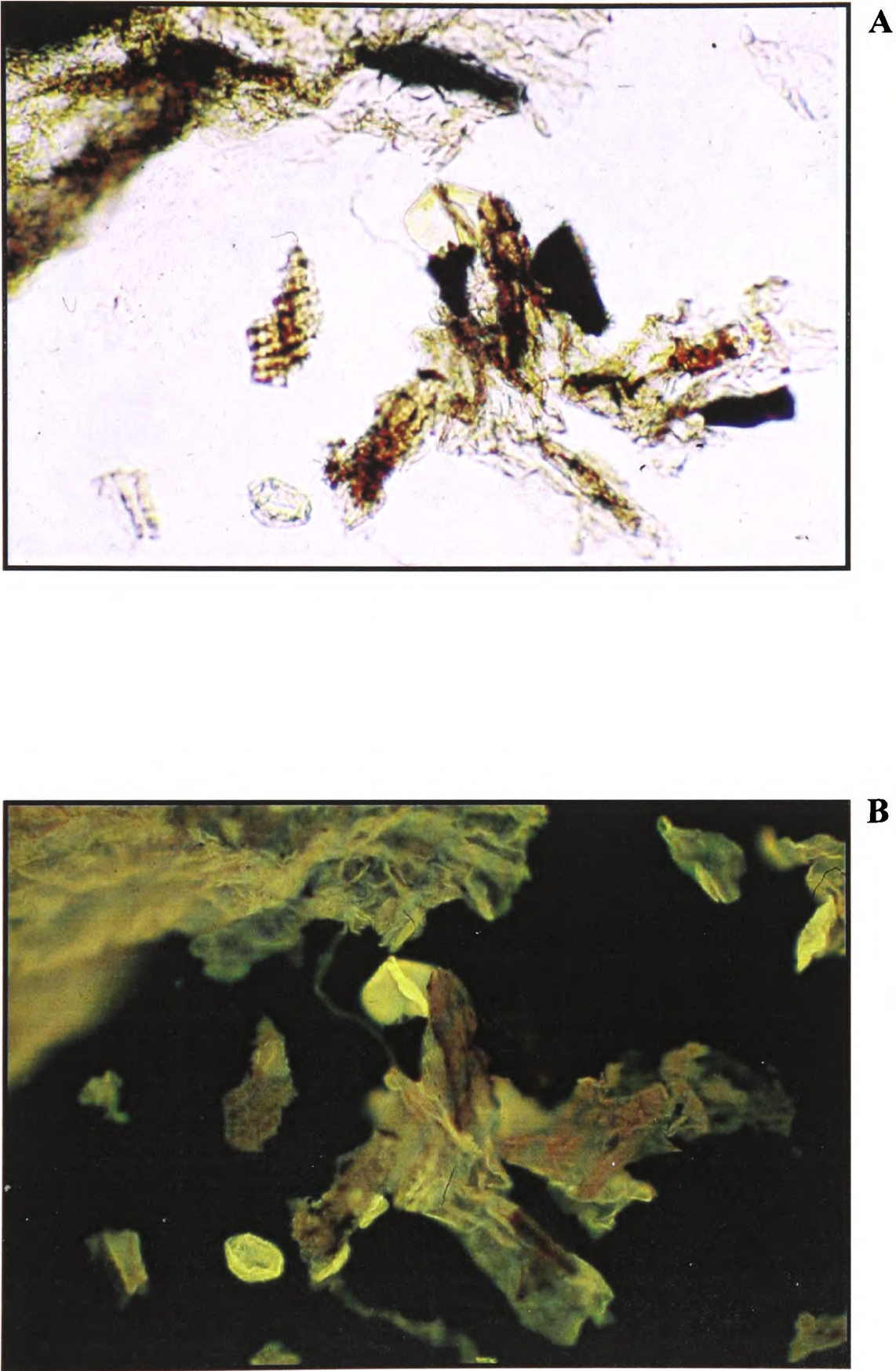


Figure B.1: Images A and B display organic matter retrieved from sample 134. This is dominated by well-preserved diffuse-edged SOM seen in transmitted white light in the upper image and ultra-violet light in the lower image. The form of the edges indicates that these particles are structureless and therefore not discrete fragments. A small fragment of vascular bundles lies to the left of centre. This would be classified as a vita fragment. Fluorescent light clarifies the outline of the fungal hyphae (thin filament) which lies across the centre of the images.

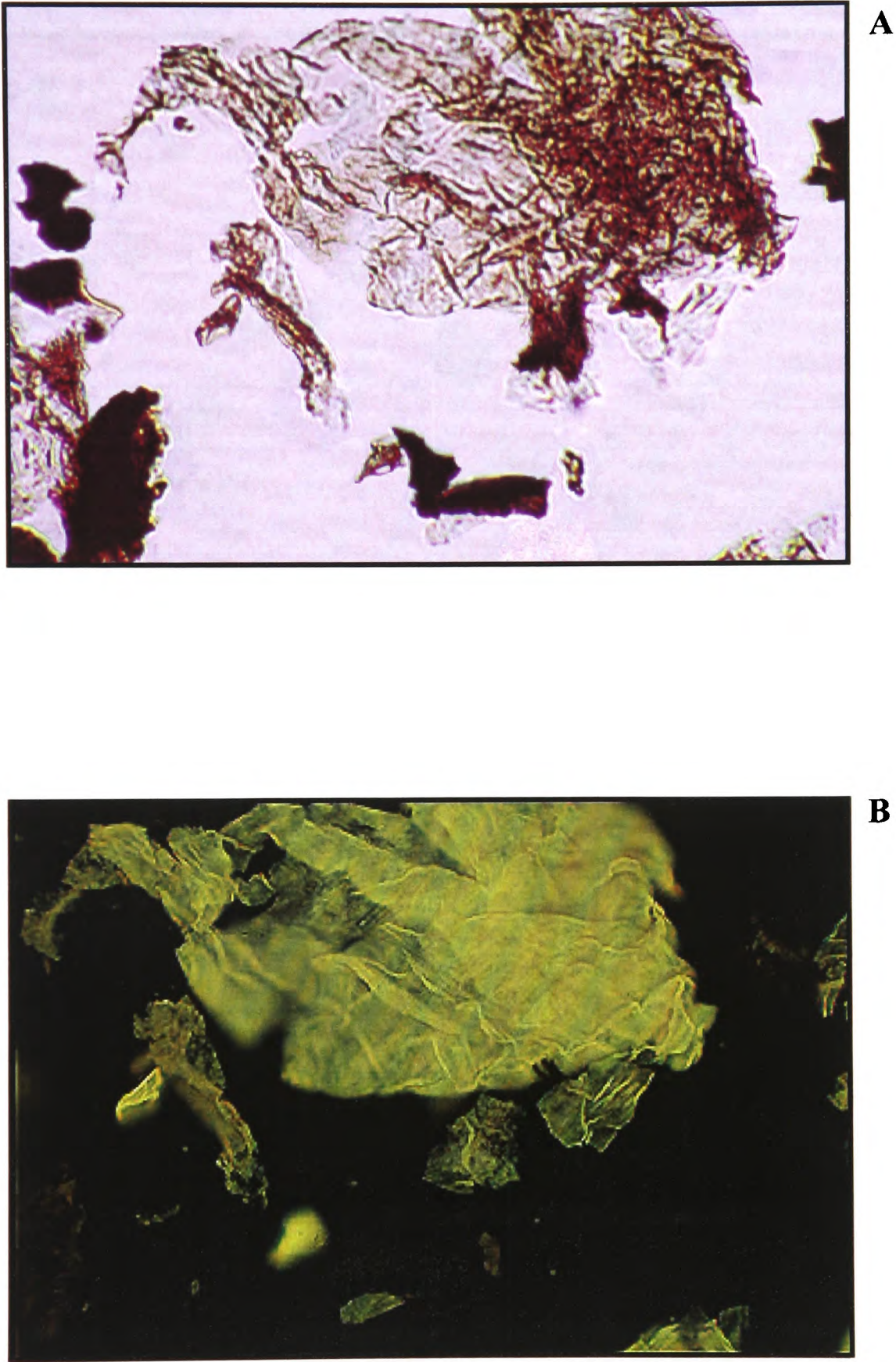


Figure B.2: A and B show images of organic matter from sample 134. Note the very-high fluorescence of the SOM and its overwhelming dominance in the sample. The surface of the SOM exhibits folds and no cellular or fibrous structure. Thus, it is classified as transparent-yellow, fluorescent, non-fibrous SOM. The association of organic matter displayed in these images suggest deposition occurred close to source in low-energy, reducing conditions which concurs with the sedimentology because this sample is from the ‘coal marker bed’ found in the upper part of the Gristhorpe Member, Cloughton Wyke.

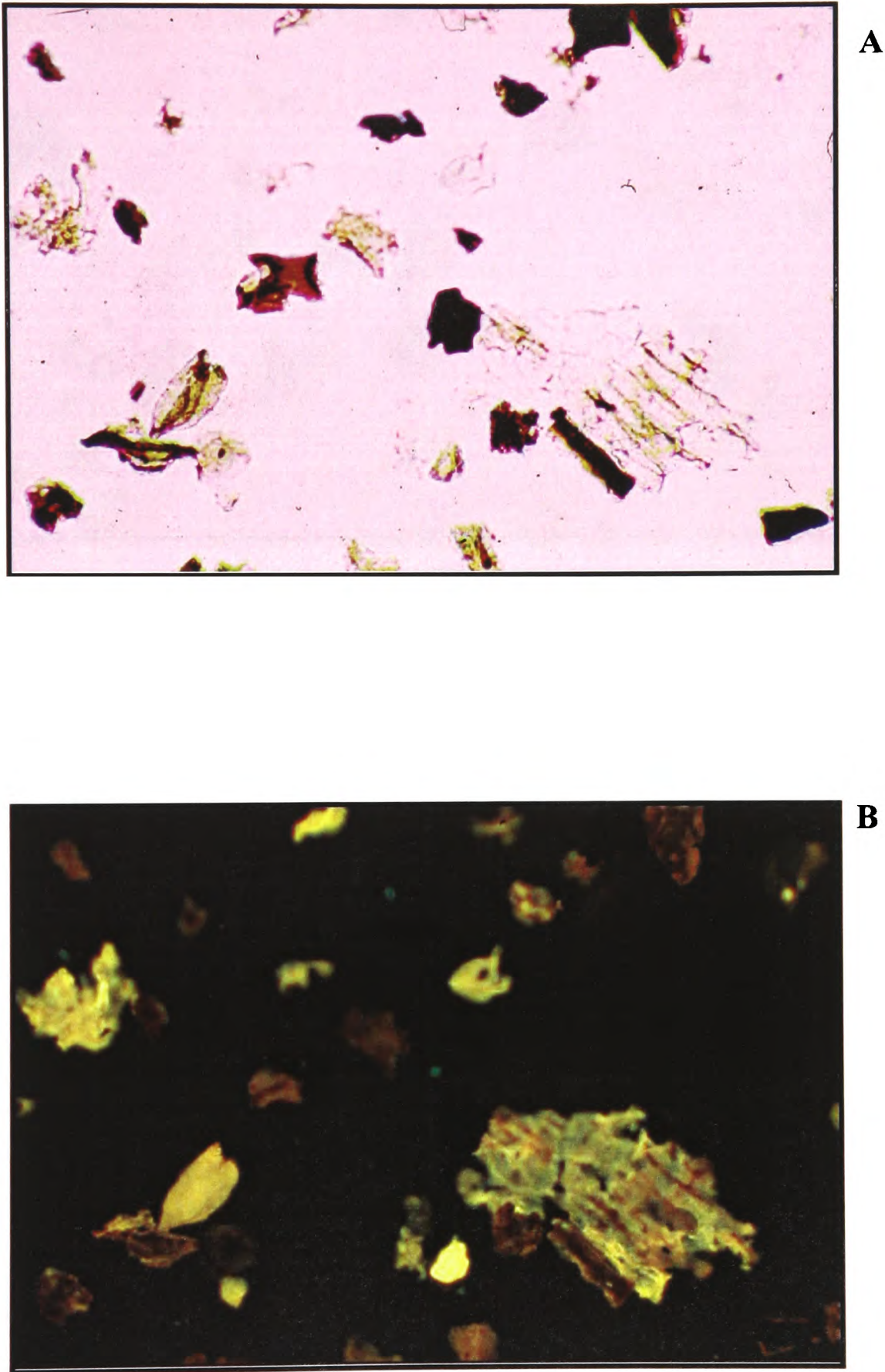


Figure B.3: Images A and B display organic matter from sample 16. Fibrous, fluorescent transparent-yellow SOM is visible in the right lower part of the images. The fibrous nature may be a relict of cell outlines. These images also comprise a range of non-vita fragments and sporomorphs.

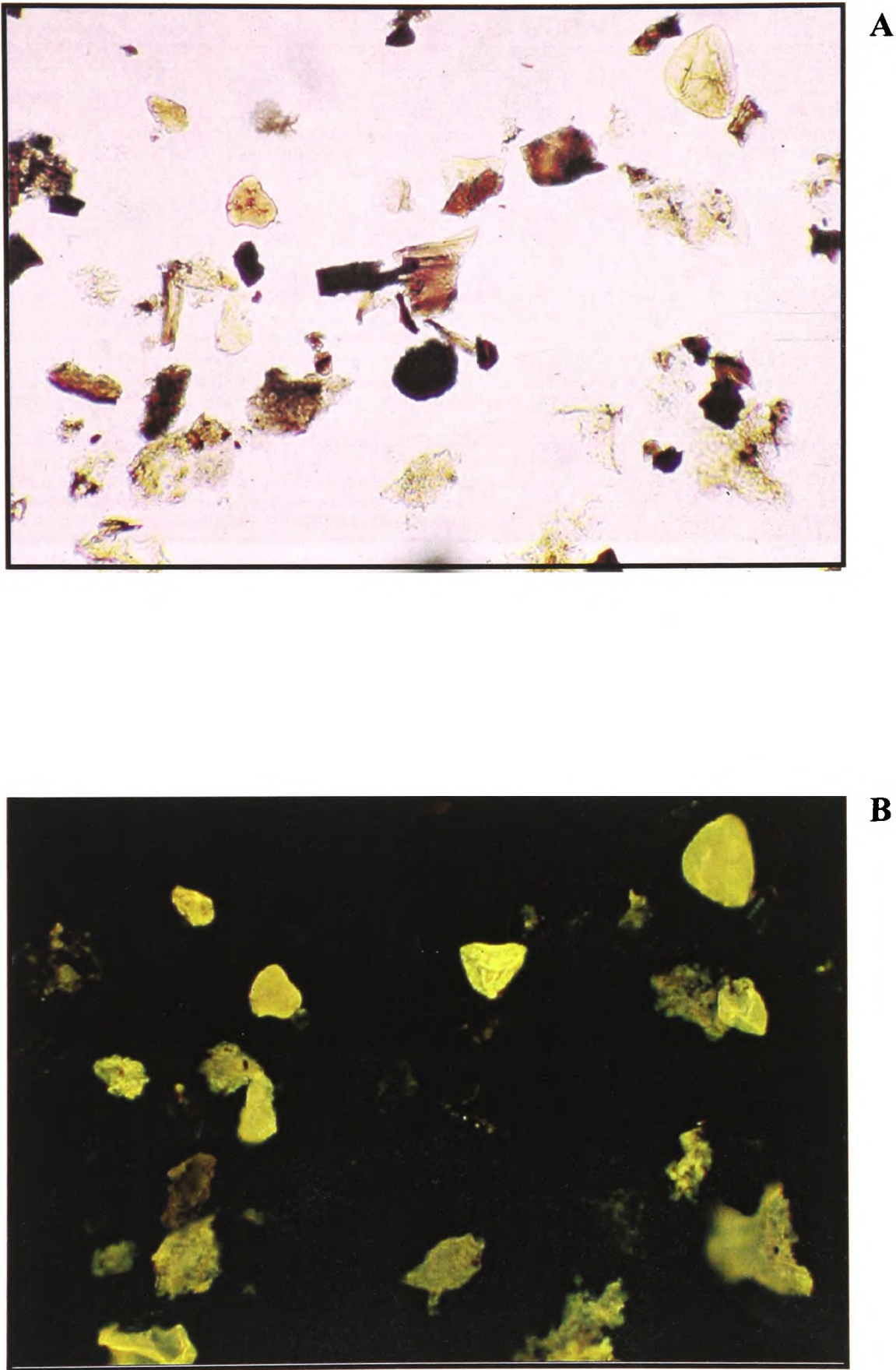


Figure B.4: Images A and B display brown- and black-equidimensional and -bladed, non-fluorescent, non-cellular, non-vita fragments; transparent-yellow, fluorescent, non-fibrous SOM, and yellow-brown and brown-black, fluorescent, non-fibrous SOM. Note the coherent edges of the vita fragments and the diffuse edges of the SOM. This palynofacies contains less well-preserved SOM than Figures B.1 and B.2. This suggests that the organic matter was subject to higher levels of degradation and/or more oxic conditions than the organic matter from sample 134. (Sample from 27).

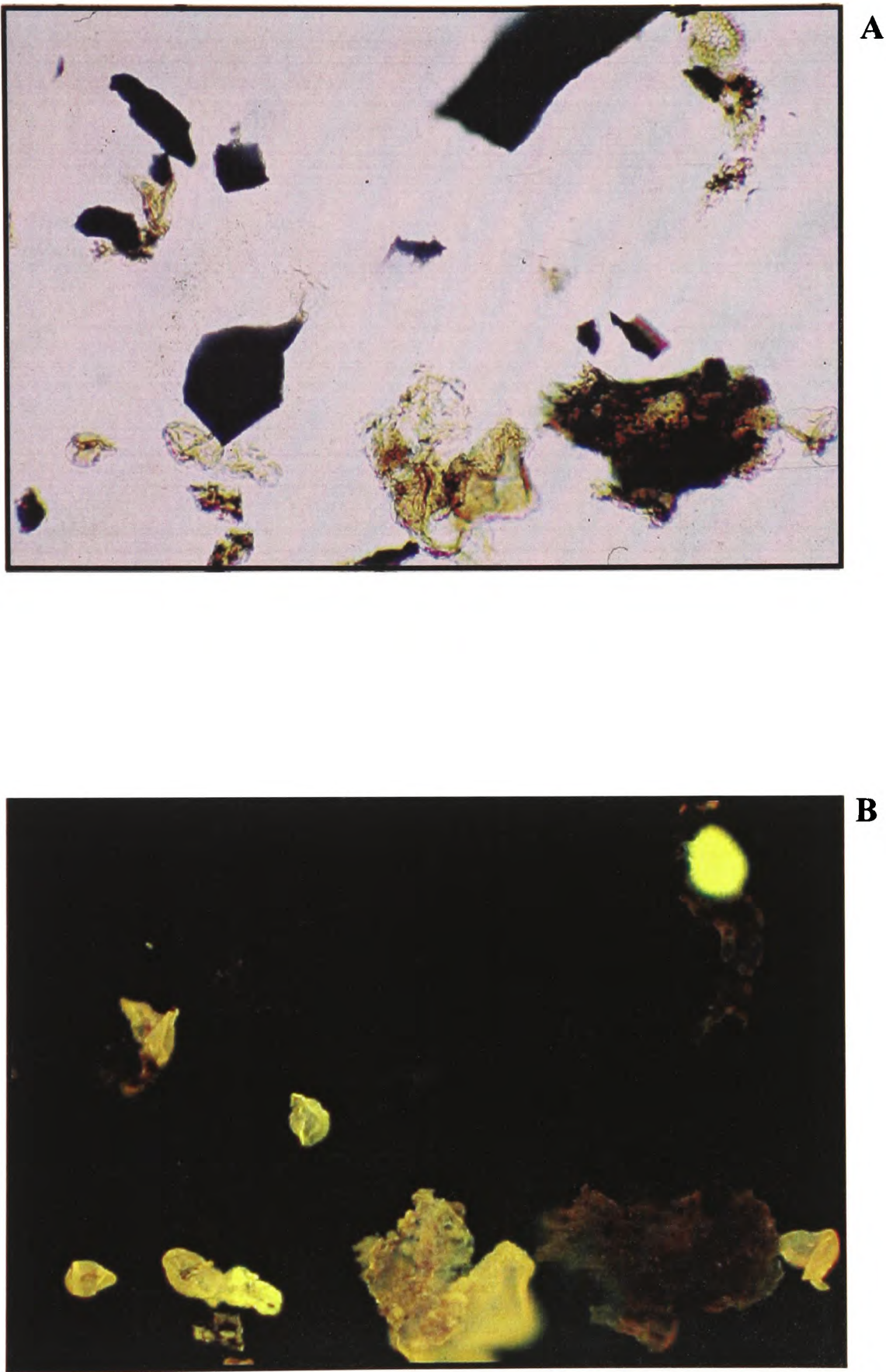


Figure B.5: Images A and B display both transparent-yellow, fluorescent, non-fibrous SOM and brown-black, fluorescent, non-fibrous SOM. This association of well- and relatively poorly-preserved SOM either suggests that the original material was from different sources or has different susceptibilities to degradation. Variations in the levels of fluorescence lend support to the differences observed under transmitted white light. A *Lycopodium* c. (spike) is present in the upper right hand corner of the image. Note the homogeneous nature of the colour of the non-vita fragments in comparison to the SOM. The majority of the non-vita fragments would be classified as black-equidimensional, non-fluorescent, non-cellular (*i.e.*, the fragments are complete black.) (From sample 27).

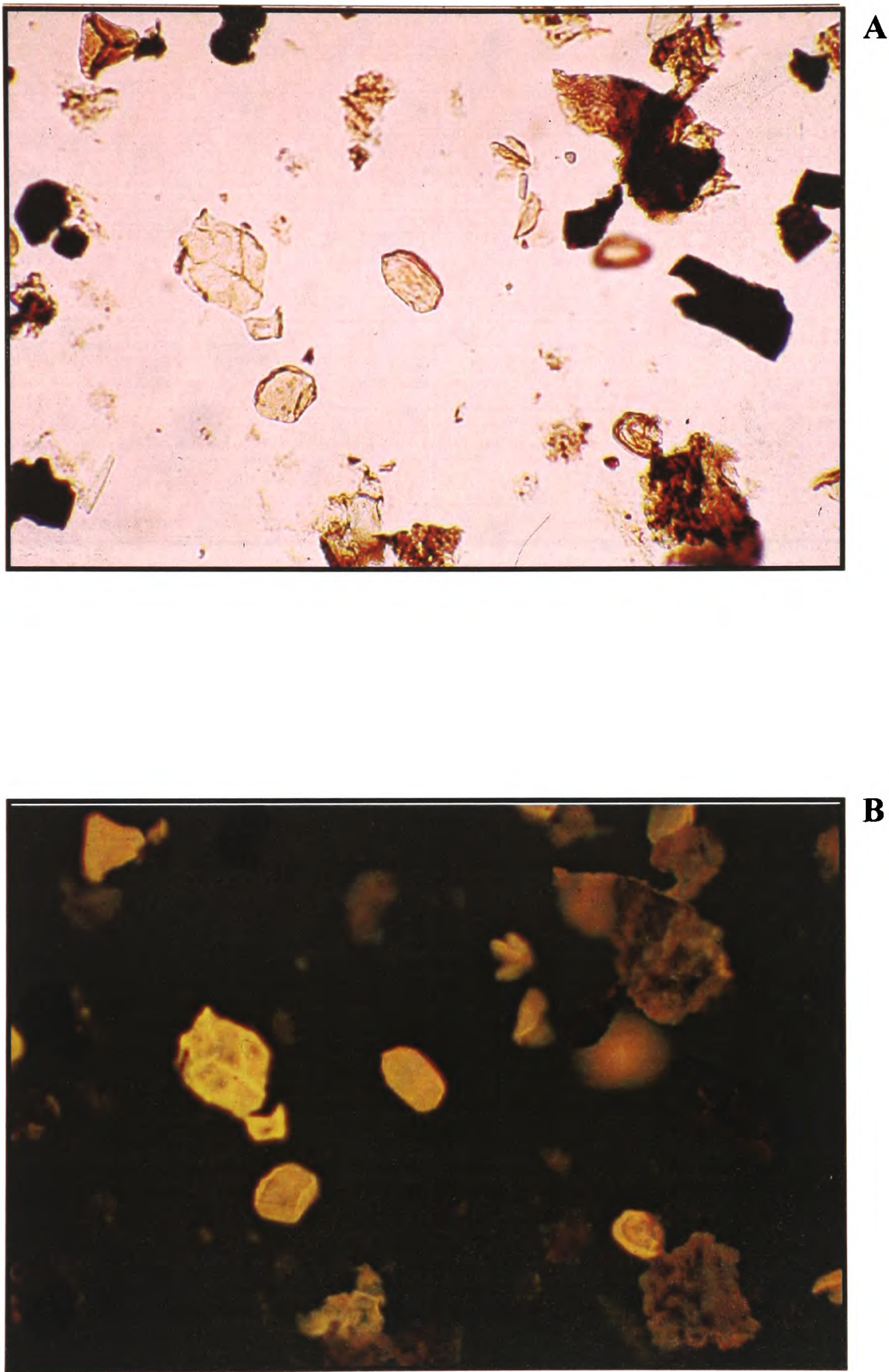


Figure B.6: Palynofacies includes brown-equidimensional and -bladed, non-fluorescent, non-vita fragments, transparent-yellow, fluorescent, non-fibrous SOM and yellow-brown, fluorescent, non-fibrous SOM. Although the non-vita fragments appear 'black' they have very-thin brown margins. Thus, these particles would be classified as brown, non-vita fragments. The presences of darker SOM indicates that the organic matter was subject to higher levels of degradation than Figures B.1 and B.2 (Sample 139)

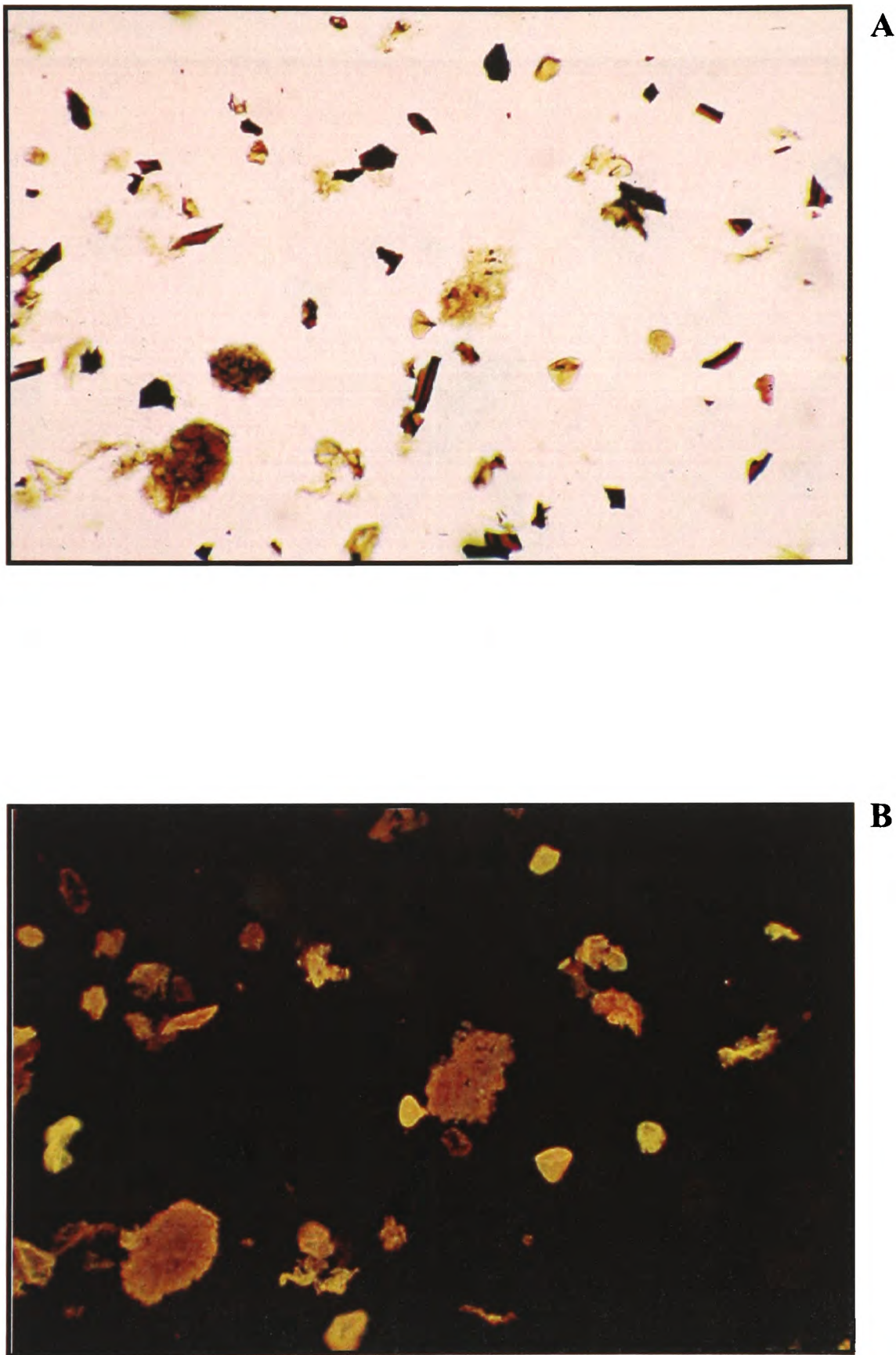


Figure B.7: Images A and B display organic matter yielded from sample 4 (x 320). This preparation contains more bladed than equidimensional non-vita fragments and less SOM than previous samples. Bladed non-vita fragments are occasionally brown-and black-striped. This is probably a relict of tracheidal elements. Transparent-yellow, fluorescent, non-fibrous SOM is scattered throughout the field of view. In the lower left-hand side of the image both fluorescent and non-fluorescent yellow-brown, non-fibrous SOM is visible. Note that the latter material displays a lower level of fluorescence than the SOM displayed in Figures B.1 and B.2. The increase in fragments and decrease in SOM, in comparison to the previous images indicates that the organic matter accumulated in a higher energy, more oxic setting.

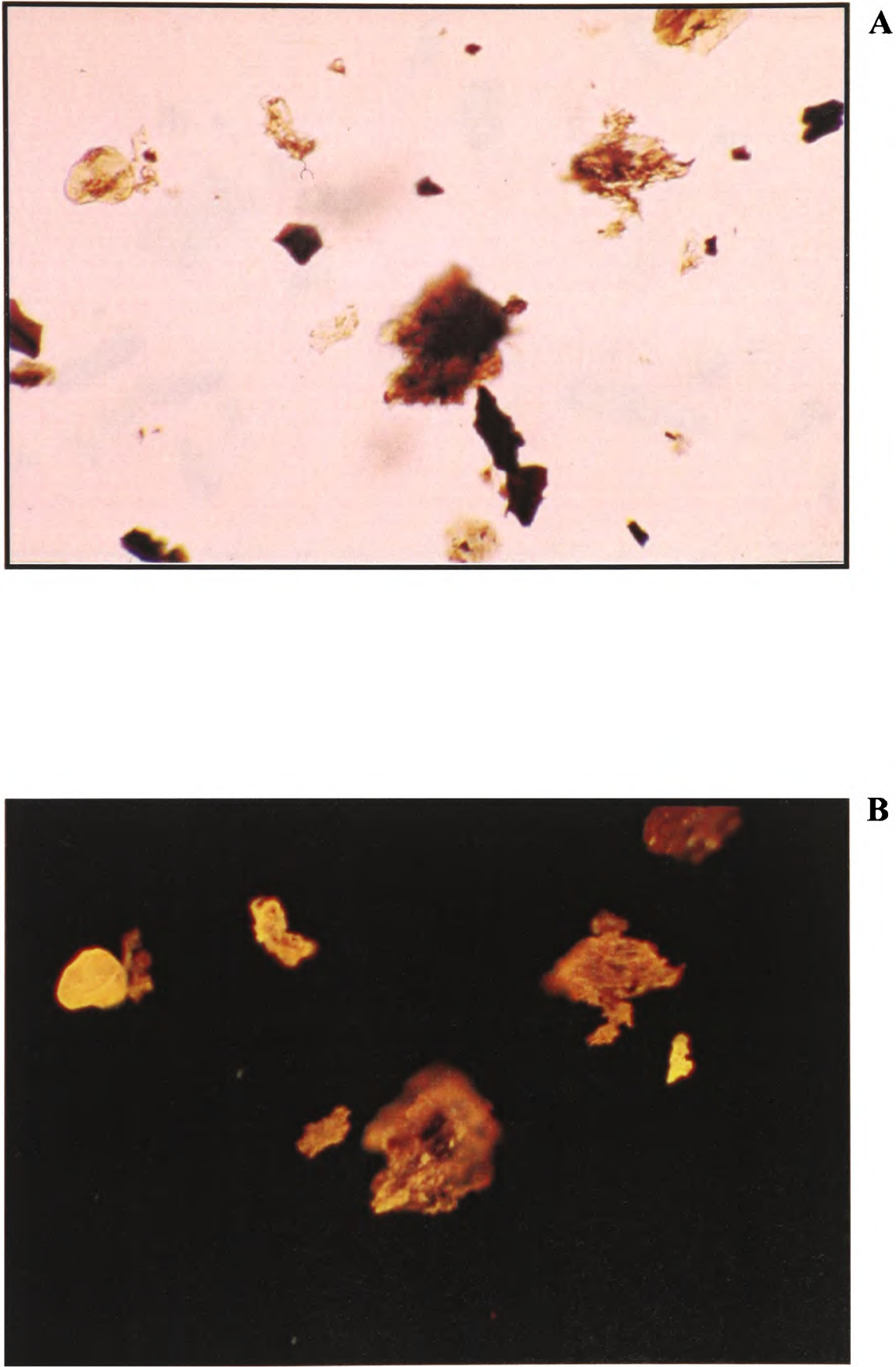


Figure B.8: Images A and B display transparent-yellow, yellow-brown and brown-black SOM, and brown-equidimensional and bladed, non-fluorescent, non-vita fragments from sample 4. Note that the small particle of transparent-yellow, non-fibrous SOM which lies below the non-vita fragments at the base of the image is non-fluorescent.

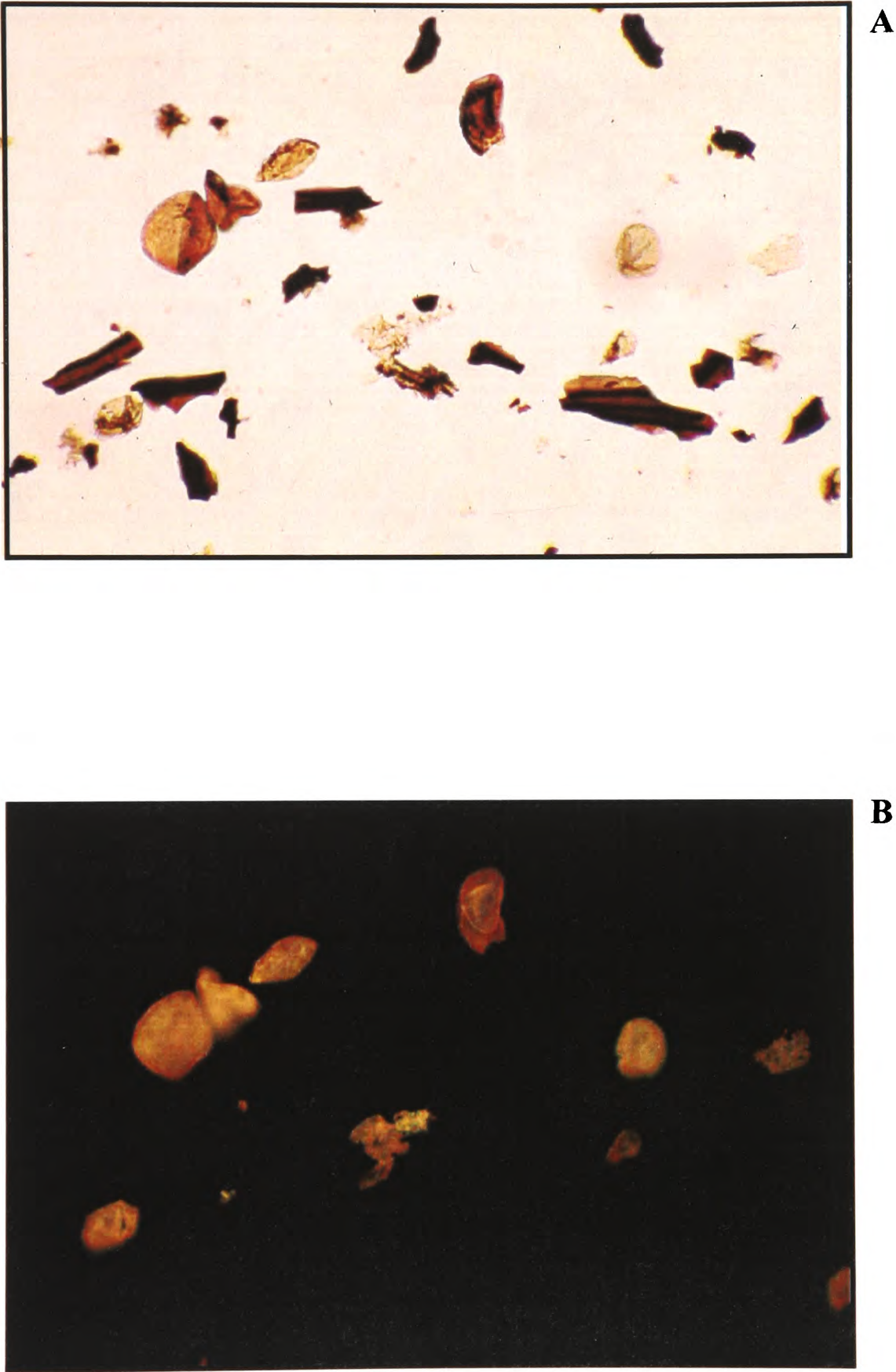


Figure B.9: Dominated by brown- and black-striped, bladed, non-vita fragments and sporomorphs. The low occurrence of SOM indicates that the organic matter was either transported over a relatively large distance/duration and/or accumulated in well-aerated sediments. All the non-vita fragments are non-fluorescent (sample 20).

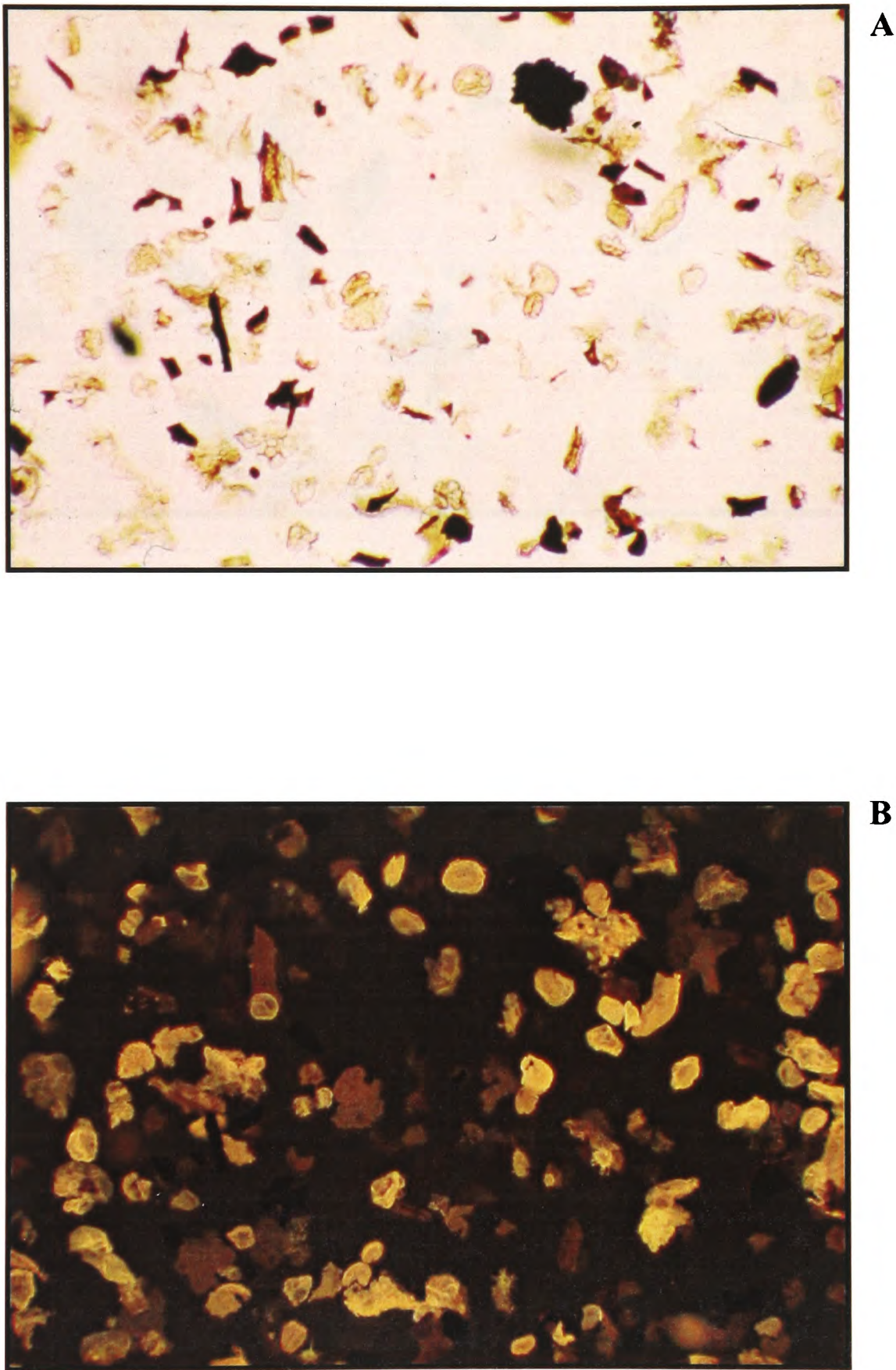


Figure B.10: Images of organic matter from sample 202 (x 320). Abundant palynomorphs, well-preserved SOM and occasional non-vita fragments which accumulated in a brackish shallow-water setting.

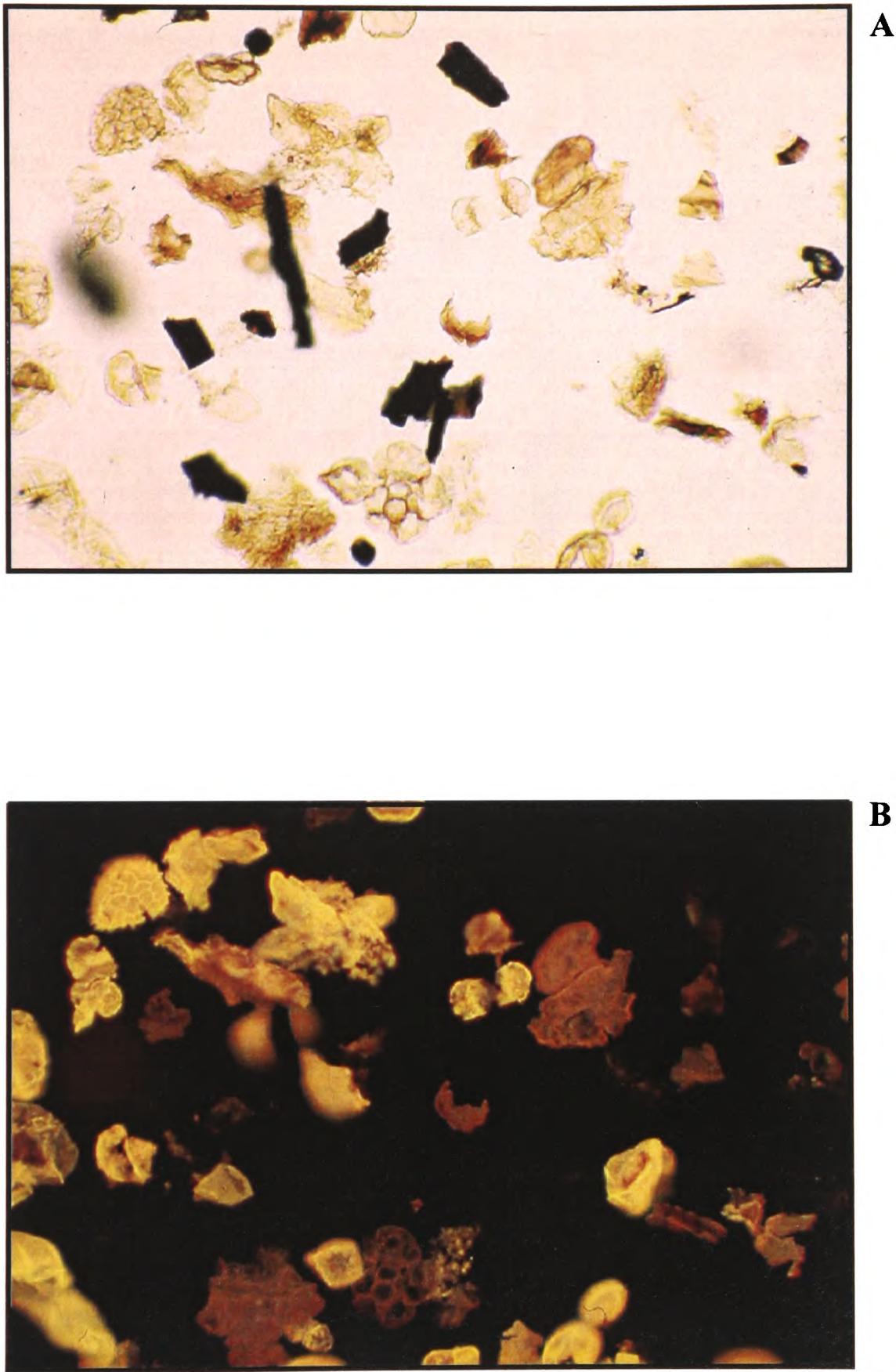


Figure B.11: These images comprise a range of palynomorphs including a foraminiferiferous lining (lower left of centre), a *Lycopodium* spp. (indigenous) in upper left-hand side of the images, and a small bisaccate pollen (middle right). The non-vita fragment above the foraminiferiferous lining is partial tubular in form. Although it lacks pitting it is almost certainly a tracheid. This particle would, however, be classified as a non-vita fragment, due to the lack of clear botanical characteristics. The majority of the SOM is transparent-yellow, fluorescent, non-fibrous. This association of organic matter indicates deposition in a saline, reducing environment. The host sediment is from the Gristhorpe plant bed. (Sample 202).

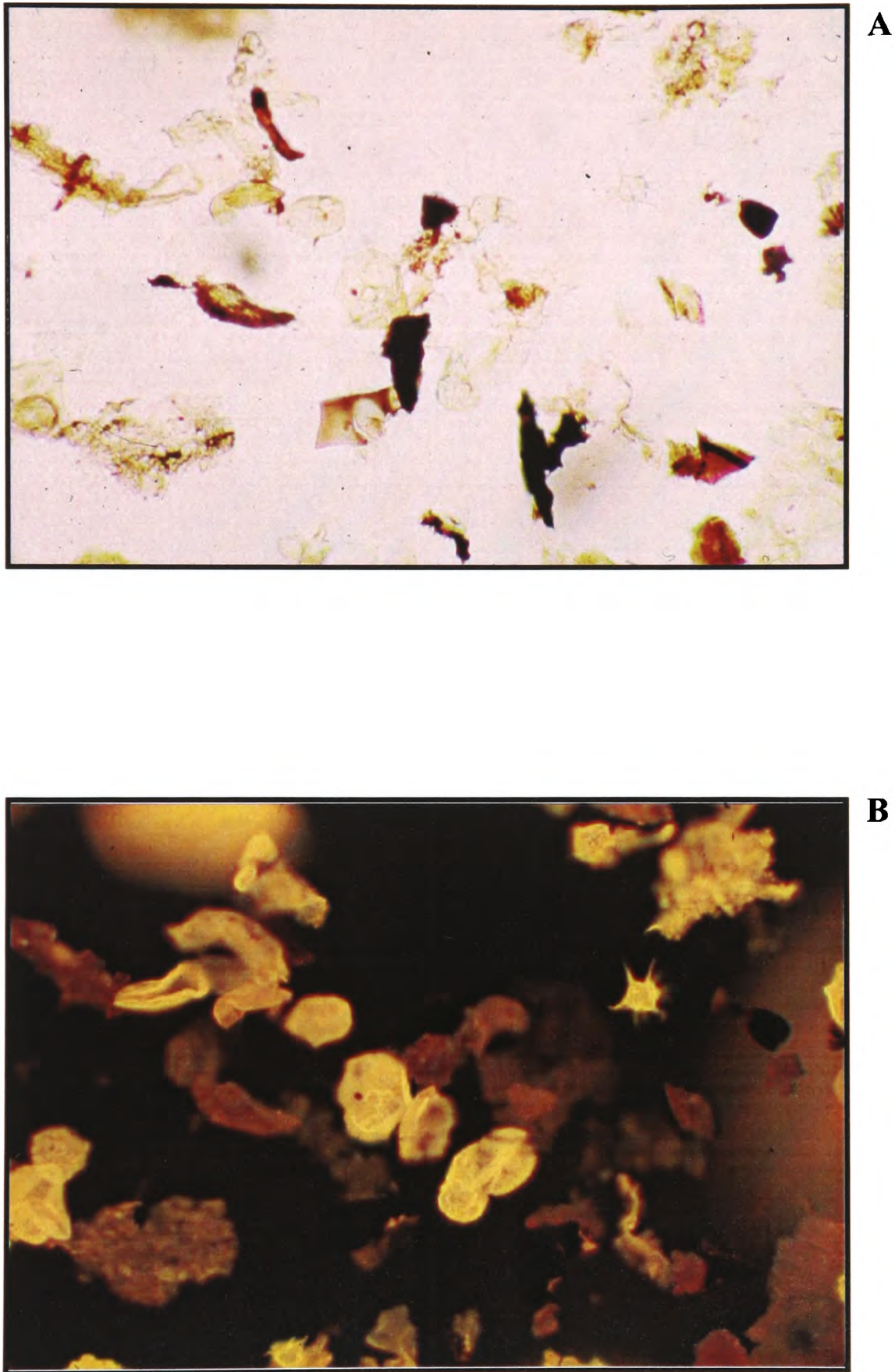


Figure B.12: The saline influence during the deposition of the Gristhorpe plant bed is clearly confirmed by the presence of acritarchs, as illustrated in these images. One lies in the upper right of centre and another at the base of the images. Note that these palynomorphs are clarified under fluorescent light. Preparation dominated by transparent-yellow, fluorescent, non-fibrous SOM.

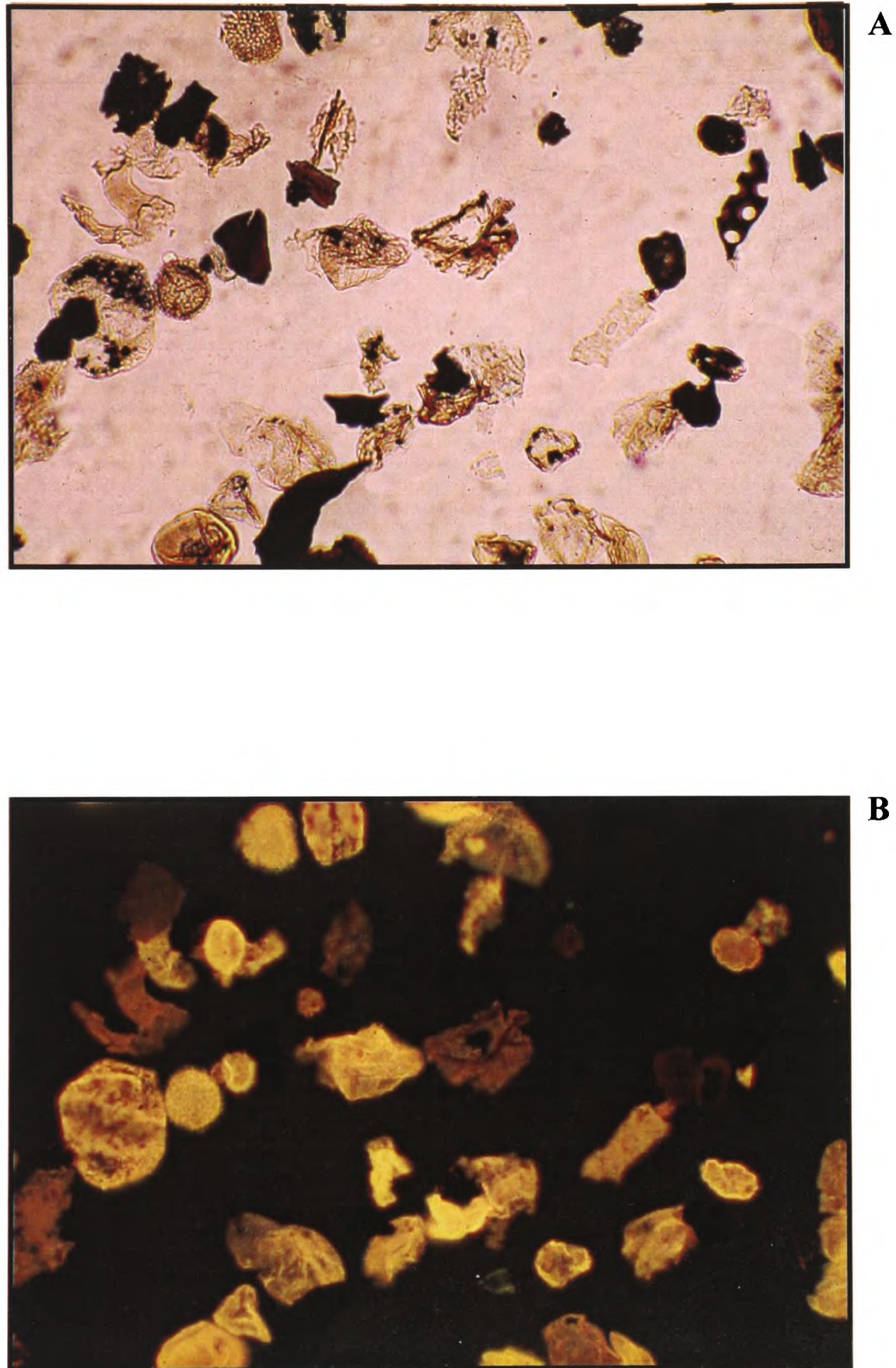


Figure B.13: Vita fragment (definite tracheid) in upper right of image A. Note the conspicuous perforated bordered pits (circular holes if complete). Each pit contains a concentric darker (thickened) zone. The pits show a biserial arrangement of two slightly offset rows. The tracheid is non-fluorescent. Small iron sulphide particles are evident in the palynomorphs, *e.g.*, the bisaccate pollen on the left-hand side of the image. (Sample 149).

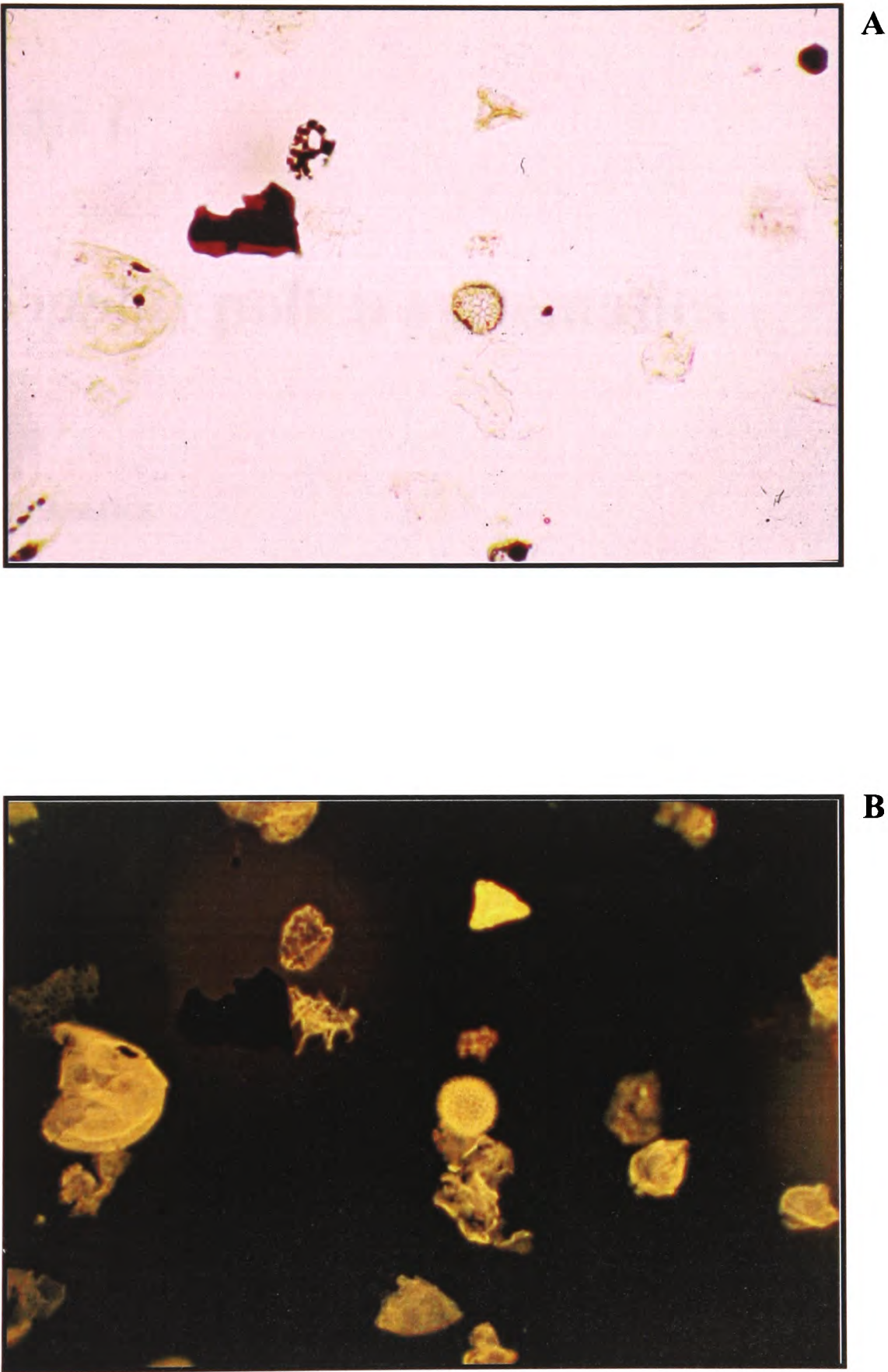


Figure B.14: Palynofacies dominated by palynomorphs. Dinoflagellate cysts are clearly clarified under fluorescent light, e.g., the dinoflagellate cysts to the right of the brown-striped non-vita fragment. (Sample 153).

Appendix C

Classopollis pollen systematics

C.1 Systematics

Genus *Classopollis* Pflug, 1953, emended, Pocock and Janisonius

Diagnosis: Pollen grains, distally monoporate; ovoid, spherical, or flatly acorn-shaped; exine two-layered; exoexine absent or much reduced over a circular area surrounding the distal pole, and absent or reduced over a triangular area with its centre at the proximal pole; intexine frequently bearing a reduced trilete scar, which has no germinal function, at the proximal pole; exine always ornamented by striations in a band or girdle surrounding the equator and interrupted (if at all) only at one point; the band usually, but not always, marking a zone of exinal thickening. The type species is *Classopollis classoides* Pflug, 1953

C.1.1 Occurrence and possible depositional environment

This description and the description of the possible affinities in subsection C.1.2A is from the detailed assessment of *Classopollis* genus by Pocock & Jansonius [1961].

Grains assignable to the genus *Classopollis* have been recorded from almost every microfloral assemblage of Jurassic or Lower Cretaceous age, in varying abundance. At some horizons, particularly in the Jurassic, it occurs at considerable abundance and is frequently dominant. It may, in rare cases constitute up to 98% of the entire assemblage. These assemblages, rich in *Classopollis*, frequently carry a very characteristic microflora containing, in addition to *Classopollis*, a moderate abundance

of inaperturate pollen, fairly abundant Monosulcites, and a varying, but usually small, percentage of trilete spores. Marine microflora is never abundant, but a small percentage of Dinophyceae and Hystrichosperidea are present in a majority of the assemblages.

Lithologically, samples rich in *Classopollis* are usually soft, light, grey, grey-green or brown shales or mudstones of the type developed in shallow water. Strata carrying assemblages of this type frequently grade laterally in one direction into strata carrying predominantly marine assemblages rich in Monosulcites-type pollen. Since *Classopollis*-type pollen is obviously not of a nature that would be carried over great distances, it is reasonable to assume that almost pure thickets of the plant must have occurred in areas where *Classopollis* pollen makes up the bulk of the spore and pollen spectrum. Both the occurrence of marine microflora and the predominant lithology of the deposits containing the species in abundance suggest that the plants producing *Classopollis* pollen favoured a coastal environment. The rarity of conifer pollen and trilete spores in such assemblages, together with the abundance of Monosulcites, probably derived from the Cycadaceae in laterally adjacent areas, suggests dry climatic conditions. Thus, it appears probably that an abundance of *Classopollis* pollen in a sample indicates that it was deposited in a coastal region under dry climatic conditions which is in accord with available geological evidence.

van Konijnenburg-van Cittert [1971] noted that pollen grains from *Brachyphyllum crucis* Kendall yielded *Classopollis*-type of pollen grain. Cones like *Brachyphyllum crucis* Kendall yielding *Classopollis*-type are also known from Germany, France, England, Iran and Argentina: *Hirmerella muensteri* (Schenk) Jung, (= *Cheirolepis muensteri* Schenk), *Hirmerella airelensis* Muir et v. Konijnenburg, *Brachyphyllum scotti* Kendall, *Pagiophyllum connivens* Kendall, *Masculostrobus risha* Barnard (attributed to *Brachyphyllum expansum* (Sternberg) Seward), and *Tomaxellia biforme* Archangelky. Finally, there is one more possible member of the Cheirolepidaceae: *Pagiophyllum maculosum* Kend. which has female cones rather like female cones of *Hirmerella*, thus belonging very probably to the *Hirmerella*-group [van Konijnenburg-van Cittert, 1971]. Harris [1979] stated that *Pagiophyllum maculosum* grew close to river channels and in *Equisetum* swamps during the deposition of the Cloughton Formation.

In 1987 van Konijnenburg-van Cittert noted that several more cones yielding *Classopollis* have been found: *Masculostrobus harrisianus* Lorch 1968 (attributed to *Cupressinocladus ramonensis*

Chaloner et Lorch); male cones attached to *Frenelopsis alata* (Feistmantel) Knobloch (Pons 1979, with associated female scales); *Frenelopsis oligostomata* Romariz emend. Alvin (Pons et Broutin 1978, with associated female scales); *Classostrobus comptonensis* Alvin, Spicer et Watson 1978 [associated with *Pseudofrenelopsis parceramosa* (Fontaine) Watson and *Hirmeriella*-type female cone-scales]. *Classostrobus* sp. A. of Francis (1983), associated with *Cupressinocladus valdenis* (Seward) Seward and *Classostrobus cathayanus* Zhou 1983 associated with *Suturovagina intermedia* Chow et Tsao. The general trend that is clearly evident in Cheirolepidaceae is an overall increase in diversity of form and structure with time, as is to be expected of evolution [van Konijnenburg-van Cittert, 1987].

C.1.2 Possible affinities of *Classopollis* pollen

A)

No Recent pollen of a type similar to *Classopollis* has been recorded, and therefore the only certain manner by which it can be related to its parent plant is by the discovery of sporangia containing grains assignable to the genus, attached to identifiable megafloreal parts. Such a discovery has not yet been made, and until such time, only very general conclusions regarding its affinities can be made. The general structure of the pollen grains, in particular the inverse tectate and internal caniculate structure of the exoexine indicates gymnospermous affinity. This conclusion has been accepted by most authors.

B)

van Konijnenburg-van Cittert & van der Burgh [1996] noted that *Classopollis*-type pollen grains have been recorded from the family Cheirolepidiaceae and are very common in Jurassic sediments both as macrofossils (male cones containing *Classopollis* grains have been recorded from all over the world) and as dispersed pollen. Taylor & Alvin [1984] suggested that this type of pollen grain can be transported by wind over long distances. van Konijnenburg-van Cittert & van der Burgh [1996] presumed that the plants that produced the *Classopollis*-type pollen in their study of the late Jurassic Sutherland coast, grew in upland forests and not near the coast from where most of the plant beds originate. This is contrary to the generally accepted idea that Jurassic Cheirolepidaceous species such as the tree *Hirmeriella muensteri* (Schenk) Jung might have grown in mangroves or at least near the coast,

later (mainly Cretaceous) species may have occupied varied habitats including arid uplands. Their proposal was based on the lack of cuticular remains in the plant beds.

Appendix D

Relative Abundances and Environmental Data

D.1 Data from Dogger and Saltwick Formations

Categories	Species No.	Sample No.									
		Particulate Organic Matter Categories (Species)									
Palynomorphs	1	Undifferentiated Palynomorphs	1.00	2.67	0.33	0.33	0.00	0.33	0.33	0.33	0.33
	2	Bisaccate Pollen	0.67	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.33
	3	Non-Bisaccate Pollen	10.33	4.67	11.67	0.33	0.33	0.00	1.33	2.00	3.67
	4	<i>Classopollis</i> Pollen	0.33	0.00	0.33	0.00	0.00	0.00	0.00	0.33	1.00
	5	Spores	3.33	2.00	3.33	4.33	0.67	0.00	0.33	2.33	7.00
	6	Fresh-Water Algae	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33
	7	Leiospheres	2.00	0.67	0.67	0.33	0.00	0.00	0.00	0.00	1.33
	8	Tasmanitids	1.33	1.33	1.00	0.00	0.33	0.00	0.00	0.00	2.00
	9	Acritarchs	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	Dinoflagellate cysts	3.00	1.33	1.33	0.00	0.00	0.00	0.00	0.33	1.00
Vita Fragments	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	13	Cuticle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.00	0.00	0.00	0.67	0.67	0.00	0.00	0.00	1.33
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.00	1.00	1.33	3.00	1.67	2.33	1.67	0.67	0.67
Non-Vita Fragments	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.33
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	8.67	7.00	12.00	22.00	22.00	24.67	15.67	16.67	9.00
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.33	0.33	0.67	3.00	5.33	8.67	2.00	1.33	2.33
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	1.33	0.67	0.00	0.00	0.00	0.00	0.33
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular,	3.33	3.33	5.33	8.00	4.33	7.00	7.00	6.67	3.67
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	4.33	6.67	3.33	4.67	9.33	10.33	4.67	9.33	6.67
Structureless Organic Matter	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	1.33	2.00	2.33	1.00	3.33	2.67	0.67	3.67	2.33
	35	Transparent-Yellow, Fluorescent, Fibrous	10.67	11.33	9.33	8.00	0.67	0.67	1.33	11.00	9.67
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	35.33	41.33	30.67	20.67	1.67	2.00	0.00	6.00	33.67
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.67	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	2.67	0.67	0.33	0.33	39.67	22.33	18.67	14.67	3.67
	39	Yellow-Brown, Fluorescent, Fibrous	6.00	5.33	7.67	6.00	0.33	1.33	3.33	5.00	5.67
	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.67	1.67	2.67	6.33	0.00	0.00	0.00	0.00	2.33
	41	Yellow-Brown, Non-Fluorescent, Fibrous	0.33	0.00	0.00	0.00	0.67	0.67	0.33	1.67	0.00
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	1.33	0.67	0.00	0.67	1.67	5.33	1.67	2.33	0.00
	43	Brown-Black, Fluorescent, Fibrous	0.00	3.33	2.00	4.33	1.67	0.00	0.33	0.33	0.00
	44	Brown-Black, Fluorescent, Non-Fibrous	0.33	0.67	1.00	0.00	1.00	0.33	0.33	0.00	0.33
	45	Brown-Black, Non-Fluorescent, Fibrous	0.33	1.33	0.00	2.00	3.00	7.67	8.67	8.33	0.67
Total	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	0.33	0.00	3.33	1.67	3.33	3.33	5.33	0.00
			15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Tablets		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Total Spikes		188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00
	Particles of O.M.		1126526.95	268220.70	5638261.74	103028.48	33265.94	59768.08	1261770.62	298240.33	107934.60
Weight processed (g)			5.01	15.03	10.01	4.98	9.98	4.97	4.97	4.98	14.94
Normalised O.M. p/g	47		0.83	0.20	4.17	0.08	0.02	0.04	0.93	0.22	0.08

Figure D.1: Relative percentage abundance of each palynomorph/palynodebris category of Boulby Quarry (Dogger-lower Saltwick Formation) samples.

Category	Species No.	Sample No.	11	12	13	14	15	16	17	18	19	20	
Palynomorphs		Particulate Organic Matter Categories (Species)											
	1	Unidentified Palynomorphs	1.00	0.00	0.67	0.00	2.00	0.00	0.67	0.00	1.00	0.67	
	2	Bisaccate Pollen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	
	3	Non-Bisaccate Pollen	0.67	2.00	0.00	0.33	1.00	2.67	3.00	0.00	3.33	2.67	
	4	Classopollis Pollen	0.00	0.00	0.00	0.00	1.33	0.00	0.33	0.00	9.33	0.33	
	5	Spores	2.33	1.67	0.67	0.67	7.00	1.33	1.33	2.33	0.00	11.00	6.67
	6	Fresh-Water Algae	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	7	Leiospheres	0.00	0.00	0.00	0.00	0.67	0.67	0.33	0.33	0.00	0.67	1.00
	8	Tasmanitids	0.00	0.00	0.00	0.00	1.33	0.00	1.00	1.00	0.00	0.33	0.33
	9	Acritarchs	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vita Fragments	10	Dinoflagellate cysts	0.33	0.33	0.00	0.33	0.00	0.00	0.67	0.00	0.00	0.00	
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	12	Fungal Bodies	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	
	13	Cuticle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	15	Definite Wood	0.33	0.00	0.33	0.00	0.00	0.33	0.00	0.67	0.00	0.00	0.33
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	
	17	Resin	1.33	0.33	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.00	0.00	0.00	1.33	1.33	0.33	0.33	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.33	3.33	1.00	1.67	0.67	1.00	0.33	0.67	2.00	5.33	
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	2.00	0.00	0.00	1.00	0.67	0.67	2.67	0.00	0.00	0.33	
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	16.67	18.67	22.00	20.67	8.33	12.00	25.33	20.33	10.33	28.00	
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.67	2.00	0.33	1.33	0.33	1.67	0.00	0.00	2.00	4.33	
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular,	2.33	6.00	6.33	9.00	4.00	8.00	6.67	5.33	2.67	10.00	
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Structureless Organic Matter	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	7.33	16.67	9.33	7.00	2.00	2.00	12.00	10.33	4.33	8.67	
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	0.67	2.67	1.33	1.00	1.00	0.33	2.00	1.67	0.67	1.67	
	35	Transparent-Yellow, Fluorescent, Fibrous	7.00	7.67	8.33	2.33	21.67	23.67	16.33	1.00	20.67	4.33	
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	8.00	8.00	5.33	4.00	18.33	18.67	11.00	0.00	14.67	1.33	
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	1.67	1.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	15.33	16.00	22.67	31.33	0.67	0.67	8.67	0.00	2.67	4.67	
	39	Yellow-Brown, Fluorescent, Non-Fibrous	10.00	2.67	7.00	1.67	11.67	17.67	4.33	0.33	4.67	3.67	
Total	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.33	
	41	Yellow-Brown, Non-Fluorescent, Fibrous	6.67	2.67	3.00	2.67	1.33	0.00	0.33	8.33	2.33	1.67	
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	2.33	2.67	4.00	7.33	0.00	0.00	0.67	5.67	1.00	6.00	
	43	Brown-Black, Fluorescent, Fibrous	2.67	0.33	0.33	0.33	12.67	5.00	0.33	0.00	1.33	0.67	
	44	Brown-Black, Fluorescent, Non-Fibrous	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	45	Brown-Black, Non-Fluorescent, Fibrous	9.00	5.00	6.33	6.67	1.00	0.00	1.00	3.67	3.33	3.00	
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.33	0.00	0.33	0.00	0.00	0.00	1.00	0.67	0.67	3.00	
	Total		15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
	Tablets		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
	Tablets		188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	
Total Spikes		70992.45	186162.88	98229.95	46273.61	1122047.71	1606118.38	380060.61	79650.85	112204.77	1020043.38		
Particles of O.M.		5.00	4.97	5.04	5.04	5.03	5.02	4.95	9.98	5.03	5.03		
Weight processed (g)		0.05	0.14	0.07	0.03	0.83	1.19	0.28	0.06	0.08	0.76		
Normalised O.M. p/g	47												

Category	Species No.	Sample No.	Particulate Organic Matter Categories (Species)										HH CF										
			Unidentified Palynomorphs										HH CF										
Palynomorphs	1		Unidentified Palynomorphs										HH CF										
	2		Bisaccate Pollen										HH CF										
	3		Non-Bisaccate Pollen										HH CF										
	4		Classopollis Pollen										HH CF										
	5		Spores										HH CF										
	6		Fresh-Water Algae										HH CF										
	7		Leiospheres										HH CF										
	8		Tasmanitids										HH CF										
	9		Acritarchs										HH CF										
	10		Dinoflagellate cysts										HH CF										
	11		Zoomorphs										HH CF										
	12		Fungal Bodies										HH CF										
Vita Fragments	13		Cuticle										HH CF										
	14		Epidermal Tissue										HH CF										
	15		Definite Wood										HH CF										
	16		Vascular Bundles										HH CF										
	17		Resin										HH CF										
	18		Plant Tissues										HH CF										
	Non-Vita Fragments	19		Brown-Equidimensional, Fluorescent, Cellular										HH CF									
		20		Brown-Equidimensional, Non-Fluorescent, Cellular										HH CF									
		21		Brown-Equidimensional, Fluorescent, Non-Cellular										HH CF									
		22		Brown-Equidimensional, Non-Cellular, Non-Fluorescent										HH CF									
		23		Brown-Bladed, Fluorescent, Cellular										HH CF									
		24		Brown-Bladed, Non-Fluorescent, Cellular										HH CF									
25			Brown-Bladed, Fluorescent, Non-Cellular										HH CF										
26			Brown-Bladed, Non-Fluorescent, Non-Cellular										HH CF										
27			Black-Equidimensional, Fluorescent, Cellular										HH CF										
28			Black-Equidimensional, Non-Fluorescent, Cellular										HH CF										
29			Black-Equidimensional, Fluorescent, Non-Cellular										HH CF										
30			Black-Equidimensional, Non-Fluorescent, Non-Cellular										HH CF										
Structureless Organic Matter	31		Black-Bladed, Fluorescent, Cellular										HH CF										
	32		Black-Bladed, Non-Fluorescent, Cellular										HH CF										
	33		Black-Bladed, Fluorescent, Non-Cellular										HH CF										
	34		Black-Bladed, Non-Fluorescent, Non-Cellular										HH CF										
	35		Transparent-Yellow, Fluorescent, Fibrous										HH CF										
	36		Transparent-Yellow, Non-Fluorescent, Non-Fibrous										HH CF										
	37		Transparent-Yellow, Non-Fluorescent, Fibrous										HH CF										
	38		Transparent-Yellow, Non-Fluorescent, Non-Fibrous										HH CF										
	39		Yellow-Brown, Fluorescent, Non-Fibrous										HH CF										
	40		Yellow-Brown, Non-Fluorescent, Non-Fibrous										HH CF										
	41		Yellow-Brown, Non-Fluorescent, Fibrous										HH CF										
	42		Yellow-Brown, Non-Fluorescent, Non-Fibrous										HH CF										
Total Spikes	43		Brown-Black, Fluorescent, Fibrous										HH CF										
	44		Brown-Black, Fluorescent, Non-Fibrous										HH CF										
	45		Brown-Black, Non-Fluorescent, Fibrous										HH CF										
	46		Brown-Black, Non-Fluorescent, Non-Fibrous										HH CF										
	Total																						
	Tablets																						
	Total Spikes																						
	Particles of O.M.																						
	Weight processed (g)																						
	Normalised O.M. p/g	47																					

Category	Species No.	Sample No.	32	33	34	35	36	37	38	39	40	41	42	43
Palynomorphs		Particulate Organic Matter Categories (Species)												
	1	Unidentified Palynomorphs	0.33	0.67	0.67	0.67	1.33	0.00	0.00	0.67	0.00	0.67	1.00	0.33
	2	Bisaccate Pollen	1.00	0.67	0.33	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	Non-Bisaccate Pollen	1.33	8.00	5.33	1.33	8.33	2.33	0.00	3.33	0.33	1.67	0.67	1.67
	4	Classopollis Pollen	0.33	0.00	0.00	0.00	1.00	0.00	0.00	0.33	0.33	0.00	0.00	0.00
	5	Spores	4.33	3.33	2.00	0.33	4.33	8.00	0.33	6.67	0.67	2.33	2.00	0.33
	6	Fresh-Water Algae	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	Leiospheres	0.00	0.67	0.33	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	Tasmanids	0.00	0.67	0.33	0.00	0.67	0.33	0.00	0.00	0.00	0.33	0.33	0.00
	9	Acriarchs	0.33	1.33	2.33	0.67	3.33	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	10	Dinoflagellate cysts	0.33	2.67	1.33	1.33	5.33	0.33	0.00	1.33	0.67	0.00	0.33	0.00
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vita Fragments	15	Definite Wood	1.00	0.00	0.33	1.33	0.00	0.33	0.00	0.00	0.33	0.00	0.67	1.00
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.33	0.00	0.00	0.33	0.67	3.33	1.00	4.00	4.67	0.33	8.00	2.33
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.67	0.00	0.00	0.00	0.00	0.67	0.67	0.00	0.00	0.33	0.00	0.00
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	16.67	1.33	5.67	2.33	4.33	17.00	27.00	16.00	31.67	1.33	39.33	37.67
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.33	0.67	0.33	1.33	1.00	2.67	0.33	0.67	1.00	0.33	7.67	5.33
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	4.00	1.67	2.00	3.67	0.67	4.67	3.00	11.00	7.33	1.33	13.00	11.33
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	9.00	2.00	5.00	3.00	3.00	4.67	5.67	12.33	19.33	0.00	10.00	9.00
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	3.00	0.67	1.00	2.00	1.00	0.67	0.00	2.00	3.67	0.67	1.33	1.33
	35	Transparent-Yellow, Fluorescent, Fibrous	1.33	7.67	4.00	6.00	27.67	13.33	1.33	9.67	0.33	15.67	6.33	9.33
	36	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	11.00	7.67	7.67	15.33	19.00	25.67	12.67	15.33	6.33	58.00	2.00	10.00
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	0.67	0.33	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	10.33	32.33	28.67	38.00	3.67	0.00	28.67	3.00	11.00	0.00	0.00	0.00
	39	Yellow-Brown, Fluorescent, Non-Fibrous	3.33	5.67	6.33	4.00	3.00	7.33	1.67	7.33	1.00	10.00	6.00	9.67
	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.67	1.67	1.00	0.00	1.67	2.67	0.33	2.67	0.33	2.00	0.00	0.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous	6.00	6.00	6.67	3.67	4.00	1.00	4.33	1.00	1.33	0.00	0.33	0.00
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	5.00	8.33	5.33	8.00	2.00	0.33	2.33	0.67	1.33	0.00	0.00	0.00
Total	43	Brown-Black, Fluorescent, Fibrous	3.00	1.00	0.00	0.67	0.33	2.33	1.00	0.00	1.00	3.33	0.33	0.33
	44	Brown-Black, Fluorescent, Non-Fibrous	0.00	1.00	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	12.67	1.33	9.00	3.33	1.67	1.33	9.33	1.33	6.33	1.00	0.00	0.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	3.67	2.33	1.67	0.00	0.00	1.00	0.33	0.67	0.67	0.00	0.33	0.33
			15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
			188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00
			117268.53	313863.86	536798.55	129744.83	55166.85	11401818.18	355588.46	3770140.28	374760.96	5655210.42	2827605.21	3747609.56
			15.04	9.99	15.02	15.00	20.06	4.95	4.96	4.99	5.02	4.99	4.99	5.02
			0.09	0.23	0.40	0.10	0.04	8.44	0.26	2.79	0.28	4.19	2.09	2.77
	47	Normalised O.M. p/g												

Figure D.4: Relative percentage abundance of each palynomorph/palynodebris category of Blea Wyke Point (Dogger-lower Saltwick Formation) samples.

Category	Species No.	Sample No.		44	45	46	47	48	49	50	51	52	53
Palynomorphs		Particulate Organic Matter Categories (Species)											
	1	Unidentified Palynomorphs		2.33	0.33	0.33	0.00	0.33	0.33	0.33	0.00	0.00	1.33
	2	Bisaccate Pollen		0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.33
	3	Non-Bisaccate Pollen		7.00	1.33	0.33	0.67	1.67	0.67	0.67	0.67	1.33	2.33
	4	Clasopollis Pollen		0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	5	Spores		5.33	8.00	1.00	2.67	0.67	0.67	9.33	1.00	4.67	5.67
	6	Fresh-Water Algae		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	Leiospheres		1.00	0.33	0.33	0.00	0.33	0.00	0.00	0.00	0.00	0.33
	8	Tasmanitids		1.00	0.33	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	9	Acritarchs		0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
Vita Fragments	10	Dinoflagellate cysts		0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11	Zoomorphs		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	14	Epidermal Tissue		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood		1.00	0.33	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.33
	16	Vascular Bundles		0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	Resin		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues		0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.67
	19	Brown-Equidimensional, Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	20	Brown-Equidimensional, Non-Fluorescent, Cellular		2.67	1.00	1.00	0.00	2.00	2.33	0.00	0.00	0.00	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular		0.00	1.67	0.33	0.00	0.33	1.67	0.00	0.00	0.00	0.33
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent		7.67	10.00	14.00	20.67	26.33	20.00	12.00	15.67	20.33	11.00
	23	Brown-Bladed, Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular		1.67	0.00	1.33	0.00	0.33	2.33	0.33	0.00	1.00	0.33
	25	Brown-Bladed, Fluorescent, Non-Cellular		0.00	0.00	6.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular		5.67	3.67	0.00	2.33	4.67	3.00	3.67	5.00	2.00	3.67
	27	Black-Equidimensional, Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular		2.33	0.33	3.33	7.00	11.00	6.33	4.67	5.33	2.00	2.67
	31	Black-Bladed, Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular		0.00	0.33	0.67	0.00	0.33	1.67	2.33	0.33	0.67	1.67
	35	Transparent-Yellow, Fluorescent, Fibrous		5.00	13.33	7.00	4.00	7.00	2.33	17.33	4.00	3.67	6.00
	36	Transparent-Yellow, Fluorescent, Non-Fibrous		15.33	30.33	9.33	3.33	20.00	7.00	28.00	5.67	9.00	33.33
	37	Transparent-Yellow, Non-Fluorescent, Fibrous		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous		4.33	0.33	6.67	21.67	4.00	7.33	3.67	39.67	1.33	2.00
	39	Yellow-Brown, Fluorescent, Non-Fibrous		10.33	9.00	19.00	2.00	8.33	10.00	9.67	0.67	10.00	9.00
Total	40	Yellow-Brown, Fluorescent, Non-Fibrous		1.00	4.67	2.33	0.33	0.67	0.67	0.33	0.33	3.00	8.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous		0.33	1.33	6.67	2.67	1.67	11.33	0.00	1.67	0.67	0.33
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous		3.00	0.67	0.67	20.00	1.33	3.00	1.67	1.67	1.00	0.67
	43	Brown-Black, Fluorescent, Fibrous		1.67	7.33	9.33	1.00	1.33	6.00	0.67	1.00	22.00	7.33
	44	Brown-Black, Fluorescent, Non-Fibrous		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.33
	45	Brown-Black, Non-Fluorescent, Fibrous		7.67	5.00	10.00	9.67	5.33	13.00	2.33	11.33	3.67	0.67
	46	Brown-Black, Non-Fluorescent, Non-Fibrous		13.00	0.33	0.33	2.00	1.67	0.33	2.33	4.33	0.33	0.00
	Total			15.00	15.00	15.00	15.00	100.00	15.00	15.00	15.00	15.00	15.00
	Tablets			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Total Spikes			188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00
	Particles of O.M.			5655210.42	11287800.00	247365.88	117463.79	467519.88	391583.99	940650.00	283328.31	2816317.37	430700.55
	Weight processed (g)			4.99	5.00	4.96	10.01	5.03	4.97	5.00	4.98	5.01	5.04
	Normalised O.M. p/g			4.19	8.36	0.18	0.09	0.35	0.29	0.70	0.21	2.09	0.32

Figure D.5: Relative percentage abundance of each palynomorph/palynodebris category of Blea Wyke Point (Saltwick Formation) samples.

Category	Species No.	Sample No.	54	55	56	57	58	59	60
Palynomorphs		Particulate Organic Matter Categories (Species)							
	1	Unidentified Palynomorphs	0.67	0.67	0.00	0.00	0.33	0.33	0.00
	2	Bisaccate Pollen	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	Non-Bisaccate Pollen	1.67	2.00	0.00	0.33	1.67	4.33	2.67
	4	Classopollis Pollen	0.33	1.00	0.00	0.00	0.00	2.00	7.33
	5	Spores	3.67	3.33	0.33	0.00	3.33	19.33	15.67
	6	Fresh-Water Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	Leisospheres	0.00	0.00	0.00	0.00	0.33	0.33	0.33
	8	Tasmanids	0.00	0.00	0.00	0.00	0.00	0.67	0.67
	9	Acritarchs	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	Dinoflagellate cysts	0.00	0.00	0.00	0.00	0.33	0.00	0.00
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vita Fragments	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.00	0.33	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.67	0.00	0.00	0.00	0.00	1.00	0.00
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.00	0.00	0.33	0.00	0.00	0.00
Non-Vita Fragments	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.67	1.00	0.00	1.00	0.67	0.00	2.67
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	1.33	0.67	0.00	1.67	0.00	0.33	0.33
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	12.33	8.67	10.00	15.00	17.33	5.33	11.00
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	1.67	2.00	0.00	0.33	0.33	0.00	4.33
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	5.33	4.00	2.00	3.00	1.67	4.33	11.67
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	12.67	14.33	4.67	9.00	11.00	19.33	4.00
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	3.67	3.00	1.33	1.00	2.33	5.00	1.00
Structureless Organic Matter	35	Transparent-Yellow, Fluorescent, Fibrous	2.00	4.67	0.33	0.00	2.33	5.67	3.33
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	18.33	25.00	0.00	2.33	6.00	22.67	13.67
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.33	0.00	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	3.67	4.33	57.33	36.00	14.33	0.00	5.33
	39	Yellow-Brown, Fluorescent, Non-Fibrous	12.67	7.00	0.00	1.67	2.00	4.67	3.33
	40	Yellow-Brown, Fluorescent, Non-Fibrous	3.67	5.33	0.00	0.00	0.00	1.33	0.67
	41	Yellow-Brown, Non-Fluorescent, Fibrous	2.33	2.00	1.33	1.33	2.00	0.00	2.67
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	1.00	0.67	8.67	3.33	1.00	0.33	3.00
	43	Brown-Black, Fluorescent, Fibrous	3.33	4.67	0.67	1.33	1.00	0.00	0.33
	44	Brown-Black, Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	7.67	4.00	10.00	17.00	30.00	3.00	4.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.67	1.33	3.33	5.00	1.67	0.00	2.00
Total			15.00	15.00	15.00	15.00	15.00	15.00	15.00
Tablets			100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Spikes			188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00
Particles of O.M.			306300.88	466592.26	54159.95	85685.01	52433.11	234693.11	119366.78
Weight processed (g)			4.98	5.04	5.01	4.99	14.95	10.02	5.03
Normalised O.M. p/g	47		0.23	0.35	0.04	0.06	0.04	0.17	0.09

Figure D.6: Relative percentage abundance of each palynomorph/palynodebris category of Blea Wyke Point (Saltwick Formation) samples.

D.2 Data from Eller Beck to Scalby Formations: Iron Scar to Scalby Ness

Category	Species No.	Sample No.	61	62	63	64	65	66	67	68	69	70	71	72	73
Palynomorphs		Particulate Organic Matter Categories (Species)													
	1	Unidentified Palynomorphs	0.00	0.00	0.67	1.67	1.67	1.00	0.67	1.33	0.67	4.33	1.33	1.67	0.67
	2	Bisaccate Pollen	0.00	0.00	0.67	1.33	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.67
	3	Non-Bisaccate Pollen	0.33	0.00	2.00	2.33	12.00	6.67	9.33	2.67	1.67	4.33	8.67	1.67	1.33
	4	Classopollin Pollen	0.00	0.00	0.00	2.33	1.00	0.67	1.00	0.33	0.33	1.33	1.00	2.00	1.33
	5	Spores	0.00	0.00	5.33	7.00	1.67	2.67	2.00	2.33	1.00	9.33	7.00	6.33	6.67
	6	Fresh-Water Algae	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.67
	7	Leiospheres	0.00	0.00	3.00	0.00	0.67	0.00	0.33	0.00	0.00	2.00	2.00	2.00	0.33
	8	Tasmanitids	0.00	0.00	0.00	1.67	0.00	0.00	0.00	0.00	0.00	2.33	2.33	1.33	0.33
	9	Acritarchs	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
Vita Fragments	10	Dinoflagellate cysts	0.00	0.00	1.00	0.67	1.33	1.67	2.33	1.00	0.00	2.33	2.67	1.00	1.67
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	16	Vascular Bundles	0.00	0.33	0.67	0.67	0.67	1.00	0.67	0.67	0.67	0.67	1.67	0.33	0.67
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.33	0.00	0.33	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.33	0.00	0.33	0.67
Non-Vita Fragments	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.00	17.00	11.00	0.00	0.00	0.00	3.67	1.33	0.00	0.33	0.00	0.00	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.33	0.00	0.00	0.00	1.00	0.67	3.67	1.33	0.00	0.67	4.00	0.67	1.33
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	2.67	31.00	26.33	23.33	8.33	9.67	17.00	11.67	3.33	11.00	14.33	20.33	14.67
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.00	11.33	2.67	3.00	1.00	1.33	4.67	1.00	0.67	1.00	1.00	1.00	2.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.67	0.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	0.00	10.00	5.33	3.33	1.67	4.00	9.33	3.33	1.00	7.00	7.00	6.00	3.67
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	3.33	23.00	7.33	12.67	5.67	4.67	5.33	10.00	1.00	2.33	2.67	4.67	6.33
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	35	Transparent-Yellow, Fluorescent, Fibrous	0.67	2.33	4.00	1.00	1.33	0.67	2.33	2.33	2.00	1.00	0.67	2.33	0.67
	36	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	1.00	0.67	19.33	17.33	23.00	3.33	3.67	5.33	5.00	10.00	1.00	11.67	12.00
	37	Transparent-Yellow, Fluorescent, Non-Fibrous	4.00	1.00	5.67	4.67	9.67	23.00	25.67	32.67	27.67	14.67	17.33	10.00	9.33
	38	Transparent-Yellow, Non-Fluorescent, Fibrous	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.67	0.00	0.33
	39	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	45.67	1.00	0.00	0.67	11.33	7.67	4.67	6.33	28.33	0.67	1.00	2.67	0.00
Total	40	Yellow-Brown, Fluorescent, Non-Fibrous	1.33	0.00	2.33	3.67	9.00	11.67	2.00	6.00	8.33	3.33	4.00	4.67	15.00
	41	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.67	5.00	0.33	1.00	5.33	2.67	0.00	0.00	0.33
	42	Yellow-Brown, Non-Fluorescent, Fibrous	6.33	2.00	0.00	1.33	0.33	1.33	0.67	1.67	0.33	3.00	9.67	5.33	3.00
	43	Brown-Black, Fluorescent, Fibrous	20.67	0.00	0.33	0.33	0.67	1.00	0.67	1.33	2.67	1.00	0.67	0.67	0.00
	44	Brown-Black, Non-Fluorescent, Non-Fibrous	0.33	0.00	0.33	0.33	1.67	5.33	0.33	3.33	1.33	4.67	0.67	3.67	11.00
	45	Brown-Black, Non-Fluorescent, Fibrous	10.33	0.33	1.67	6.67	1.00	4.33	2.00	0.00	1.00	2.33	0.00	0.00	0.33
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	2.33	0.00	0.00	0.00	0.33	0.67	0.33	0.00	2.33	5.00	7.33	4.67	3.67
		Total	20.00	15.00	10.00	10.00	10.00	10.00	15.00	15.00	15.00	10.00	10.00	10.00	10.00
		Tablets	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Spikes			250840.00	188130.00	125420.00	125420.00	125420.00	125420.00	188130.00	188130.00	125420.00	125420.00	125420.00	125420.00	125420.00
		Particles of O.M.	113790.60	67166.90	187848.23	311393.30	1251364.42	29498.79	2275766.13	1251696.61	371798.42	1251696.61	3770140.28	1261770.62	943480.44
		Weight processed (g)	15.03	30.01	20.03	20.01	30.02	25.01	4.96	5.01	5.06	10.02	9.98	9.94	9.97
	47	Normalised O.M. p/g	0.08	0.05	0.14	0.23	0.93	0.02	1.68	0.93	0.28	0.93	2.79	0.93	0.70

Figure D.7: Relative percentage abundance of each palynomorph/palynodebris category of Eller Beck Formation-lower Sycarham Member samples from Iron Scar.

Category	Species No.	Sample No.	74	75	76	77	78	79	80	81	82	83	84
Palynomorphs		Particulate Organic Matter Categories (Species)											
	1	Unidentified Palynomorphs											
	2	Bisaccate Pollen	1.00	0.00	0.00	2.00	0.33	0.67	0.67	0.67	1.33	0.00	0.67
	3	Non-Bisaccate Pollen	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	4	Classopolis Pollen	3.33	0.67	0.33	3.66	0.33	0.00	0.00	0.67	5.67	0.00	0.00
	5	Spores	5.33	0.00	0.00	2.67	0.00	0.33	0.33	0.00	0.33	0.00	0.00
	6	Fresh-Water Algae	13.00	1.33	0.00	12.00	4.33	1.33	1.33	3.67	23.67	0.33	1.67
	7	Leiospheres	0.33	0.00	0.33	0.00	0.33	0.00	0.33	0.00	0.00	0.33	0.00
	8	Tasmanitids	2.67	0.00	0.00	0.00	1.00	0.00	0.67	0.00	0.33	0.00	0.00
	9	Acritarchs	0.67	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.67	0.00	0.00
	10	Dinoflagellate cysts	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00	0.00
	11	Zoomorphs	1.33	1.33	0.00	2.33	0.67	0.67	0.67	0.67	1.67	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.33	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.67	0.00	0.00	0.33	0.67	0.33	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	16	Vascular Bundles	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
Non-Vita Fragments	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.00	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.33	0.00	0.00	0.00	1.67	0.00	0.33	0.00	0.00	0.33	0.67
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.33	0.00	0.00	0.00	1.33	0.33	0.67	1.00	0.00	1.00	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	7.33	1.33	0.67	0.67	1.33	1.67	1.00	2.67	0.33	0.33	0.33
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	11.67	29.33	24.00	15.00	4.33	19.00	2.33	13.67	10.33	37.67	30.67
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	2.00	0.00	0.00	1.00	2.67	1.67	0.00	1.33	0.00	0.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	5.00	8.00	1.00	4.67	2.33	0.67	0.67	0.33	0.00	0.00	0.00
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.67	0.00	11.67	4.67
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.67	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	8.33	25.00	16.00	2.00	3.67	2.33	2.33	0.00	0.00	0.00	10.33
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.67	3.00	0.00	0.00
Structureless Organic Matter	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	35	Transparent-Yellow, Fluorescent, Fibrous	15.00	3.00	0.00	1.00	1.33	0.33	0.33	2.33	0.00	0.00	0.00
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	11.00	0.00	0.00	13.33	9.00	11.00	7.67	13.33	7.33	0.00	2.00
	37	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	0.00	2.00	0.00	15.33	9.67	7.67	0.00	6.33	29.33	0.33	1.00
	38	Transparent-Yellow, Non-Fluorescent, Fibrous	0.33	0.67	9.33	5.00	0.33	0.00	0.33	0.00	0.00	0.00	3.33
	39	Yellow-Brown, Fluorescent, Non-Fibrous	6.33	1.67	0.33	1.67	12.00	13.67	15.67	20.67	7.33	8.00	7.00
	40	Yellow-Brown, Fluorescent, Fibrous	0.00	0.67	0.33	0.00	1.00	1.33	4.00	1.00	0.33	0.00	6.33
	41	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.67	0.33	3.33	0.67	2.00	4.33	0.67	0.33	1.00	0.00	2.67
	42	Yellow-Brown, Non-Fluorescent, Fibrous	0.33	2.33	5.67	2.33	0.67	0.67	1.67	2.67	0.33	1.33	3.67
	43	Brown-Black, Fluorescent, Fibrous	1.00	4.33	9.33	0.33	22.67	13.67	17.00	9.33	3.67	8.00	6.00
	44	Brown-Black, Fluorescent, Non-Fibrous	0.00	2.00	1.33	0.33	1.33	0.00	2.33	1.67	1.33	1.00	4.00
	45	Brown-Black, Non-Fluorescent, Fibrous	0.33	8.00	23.67	4.00	6.33	9.00	1.67	1.67	0.33	0.67	4.33
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	3.33	0.00	9.33	2.00	1.00	7.67	0.33	0.00	14.67	5.00
Total			100.00	100.00	100.00	100.00	100.00	20.00	10.00	10.00	0.00	0.67	3.33
Tablets													
Total Spikes			125420.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Particles of O.M.			125420.00	125420.00	125420.00	125420.00	125420.00	250840.00	125420.00	125420.00	125420.00	125420.00	125420.00
Weight processed (g)			632795.16	77919.98	45423.38	187194.03	1257973.92	624601.59	290010.79	198031.58	3766366.37	92533.57	36676.80
Normalised O.M. p/g	47		0.47	0.06	0.03	0.14	0.93	10.04	9.98	10.00	9.99	15.06	9.96
								0.46	0.21	0.15	2.79	0.07	0.03

Figure D.8: Relative percentage abundance of each palynomorph/palynodebris category of lower-middle Sycarham Member samples from south of Iron Scar.

Category	Species No.	Sample No.	85	86	87	88	89	90	91	92	93	94	95
Palynomorphs		Particulate Organic Matter Categories (Species)											
	1	Unidentified Palynomorphs	1.67	0.00	1.00	0.33	0.67	0.33	0.67	0.67	2.00	1.00	1.00
	2	Bisaccate Pollen	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00
	3	Non-Bisaccate Pollen	1.33	0.00	0.67	1.00	0.67	0.00	0.00	1.67	1.33	2.33	0.00
	4	Classopollis Pollen	5.67	0.00	0.33	2.00	0.33	0.33	1.33	7.33	0.33	0.00	1.67
	5	Spores	6.33	3.00	8.33	7.67	3.33	6.67	1.67	7.00	3.00	3.67	8.33
Vita Fragments	6	Fresh-Water Algae	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
	7	Leiospheres	0.00	0.00	0.00	0.67	0.00	0.33	0.33	0.00	0.33	0.00	0.00
	8	Tasmanitids	0.67	0.00	0.33	0.33	1.00	0.33	0.00	0.00	0.67	0.00	0.00
	9	Acritarchs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	Dinoflagellate cysts	1.00	0.00	0.00	0.00	0.00	0.00	0.67	1.00	1.33	2.33	2.00
	11	Zoomorphs	0.00	0.00	0.33	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33
	15	Definite Wood	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	16	Vascular Bundles	0.00	0.33	0.00	1.00	0.00	0.00	0.33	0.33	0.00	0.00	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.33	0.00	1.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	3.33	0.33	0.67	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	5.00	2.00	2.33	1.00	0.33	1.00	0.67	0.00	1.67
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	32.00	18.00	17.67	15.00	21.00	19.67	13.00	12.33	9.00	13.33	15.67
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.33	1.00	0.00	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	1.33	0.00	0.00	0.33	1.00	2.33	1.00	2.00	0.33	0.00	0.67
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	8.33	3.33	4.00	6.67	8.00	5.33	6.00	8.33	4.67	3.00	9.67
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	1.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	6.67	14.33	6.33	7.33	3.33	4.67	1.00	3.33	6.00	13.33	8.00
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	1.33	0.33	4.00	1.33	4.00	0.67	1.00	1.67	2.33	6.33	2.33
	35	Transparent-Yellow, Fluorescent, Fibrous	8.33	3.00	7.33	7.67	7.67	4.67	18.00	7.67	11.33	12.00	8.00
Tablets	36	Transparent-Yellow, Fluorescent, Non-Fibrous	5.67	5.67	18.33	19.67	13.33	5.33	13.33	18.33	14.67	15.33	11.00
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.33	0.33	0.00	0.33	1.33	0.67	0.67	0.00	0.00	0.00	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	1.33	20.00	1.33	1.00	6.00	10.67	1.33	0.33	2.33	3.33	6.00
	39	Yellow-Brown, Fluorescent, Non-Fibrous	2.33	5.00	16.00	12.00	8.33	7.00	22.33	9.67	16.67	4.00	3.00
	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.67	0.00	1.33	3.33	3.67	0.00	2.33	1.67	2.00	1.00	2.67
	41	Yellow-Brown, Non-Fluorescent, Fibrous	1.00	4.33	0.00	1.00	3.67	8.33	1.00	0.33	0.33	2.33	1.67
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	1.33	4.67	0.33	0.33	1.33	5.67	0.00	0.67	0.00	0.33	1.00
	43	Brown-Black, Fluorescent, Fibrous	2.00	3.33	3.33	5.00	5.00	1.33	8.67	7.00	11.00	6.33	0.67
	44	Brown-Black, Fluorescent, Non-Fibrous	2.33	0.33	0.00	0.67	1.67	0.00	0.00	0.00	2.00	0.00	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	3.00	12.00	0.00	1.33	0.00	10.00	1.00	5.33	2.00	6.33	10.33
Particles of O.M.	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.33	1.67	0.33	1.00	0.00	1.33	0.00	0.00	0.33	0.00	0.00
		Total	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
		Tablets	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
		Total Spikes	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00
Weight processed (g)			35138.40	58010.50	5666566.27	11660950.41	1881300.00	57009.09	708320.78	1606118.38	2794009.90	798288.54	121238.61
		Normalised O.M. P/g	5.02	10.03	4.98	4.84	5.00	10.00	4.98	5.02	5.05	5.05	5.06
	47		0.26	0.04	4.20	8.63	1.39	0.04	0.52	1.19	2.07	0.59	0.09

Figure D.9: Relative percentage abundance of each palynomorph/palynodebris category of middle Sycarham Member to basal Millepore Bed samples from south of Iron Scar.

Category	Species No.	Sample No.	96	97	98	99	100	101	102	103	104	105	106
Palynomorphs		Particulate Organic Matter Categories (Species)											
	1	Unidentified Palynomorphs	1.00	0.00	0.33	1.00	1.00	1.33	0.33	1.00	0.33	0.00	0.33
	2	Bisaccate Pollen	0.33	0.00	0.33	0.33	0.33	0.00	0.67	0.00	0.00	0.00	0.00
	3	Non-Bisaccate Pollen	1.67	0.00	0.00	4.33	3.67	1.00	2.33	3.00	0.33	1.00	1.33
	4	Classopollis Pollen	1.33	0.00	1.00	0.00	0.00	0.00	2.00	1.00	0.00	0.00	1.33
	5	Spores	2.67	1.33	1.67	6.67	6.67	8.33	4.67	3.67	2.00	5.00	1.67
	6	Fresh-Water Algae	0.00	0.00	0.00	2.00	2.00	0.33	0.00	0.00	0.33	0.33	0.00
	7	Leiospheres	0.00	0.00	1.00	0.67	1.33	2.33	2.00	0.67	0.00	0.00	0.33
	8	Tasmanitids	0.33	0.00	0.33	1.00	0.67	0.67	1.33	1.00	0.00	0.00	0.33
	9	Acritarchs	0.67	0.00	0.00	0.33	0.67	1.00	1.00	0.00	0.00	0.00	0.33
	10	Dinoflagellate cysts	0.67	0.00	0.33	2.67	2.67	2.00	2.67	2.67	1.33	0.00	0.67
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.00
	13	Cuticle	0.00	0.00	0.00	0.33	2.00	0.67	0.00	1.00	0.67	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	15	Definite Wood	0.33	0.00	0.00	2.33	1.00	2.33	0.67	2.00	0.33	0.00	0.33
Non-Vita Fragments	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.67	0.33	0.00	0.00	1.67	0.00	0.67
	17	Resin	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
	18	Plant Tissues	0.67	0.00	0.67	0.00	0.67	0.00	0.00	0.00	0.00	1.67	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.33	0.00	0.00	0.00	0.00	1.33	1.00	0.33	0.33	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	2.33	0.33	0.33	0.00	3.67	0.33	0.00	2.00	5.33	1.00	0.33
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	2.67	0.67	3.67	1.33	7.33	3.67	1.33	4.33	1.00	0.33	4.67
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	5.67	7.00	8.33	19.00	5.00	13.67	18.33	2.00	11.67	9.00	1.00
	23	Brown-Bladed, Fluorescent, Cellular	0.33	0.00	0.33	0.00	2.33	0.33	0.33	1.00	0.00	6.33	13.67
	24	Brown-Bladed, Non-Fluorescent, Cellular	1.33	0.00	0.33	0.00	0.67	0.67	1.33	0.33	0.67	0.00	0.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	3.33	0.33	0.67	2.00	3.00	0.67	1.67	1.33	2.00	0.00	1.33
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	2.67	0.67	3.33	5.00	0.67	3.67	5.67	2.00	1.00	2.00	5.33
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.67	2.33	1.00	0.00	1.00	1.33	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	4.00	2.67	1.00	5.00	1.67	3.33	2.33	5.67	2.67	0.67	1.67
Structureless Organic Matter	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	1.00	0.67	1.00	0.33	0.33	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	1.33	1.67	1.33	1.67	0.33	1.67	1.00	0.67	1.33	0.00	0.00
	35	Transparent-Yellow, Fluorescent, Fibrous	5.67	1.67	20.33	7.67	8.67	6.33	3.67	7.67	3.00	3.67	2.00
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	26.00	5.33	20.33	5.00	21.00	13.00	4.00	9.33	9.00	0.00	6.33
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	1.00	0.00	0.67	0.00	0.00	3.67	0.00	0.00	9.00	0.33
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	5.00	45.67	1.33	1.33	0.00	0.00	8.00	0.33	1.33	14.00	2.67
	39	Yellow-Brown, Fluorescent, Non-Fibrous	7.00	3.67	23.33	2.00	9.33	5.33	3.67	13.67	17.00	1.67	4.33
	40	Yellow-Brown, Fluorescent, Fibrous	2.00	1.33	2.33	1.00	3.33	0.33	1.67	2.00	4.00	0.00	0.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous	2.33	1.67	1.33	3.67	0.00	6.67	6.00	2.33	0.67	14.67	17.67
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.00	6.67	0.00	0.33	0.00	4.00	2.67	0.00	0.00	11.33	2.67
	43	Brown-Black, Fluorescent, Fibrous	9.00	9.33	5.00	4.33	4.00	2.00	2.00	21.00	21.00	0.33	2.33
	44	Brown-Black, Fluorescent, Non-Fibrous	2.33	3.00	0.00	0.67	0.33	0.33	0.00	2.00	0.67	0.00	1.33
	45	Brown-Black, Non-Fluorescent, Fibrous	6.33	1.67	1.00	13.00	0.00	5.33	8.00	4.33	2.00	17.00	22.33
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.67	4.00	0.00	0.67	0.67	0.00	1.00	0.00	0.33	0.33	1.00
Total			15.00	15.00	15.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	15.00
Tablets			188130.00	188130.00	188130.00	125420.00	125420.00	125420.00	125420.00	125420.00	125420.00	125420.00	188130.00
Total Spikes			176019.84	40441.83	1413802.61	99263.95	1882241.12	626160.76	1883183.18	377014.03	375508.98	12537.82	104551.52
Particles of O.M.			10.02	10.04	4.99	19.95	19.99	20.03	19.98	19.96	20.04	30.01	29.99
Weight processed (g)			0.13	0.03	1.05	0.07	1.39	0.46	1.39	0.28	0.28	0.01	0.08
Normalised O.M. p/g	47												

Figure D.10: Relative percentage abundance of each palynomorph/palynodebris category of Millepore Bed samples from south of Iron Scar.

Category	Species No.	Sample No.	107	108	109	110	111	112	113	114	115	116	117
Palynomorphs	1	Unidentified Palynomorphs	2.00	1.67	0.67	0.33	0.33	0.00	0.33	0.00	0.33	0.00	0.33
	2	Bisaccate Pollen	0.33	0.33	0.00	0.33	0.00	0.00	0.00	0.67	0.00	0.00	0.33
	3	Non-Bisaccate Pollen	5.00	1.00	2.33	2.00	0.33	0.33	2.67	4.33	2.00	0.67	2.67
	4	Classopollis Pollen	1.00	3.67	0.67	4.00	0.33	0.33	1.67	2.33	3.67	0.67	1.67
	5	Spores	7.67	15.67	5.33	14.33	8.00	3.67	3.67	40.67	7.33	2.00	4.00
	6	Fresh-Water Algae	0.33	0.33	0.33	0.33	0.00	0.33	0.33	0.00	0.33	0.33	0.33
Vita Fragments	7	Leiospheres	2.00	2.67	0.33	1.00	2.00	0.00	4.00	0.00	0.00	3.00	1.00
	8	Acritarchs	1.33	0.67	0.33	0.33	0.00	0.67	0.00	0.33	1.00	1.67	0.67
	9	Dinoflagellate cysts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00
	10	Zoomorphs	2.67	2.67	1.00	0.67	0.00	1.00	1.00	2.67	2.00	0.67	0.00
	11	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Cuticle	0.67	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	13	Epidermal Tissue	0.67	0.67	1.33	0.67	0.00	1.33	0.67	1.00	1.00	1.00	3.33
	14	Definite Wood	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
	15	Vascular Bundles	0.00	0.33	0.67	0.33	0.00	1.33	1.33	0.33	1.33	0.00	1.00
	16	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00
	17	Plant Tissues	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.67	0.67	0.00	0.33	0.00	0.33
Structureless Organic Matter	19	Brown-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	10.00	2.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33
	20	Brown-Equidimensional, Fluorescent, Non-Cellular	0.00	0.67	1.33	0.33	2.33	0.33	4.33	1.33	2.67	2.00	0.67
	21	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	0.00	13.33	7.33	12.00	15.33	13.33	13.33	2.33	22.00	11.00	4.67
	22	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	3.33	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.33
	23	Brown-Bladed, Non-Fluorescent, Cellular	0.00	0.00	1.00	0.67	3.33	0.00	2.33	0.67	1.67	0.00	0.67
	24	Brown-Bladed, Fluorescent, Non-Cellular	0.67	0.00	2.00	1.67	0.00	2.33	2.33	0.00	1.00	0.00	0.33
	25	Black-Equidimensional, Fluorescent, Cellular	0.00	3.00	2.33	2.33	3.33	0.00	3.33	0.33	6.33	6.00	8.33
	26	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00
	27	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.00	0.33	0.00
	28	Black-Equidimensional, Non-Fluorescent, Non-Cellular	0.00	0.00	0.33	1.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
Total	29	Black-Bladed, Fluorescent, Cellular	0.00	0.67	0.00	0.00	13.00	8.67	1.67	17.33	10.00	6.67	4.67
	30	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	31	Transparent-Yellow, Fluorescent, Fibrous	8.67	9.00	7.33	10.33	23.67	16.00	28.67	1.67	3.67	4.67	2.67
	32	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	40.33	32.67	11.33	11.00	5.00	5.00	1.00	6.00	3.00	2.33	5.33
	33	Transparent-Yellow, Non-Fluorescent, Fibrous	0.33	0.67	0.33	0.67	0.00	1.00	1.00	0.00	0.00	0.33	0.33
	34	Yellow-Brown, Fluorescent, Non-Fibrous	14.33	1.33	10.33	4.33	1.33	6.33	3.00	1.33	1.33	4.33	7.00
	35	Yellow-Brown, Fluorescent, Fibrous	3.00	0.00	0.67	0.00	4.67	6.33	1.67	1.67	0.33	2.00	3.00
	36	Yellow-Brown, Non-Fluorescent, Non-Fibrous	1.33	0.67	3.33	1.33	0.00	0.33	7.67	0.00	4.33	2.33	0.67
	37	Yellow-Brown, Non-Fluorescent, Fibrous	0.00	0.00	0.00	1.00	0.00	2.00	1.67	0.00	1.67	2.00	1.67
	38	Brown-Black, Fluorescent, Non-Fibrous	1.67	3.33	8.33	4.00	0.00	0.00	0.00	1.00	2.33	1.33	0.00
Tablets	39	Brown-Black, Fluorescent, Fibrous	0.67	0.00	0.00	0.00	13.33	0.00	1.00	0.00	5.67	1.00	15.33
	40	Brown-Black, Non-Fluorescent, Non-Fibrous	0.67	3.33	4.33	4.33	0.00	5.33	1.33	4.00	0.00	0.33	0.00
	41	Brown-Black, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.33	13.00	2.67
	42	Tablets	10.00	10.00	10.00	10.00	5.00	5.00	10.00	0.00	10.00	10.00	10.00
	43	Total Spikes	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	44	Particles of O.M.	125420.00	125420.00	125420.00	125420.00	62710.00	62710.00	125420.00	125420.00	125420.00	125420.00	125420.00
	45	Weight processed (g)	187544.91	1879420.58	1878482.28	999710.29	1873804.78	1885070.14	625848.30	144643.06	66054.56	941120.56	940650.00
	46	Normalised O.M. p/g	20.04	20.02	20.03	20.02	10.04	9.98	20.04	20.01	29.98	19.99	20.00
	47		1.39	1.39	1.39	0.70	1.39	1.40	0.46	0.11	0.05	0.70	0.70

Figure D.11: Relative percentage abundance of each palynomorph/palynodebris category of upper Leberston Member to lower Gristhorpe Member samples, Cloughton Wyke.

Category	Species No.	Sample No.	118	119	120	121	122	123	124	125	126	127
Palynomorphs		Particulate Organic Matter Categories (Species)										
	1	Unidentified Palynomorphs	0.67	1.00	0.00	0.33	0.00	1.00	0.00	0.33	1.33	0.67
	2	Bisaccate Pollen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	3	Non-Bisaccate Pollen	2.33	3.33	0.33	3.00	4.00	5.00	2.33	0.67	1.33	1.33
	4	<i>Classopollis</i> Pollen	1.33	0.33	0.67	0.33	0.67	2.00	1.67	1.33	4.33	1.00
	5	Spores	4.00	7.33	4.00	9.33	6.33	10.67	9.67	3.67	2.33	1.33
	6	Fresh-Water Algae	0.67	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	7	Leiospheres	0.67	0.00	0.00	0.33	1.33	1.33	1.33	0.00	0.00	0.33
	8	Tasmanids	0.67	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00
	9	Acriarchs	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00	0.00
	10	Dinoflagellate cysts	1.00	0.00	0.00	0.33	0.67	1.00	1.00	0.00	0.33	0.33
	11	Zooorophs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.33	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
	13	Cuticle	1.67	0.00	0.00	2.00	0.33	0.33	1.33	0.00	0.67	0.33
	14	Epidermal Tissue	0.33	0.00	0.00	0.33	0.33	0.00	0.33	0.00	0.00	0.33
	15	Definite Wood	0.67	0.00	0.00	0.67	1.00	0.00	1.33	0.33	0.00	0.67
	16	Vascular Bundles	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	2.67	0.00	0.67	0.00	1.33	2.67	8.67	6.33	2.33	0.67
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	3.00	0.00	0.67	2.00	0.67	0.33	0.00	0.00	0.00	0.00
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	6.00	0.00	36.33	0.67	20.33	23.33	14.00	16.67	16.33	8.00
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.67	0.00	0.00	0.00	1.67	1.67	2.33	2.00	0.00	0.33
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.33	0.00	0.00	1.00	0.33	0.00	0.00	0.00	0.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	3.33	0.00	6.00	0.00	5.00	3.33	7.00	4.67	1.00	2.67
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.33	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	4.33	3.00	21.67	0.00	5.67	24.00	12.67	18.33	23.00	10.67
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	1.00	1.00	0.67	0.00	1.33	5.67	2.33	2.33	0.67	3.00
	35	Transparent-Yellow, Fluorescent, Fibrous	4.00	13.67	1.67	12.33	1.67	1.00	2.67	0.33	2.33	5.33
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	6.33	16.00	11.00	41.33	20.00	12.00	15.00	6.00	13.00	7.67
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	1.00	0.67	0.33	0.00	0.33	0.00	0.33	0.67	5.00	1.67
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	1.67	5.00	0.67	2.67	4.67	0.67	3.00	9.00	5.67	0.67
	39	Yellow-Brown, Fluorescent, Non-Fibrous	6.00	26.33	4.00	13.00	3.33	0.00	3.00	2.00	0.67	0.00
	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.00	3.33	1.00	2.67	1.00	0.00	0.00	0.33	1.33	0.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous	6.33	1.00	1.33	0.00	7.67	1.00	3.00	5.33	2.00	2.67
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.00	2.33	0.33	0.00	0.67	0.00	0.33	1.33	0.33	0.00
	43	Brown-Black, Fluorescent, Fibrous	9.67	6.67	2.00	6.00	2.00	1.00	3.00	0.67	1.00	2.67
	44	Brown-Black, Fluorescent, Non-Fibrous	0.33	1.33	0.00	0.00	0.00	0.00	0.00	14.33	0.00	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	27.00	5.00	6.67	0.33	6.00	2.00	3.00	2.00	13.00	45.67
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	1.00	2.33	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.33
Total			10.00	10.00	10.00	15.00	15.00	15.00	15.00	10.00	10.00	10.00
Tablets			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Spikes			125420.00	125420.00	125420.00	188130.00	188130.00	188130.00	188130.00	125420.00	125420.00	125420.00
Particles of O.M.			269160.88	15870.66	235162.50	3767623.50	939710.29	201567.86	941277.52	113866.36	110830.95	627100.00
Weight processed (g)			19.97	30.01	10.00	14.98	20.02	20.00	29.98	30.04	19.97	30.00
Normalised O.M. p/g	47		0.20	0.01	0.17	2.79	0.70	0.15	0.70	0.08	0.08	0.46

Figure D.12: Relative percentage abundance of each palynomorph/palynodebris category from lower-mid Gristhorpe Member, Cloughton Wyke.

Category	Species No.	Particulate Organic Matter Categories (Species)	Sample No.	128	129	130	131	132	133	134	135	136
Palynomorphs	1	Unidentified Palynomorphs		0.00	0.67	0.67	1.00	0.33	0.00	0.00	0.67	0.00
	2	Bisaccate Pollen		0.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00
	3	Non-Bisaccate Pollen		1.67	2.67	1.33	1.33	0.00	0.00	1.00	2.67	0.00
	4	Classopollis Pollen		2.00	0.33	0.00	0.33	0.00	0.00	0.00	0.00	0.00
	5	Spores		7.00	2.33	5.67	1.67	1.33	1.33	4.67	8.33	0.00
	6	Fresh-Water Algae		0.00	0.00	1.67	0.00	0.00	0.00	0.00	10.33	1.00
	7	Leiospheres		4.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	8	Tasmanitids		1.00	0.00	0.00	0.33	0.00	0.00	0.33	0.33	0.00
	9	Acrinitarchs		0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00
	10	Dinoflagellate cysts		2.33	2.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00
	11	Zoomorphs		0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
	12	Fungal Bodies		0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
	13	Cuticle		0.33	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue		0.00	0.00	0.00	0.00	0.00	0.00	2.67	1.00	0.00
	15	Definite Wood		0.67	0.33	1.33	1.67	1.33	0.00	0.00	0.00	0.00
	16	Vascular Bundles		0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
	17	Resin		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	18	Plant Tissues		0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular		0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.33
	20	Brown-Equidimensional, Non-Fluorescent, Cellular		0.33	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular		0.00	1.00	0.00	3.00	0.00	0.00	0.00	3.67	1.33
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent		13.33	16.00	2.00	13.33	12.00	6.00	8.33	4.67	8.33
	23	Brown-Bladed, Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	4.00
	24	Brown-Bladed, Non-Fluorescent, Cellular		0.67	2.67	0.00	0.00	0.00	0.00	0.00	0.00	1.00
	25	Brown-Bladed, Fluorescent, Non-Cellular		0.00	0.67	0.00	0.33	0.00	0.00	0.00	0.67	1.67
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular		3.67	5.00	3.33	5.00	6.33	0.33	1.00	0.00	2.00
	27	Black-Equidimensional, Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular		21.33	9.00	5.00	15.00	23.67	34.33	2.00	2.33	20.00
	31	Black-Bladed, Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	34	Black-Bladed, Non-Fluorescent, Non-Cellular		4.67	5.67	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	35	Transparent-Yellow, Fluorescent, Fibrous		7.00	11.00	3.67	2.00	8.00	3.00	0.33	0.00	6.67
	36	Transparent-Yellow, Fluorescent, Non-Fibrous		17.00	16.00	18.00	2.00	6.00	0.33	8.67	8.00	2.67
	37	Transparent-Yellow, Non-Fluorescent, Fibrous		0.00	0.00	0.67	3.00	26.33	3.33	55.00	35.00	3.33
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous		0.33	1.33	1.33	0.00	0.00	0.00	0.00	0.00	0.00
	39	Yellow-Brown, Fluorescent, Non-Fibrous		6.33	3.33	1.33	14.67	0.00	5.00	0.00	0.00	19.33
	40	Yellow-Brown, Fluorescent, Fibrous		0.33	3.33	1.33	3.33	2.00	0.33	3.67	10.33	16.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous		1.33	2.67	1.00	0.67	2.00	0.33	0.00	0.00	0.33
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous		0.00	0.00	1.67	1.67	1.00	3.00	0.33	0.00	0.00
	43	Brown-Black, Fluorescent, Fibrous		2.67	1.67	11.33	3.67	0.33	0.33	0.00	0.00	6.67
	44	Brown-Black, Fluorescent, Non-Fibrous		0.00	0.33	2.00	1.33	2.00	0.00	2.67	9.00	5.00
	45	Brown-Black, Non-Fluorescent, Fibrous		1.67	11.67	31.67	19.67	5.00	0.00	1.67	0.00	0.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous		0.00	0.00	5.33	0.00	2.00	40.00	1.67	0.67	0.33
				10.00	15.00	10.00	15.00	10.00	2.33	0.33	0.00	0.00
Total				100.00	100.00	100.00	100.00	100.00	10.00	10.00	10.00	10.00
Tablets				125420.00	188130.00	100.00	100.00	100.00	10.00	10.00	10.00	10.00
Total Spikes				125420.00	188130.00	125420.00	188130.00	125420.00	125420.00	125420.00	125420.00	125420.00
Particles of O.M.				125420.00	536798.55	52768.43	76890.28	1882241.12	24079.10	1255455.46	939710.29	33908.60
Weight processed (g)				30.00	15.02	29.71	14.98	19.99	30.05	9.99	20.02	29.99
Normalised O.M. p/g	47			0.93	0.40	0.04	0.06	1.39	0.02	0.93	0.70	0.03

Figure D.13: Relative percentage abundance of each palynomorph/palynodebris category for samples from mid Gristhorpe Member, Cloughton Wyke.

Category	Species No.	Particulate Organic Matter Categories (Species)	Sample No.	137	138	139	140	141	142	143	144	145	146	147
Palynomorphs	1	Unidentified Palynomorphs		0.33	0.00	0.00	0.67	0.33	0.00	0.33	1.00	2.00	2.00	2.67
	2	Bisaccate Pollen		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33
	3	Non-Bisaccate Pollen		1.67	0.00	2.67	5.67	7.67	0.00	0.00	0.67	4.67	6.33	4.67
	4	Classopollis Pollen		2.33	0.00	4.00	20.67	0.33	0.00	0.00	0.00	0.33	0.33	0.33
	5	Spores		9.00	0.33	18.67	11.33	2.00	0.00	0.33	3.00	2.33	2.33	8.33
	6	Fresh-Water Algae		0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00
	7	Leiospheres		2.00	0.00	1.33	0.00	0.67	0.00	0.00	0.00	0.00	0.33	0.00
	8	Tasmanitids		0.00	0.00	0.00	0.33	2.33	0.00	0.33	1.33	3.33	2.00	3.33
	9	Acritarchs		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.33
	10	Dinoflagellate cysts		1.00	0.00	2.00	1.00	2.33	0.00	0.00	3.33	2.67	6.00	5.00
	11	Zoomorphs		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle		0.67	0.00	2.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue		0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood		0.33	0.00	0.00	0.00	1.33	0.00	0.33	0.00	0.00	0.00	0.00
	16	Vascular Bundles		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	Resin		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	18	Plant Tissues		0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular		0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular		2.67	1.00	1.67	0.00	1.67	0.00	0.00	1.00	1.00	0.67	1.67
	21	Brown-Equidimensional, Fluorescent, Non-Cellular		0.33	0.67	4.00	1.33	0.00	0.00	0.00	0.00	2.33	0.67	0.00
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent		14.00	29.33	9.00	6.33	8.67	11.33	20.33	4.00	6.67	3.00	5.00
	23	Brown-Bladed, Fluorescent, Cellular		0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.33
	24	Brown-Bladed, Non-Fluorescent, Cellular		1.00	0.67	0.67	2.00	3.33	1.33	3.33	0.33	0.33	1.00	0.33
	25	Brown-Bladed, Fluorescent, Non-Cellular		0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular		1.33	7.00	0.67	2.33	5.67	4.33	9.33	3.00	2.67	1.67	3.00
	27	Black-Equidimensional, Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular		28.33	32.33	5.00	17.67	12.67	30.00	36.33	10.33	10.33	6.67	9.00
	31	Black-Bladed, Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	34	Black-Bladed, Non-Fluorescent, Non-Cellular		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	35	Transparent-Yellow, Fluorescent, Fibrous		2.00	5.33	1.00	2.33	6.67	0.00	0.00	7.00	5.67	8.33	4.33
	36	Transparent-Yellow, Fluorescent, Non-Fibrous		2.00	0.67	5.67	6.33	2.00	0.33	0.33	4.00	8.00	3.67	4.33
	37	Transparent-Yellow, Non-Fluorescent, Non-Fibrous		16.00	1.67	18.67	10.67	36.67	4.00	4.67	46.67	28.00	44.33	42.67
	38	Transparent-Yellow, Non-Fluorescent, Fibrous		0.00	0.67	0.00	0.67	0.00	0.67	0.67	0.00	0.00	0.00	0.00
	39	Yellow-Brown, Fluorescent, Non-Fibrous		0.33	4.00	3.67	2.33	0.00	25.67	4.00	0.00	0.00	2.67	0.00
	40	Yellow-Brown, Fluorescent, Non-Fibrous		4.00	0.67	7.67	5.33	0.67	0.33	2.00	6.00	7.00	2.00	1.33
	41	Yellow-Brown, Non-Fluorescent, Fibrous		0.33	0.33	0.33	0.00	0.33	0.67	0.33	1.00	1.00	1.67	1.00
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous		0.33	0.33	0.00	0.00	0.33	0.00	1.00	0.00	0.00	0.00	0.67
	43	Brown-Black, Fluorescent, Fibrous		3.67	1.67	0.00	1.00	1.33	0.67	0.00	0.00	0.00	0.00	0.00
	44	Brown-Black, Fluorescent, Non-Fibrous		0.00	0.33	5.33	0.00	0.00	0.00	0.00	6.67	7.67	2.67	0.67
	45	Brown-Black, Non-Fluorescent, Fibrous		5.33	11.33	5.33	1.00	2.00	6.00	1.67	0.33	0.33	0.00	0.67
	46	Brown-Black, Non-Fluorescent, Non-Fibrous		0.00	0.33	0.33	0.00	0.67	2.00	0.00	0.00	1.00	0.33	0.00
Total	Tablets			10.00	10.00	15.00	15.00	15.00	10.00	10.00	10.00	10.00	10.00	10.00
	Total Spikes			125420.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Particles of O.M.			209382.30	125420.00	188130.00	188130.00	188130.00	125420.00	125420.00	125420.00	125420.00	125420.00	125420.00
	Weight processed (g)			29.95	30.00	19.99	19.97	20.02	29.95	20.00	19.93	19.96	19.98	20.00
Normalised O.M. p/g				0.16	0.04	0.17	0.19	0.00	0.02	0.28	0.70	1.40	0.46	0.70
47														

Figure D.14: Relative percentage abundance of each palynomorph/palynodebris category for samples from uppermost Gristhorpe Member, Cloughton Wyke to mid Scarborough Formation.

Category	Species No.	Sample No.	148	149	150	151	152	153	154	155	156	157
Palynomorphs	Particulate Organic Matter Categories (Species)											
	1	Unidentified Palynomorphs										
	2	Bisaccate Pollen	2.00	5.67	3.33	3.33	1.33	5.67	2.00	1.00	1.67	0.00
	3	Non-Bisaccate Pollen	0.33	1.00	1.33	1.67	2.67	1.33	0.33	0.33	2.33	0.00
	4	Classopollis Pollen	4.67	6.67	5.33	8.33	8.33	13.00	3.33	1.67	4.00	0.00
	5	Spores	0.67	0.33	1.00	0.33	0.67	1.67	0.00	1.33	1.00	0.00
	6	Fresh-Water Algae	3.67	3.67	7.00	3.33	5.67	5.33	5.00	2.67	1.33	0.00
	7	Leiospheres	0.00	0.00	0.00	0.00	1.00	0.67	0.00	0.00	0.00	0.00
	8	Tasmanitids	0.67	1.00	0.33	2.00	1.00	0.67	0.00	0.00	0.00	0.00
	9	Acritarchs	0.33	2.67	1.67	1.67	1.33	1.67	1.33	0.00	0.67	0.00
	10	Dinoflagellate cysts	4.00	5.00	5.67	7.67	9.00	10.33	3.67	0.33	3.00	1.00
	11	Zoomorphs	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	15	Definite Wood	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	16	Vascular Bundles	0.00	0.00	0.00	0.00	1.00	1.00	1.33	0.00	0.67	0.67
Non-Vita Fragments	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	18	Plant Tissues	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	1.33	0.33	0.67	0.67	0.00	0.00	0.00	0.00	0.33	0.33
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.33	0.00	0.33	0.00	0.33	0.33	0.00	1.67	1.33	0.33
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	4.00	2.33	1.00	2.67	4.67	3.33	2.33	16.33	3.33	39.67
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.33	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	1.33	0.67	1.00	0.33	0.67	0.67	0.33	1.33	1.00	0.67
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	2.67	2.00	1.33	2.67	4.00	3.33	7.00	4.00	3.33	11.33
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	5.00	8.33	2.67	1.67	7.67	6.00	8.33	19.67	7.00	19.33
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	8.33	6.33	3.00	2.33	4.33	3.00	10.67	2.00	2.00	7.67
	35	Transparent-Yellow, Fluorescent, Fibrous	8.33	11.00	11.33	6.67	5.00	2.00	2.00	3.67	4.33	4.00
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	44.00	36.67	50.33	53.67	38.67	35.33	45.67	13.00	32.00	5.67
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.33	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	0.33	0.00	0.00	0.00	1.33	0.33	0.67	3.67	0.67	1.00
	39	Yellow-Brown, Fluorescent, Non-Fibrous	4.33	1.67	0.00	0.33	0.00	1.67	1.67	3.33	16.00	1.33
	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.33	1.67	0.33	0.00	0.00	0.33	0.00	0.33	4.00	0.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.67	0.33	0.33
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.67	0.00	0.00
	43	Brown-Black, Fluorescent, Fibrous	3.33	1.67	0.00	0.33	0.00	0.67	0.00	1.33	3.00	1.00
	44	Brown-Black, Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.67
	45	Brown-Black, Non-Fluorescent, Fibrous	0.00	1.00	0.00	0.00	0.00	0.67	0.67	15.33	2.00	4.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.67
Total			10.00	10.00	10.00	10.00	15.00	15.00	15.00	15.00	15.00	15.00
Tablets			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Spikes			125420.00	125420.00	125420.00	125420.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00
Particles of O.M.			471031.55	1880359.82	0.00	1879420.58	704782.72	565521.04	281772.34	175844.34	314703.91	1881927.31
Weight processed (g)			19.97	20.01	19.98	20.02	20.02	19.96	20.03	20.06	29.89	29.99
Normalised O.M. p/g	47		0.35	1.39	0.00	1.39	0.52	0.42	0.21	0.13	0.23	1.39

Figure D.15: Relative percentage abundance of each palynomorph/palynodebris category for samples from mid Scarborough Formation to basal Scalby Formation.

Category	Species No.	Sample No.	158	159	160	161	162	163	164	165	166	167	168	169	170	171
Palynomorphs	1	Unidentified Palynomorphs	0.33	3.00	1.00	0.00	0.00	0.67	4.67	1.67	0.00	1.00	1.00	0.33	0.67	0.33
	2	Bisaccate Pollen	0.00	1.00	0.00	0.00	0.00	0.00	2.00	1.00	0.00	0.33	1.00	0.00	0.00	0.00
	3	Non-Bisaccate Pollen	0.33	5.00	0.67	0.00	0.67	2.67	13.33	3.00	2.33	1.33	0.67	1.00	0.67	1.00
	4	Clasopollis Pollen	0.67	0.67	0.00	0.00	0.00	0.00	0.67	1.00	0.00	0.33	0.00	0.00	0.00	0.00
	5	Spores	0.00	7.00	2.00	0.67	3.00	9.67	9.00	3.00	4.00	4.33	2.67	2.67	1.33	1.33
	6	Fresh-Water Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00	0.33	0.00	0.00	0.00	0.00
	7	Leisospheres	0.33	0.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00	0.33	0.00	0.00	0.00	0.00
	8	Tasmanites	0.00	1.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00	0.33	0.00	0.00	0.00	0.00
	9	Acritarchs	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00	0.33	0.00	0.00	0.00	0.00
	10	Dinoflagellate cysts	0.00	0.33	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.33	0.00
Vita Fragments	11	Zoanorhops	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuicula	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00	0.67
	15	Definite Wood	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	16	Vascular Bundles	0.00	0.00	0.33	0.00	0.00	0.00	1.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	1.00	0.00
	18	Plant Tissues	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.00	0.67	0.67	0.00	0.00	0.00	0.00	1.00	0.33	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.67	1.33	0.67	0.00	2.00	1.00	1.33	0.67	3.00	1.33	0.00	0.33	0.00	0.00
	22	Brown-Equidimensional, Non-Fluorescent, Non-Cellular	0.00	0.67	0.67	0.00	0.00	0.67	0.67	2.67	0.33	10.33	4.00	0.00	0.00	0.00
	23	Brown-Equidimensional, Fluorescent, Cellular	2.33	8.67	2.00	0.67	22.00	22.67	5.67	3.00	37.33	3.00	7.67	6.00	18.00	9.00
	24	Brown-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	1.33	0.00	0.67	0.00	0.67	3.00	0.00	1.67	0.33	0.00	0.00	0.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	2.33	0.67	0.00	0.00	0.00	0.67	0.33	0.00	0.67	1.33	0.33	11.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	0.00	0.33	0.67	0.33	0.00	0.00	0.00	2.33	0.00	4.00	1.67	0.00	0.00	0.00
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	6.67	0.67	0.00	4.00	2.67	4.67	0.67	6.33	2.33	2.33	4.67	10.33	1.33
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	1.33	2.33	0.00	1.33	2.67	4.67	9.00	3.00	6.67	2.00	0.67	8.67	18.67	3.33
Structureless Organic Matter	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	35	Transparent-Yellow, Fluorescent, Fibrous	0.00	2.33	1.00	0.33	0.33	1.00	3.67	1.00	0.33	1.00	0.67	3.00	7.00	0.33
	36	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	1.33	5.00	2.00	4.33	20.67	32.33	20.67	23.33	11.67	21.67	20.00	16.00	5.67	8.00
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	21.00	28.33	25.33	68.67	20.33	32.33	20.67	23.33	11.67	21.67	20.00	16.00	5.67	8.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.67	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39	Yellow-Brown, Fluorescent, Fibrous	39.67	3.00	8.00	1.67	1.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	Yellow-Brown, Non-Fluorescent, Non-Fibrous	2.00	7.67	15.33	0.67	5.00	3.33	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	41	Yellow-Brown, Fluorescent, Non-Fibrous	5.67	1.33	6.67	0.00	3.67	0.00	0.67	6.00	0.67	7.00	3.00	0.00	1.33	2.33
	42	Yellow-Brown, Non-Fluorescent, Fibrous	2.00	3.00	1.00	0.00	4.33	2.00	0.00	0.67	1.33	0.00	8.00	0.00	1.33	0.00
	43	Yellow-Brown, Non-Fluorescent, Non-Fibrous	7.00	1.33	1.00	0.00	0.67	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.67
	44	Brown-Black, Fluorescent, Fibrous	2.33	2.00	12.67	3.67	11.33	4.67	2.67	3.67	1.67	7.33	1.67	9.00	3.67	14.67
	45	Brown-Black, Non-Fluorescent, Non-Fibrous	2.67	0.00	4.00	2.33	0.67	0.00	0.00	0.00	1.67	0.33	2.33	0.33	0.67	0.00
	46	Brown-Black, Non-Fluorescent, Fibrous	3.00	5.00	0.67	0.67	7.33	4.00	1.33	1.00	15.67	0.33	12.00	10.33	2.33	5.67
	47	Brown-Black, Non-Fluorescent, Non-Fibrous	7.33	0.00	0.33	1.00	0.33	0.00	1.00	0.00	0.00	0.00	0.00	18.33	1.67	24.67
	Total		15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Tablets		188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	188130.00
	Particles of O.M.		49136.35	326765.86	67863.07	51778.90	95112.23	0.00	142527.27	1886960.88	251342.69	1408158.68	1126526.95	234225.60	66549.67	23064.92
	Weight processed (g)		5.06	5.08	4.98	5.00	9.89	10.09	4.95	9.97	14.97	10.02	10.02	15.06	10.05	10.09
	Normalised O.M. p/g		0.04	0.24	0.05	0.04	0.70	0.00	1.06	1.40	0.19	1.04	0.83	0.17	0.05	0.17

Figure D.16: Relative percentage abundance of each palynomorph/palynodebris category for samples from the Scalby Formation, north of Scalby Ness.

D.3 Data from Osgodby Nab and Yons Nab

Category	Species No.	Sample No.	172	173	174	175	176	177	178	179	180
Palynomorphs	Particulate Organic Matter Categories (Species)										
	1	Unidentified Palynomorphs	0.00	0.67	0.67	0.33	0.00	0.00	1.00	0.00	0.33
	2	Bisaccate Pollen	0.00	0.00	1.33	0.67	0.00	0.00	0.67	0.00	0.00
	3	Non-Bisaccate Pollen	0.33	3.67	2.33	3.67	1.33	0.00	2.33	0.00	0.00
	4	Classopollis Pollen	0.00	0.00	0.33	0.00	0.33	0.00	0.00	0.00	0.00
	5	Spores	0.67	0.33	4.00	1.00	6.00	0.00	2.00	0.33	0.00
	6	Fresh-Water Algae	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00
	7	Leiospheres	0.00	3.00	1.00	1.00	0.33	0.33	0.67	0.00	0.00
	8	Tasmanitids	0.33	0.00	0.33	0.33	0.67	0.00	0.67	0.00	0.00
	9	Acrithacids	0.33	0.00	0.67	0.00	0.33	0.00	0.67	0.00	0.00
Vita Fragments	10	Dinoflagellate cysts	1.33	1.67	3.00	1.33	1.00	0.00	1.66	0.00	0.00
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.00	0.00	0.33	0.00	0.00	0.00	0.67	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.00	0.00	0.00	0.00	0.67	0.33	0.33	0.00	0.33
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.33	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.33	3.33	0.67	1.33	0.67	3.33	2.67
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	14.33	3.00	17.33	25.00	30.67	31.67	20.00	27.67	21.33
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.33	0.00	2.33	1.33	0.33	2.33
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.00	1.00	0.33	1.00	0.33	0.00	0.00	0.00	0.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	4.67	1.33	5.00	3.67	6.67	7.00	5.67	6.00	3.00
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	10.67	2.67	6.67	4.67	7.33	6.67	10.67	7.33	10.00
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	2.67	0.33	2.00	3.00	1.67	3.33	2.33	1.33	7.67
	35	Transparent-Yellow, Fluorescent, Fibrous	4.67	0.00	18.33	5.00	8.33	32.67	13.33	0.67	0.33
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	43.67	79.00	7.33	26.00	14.33	0.00	16.00	1.33	3.33
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	0.00	1.00	0.00	1.33	0.00	0.00	0.67	0.33
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	8.33	1.67	9.00	3.00	2.00	1.00	14.33	15.67	18.33
	39	Yellow-Brown, Fluorescent, Fibrous	2.00	0.67	10.33	2.67	3.33	0.67	0.33	0.67	0.00
Total	40	Yellow-Brown, Fluorescent, Non-Fibrous	2.33	0.00	1.67	0.33	0.00	0.00	0.00	0.33	0.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous	0.33	0.00	1.00	0.33	2.00	0.00	2.33	4.00	3.67
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.33	0.00	0.00	0.00	0.00	1.00	0.33	8.33	1.00
	43	Brown-Black, Fluorescent, Fibrous	0.00	0.33	3.67	2.00	4.00	2.67	0.67	0.67	1.33
	44	Brown-Black, Fluorescent, Non-Fibrous	0.33	0.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	1.67	0.00	1.33	7.00	4.67	6.33	2.00	18.67	22.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.33	0.00	0.00	0.33	0.00	1.00	0.00	2.33	1.33
	Total		20.00	20.00	20.00	20.00	20.00	15.00	20.00	20.00	20.00
	Tablets		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Total Spikes		250840.00	250840.00	250840.00	250840.00	250840.00	188130.00	250840.00	250840.00	250840.00
Particles of O.M.	Weight processed (g)		28827.77	69677.78	205348.47	832249.50	52808.42	402130.39	260911.17	207374.34	52181.87
	Normalised O.M. p/g		5.02	5.00	5.02	15.07	5.00	20.05	5.06	5.04	4.99
			0.02	0.05	0.15	0.62	0.04	0.30	0.19	0.15	0.04

Figure D.17: Relative percentage abundance of each palynomorph/palynodebris category for samples from Osgodby Nab.

Category	Species No.	Sample No.	181	182	183	184	185	186	187	188
Palynomorphs	1	Unidentified Palynomorphs	0.33	0.33	0.67	1.00	0.33	0.00	0.00	0.33
	2	Bisaccate Pollen	0.00	0.33	0.00	0.00	0.33	0.00	0.33	0.00
	3	Non-Bisaccate Pollen	0.00	0.00	2.00	0.67	2.00	0.00	0.67	1.67
	4	Glasspollis Pollen	0.00	0.00	0.33	0.67	0.33	0.33	0.67	1.00
	5	Spores	0.00	0.33	1.33	0.00	2.67	0.33	1.00	0.67
	6	Fresh-Water Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vita Fragments	7	Leisospheres	0.33	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	8	Tasmanitids	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.33
	9	Acriarchs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	Dinoflagellate cysts	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	13	Cuticle	0.00	0.33	0.00	0.00	0.00	0.00	0.33	0.33
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
	15	Definite Wood	0.00	0.00	0.33	0.33	0.67	0.00	0.67	0.00
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	2.67	4.67	6.00	2.33	5.00	0.00	0.00	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.00	0.33	0.00	1.67	0.00	0.00	0.00	0.00
	22	Brown-Equidimensional, Non-Fluorescent, Non-Cellular	34.67	33.67	23.67	29.33	15.67	25.00	20.67	19.00
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	3.00	3.33	4.33	1.67	4.67	1.67	4.67	1.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	4.67	7.67	4.67	7.33	4.00	11.67	3.67	1.67
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	9.67	15.33	18.33	16.00	13.67	17.33	27.33	22.00
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	1.00	4.67	4.00	4.67	1.00	3.33	3.00	2.33
	35	Transparent-Yellow, Fluorescent, Fibrous	1.67	1.00	2.67	3.00	5.00	3.00	4.00	3.67
	36	Transparent-Yellow, Non-Fluorescent, Fibrous	1.33	14.67	14.67	5.67	16.00	13.00	17.33	17.67
	37	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	17.67	5.33	1.67	3.67	9.33	9.67	2.33	11.33
	39	Yellow-Brown, Fluorescent, Fibrous	1.00	2.00	2.00	4.67	5.00	0.33	0.67	4.67
	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.00	0.33	0.33	0.00	0.33	0.00	0.00	1.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous	1.33	2.67	4.67	1.00	6.33	1.33	1.67	3.33
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.33	0.00	2.33	0.33	0.33	0.33	0.67	0.00
	43	Brown-Black, Fluorescent, Fibrous	0.67	0.00	0.00	2.67	0.00	0.00	0.33	0.33
	44	Brown-Black, Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	19.33	2.33	5.67	10.33	6.67	7.33	2.00	3.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	2.67	0.00	1.00	0.00	0.00
Total			20.00	20.00	20.00	20.00	20.00	100.00	100.00	100.00
Tablets			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Spikes			250840.00	250840.00	250840.00	250840.00	250840.00	188130.00	250840.00	250840.00
Particles of O.M.			144673.65	437409.90	2435339.81	74371.44	135735.93	94855.46	421438.17	400653.80
Weight processed (g)			5.05	5.06	5.15	4.96	5.04	5.00	4.96	4.95
Normalised O.M. p/g	47		0.11	0.32	1.80	0.06	0.10	0.07	0.31	0.30

Figure D.18: Relative percentage abundance of each palynomorph/palynodebris category for samples from Osgodby Nab.

Category	Species No.	Sample No.	189	190	191	192	193	194	195	196	197	198
Palynomorphs	Particulate Organic Matter Categories (Species)											
	1	Unidentified Palynomorphs	0.67	0.67	0.67	0.33	0.67	1.33	1.67	0.33	0.33	0.33
	2	Bisaccate Pollen	0.33	0.33	1.33	0.00	0.00	0.00	2.00	1.67	0.00	1.33
	3	Non-Bisaccate Pollen	5.67	4.00	1.67	0.67	2.33	4.67	6.67	6.33	1.00	3.00
	4	<i>Classopollis</i> Pollen	0.67	2.33	0.33	0.00	0.67	0.67	0.67	2.00	0.33	1.00
	5	Spores	1.33	4.33	3.67	1.67	1.33	4.67	2.67	4.67	2.00	4.67
	6	Fresh-Water Algae	0.00	0.00	0.33	0.00	0.00	0.67	1.00	1.00	0.33	1.00
	7	Leiospheres	0.00	1.00	0.67	1.00	0.00	0.00	0.33	2.67	1.00	0.67
	8	Tasmanitids	0.00	0.33	0.33	0.33	0.67	0.00	0.33	0.00	0.00	0.00
	9	Acritarchs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.33	1.67	0.33
	10	Dinoflagellate cysts	3.67	3.33	1.33	1.33	1.33	2.33	2.33	2.66	1.33	3.33
	11	Zoomorphs	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.33	0.33	0.33	0.00	0.00	0.00	0.00
	13	Cuticle	1.33	2.33	0.67	0.33	0.00	0.00	0.67	0.67	0.67	1.00
	14	Epidermal Tissue	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.33	2.33	1.00	0.67	0.00	1.00	0.00	2.00	0.33	0.67
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
Non-Vita Fragments	17	Resin	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	18	Plant Tissues	0.00	2.67	0.67	0.33	0.33	0.00	1.00	1.33	0.67	1.33
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	1.00	5.67	0.00	0.00	1.33	3.67	0.67	0.00	1.33
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	1.33	0.67	0.00	1.00	0.33	2.67	0.67	0.67	1.33	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.00	8.33	12.33	1.67	4.33	1.67	3.67	4.33	2.67	11.00
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	10.00	5.67	1.33	5.33	2.00	8.67	4.67	2.67	14.67	2.67
	23	Brown-Bladed, Fluorescent, Cellular	0.67	2.00	0.33	0.00	0.33	0.67	1.67	0.33	0.00	2.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.67	1.67	0.00	0.00	0.33	1.00	0.67	0.00	0.67	0.33
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.67	2.33	0.67	2.67	0.00	0.67	0.67	0.33	2.33
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	2.67	2.33	1.33	1.33	0.33	2.00	1.33	1.67	0.33	1.00
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	7.00	3.67	5.00	3.00	5.67	1.00	7.00	3.67	0.00	7.67
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
Structureless Organic Matter	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	1.00	1.33	1.33	1.67	2.00	0.67	3.67	3.33	0.33	1.00
	35	Transparent-Yellow, Fluorescent, Fibrous	5.00	2.33	0.67	2.67	4.00	7.33	4.33	0.00	0.67	4.67
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	42.33	15.33	23.67	24.67	38.67	33.67	13.67	24.00	9.00	16.33
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	1.33	0.00	0.67	0.00	0.33	0.33	0.00	1.00	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	1.00	8.67	5.67	10.33	0.00	1.67	0.67	1.67	18.67	0.33
	39	Yellow-Brown, Fluorescent, Fibrous	8.67	3.33	12.33	8.33	21.00	16.33	12.00	15.00	5.67	18.00
	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.00	0.33	1.00	1.33	2.33	1.00	0.00	0.00	1.67	0.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous	0.00	4.33	5.33	2.67	0.00	0.00	0.67	1.67	6.67	3.33
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	1.67	2.67	1.33	3.67	0.00	0.33	0.67	0.33	2.67	0.00
	43	Brown-Black, Fluorescent, Fibrous	3.67	2.67	5.67	7.67	8.33	3.67	15.67	9.67	4.00	8.00
	44	Brown-Black, Fluorescent, Non-Fibrous	0.00	1.00	0.00	6.67	0.00	0.33	1.00	0.33	6.67	0.33
	45	Brown-Black, Non-Fluorescent, Fibrous	0.00	1.00	1.33	4.67	0.00	0.00	2.33	1.67	7.67	0.67
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	6.00	0.00	4.33	0.00	0.00	0.00	0.67	5.67	0.00
			15.00	15.00	15.00	15.00	15.00	15.00	11.00	10.00	15.00	10.00
Total			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Tablets			188130.00	188130.00	188130.00	188130.00	188130.00	188130.00	137962.00	125420.00	188130.00	125420.00
Total Spikes			488818.64	1126526.95	1249203.19	255518.83	708320.78	1408158.68	4150598.80	125107.23	17842.60	943007.52
Particles of O.M.			5.02	5.01	5.02	5.02	9.96	5.01	5.01	20.05	20.02	19.95
Weight processed (g)			0.36	0.83	0.92	0.19	0.52	1.04	3.06	0.09	0.01	0.70
Normalised O.M. p/g	47											

Figure D.19: Relative percentage abundance of each palynomorph/palynodebris category for samples from mid-upper Lebberston Member Cloughton Formation, Yons Nab.

Category	Species No.	Sample No.	199	200	201	202	203	204	205	206	207	208
Palynomorphs		Particulate Organic Matter Categories (Species)										
	1	Unidentified Palynomorphs										
	2	Bisaccate Pollen	1.67	0.67	0.33	0.67	1.00	0.00	0.33	1.00	1.00	0.33
	3	Non-Bisaccate Pollen	0.33	0.33	0.00	3.67	1.33	0.00	2.33	0.33	0.67	0.33
	4	Classopollis Pollen	9.67	6.00	3.33	3.33	3.33	0.00	0.33	2.33	1.33	0.33
	5	Spores	2.00	0.33	1.00	1.33	0.00	0.00	0.33	1.33	0.33	0.00
	6	Fresh-Water Algae	14.33	6.67	21.00	7.00	6.00	0.67	3.33	1.67	1.67	1.67
	7	Leiospheres	0.00	0.00	0.00	2.67	1.00	0.00	0.00	0.33	0.00	0.00
	8	Tasmanitids	2.00	2.67	2.67	2.00	0.00	0.00	0.67	1.67	0.00	0.00
	9	Acritarchs	1.33	1.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	10	Dinoflagellate cysts	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
	11	Zoomorphs	1.33	1.67	1.67	1.00	1.33	0.67	2.33	2.33	0.33	0.33
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vita Fragments	13	Cuticle	0.33	0.00	0.00	1.00	0.00	0.00	0.67	0.00	0.00	0.00
	14	Epidermal Tissue	1.00	3.00	3.33	0.67	0.33	0.00	0.33	0.33	0.00	0.00
	15	Definite Wood	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	16	Vascular Bundles	0.67	0.33	0.67	1.67	1.67	0.67	1.67	0.67	0.33	0.00
	17	Resin	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.00	0.00	1.33	0.33	0.33	0.00	0.00	0.00	0.00
Non-Vita Fragments	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.67	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	1.67	3.67	4.67	0.67	1.00	1.67	0.67	0.33	0.00	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	1.00	0.33	0.33	0.00	0.33	1.67	0.33	1.00	0.00	0.00
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	11.00	11.67	13.00	1.67	1.00	0.00	3.67	5.33	2.33	8.33
	23	Brown-Equidimensional, Non-Cellular, Cellular	2.67	1.00	0.00	5.67	7.33	25.33	6.00	7.67	11.33	4.67
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.00	1.67	5.00	0.67	0.67	0.00	0.00	1.33	0.00	0.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.33	0.33	0.00	0.33	1.33	3.00	0.33	2.33	0.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	0.00	1.67	4.00	0.33	0.33	0.00	2.33	1.00	0.67	1.67
	27	Black-Equidimensional, Fluorescent, Cellular	1.33	0.00	1.33	3.33	3.00	7.00	3.67	6.67	1.33	1.33
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.33	0.00	5.33	18.00	38.33	13.00	12.00	4.67	7.33
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	0.00	0.00	0.00	2.00	8.00	8.67	7.00	7.67	3.00	5.33
Structureless Organic Matter	35	Transparent-Yellow, Fluorescent, Fibrous	3.67	6.67	2.33	3.00	3.00	0.33	4.67	3.67	2.67	4.67
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	25.00	19.67	2.33	19.00	27.00	0.00	25.00	26.00	41.00	5.00
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	1.00	0.00	0.00	0.00	1.33	0.00	0.00	0.00	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	1.67	1.67	18.33	18.67	1.00	0.00	0.00	0.33	0.00	0.00
	39	Yellow-Brown, Fluorescent, Fibrous	6.33	11.00	1.00	5.33	4.67	0.00	12.67	8.00	8.67	28.00
	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.33	0.00	6.33	0.33	0.00	1.00	0.00	0.00	0.00	5.67
	41	Yellow-Brown, Non-Fluorescent, Fibrous	0.00	2.67	0.00	4.33	1.33	0.67	1.00	0.67	4.33	0.00
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.00	0.00	1.33	1.33	2.33	0.33	1.00	0.00	0.00	0.00
	43	Brown-Black, Fluorescent, Fibrous	8.33	11.33	0.00	0.00	2.33	0.00	3.33	3.00	10.33	25.00
	44	Brown-Black, Fluorescent, Non-Fibrous	0.67	0.00	3.67	0.00	0.00	4.00	0.33	0.00	0.33	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	0.00	2.67	0.00	0.33	0.67	4.33	0.67	0.33	1.00	0.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	0.00	2.00	0.00	0.33	1.00	1.00	0.00	0.00	0.00
Total			15.00	20.00	15.00	15.00	15.00	15.00	15.00	20.00	20.00	20.00
Tablets			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Spikes			188130.00	250840.00	188130.00	188130.00	188130.00	188130.00	188130.00	250840.00	250840.00	250840.00
Particles of O.M.			2819130.87	3766366.37	5660882.65	940650.00	352743.75	282618.93	1408158.68	2167396.31	7480318.09	7555421.69
Weight processed (g)			20.02	19.98	9.97	20.00	20.00	19.97	5.01	4.96	5.03	4.98
Normalised O.M. p/g	47		2.09	2.79	4.19	0.70	0.26	0.21	1.04	1.60	5.54	5.59

Figure D.20: Relative percentage abundance of each palynomorph/palynodebris category for samples from lower Gristhorpe Member, Cloughton Formation, Yons Nab.

Category	Species No.	Sample No.	209	210	211	212	213	214	215	216	217	218
Palynomorphs	Particulate Organic Matter Categories (Species)											
	1	Unidentified Palynomorphs	0.00	0.00	3.00	0.67	0.33	1.00	2.00	1.00	2.67	1.33
	2	Bisaccate Pollen	0.33	0.67	0.67	0.00	0.00	0.33	1.00	0.33	1.00	0.67
	3	Non-Bisaccate Pollen	0.33	3.67	12.00	0.67	1.33	2.67	6.33	7.67	6.33	4.00
	4	Classopollis Pollen	0.00	3.33	0.67	0.00	0.00	0.33	1.00	0.00	0.33	0.00
	5	Spores	1.00	16.33	6.00	0.33	1.00	0.00	1.67	3.33	2.33	5.00
	6	Fresh-Water Algae	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	Leiospheres	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	Tasmanitids	0.00	0.00	1.00	0.33	0.33	0.33	0.33	1.33	0.67	0.67
	9	Acritarchs	0.00	0.00	0.33	0.33	0.00	0.00	2.00	1.67	2.00	0.67
	10	Dinoflagellate cysts	1.33	1.00	4.00	1.67	1.67	1.67	5.67	6.67	5.67	
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.33	1.33	
Vita Fragments	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
	13	Cuticle	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.33
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.33	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.33	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.33	0.33	1.33
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.67
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	2.67	1.00	1.33	1.00	0.00	0.33	0.67	0.67	1.00	2.33
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.33	0.67	0.33	0.00	4.33	0.67	0.67	0.00	0.33	0.67
Non-Vita Fragments	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	20.33	6.67	5.33	10.67	2.67	3.33	1.67	3.00	3.00	0.00
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.33	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	1.67	0.00	2.67	0.00	0.33	1.67	1.33	1.33	0.67	1.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	1.67
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	4.00	1.67	3.67	1.33	1.00	2.33	1.33	1.67	2.33	2.00
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	19.00	15.00	11.00	49.67	17.33	6.33	7.00	6.00	9.33	3.67
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	32	Black-Bladed, Non-Fluorescent, Cellular	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	6.67	4.33	5.33	10.33	4.00	5.33	4.33	2.33	2.33	1.00
	35	Transparent-Yellow, Fluorescent, Fibrous	2.00	1.00	2.33	1.67	2.33	6.33	6.33	3.67	4.67	5.00
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	9.33	29.33	35.33	14.67	39.33	55.00	54.00	53.00	53.00	31.67
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	5.00	4.67	1.67	0.33	0.33	0.00	0.00	0.00	0.00	0.00
	39	Yellow-Brown, Fluorescent, Fibrous	3.33	2.33	1.67	0.00	17.33	1.67	4.33	4.33	2.67	26.33
	40	Yellow-Brown, Fluorescent, Non-Fibrous	1.67	0.00	0.33	0.00	0.67	5.00	0.67	0.67	0.00	2.67
	41	Yellow-Brown, Non-Fluorescent, Fibrous	0.00	1.33	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00
Total	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00
	43	Brown-Black, Fluorescent, Fibrous	7.33	4.00	0.67	4.00	3.33	0.33	0.67	0.00	0.00	4.33
	44	Brown-Black, Fluorescent, Non-Fibrous	5.67	1.00	0.00	1.67	1.00	4.33	0.00	0.00	0.00	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	1.33	0.67	0.33	1.67	0.33	0.00	0.33	0.00	0.00	0.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	5.67	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	Total		20.00	20.00	20.00	20.00	20.00	20.00	20.00	15.00	20.00	20.00
	Tablets		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Total Spikes		250840.00	250840.00	250840.00	250840.00	250840.00	250840.00	250840.00	188130.00	250840.00	250840.00
	Particles of O.M.		278154.80	686167.59	5016800.00	278711.11	1505040.00	834464.40	1261770.62	3755089.82	1505040.00	440018.71
	Weight processed (g)		5.01	9.97	5.00	10.00	5.00	5.01	4.97	5.01	5.00	5.03
Normalised O.M. p/g		0.21	0.51	3.71	0.21	1.11	0.62	0.93	2.78	1.11	0.33	

Figure D.21: Relative percentage abundances of samples from Gristhorpe Member to Scalby Formation, Yon Nab.

Category	Species No.	Sample No.	219	220	221	222	223	224	225	226	227	228	229
Palynomorphs		Particulate Organic Matter Categories (Species)											
	1	Unidentified Palynomorphs											
	2	Bisaccate Pollen	1.00	0.33	0.67	0.00	0.00	0.33	0.33	0.00	0.00	0.33	0.00
	3	Non-Bisaccate Pollen	3.33	9.67	7.67	15.00	16.33	1.00	4.67	9.33	6.00	3.67	0.00
	4	Classopollis Pollen	0.00	0.00	2.00	0.33	0.67	0.00	1.33	0.33	1.67	4.00	0.33
	5	Spores	3.33	4.67	3.00	4.67	14.00	3.00	5.67	13.33	3.33	0.00	7.33
	6	Fresh-Water Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	Leiosphaerids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	Tasmanitids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	Acriarachis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	Dinoflagellate cysts	0.00	0.00	0.00	1.00	0.33	0.00	0.33	0.33	0.33	0.67	0.00
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vita Fragments													
	13	Cuticle	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.67	0.00	0.33	0.00	0.00	0.00	0.33	0.33	0.00	0.00
Non-Vita Fragments													
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.33	0.33	0.67	2.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	3.00	4.67	4.00	4.67	1.33	0.00	0.33	1.00	1.00	0.00	0.00
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	11.67	1.67	6.33	1.67	2.00	9.00	7.33	1.33	6.00	6.00	7.67
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	1.00	2.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.33	1.33	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.33	2.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.33	3.67	3.67	0.33	0.67	2.67	4.33	1.33	4.00	2.33	2.33
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	4.00	0.33	3.67	0.00	0.00	0.67	2.33	0.00	0.00	0.33	0.00
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	2.67	0.67	0.33	0.33	0.33	0.33	0.00	0.00	2.67	0.33	0.33
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	0.00	0.00	0.67	0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Structureless Organic Matter													
	35	Transparent-Yellow, Fluorescent, Fibrous	6.67	10.00	3.00	2.00	1.67	0.33	6.33	7.33	4.00	4.33	1.33
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	44.33	42.67	42.67	56.00	41.33	45.67	28.33	36.00	39.67	55.00	47.67
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	1.33	3.33	0.00	0.00	0.00
	39	Yellow-Brown, Fluorescent, Fibrous	16.00	13.00	8.67	9.00	17.33	33.67	13.00	3.33	14.00	13.00	19.67
	40	Yellow-Brown, Fluorescent, Non-Fibrous	1.33	1.00	2.33	1.67	1.00	0.67	3.33	5.67	4.33	0.67	0.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous	0.00	0.00	1.67	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.33	0.00
	43	Brown-Black, Fluorescent, Fibrous	2.00	4.67	7.33	1.67	2.33	1.33	5.67	10.33	5.00	5.00	3.33
	44	Brown-Black, Fluorescent, Non-Fibrous	0.00	0.00	1.33	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	0.00	0.00	2.33	0.00	0.00	0.00	0.00	0.00	0.67	0.33	0.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Total			20.00	20.00	20.00	40.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Tablets			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Spikes			250840.00	250840.00	250840.00	501680.00	250840.00	250840.00	250840.00	250840.00	250840.00	250840.00	250840.00
Particles of O.M.			3765600.00	0.00	999362.55	0.00	15050400.00	755421.69	385137.42	15110843.37	1888855.42	4996812.75	1508056.11
Weight processed (g)			5.00	5.01	5.02	5.02	5.00	4.98	5.01	4.98	4.98	5.02	4.99
Normalised O.M. p/g	47		2.79	0.00	0.74	0.00	11.14	5.59	0.29	11.19	1.40	3.70	20.00

Figure D.22: Relative percentage abundances of samples from the Gristhorpe Plant Bed Cloughton

D.4 Brent Core data

Category	Species No.	Sample No.	230.00	231.00	232.00	233.00	234.00	235.00	236.00	237.00	238.00	239.00
Palynomorphs		Particulate Organic Matter Categories (Species)										
	1	Unidentified Palynomorphs	0.00	0.00	0.67	0.67	0.00	0.33	0.00	0.00	0.00	0.00
	2	Bisaccate Pollen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	Non-Bisaccate Pollen	4.67	0.00	1.00	1.00	0.00	0.67	1.33	0.00	1.33	0.00
	4	Classopollis Pollen	0.33	0.00	0.67	0.67	0.00	0.00	0.00	0.00	0.00	0.00
	5	Spores	4.67	0.00	3.00	3.00	0.00	2.33	4.00	0.00	1.67	0.00
	6	Fresh-Water Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	Leiospheres	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	Tasmanitids	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	9	Acritarchs	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	10	Dinoflagellate cysts	10.33	0.33	5.00	5.00	0.00	0.33	0.00	0.00	0.00	0.00
	11	Zooomorphs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Vita Fragments	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	Plant Tissues	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	19	Plant Tissues	0.33	0.33	0.00	0.00	0.00	0.00	0.33	0.00	0.33	0.00
	20	Brown-Equidimensional, Fluorescent, Cellular	0.00	1.33	0.33	0.33	0.00	0.67	0.33	0.00	0.00	0.00
	21	Brown-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.33
	22	Brown-Equidimensional, Fluorescent, Non-Cellular	0.00	0.33	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00
	23	Brown-Equidimensional, Non-Fluorescent, Non-Cellular	4.67	7.67	3.67	3.67	0.00	3.67	2.00	0.67	3.33	0.00
	24	Brown-Bladed, Fluorescent, Cellular	0.00	1.33	0.00	0.00	0.00	0.33	0.33	1.33	13.67	0.33
	25	Brown-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.00	0.00	0.00
	26	Brown-Bladed, Fluorescent, Non-Cellular	1.33	0.00	0.33	0.33	0.00	1.67	1.33	0.00	0.00	0.00
	27	Brown-Bladed, Non-Fluorescent, Non-Cellular	2.33	4.67	0.33	0.33	1.67	0.00	2.67	0.00	1.33	0.00
	28	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	31	Black-Equidimensional, Non-Fluorescent, Non-Cellular	0.67	7.67	2.67	2.67	1.00	1.33	1.00	0.33	3.00	0.00
Structureless Organic Matter	32	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	35	Black-Bladed, Non-Fluorescent, Non-Cellular	1.00	4.67	0.67	0.67	0.00	0.33	0.00	0.00	0.00	0.00
	36	Transparent-Yellow, Fluorescent, Fibrous	34.67	2.33	8.67	8.67	4.00	4.00	4.33	0.33	5.00	92.00
	37	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	28.67	1.33	44.67	44.67	65.33	39.67	38.00	93.67	48.33	0.00
	38	Transparent-Yellow, Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	0.67	0.00	2.33	2.33	0.00	0.00	0.00	0.00	0.00	0.00
	40	Yellow-Brown, Fluorescent, Fibrous	2.00	4.33	10.67	10.67	10.67	26.67	21.67	1.00	15.33	0.00
	41	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.33	0.00	0.00	0.00	4.00	3.33	0.67	2.00	3.00	6.67
	42	Yellow-Brown, Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	43	Yellow-Brown, Non-Fluorescent, Fibrous	1.33	44.67	9.67	9.67	6.67	5.00	14.67	0.00	2.33	0.00
	44	Brown-Black, Fluorescent, Non-Fibrous	0.33	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	0.33	4.00	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.33
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total			15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Tablets			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Spikes			1416641.57	1609324.21	2257560.00	269295.73	179530.49	3762600.00	3747609.56	282195.00	1251696.61	592908.92
Particles of O.M.			4.98	5.01	5.00	4.99	4.99	5.00	5.02	5.00	5.01	5.01
Weight processed (g)			15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Normalised O.M. p/g	47		1.05	1.19	1.67	0.20	0.13	2.79	2.77	0.21	0.93	0.44

Figure D.23: Relative percentage abundances of samples from Brent Core

Category	Species No.	Sample No.	240.00	241.00	242.00	243.00	244.00	245.00	246.00	247.00	248.00	249.00
Particulate Organic Matter Categories (Species)												
Palynomorphs	1	Unidentified Palynomorphs	0.00	0.00	0.33	0.67	0.00	0.33	0.00	0.67	0.00	0.67
	2	Bisaccate Pollen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	Non-Bisaccate Pollen	0.33	0.00	0.67	1.33	0.00	8.00	1.33	4.00	5.33	1.67
	4	Classopollis Pollen	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.00	4.00	0.33
	5	Spores	0.67	0.00	1.33	0.33	0.33	2.00	1.33	1.33	10.00	2.00
	6	Fresh Water Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
	7	Leiospheres	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	Tasmanitids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	Acriolarchs	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00
	10	Dinoflagellate cysts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11	Zoomorphs	0.00	0.00	0.00	0.00	0.00	1.33	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.33	0.33	0.00
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	18	Plant Tissues	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.33	0.33	0.00	2.33	3.00	0.00	5.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	1.33	0.00	0.00	0.33	1.00	21.00	5.67	14.33	23.33	5.33
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	0.00	0.00	15.00	20.33	0.00	0.00	0.00	0.00	0.00	0.00
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.67	1.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.33	0.00	0.00	0.33	0.33	0.00	0.00	0.00
	25	Brown-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.33	0.00	0.00	0.67	0.00	0.00	0.00
	26	Brown-Bladed, Non-Fluorescent, Non-Cellular	0.33	0.00	3.33	9.67	0.00	7.33	2.67	6.67	9.67	5.33
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	0.00	0.00	1.33	3.33	0.00	0.67	1.00	1.67	20.67	11.33
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	34	Black-Bladed, Non-Fluorescent, Non-Cellular	0.00	0.00	0.33	0.67	0.00	0.67	0.00	0.33	0.67	2.33
	35	Transparent-Yellow, Fluorescent, Fibrous	5.33	4.67	2.33	13.67	1.67	19.00	3.00	5.33	7.00	4.33
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	69.33	82.67	42.33	29.33	81.00	31.33	44.33	46.33	11.00	37.00
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	0.00	0.00	2.67	0.00	0.00	1.33	1.00	0.00	1.00	0.00
	39	Yellow-Brown, Fluorescent, Fibrous	11.67	7.00	19.67	15.33	7.67	1.33	25.33	7.67	2.67	22.33
	40	Yellow-Brown, Fluorescent, Non-Fibrous	5.00	3.00	2.00	0.00	5.33	0.00	4.00	3.67	0.33	0.00
	41	Yellow-Brown, Non-Fluorescent, Fibrous	0.00	0.00	0.33	0.00	0.00	0.33	0.67	0.00	0.67	0.00
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	43	Brown-Black, Fluorescent, Fibrous	0.00	2.67	7.33	3.67	2.33	1.00	3.33	2.00	1.00	2.00
	44	Brown-Black, Fluorescent, Non-Fibrous	6.00	0.00	0.33	0.00	0.00	0.33	2.33	0.00	0.00	0.00
	45	Brown-Black, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.00	1.33	2.33	0.00	0.33	0.00
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Total Tablets			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Spikes			364122.58	866559.19	5621414.34	1870079.52	946327.97	5599107.14	751017.96	2862018.26	746547.62	1873804.78
Particles of O.M.			5.00	5.01	5.02	5.03	4.97	5.04	5.01	4.93	5.04	5.02
Weight processed (g)			15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Normalised O.M. p/g	47		0.27	0.64	4.16	1.38	0.70	4.15	0.56	2.12	0.55	1.39

Figure D.24: Relative percentage abundances of samples from Brent Core

Category	Species No.	Sample No.																
		Particulate Organic Matter Categories (Species)																
Palynomorphs	1	Unidentified Palynomorphs																
	2	Bisaccate Pollen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	3	Non-Bisaccate Pollen	2.33	0.67	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	4	<i>Classopollis</i> Pollen	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	5	Spores	4.67	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
	6	Fresh Water Algae	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	7	Leiospheres	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	Tasmanids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	Acritarchs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	Dinoflagellate cysts	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11	Zooconids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	Fungal Bodies	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	13	Cuticle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	14	Epidermal Tissue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	Definite Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	16	Vascular Bundles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	17	Resin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Vita Fragments	18	Plant Tissues	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	19	Brown-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	20	Brown-Equidimensional, Non-Fluorescent, Cellular	0.67	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	21	Brown-Equidimensional, Fluorescent, Non-Cellular	0.33	2.67	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	22	Brown-Equidimensional, Non-Cellular, Non-Fluorescent	18.00	7.67	3.67	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	23	Brown-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	Brown-Bladed, Non-Fluorescent, Cellular	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	25	Brown-Bladed, Non-Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	Brown-Bladed, Fluorescent, Non-Cellular	5.33	3.00	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
	27	Black-Equidimensional, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	28	Black-Equidimensional, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	29	Black-Equidimensional, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	Black-Equidimensional, Non-Fluorescent, Non-Cellular	21.67	35.00	5.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	31	Black-Bladed, Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	32	Black-Bladed, Non-Fluorescent, Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	33	Black-Bladed, Fluorescent, Non-Cellular	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	34	Black-Bladed, Non-Fluorescent, Non-Cellular	4.67	4.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Structureless Organic Matter	35	Transparent-Yellow, Fluorescent, Fibrous	5.00	2.33	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	36	Transparent-Yellow, Fluorescent, Non-Fibrous	25.67	25.67	48.00	84.67	71.67	33.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.33
	37	Transparent-Yellow, Non-Fluorescent, Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.67
	38	Transparent-Yellow, Non-Fluorescent, Non-Fibrous	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	39	Yellow-Brown, Fluorescent, Fibrous	9.33	9.00	5.33	10.33	8.67	6.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	40	Yellow-Brown, Fluorescent, Non-Fibrous	0.33	2.00	10.00	10.33	0.00	1.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
	41	Yellow-Brown, Non-Fluorescent, Fibrous	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.67
	42	Yellow-Brown, Non-Fluorescent, Non-Fibrous	0.00	0.00	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	43	Brown-Black, Fluorescent, Fibrous	1.00	3.33	11.67	0.00	0.67	3.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	44	Brown-Black, Fluorescent, Non-Fibrous	0.00	0.00	5.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.67
	45	Brown-Black, Non-Fluorescent, Fibrous	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.67
	46	Brown-Black, Non-Fluorescent, Non-Fibrous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total		15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	0.67
	Tablets		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	15.00
	Total Spikes		2339925.37	1615774.41	5666566.27	515142.39	1251696.61	3725346.53	241615.65	709745.98	321223.68	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Particles of O.M.		6.03	4.99	4.98	5.01	5.05	4.97	5.02	4.97	5.03	5.00	5.00	5.00	5.00	5.00	5.00	5.03
	Weight processed (g)		15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Normalised O.M. p/g		1.73	1.20	4.20	0.38	0.93	2.76	0.18	0.53	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.24

Figure D.25: Relative percentage abundances of samples from Brent Core

Appendix E

Assemblage Groups and Descriptions of Assemblage-types

Group A	Group B	Group C	Group D	Group E	Group F	Group G
41	9	4	15	6	20	1
53	16	5	19	12	39	2
68	24	7	34	17	63	3
121	26	8	37	25	64	10
134	29	11	44	40	85	21
135	31	13	50	42	123	22
161	45	14	59	43	124	23
172	46	18	60	62	137	33
219	47	27	65	75	140	35
220	51	28	72	83	248	36
221	56	30	74	115		66
222	61	32	87	120		67
223	69	38	88	125		70
226	78	48	92	138		71
227	80	49	109	142		73
228	91	52	110	143		77
229	96	54	111	157		82
233	97	55	116	166		93
234	98	57	117	170		94
237	105	58	118	176		95
238	106	76	119	177		99
239	127	79	122	181		100
240	130	81	159	182		101
241	158	84	163	183		102
242	160	86	165	184		103
244	167	89	202	186		107
245	168	90	203	187		108
247	169	104	210	188		113
252	171	112	218	204		114
253	207	126	225	209		128
254	208	131		250		129
255	213	132		251		139
256	224	133				141
257	235	136				144
258	236	155				145
	246	162				146
	249	179				147
		180				148
		185				149
		231				150
		243				151
						152
						153
						154
						156
						164
						173
						174
						175
						178
						189
						190
						191
						192
						193
						194
						195
						196
						197
						198
						199
						200
						201
						205
						206
						211
						212
						214
						215
						216
						217
						230
						232

Figure E.1: Samples assigned to Assemblage Groups A-G which are defined in Section 3.3. Blue signifies relative abundance of fluorescent SOM is 11% greater than non-fluorescent SOM. Green represents less than or equal to occasional (*i.e.*, $\leq 11\%$) difference between relative abundance of total fluorescent and non-fluorescent SOM. Red signifies non-fluorescent SOM is 11% more abundant than fluorescent SOM.

E.1 Introduction to Assemblage Descriptions

This appendix presents the descriptions of the different acid-insoluble organic matter assemblage groups, assemblage-types, and their relationship to environmental variables, including their grain-size, palyno-lithofacies and stratigraphic distribution. The proportions of key components are expressed qualitatively, [after Lewis, 1995], as illustrated in Table E.1. This allows the abundance of particular components to be envisaged more clearly than if the ranges of relative abundances were presented. For convenience, the assemblage-types are denoted by a code for the abundance and identity number of the key component(s) (species) at the beginning of each description, *e.g.*, ‘AB36-AS22/34’ denotes that the assemblage group/type contains abundant transparent-yellow, fluorescent, non-fibrous SOM; absent brown-equidimensional, non-fluorescent, non-cellular, and black-equidimensional, non-fluorescent, non-cellular fragments respectively. The identity numbers of the organic matter components (species) were introduced in Figure 3.14. These are illustrated in Table E.2.

Relative Percentage Abundance	Qualitative Nomenclature	Code
0%	Absent	AS
0-1 %	Rare	R
1-5 %	Very-Occasional	V O
6-10 %	Occasional	O
11-15 %	Frequent	F
16-20 %	Very-Frequent	VF
21-30 %	Common	C
31-50 %	Very-Common	V C
>50 %	Abundant	AB

Table E.1: Relationship between relative percentage abundance and qualitative terms

In this section, the grain-size of the host sediments are divided into the following categories: clay, mud, silt, very-fine-grained sand, fine-grained sand and medium-grained sand. The lithofacies groups, in this thesis, are defined using the sedimentary facies scheme proposed by Morgans [1997]. She developed this scheme to interpret and classify the diverse lithologies found in the Middle Jurassic

Legend for Species Score Data		
Palynomorphs (1-12) 1: Unidentified Palynomorphs 2: Non-Bisaccate Pollen 3: Bisaccate Pollen 4: <i>Classopollis</i> Pollen 5: Spores 6: Fresh -Water Algae 7: Leiosphere 8: Tasmanitids 9: Acritarchs 10: Dinoflagellate cysts 11: Zoomorphs 12: Fungal palynomorphs	Non-Vita Fragments Brown-Equidimensional (19-22) 19: Brown-Equidimensional-Fluorescent-Cellular 20: Brown-Equidimensional-Non-Fluorescent-Cellular 21: Brown-Equidimensional-Fluorescent-Non-Cellular 22: Brown-Equidimensional-Non-Fluorescent-Non-Cellular Brown-Bladed (23-26) 23: Brown-Bladed-Fluorescent-Cellular 24: Brown-Bladed-Non-Fluorescent-Cellular 25: Brown-Bladed-Fluorescent-Non-Cellular 26: Brown-Bladed-Non-Fluorescent-Non-Cellular Black-Equidimensional (27-30) 27: Black-Equidimensional-Fluorescent-Cellular 28: Black-Equidimensional-Non-Fluorescent-Cellular 29: Black-Equidimensional-Fluorescent-Non-Cellular 30: Black-Equidimensional-Non-Fluorescent-Non-Cellular Black-Bladed (31-34) 31: Black-Bladed-Fluorescent-Cellular 32: Black-Bladed-Non-Fluorescent-Cellular 33: Black-Bladed-Fluorescent-Non-Cellular 34: Black-Bladed-Non-Fluorescent-Non-Cellular	Structureless Organic Matter Transparent-Yellow (35-38) 35: Transparent-Yellow-Fluorescent-Fibrous 36: Transparent-Yellow-Fluorescent-Non-Fibrous 37: Transparent-Yellow-Non-Fluorescent-Fibrous 38: Transparent-Yellow-Non-Fluorescent-Non-Fibrous Yellow-Brown (39-42) 39: Yellow-Brown-Fluorescent-Fibrous 40: Yellow-Brown-Fluorescent-Non-Fibrous 41: Yellow-Brown-Non-Fluorescent-Fibrous 42: Yellow-Brown-Non-Fluorescent-Non-Fibrous Brown-Black (43-46) 43: Brown-Black-Fluorescent-Fibrous 44: Brown-Black-Fluorescent-Non-Fibrous 45: Brown-Black-Non-Fluorescent-Fibrous 46: Brown-Black-Non-Fluorescent-Non-Fibrous Abundance (47) 47: Particulate Organic Matter per gram of sediment
Vita-Fragments (13-18) 13: Cuticle 14: Epidermal Tissue 15: Definite Wood 16: Vascular Bundles 17: Resin 18: Plant Tissue		

Table E.2: Species code numbers used in the description of the assemblage-types

Ravenscar Group of Yorkshire. A summary of Morgans [1997] sedimentary facies scheme and distinguishing criteria are displayed in Figure E.2. Her scheme comprises four major lithofacies types; Alluvial, Estuarine, Lagoonal and Marine. Each category contains further subdivisions. For a more comprehensive account the reader is referred to Morgans [1997]. Ichron [1996] classified the sediments from the Brent core which was investigated in the present study. Where appropriate, the lithofacies interpretations by Ichron [1996] and Morgans [1997] are employed. In the present study, samples were collected from a number of sections in the Cleveland Basin which were not examined by Morgans [1997]. New *palyno-lithofacies* interpretations are proposed for samples collected from these sections. The term *palyno-facies* is used, in this investigation, to reflect the use of both palyno-facies and sedimentological data in the interpretation. In a number of cases, the nature of the organic matter from the sections investigated by Morgans [1997] and Ichron [1996] provided extra information concerning the environment of deposition. New palyno-lithofacies interpretations are proposed for these sediments.

Facies Association	Lithology	Interpretation
Alluival Facies		
A1a	Sandy, low-angle inclined stratification within lenticular bodies	Meandering river-point
A1b	Erosive-based, coarse-grained lenticular bodies	Braided river sediments
A1c	Mudstone lenses	Abandoned channels
A2	Sharp-bottomed, planar laminated silty sandstone	Crevasse splays
A3	Heterolithic sandstone and siltstone	Lake sediments
A4	Dark, organic-rich mudstones	Poorly-drained areas of the floodplain
A5	Heavily-rooted silty mudstones	Well-drained areas of the floodplain
Esturaine Facies		
E1	Bi-directional cross-bedded sandstones and silstones	Tidal channel deposit
E2	Bioturbated, muddy sheet-sandstones	Littoral Sand
Lagoonal Facies		
L1a	Structureless sandy siltstones	Brackish interdistributary bay
L1b	Laminated sandy siltstones	Brackish interdistutary bay
L2	Weakly bioturbated, rippled, flaser and lenticular bedded fine sandstone and siltstone	High-energy interdistributary bay
L3	Plant-rich, heterolithic sandstones, siltstones and mudstones	Coastal Marsh
Marine Facies		
M1	Bioturbated, heterolithic sands and silts	Siliciclastic embayment
M2	Wave-rippled and hummocky cross-stratified sands	Shoreface deposits
M3	Coarsening-upward sandy limestone sequence	Siliciclastic shelf shoal
M4	Cyclic bioturbated siltstones and sandy limestones	Mixed siliciclastic/carbonate shelf
M5	Black silty mudstone	Muddy outer shelf
M6	Sideritic silty sandstone	Nearshore environment
M7	Wave-rippled silty sandstones, containing plant debris and marine trace fossils	Prograding sandy shoreface
M8	Cross-stratified sandy oolite	Tidal sand belt

Figure E.2: Lithofacies scheme established by Morgans [1997] to interpret and classify the Middle Jurassic Ravenscar Group of Yorkshire.

As mentioned in Section 3.11 the organic matter was separated into assemblage groups and assemblage-types following the integration of the results from the conventional and statistical analysis. A synopsis of the different assemblage groups is displayed in Table E.1. 19 assemblage groups were identified: 1-19. These were further separated. The different associations may be distinguished by the letter following the assemblage group number. For example Assemblage Group 2B. The latter groups were further subdivided into major (five or more samples) or minor (4 samples or less) assemblage-types. In one case the assemblage-type was divided into sub-assemblage-types.

The first 12 assemblage groups contain absent or rare dinoflagellate cysts and the remaining seven contain greater than or equal to very-occasional dinoflagellate cysts. The order of description of the different groups is designed to reflect the change from well-preserved organic matter to poorly-preserved organic matter, *i.e.*, the change from low-energy, anoxic-dysoxic conditions to high-energy, oxic conditions. The same order of descriptions also applies to the description of assemblage-types within each group.

E.2 Assemblage Group 1: Abundant Fluorescent Transparent-Yellow SOM

The key character in this assemblage group is the presence of $\geq$ very-common transparent-yellow, fluorescent, non-fibrous SOM and $\leq$ very-frequent occurrence of any other component. As determined from the statistical analysis this type of organic matter is usually typical of anoxic-dysoxic, low-energy conditions. The preservation of this material, in the non-marine setting, is related to accumulation close to source in sub-aqueous and/or water-saturated sediments, which were not disturbed, to any great extent, by water circulation and/or burrowing. The 35 samples assigned to this group have been subdivided into assemblage groups 1A-1C, in reflection of variations in the relative abundance of sporomorphs and non-vita fragments.

E.2.1 Assemblage Group 1A: Abundant Transparent-Yellow, Fluorescent, Non-Fibrous SOM

Major assemblage-type 1A (AB36-AS/R1-12-R39)

Number of samples: 7 (237, 239, 240, 241, 244, 253, 256)

Key characters: Abundant transparent-yellow, fluorescent, non-fibrous SOM and very-low occurrence of any other components, in particular sporomorphs which are absent to rare in all samples.

Minor associations: Absent to rare brown-equidimensional, non-fluorescent, non-cellular fragments and predominantly rare brown-bladed fragments. Absent to rare black-equidimensional, non-fluorescent, cellular fragments except in 253 and 256 which contain very-occasional amounts. Absent to occasional transparent-yellow, fluorescent, fibrous SOM. Samples with lower concentrations of transparent-yellow, fluorescent, non-fibrous SOM usually contain slightly high proportions of transparent-yellow, fluorescent, fibrous SOM. Brown-black, fluorescent, non-fibrous SOM is rare to absent in all samples except 240. Yellow-brown, fluorescent, fibrous SOM is frequent in 240 and occasional in 241 and 244.

Grain-size distribution: All samples except 239 and 253 are medium-grained sand. 239 is from a silty unit and 253 is from a fine-grained sand.

Palyno-lithofacies distribution: 237, 239, 240 and 241 are from alluvial deposits. All these samples, except 239 were collected from sand bodies that are interpreted as fluvial channel sandstones. 239 was collected from sediments that probably accumulated in a low-energy over-bank setting where anoxic-dysoxic conditions prevailed. 244 was collected from sediments which accumulated in a tidally influenced mouth-bar deposit [Ichron, 1996]. 253 and 256 were collected from sediments deposited in a shore-face environment [Ichron, 1996].

Stratigraphic distribution: All samples are from the Ness Formation, Brent Group.

Remarks: The nature of the organic matter in all the samples, except 239, is atypical because they are from relatively coarse-grained host sediments. The lack of fragments suggests that they were deposited in low-energy conditions and/or the SOM has diluted the other components. Thus, the organic matter may have accumulated during a period of low-sediment input.

Minor assemblage-type 1A:2 (AB36-AS/R1-12-F39)

Number of samples: 1 (161)

Key characters: This is very similar to assemblage-type 1A:1 because it contains abundant transparent-yellow, fluorescent, non-fibrous SOM and very-low occurrence of any other components, in particular sporomorphs which are absent to rare. 161, in comparison to 1A:1, contains frequent brown-black fluorescent SOM.

Minor associations: Rare black-equidimensional, non-fluorescent, cellular fragments. Very-occasional transparent-yellow, fluorescent, fibrous SOM. In contrast, to samples from 1A:1, this sample contains more transparent-yellow, fluorescent, fibrous SOM in relation to the levels of transparent-yellow, fluorescent, non-fibrous SOM.

Grain-size distribution: Fine-grained sand.

Palyno-lithofacies distribution: Absent to rare fragments and abundance of well-preserved pale-coloured, fluorescent SOM indicates that the host sediment accumulated close to source, away from fluvio-deltaic influences, in a low-energy setting where anoxic-dysoxic conditions prevailed. The higher concentrations of brown-black, fluorescent SOM (and an index of organic matter per gram of sediment of only 0.04), in contrast to 1A:1, implies that 161 accumulated in conditions which were slightly less anoxic-dysoxic, or the primary source and/or supply of organic matter was different. The minor change in redox status may be related to variations in the level of water-saturation of the host sediments.

Stratigraphic distribution: Scalby Formation, Ravenscar Group.

E.2.2 Assemblage Group 1B: Very-Common to Abundant Transparent-Yellow, Fluorescent, Non-Fibrous & Very-Occasional to Occasional Brown-Equidimensional Fragments**Minor assemblage-type 1B:1 (AB36-VO/O22-AS/R1-12)**

Number of samples: 4 (233, 234, 257, 258)

Key characters: Abundant transparent-yellow, fluorescent, non-fibrous SOM; very-occasional to occasional relative abundances of brown-equidimensional, non-fluorescent, non-cellular fragments, and absent to rare sporomorphs. This assemblage-type is distinguished from 1A by the increased presence of non-vita fragments and higher concentrations of degraded SOM.

Minor associations: 257 and 258 contain very-occasional levels of black-equidimensional, non-fluorescent, non-cellular fragments. This is rare in 233 and 234. Yellow-brown, fluorescent, fibrous SOM is occasional to frequent in all samples, except 258. Brown-black, fluorescent, fibrous SOM is occasional in both 234 and 258 and absent/rare in 233 and 257. Brown-equidimensional, non-fluorescent, non-cellular fragments are occasional in all samples except 257 which contains very-occasional abundances of both brown-equidimensional, non-fluorescent, non-cellular fragments and brown-equidimensional, fluorescent, non-cellular fragments.

Grain-size distribution: Medium-grained sand.

Palyno-lithofacies distribution: Shoreface environments [Ichron, 1996]. The organic matter is indicative of low-energy anoxic-dysoxic conditions. Thus, the organic matter may have accumulated during a period of low-sediment input.

Stratigraphic distribution: All samples are from the Brent core. Samples 233 and 234 are from the Rannoch Formation and samples 257 and 258 are from the Tarbert Formation. The most significant difference between the samples in this assemblage-type, is the presence of black-equidimensional, non-fluorescent, non-cellular discrete fragments in 257 and 258 which are from the uppermost part of the sequence.

Remarks: The higher relative abundance of non-vita fragments and degraded SOM, in comparison, to 1A suggests that the organic matter was subjected to more physical and/or chemical degradation.

Minor assemblage-type 1B:2 (VC36-O/F22-O30-R1-12)

Number of samples: 3 (68, 172, 255)

Key characters: Very-common fluorescent, non-fibrous SOM, rare to very-occasional sporomorphs, combined total of brown-equidimensional, non-fluorescent, fragments is frequent. Black-equidimensional, non-fluorescent, fragments are occasional.

Minor associations: Transparent-yellow, fluorescent, fibrous SOM is very-occasional in 68 and 172 and occasional in 255. Yellow-brown, fluorescent, non-fibrous SOM is very-occasional in all samples. All other components, except yellow-brown, fluorescent fibrous SOM in 68 and 255 are absent to very-occasional. Yellow-brown, fluorescent, fibrous SOM is occasional in 68 and 255.

Grain-size distribution: 68 is from a siltstone, 172 is fine-grained sand and 255 is very-fine-grained sand.

Palyno-lithofacies distribution: The host sediments of 255 are classified as a interdistributary bay (IDB) deposits [Ichron, 1996]. The organic matter suggests that these IDB sediments accumulated in

low-energy, anoxic-dysoxic setting. 68 is classified as accumulating in such an environment.

Stratigraphic distribution: 68 is from the Eller Beck Formation and 172 is from the Millepore Bed, Ravenscar Group. 255 is from the upper Ness Member, Ness Formation, Brent Group.

E.2.3 Assemblage Group 1C: Very Common to Abundant Transparent Yellow, Fluorescent, Non-Fibrous SOM and greater than rare sporomorphs

Major assemblage-type 1C:1 (VC/AB36-VO/VF39-O/VF19-22)

Number of samples: 21 (41, 53, 121, 134, 135, 207, 219, 220, 221, 222, 223, 226, 227, 228, 229, 238, 242, 245, 247, 252, 254)

Key character: This assemblage-type is quite similar to assemblage-type 1B. The most important features that distinguishes this assemblage-type are greater than rare sporomorphs and increased occurrence of discrete brown fragments (except 41, 121, 223 and 226 which do not record an increase in the latter component).

Minor associations: The combined total of brown-equidimensional fragments is above occasional, except for the samples listed above. The most common types are fluorescent and non-fluorescent, non-cellular, brown fragments. All samples, except, 41, 207, 242, 252, 254 contain greater than very-occasional sporomorphs. Transparent-yellow, fluorescent, fibrous SOM occurs at occasional levels, except in 41 and 121 which contain frequent levels. Yellow-brown, fluorescent, fibrous SOM ranges from very-occasional to very-frequent. The majority of samples contain occasional or frequent levels of the latter component. 222 and 223 contain very-frequent levels of non-bisaccate pollen. Only 254 contains occasional black-equidimensional, non-fluorescent fragments. This component is absent/very-occasional in all other samples.

Remarks: All these samples contain well-preserved organic matter suggesting that the organic matter accumulated in a low-energy environment where anoxic-dysoxic or at least temporarily dysoxic conditions prevailed and there was limited influence from fluvio-deltaic activities. The relative increase in brown fragments, except 41, 121, 223 and 226, indicates that organic matter, in this assemblage type, in comparison, to 1A was subject to slightly more oxic conditions, or slightly higher energy levels and/or accumulated slightly nearer to fluvio-deltaic sources.

Lithological distributions: All the samples are 'fine-grained sand': 121, 219, 220, 221, 222, 223, 226, 227, 228 and 229 are from clay units; 41, 53, 134, 135, 242, 245, 252 and 254 are from mud units, and 207 is from a silty unit.

Palyno-lithofacies distribution: 134 contains very-occasional cuticle and leiospheres. As mentioned in Chapter 2 leiospheres are considered to indicate brackish and shallow marine conditions [Scull *et al.*, 1966]. Samples examined from the same beds as 219-229 (Gristhorpe Plant Bed, Yons Nab) yield very-occasional abundances of dinoflagellate cyst and records of acritarchs. This suggests that, by association, these samples were deposited in an environment open to saline influences. Thus, in contrast, to Morgans [1997] who suggested a depositional setting of either abandoned channels or poorly-drained areas of the flood-plain, it is proposed that the 'Gristhorpe Plant Bed' accumulated in a poorly-drained overbank/swamp setting open to saline influences. Ichron [1996] interpreted the environment of deposition of the sediments from which 242, 247, 252 and 254 were collected as swamp/inter-distributary bay deposits. The same environment of deposition is envisaged for 41, 53, 121, 134, 135, 207.

Stratigraphic distribution: 41 and 53 are from horizons rich in plant matter collected from the Saltwick Formation. 121, 134 and 135 are from swamp/IDB deposits found within the Gristhorpe Member at Cloughton Wyke. 219, 220, 221, 222, 223, 226, 227, 228 and 229 are all from the Gristhorpe plant bed, Northern Yons Nab. 207 is collected from the Gristhorpe Member, above the Gristhorpe plant bed, Yons Nab. 238, 245, 246, 247, 252 and 254 are from the Ness Formation, Brent Group.

E.3 Assemblage Group 2: Fluorescent SOM

The description of the different groups in this section begins with samples dominated by pale-coloured, fluorescent SOM through to darker coloured fluorescent SOM. This reflects a change from low-energy, anoxic-dysoxic to slightly higher energy conditions and/or partially oxic conditions. This change may be related to fluctuations in the water table, increased transportation, an increase in the palaeotemperature, disturbance through bioturbation, localised water circulation, and/or deposition closer to fluvio-deltaic sources. The samples in assemblage group 2 are distinguished from assemblage group 1 because they contain either a combination of different types of SOM or are dominated by a particular component other than abundant transparent-yellow, fluorescent, non-fibrous SOM.

E.3.1 Assemblage Group 2A: Transparent-Yellow, Fluorescent, Fibrous and Non-Fibrous SOM

Assemblage-type 2A:1 (VF/C35-F/VF36)

Key Character: Very-frequent to common transparent-yellow, fluorescent, fibrous and frequent to very-frequent transparent-yellow, fluorescent, non-fibrous SOM. Variations in these components are used to divide this assemblage-type into three sub-assemblage-types.

Sub-assemblage-type 2A:1a (C35-VF36-O/F22-F/VF39-O/F43)

Number of samples: 2 (15, 16)

Key characters: Common transparent-yellow, fluorescent, fibrous SOM and very-frequent fluorescent, non-fibrous SOM. Occasional to frequent brown-equidimensional, non-fluorescent, non-cellular fragments. Frequent to very-frequent yellow-brown fluorescent, fibrous SOM and occasional to frequent brown-black fluorescent, fibrous SOM. 15 contains occasional sporomorphs which are very-occasional in sample 16. Index of organic matter per gram is 0.83 and 1.19 respectively.

Lithological distributions: 15 is from a mud and 16 is from a clay unit.

Palyno-lithofacies distribution: These samples are interpreted as over-bank deposits/channel infill, subject to anoxic or temporarily dysoxic conditions, that were not influenced by fluvial activities.

Stratigraphic distribution: Saltwick Formation, West Cliff, Whitby.

Assemblage-type 2A:1b (VF35-F36-F22-O30-O/F5)

Number of samples: 2 (19, 50)

Key characters: This is very similar to the above sub-assemblage. The principal differences are lower abundances of transparent-yellow, fluorescent, fibrous and non-fibrous SOM, lower concentrations of other SOM fractions, and higher abundances of sporomorphs.

Minor associations 19 contains occasional *Classopollis* pollen.

Grain-size distribution: Mud.

Palyno-lithofacies distribution: 19 and 50 are from host sediments interpreted as over-bank deposits,

which were anoxic-dysoxic. The presence of well-preserved organic matter suggests that these sediments were water-saturated, (*i.e.*, poorly-drained). 19 displays evidence of rooting.

Stratigraphic distribution: 19 is from the Saltwick Formation, West Cliff, Whitby and 50 is from the Blea Wyke exposure of the Saltwick Formation.

Sub-assemblage-type 2A:1c (F35-F36-F22-F5-O21-O26-O30)

Number of samples: 1 (74)

Key characters: Frequent transparent-yellow, fluorescent, fibrous SOM; frequent to very-frequent transparent-yellow, fluorescent, non-fibrous SOM; frequent brown-equidimensional, non-fluorescent, non-cellular fragments, and frequent sporomorphs.

Minor associations: Leisospheres are very-occasional.

Grain-size distribution: Silty unit.

Palyno-lithofacies distribution: The organic matter suggests that the environment was anoxic-dysoxic and/or the host sediments were not extensively influenced by fluvial activities. A low-energy, poorly aerated, brackish IDB deposit is envisaged.

Stratigraphic distribution: 74 is from the basal section of the Sycharham Member.

Sub-assemblage-type 2A:1d (O/F35-F/C36-F22-O/VF39-O/F43)

Number of samples: 4 (26, 27, 28, 29)

Key characters: Occasional to frequent transparent-yellow, fluorescent, fibrous SOM; frequent to common transparent-yellow, fluorescent, non-fibrous SOM; frequent brown-equidimensional, non-fluorescent, non-cellular fragments, and occasional to frequent yellow-brown and brown-black, fluorescent, fibrous SOM. Sporomorphs are very-occasional.

Grain-size distribution: 26 and 29 are from muds. 27 is from a silt to very-fine-grained sand and 28 is from a fine-grained sand.

Remarks: The darker material is probably a result of one or a combination of increased transportation, burrowing and/or a fluctuating or low water table. As 27 and 28 contain less fluorescent SOM this indicates that they were not subject to the same extent or duration of the above environmental controls as 26 and 29. This difference could be reflected in the differences in the grain-size of the

host sediments.

Palyno-lithofacies distribution: 26, 27 and 28 are from burrowed over-bank deposits, which were slightly more oxic than the previous sub-assemblage. 29 is from a rooted poorly-drained over-bank deposit. All host sediments were not extensively influence by fluvial activities.

Stratigraphic distribution: All samples are from the channel infill at High Hawsker that was deposited during the early stages of the Saltwick Formation.

Minor assemblage-type 2A:2 (C35-F38-O36/39/22/30-F3)

Number of samples: 1 (65)

Key characters: Common transparent-yellow, fluorescent, fibrous SOM; frequent yellow-brown, fluorescent, fibrous SOM and frequent non-bisaccate pollen.

Minor associations: Occasional transparent-yellow, non-fluorescent, non-fibrous SOM; occasional black-equidimensional, non-fluorescent, non-cellular and brown-equidimensional, non-fluorescent, non-cellular fragments.

Remarks: The association of common, well-preserved transparent-yellow, fluorescent, fibrous SOM, which Lewis [1995] suggested is derived from cuticle, and low occurrence of discrete fragments, indicates that this sample was deposited in an anoxic-dysoxic or temporarily dysoxic setting open to the very-occasional influence of fluvio-deltaic activities.

Grain-size distribution: Fine-grained sand.

Palyno-lithofacies distribution: The results yielded from the organic matter suggest a low-energy setting. Thus, this sample is believed to have accumulated on a low-energy, sub aqueous, anoxic-dysoxic, interdistributary bay (IDB) deposit.

Stratigraphic distribution: Eller Beck Formation.

E.3.2 Assemblage Group 2B: Transparent-Yellow Fluorescent, Non-Fibrous and Yellow-Brown, Fluorescent, Fibrous SOM

Major assemblage-type 2B:1 (VF/C36-O/F39-O22/21-0/F2-5)

Number of samples: 5 (45, 96, 159, 168, 225)

Key characters: Very-frequent to common transparent-yellow, fluorescent, non-fibrous SOM; oc-

casional to frequent yellow-brown, fluorescent, fibrous SOM; less than occasional black-equidimensional, non-fluorescent, non-cellular fragments, and occasional occurrence of brown-equidimensional, non-fluorescent, non-cellular fragments.

Minor associations: 159 and 225 contain frequent sporomorphs, whilst, 168 contains very-occasional and 45 and 96 contain occasional levels. Transparent-yellow fluorescent, fibrous SOM is very-occasional to frequent.

Remarks: The reduction in transparent-yellow fluorescent, fibrous SOM and increase in slightly darker SOM, in comparison to 2A indicates that the organic matter was either exposed to higher energy levels, *i.e.*, the prevailing conditions were slightly more oxic, either through transportation, localised water circulation, and/or burrowing. The overall association of organic matter categories suggests that the organic matter was deposited close to source, away from active fluvio-deltaic activities in a low-energy, poorly-drained setting. Variations of minor components reflect localized variations in the redox potential, source of material and hydrodynamics of the system. For example, the increased levels of sporomorphs in 159 and 225, imply that these were deposited nearer to a floral source or the conditions were slightly more oxic and/or the sporomorphs were hydrodynamically equivalent.

Grain-size distribution: 96 is medium-grained sand. 159 and 225 are from clay units. 45 and 168 are from mud units.

Palyno-lithofacies distribution: 225 is from the Gristhorpe Plant Bed, Gristhorpe Member and classified as a flood-plain deposit open to saline influences. A similar environment of deposition is proposed for 45, 159 and 168. Morgans [1997] classified the sediments from which 96 was collected as a tidal sand belt. However, the organic matter is typical of low-energy anoxic or temporarily dysoxic setting. This therefore suggests that the organic matter collected during a period of low sediment input.

Stratigraphic distribution: 45 is from the Saltwick Formation. 96 is from the Millepore Bed, Leberston Member. 225 is from the Gristhorpe Member. 159 and 168 are from the Scalby Formation.

Major assemblage-type 2B:2 (VF/VC36-VF/VC39-VO/O3/5-O35)

Number of samples: 9 (165, 167, 202, 218, 224, 235, 236, 246, 249)

Key characters: Very-frequent to very-common transparent-yellow, fluorescent, non-fibrous SOM and very-frequent to very-common yellow-brown, fluorescent, non-fibrous SOM.

Remarks: The other components are not crucial to the identification of this assemblage-type, how-

ever variations in discrete fragments and sporomorphs probably reflects minor differences in hydro-dynamism, or redox potential and/or nature of the primary organic matter, *e.g.*, 249 contains frequent black-equidimensional, non-fluorescent, non-cellular fragments. This constituent is absent to very-occasional in all other samples included in this assemblage-type. Samples 165, 202 and 218 contain occasional to frequent sporomorphs.

Lithological distribution: 201, 202 and 224 are from clay rich units. 167 and 236 are from muds. 156, 235 and 246 are from silty sediments. 249 is from a very-fine-grained sand. 218 is from a medium-grained sand.

Palyno-lithofacies distribution: 165 and 167 are from an alluvial setting. 218 is from the organic-rich base of a channel sandstone. 201, 202 and 224 are from the Gristhorpe plant bed, Yons Nab. Other samples from this unit have been classified in 1C as accumulating in poorly-drained over-bank/swamp setting open to saline influences. The presence of slightly more degraded material suggests that the samples classified in this assemblage-type were subject to slightly more oxic conditions. Ichron [1996] classified the sediments from which 235, 236, 243 and 249 were collected as swamp/interdistributary bay deposits.

Stratigraphic distribution: 165 and 167 are from the Scalby Formation. 201, 202 and 224 are from the Gristhorpe plant bed. 218 is from the Scalby Formation, Yons Nab. 235 and 236 are from the Etive Formation and 246 and 249 are from the Ness Formation.

Minor-assemblage-type 2B:3 (F/VF35-VF36-C39)

Number of samples: 3 (91, 98, 119)

Key characters: Common yellow-brown, fluorescent, non-fibrous SOM; very-frequent and frequent transparent-yellow, fluorescent, fibrous and non-fibrous SOM respectively.

Remarks: 119 contains frequent sporomorphs, whilst 91 and 98 contain only very-occasional sporomorphs. 119 was probably colonised by vegetation after deposition.

Lithological distribution: 98 is from a fine-grained sand and 119 from a medium-grained sand. 91 is from a silt to very-fine-grained sand.

Palyno-lithofacies distribution: Morgans [1997] interpreted 98 as a tidal sand belt deposit and 119 as a high-energy IDB deposit. However, the organic matter is typical of low-energy anoxic-dysoxic setting. This, therefore, suggests that the organic matter collected during a period of low sediment input. The sediments and organic matter suggest that 91 accumulated in a low-energy, weakly-bioturbated, poorly-drained IDB deposit which did not collect near fluvial activities. It is possible that the high

content of well-preserved organic matter in 119 is related to the colonisation of the unit after deposition.

Stratigraphic distribution: 91 is from the Millepore Bed, Lebberton Member, 98 is from the uppermost bed of the Millepore Bed, Lebberton Member and 119 from the uppermost bed of the Yons Nab Bed, Lebberton Member.

Minor assemblage-type 2B:4 (VF39-F22-O35/36/43/45)

Number of samples: 1 (46)

Key characters: Very-frequent, yellow-brown, fluorescent, non-fibrous SOM; frequent brown-equidimensional, non-fluorescent, non-cellular fragments, and only occasional levels of other constituents of SOM.

Grain-size distribution: Fine- to medium-grained sand.

Palyno-lithofacies distribution: The palynofacies and sedimentological evidence indicate that the environment of deposit was a relatively poorly-drained flood-plain deposit which accumulated relatively close to fluvio-deltaic sources.

Stratigraphic distribution: Lower part of the Saltwick Formation.

Minor assemblage-type 2B:5 (VC36-VF39-VF30)

Number of samples 1 (213)

Key characters: This assemblage-type is distinguished from 2B:4 by the presence of very-frequent black-equidimensional, non-fluorescent, non-cellular fragments.

Grain-size distribution: Very-fine grained sand.

Palyno-lithofacies distribution: Morgans [1997] suggested that the environment of deposition for this unit was a siliclastic embayment. The palynofacies results indicate a temporarily anoxic-dysoxic environment closer to fluvial activities than 2B:3.

Stratigraphic distribution: Helwarth Beck Member, Scarborough Formation, Yons Nab.

E.3.3 Assemblage Group 2C: Transparent-Yellow, Fluorescent, Non-Fibrous, Yellow-Brown, Fluorescent, Fibrous, SOM and Brown-Black Fluorescent, Fibrous SOM

Minor-assemblage-type 2C:1 (F/C43-F39-O/C36)

Number of samples: 4 (78, 80, 117, 160)

Key characters: Frequent to common brown-black, fluorescent, fibrous SOM; frequent yellow-brown, fluorescent, non-fibrous SOM, and occasional to common transparent-yellow, fluorescent, non-fibrous SOM.

Minor associations: The latter component is occasional in 78, very-frequent in 80 and common in 117 and 160 which suggests that the organic matter in 78 was subject to slightly more oxic conditions than 80, 117 and 160.

Lithological distribution: 160 is from a mud. 78 is from a very-fine-grained sandstone. 80 and 117 are from fine-grained sand.

Palyno-lithofacies distribution: Morgans [1997] interpreted the sediments from which 117 was collected as a high-energy IDB deposit. 78, 80 and 160 are from laterally-accreted sandstones interpreted as crevasse splays. The organic matter, in contrast, is indicative of relatively low-energy, partially anoxic-dysoxic deposits. Thus, a relatively low-energy IDB is envisaged for 117. Either a proximal setting and or period of low sediment input is considered appropriate for 78, 80 and 160.

Stratigraphic distribution: 78 and 80 are from the upper part of the Sycharham Member. 117 is from the upper part of the Yon Nabs Bed, Lebberston Member. 160 is from the Scalby Formation.

Minor assemblage-type 2C:2 (VC44-C36-C40)

Number of samples: 1 (9)

Key characters: Very-common brown-black, fluorescent, non-fibrous SOM; common transparent-yellow, fluorescent, non-fibrous SOM, and common yellow-brown fluorescent, fibrous SOM.

Lithological distribution: Fine-grained, rooted, laterally-accreted sandstone.

Palyno-lithofacies distribution: More distal part of a crevasse splay than 2C:1 with partially oxic conditions prevailing. The increase in aeration may be associated with fluctuations or lowering of the water table.

Stratigraphic distribution: Saltwick Formation, Boulby Quarry.

Minor-assemblage-type 2C:3 (C43-VF/C39-O/F21/22)

Number of samples: 2 (104, 208)

Key characters: Common brown-black, fluorescent, non-fibrous SOM; very-frequent to common yellow-brown, fluorescent, non-fibrous SOM, and occasional to frequent brown-equidimensional, non-cellular fragments.

Lithological distribution: 208 is from a silt and 104 from a very-fine-grained sand.

Palyno-lithofacies distribution: Morgans [1997] postulated that 104 was deposited in a high-energy IDB and 208 in a well-drained flood-plain setting. The nature of the organic matter indicates that oxic conditions prevailed and/or the material was subjected to some physical degradation. The presence of poorly-preserved material suggests that the sediments were well-drained, in comparison to 2A and 2B.

E.3.4 Assemblage Group 2D: Brown-Black, Fluorescent, Fibrous SOM**Minor assemblage-type 2D:1 (VC43-F22)**

Number of samples: 1 (231)

Key characters: Very-common brown-black, fluorescent, fibrous SOM; frequent brown-equidimensional, non-fluorescent, non-cellular fragments; occasional brown-equidimensional, fluorescent, non-cellular and black-equidimensional, non-fluorescent, non-cellular fragments, and less than occasional occurrence of all other types of SOM. The index of organic matter per gram is 1.19.

Grain-size distribution: Medium-grained sand.

Palyno-lithofacies distribution: The presence of dark-coloured, fluorescent SOM is indicative of transportation or an aerated or temporarily oxic environment. This may have been caused by circulation of the water and/or burrowing. The inclusion of equidimensional fragments is indicative of deposition near to the shoreline/active fluvio-deltaic sources. Ichron [1996] suggested that the sediments were deposited in a middle shore-face environment.

Stratigraphic distribution: 231 is from the Broom Formation, Brent Group.

E.4 Assemblage Group 3: Non-Fluorescent and Fluorescent SOM

E.4.1 Assemblage 3A: Transparent-Yellow, Fluorescent and Non-Fluorescent, Non-Fibrous SOM

Minor assemblage-type 3A:1 (VC36-VC38-O/F35-O22)

Number of samples: 2 (31, 69)

Key characters: Very-common transparent-yellow, non-fluorescent, non-fibrous SOM; very-common transparent-yellow, fluorescent, non-fibrous SOM, and occasional brown-equidimensional fragments.

Grain-size distribution: Very-fine- and fine-medium grained sand respectively.

Remarks: Both samples are rooted: sample 31 was probably colonised by vegetation after deposition. 31 contains iron nodules and 69 is an iron-rich sandstone.

Palyno-lithofacies distribution: Morgans [1997] postulated that sediments from which sample 31 was collected were well-drained flood-plain deposits and 69 was from shore-face deposits. The combination of well-preserved and poorly-preserved SOM may either reflect differences in the nature of material and, hence susceptibility to degradation and/or variations in the source of the material. The organic matter yielded from 69 may reflect the subsequent colonisation by vegetation or the accumulation of organic matter during a period of low sediment input.

Stratigraphic distribution: There is no stratigraphical aspect to this assemblage-type: sample 31 is from the lower part of the Saltwick Formation and sample 61 from the top of the Eller Beck Formation.

E.4.2 Assemblage Group 3B: Black-Brown, Non-Fluorescent, Fibrous and Transparent-Yellow, Fluorescent, Non-Fibrous SOM

Minor assemblage-type 3B:1 (VC45-VF36-F43)

Number of samples: 1 (130)

Key characters: Very-common brown-black, non-fluorescent, fibrous; very-frequent transparent-yellow, fluorescent, non-fibrous SOM and frequent brown-black, fluorescent, fibrous SOM.

Lithological distribution: Medium-grained sand.

Palyno-lithofacies distribution: Morgans [1997] postulated that these sediments were crevasse-splay deposits. The palynofacies data indicates that oxic conditions prevailed, and hydrodynamism

was moderate suggesting that the host sediments were deposited in a more distal part of a crevasse splay than 2C:1 or 2C:2

Stratigraphic distribution: Mid-Gristhorpe Member, Cloughton Wyke.

Minor assemblage-type 3B:2 (F36-O39-F46 (O22-O5-O3-O26))

Number of samples: 1 (44)

Key characters: Frequent and occasional transparent-yellow, fluorescent, non-fibrous and yellow-brown, fluorescent, non-fibrous SOM respectively, and frequent brown-black, non-fluorescent, non-fibrous SOM. Occasional brown-equidimensional and -bladed, non-fluorescent, non-cellular fragments.

Lithological distributions: Mud.

Palyno-lithofacies distribution: 44 is from flood-plain sediments rich in macroscopic organic matter. The low occurrence of fragments indicates accumulation occurred in a setting which was not extensively influenced by fluvial activities. The equal abundances of pale and dark SOM may be due to one or a combination of factors: 1) the darker material was more susceptible to degradation, 2) different sources, and 3) variation in the taphonomic processes effecting the organic matter prior to deposition.

Stratigraphic distribution: Lower part of the Saltwick Formation.

E.5 Assemblage Group 4: Non-Fluorescent SOM

This section describes assemblages dominated by non-fluorescent SOM which is associated with higher levels of degradation than the previous assemblage groups. Tarutis [1992] noted rates of degradation are greatest under warm and oxic conditions.

E.5.1 Assemblage Group 4A: Transparent-Yellow, Non-Fluorescent, Non-Fibrous and Transparent-Yellow, Fluorescent, Non-Fibrous SOM

Minor assemblage-type 4A:1 (AB38-VC36-O42)

Number of samples: (24, 158)

Key characters: Abundant transparent-yellow, non-fluorescent, non-fibrous SOM; very common

transparent-yellow, fluorescent, non-fibrous SOM, and occasional yellow-brown, non-fluorescent, non-fibrous SOM.

Minor associations: Low levels of sporomorphs and discrete fragments. 158 contains occasional brown-black, non-fluorescent, non-fibrous SOM suggesting that this sample was deposited in a more oxic environment than 24. Index of organic matter content per gram is 0.1 and 0.04 respectively.

Lithological distribution: Silt (158) and fine-grained sandstone (24).

Remarks: The high concentrations of transparent-yellow, non-fluorescent, non-fibrous SOM, in comparison, to assemblage-type 3A suggests that the organic matter was subjected to more degradation. This may be associated with pre- and/or post-depositional conditions. 24 also contains frequent brown-equidimensional, fluorescent, non-cellular fragments compared with very-occasional fragments in 158 suggesting that 24 accumulated closer to fluvio-deltaic activities.

Palyno-lithofacies distribution: Morgans [1997] classified the sediments from which 24 was collected as crevasse splays and well-drained areas of the flood-plain. The nature of the organic matter, concurs with this proposal. 158 also collected in a well-drained area of the flood-plain.

Stratigraphic distribution: Saltwick and Scalby Formation respectively.

Minor-assemblage-type 4A:2 (C/AB38-VO/O22-O/42/43)

Number of samples: 2 (34, 97)

Key characters: Common to abundant transparent-yellow, non-fluorescent, non-fibrous SOM.

Minor Associations: Very-occasional to occasional brown-equidimensional non-fluorescent, non-cellular fragments; occasional yellow-brown, non-fluorescent, non-fibrous SOM and occasional brown-black, fluorescent, fibrous SOM.

Lithological distribution: Fine-grained sand.

Palyno-lithofacies distribution: Morgans [1997] interpreted the sediments for 97 as tidal sand belt deposits. 34 is interpreted as a nearshore deposit. The nature of the organic matter suggests that the sediments were oxic, either through bioturbation or localised water circulation. The limited amount of fragments implies that the organic matter either accumulated during a period of low sediment input and/or the production of SOM diluted the fragments.

Stratigraphic distribution: Millepore Bed, Cloughton Wyke.

E.5.2 Assemblage Group 4B: Transparent Yellow, Non-Fluorescent, Non-Fibrous and Brown-Black, Non-Fluorescent SOM

Minor assemblage-type 4B:1 (VC/AB38-F45-VO42)

Number of samples: 2 (56, 61)

Key characters: Very-common to abundant transparent-yellow, non-fluorescent, non-fibrous SOM; occasional to common yellow-brown, non-fluorescent, non-fibrous SOM; frequent brown-black, non-fluorescent, fibrous SOM, and very-occasional transparent-yellow, fluorescent, non-fibrous SOM.

Minor Associations: Presence of brown-equidimensional non-fluorescent, non-cellular fragments and very sparse occurrence of sporomorphs. The index of organic matter per gram of sediment is extremely low: 0.04 and 0.08 for 56 and 61 respectively.

Lithological distribution: No relationship to lithology; 56 is from a fine- to medium-grained sand, whilst 61 is from a rooted clay.

Palyno-lithofacies distribution: The association of non-fluorescent, non-fibrous SOM, very-low organic matter content per gram and lack of fragments suggest that these samples accumulated in oxic sediments, (*i.e.*, well-drained, aerated sediments) away from the influence of active fluvio-deltaic sources. 56 is from a laterally-accreted sandstone interpreted as a low-energy minor crevasse splay deposit, subsequently exposed to oxic conditions. 61 is interpreted as a well-drained flood-plain deposit (mire deposit).

Stratigraphic distribution: Both samples are from the upper part of the Saltwick Formation.

Minor-assemblage-type 4B:2 (VC/C46-C/VF38-O22)

Number of samples: 2 (7 and 171)

Key characters: Very-frequent to common transparent-yellow, non-fluorescent, non-fibrous SOM; very-common to common brown-black, non-fluorescent, non-fibrous SOM, and occasional to frequent brown-equidimensional, non-fluorescent, non-cellular fragments.

Minor Associations: Low levels of sporomorphs and frequent yellow-brown, non-fluorescent, non-fibrous SOM in 171.

Grain-size distribution: Silt and clay respectively.

Palyno-lithofacies distribution: Alluvial: well-drained overbank deposits which accumulated in an area that was not substantially influenced by fluvial activities.

Stratigraphic distribution: Scalby and Saltwick Formations respectively.

E.5.3 Assemblage Group 4C: Brown-Black, Fluorescent, Fibrous SOM and Non-Fluorescent, Transparent-Yellow and Yellow-Brown Non-Fluorescent SOM

Minor assemblage-type 4C:1 (VF36-F38-O22-VF46)

Number of samples: 1 (169)

Key characters: Frequent to very-frequent, transparent-yellow, non-fluorescent, non-fibrous SOM and transparent-yellow, fluorescent, non-fibrous SOM. Occasional to frequent brown-equidimensional, non-fluorescent, non-cellular discrete fragments.

Grain-size distribution: Clay.

Palyno-lithofacies distribution: An oxic, (well-drained) low-energy flood-plain deposit which accumulated away from fluvial influences.

Stratigraphic distribution: Scalby Formation.

Minor assemblage-type 4C:2 (VF43-F41-F38-F42-O22-VO5)

Number of samples: 1 (105)

Key characters Very-common brown-black, fluorescent, fibrous SOM; frequent yellow-brown, non-fluorescent, fibrous and non-fibrous SOM; frequent transparent-yellow, non-fluorescent, non-fibrous SOM, and occasional brown-equidimensional fluorescent and non-fluorescent, non-cellular fragments.

Grain-size distribution: Fine-grained sandstone.

Palyno-lithofacies distribution: The dominance of dark delicate material in host sediments which are interpreted as IDB deposits suggests that the environment was oxic. The lack of fragments implies that there was limited disturbance from fluvial activities or bioturbation, *i.e.*, low-energy, poorly-aerated IDB.

Stratigraphic distribution: Yons Nab Bed, Lebberston Member.

E.5.4 Assemblage Group 4D: Brown-Black, Non-Fluorescent, Fibrous SOM**Minor-assemblage-type 4D:1 (C45-VF41-F22)**

Number of samples: 1 (106)

Key characters: Common brown-black and very-frequent yellow-brown, non-fluorescent, fibrous SOM. Brown-equidimensional fragments are frequent as is transparent-yellow, fluorescent, non-fibrous SOM. Index of organic matter per gram is extremely low: 0.08.

Grain-size distribution: Very-fine-grained sand.

Palyno-lithofacies distribution: The palynofacies and sedimentology data indicates a low-energy IDB deposit, slightly closer to fluvio-deltaic activities and/or more oxic (possibly through bioturbation) than 4C:1.

Stratigraphic distribution: 106 is from the Yons Nab Bed, Lebberston Member, Cloughton Wyke.

Minor-assemblage-type 4D:2 (F43/39/35-O35/45-VF22)

Number of samples: 1 (79)

Key characters: Frequent brown-black, fluorescent, fibrous SOM; frequent yellow-brown and transparent-yellow, fluorescent, fibrous SOM, and very-frequent brown-equidimensional, non-fluorescent, non-cellular fragments.

Lithological distributions: Fine-grained sand.

Palyno-lithofacies distributions: The sediments and organic matter are interpreted as accumulating in a moderate to high-energy, oxic IDB.

Stratigraphic distribution: Upper part of the Sycarham Member.

Minor-assemblage-type 4D:3 (C/VC45-O43-O39/36/35-O/F22)

Number of samples: 2 (118, 127)

Key characters: Common to very-common, brown-black, non-fluorescent, fibrous SOM; occasional, brown-black, yellow-brown and transparent-yellow, fluorescent, fibrous SOM; occasional to frequent occurrence of brown-equidimensional, non-fluorescent, non-cellular fragments, and very-occasional to frequent black-equidimensional, non-fluorescent, non-cellular fragments. The index of organic matter per gram is 0.2 and 0.46 respectively.

Lithological distributions: 118 is from a fine-grained sand sandstone. 127 from a very-fine-grained sandstone.

Palyno-lithofacies distributions: The organic matter indicates a low-energy setting. The occurrence of rare leiospheres in 127 suggests that the setting was marginal marine. This concurs with the sedimentological and ichnofabric evidence. *Diplocaterion* burrows are present in both host sediments. Thus, the environment is interpreted as a low-energy *i.e.*, limited influence from fluvio-deltaic activities well aerated (probably from the bioturbation), brackish IDB.

Stratigraphic distribution: 118 is from the Yons Nab Bed, Lebberston Member, 127 is from the Gristhorpe Member, Cloughton Wyke.

E.6 Assemblage Group 5: Fluorescent SOM and Fragments

E.6.1 Assemblage Group 5A: Transparent-Yellow, Fluorescent, Fibrous SOM & Non-Vita Fragments

The association of well-preserved SOM and non-vita fragments is probably a result of different sources of organic matter mixing, *i.e.*, the fragments are introduced by fluvial sources, whilst the more fragile material is produced locally.

Major assemblage-type 5A:1 (VF22-F35-O36)

Number of samples: 1 (72)

Key characters: Very-frequent brown-equidimensional, non-fluorescent, non-cellular fragments, frequent transparent-yellow, fluorescent, fibrous SOM, and occasional transparent-yellow, fluorescent, non-fibrous SOM.

Grain-size distribution: Mud.

Palyno-lithofacies distribution: The sediments are interpreted as flood-plain deposits. The organic matter is typical of accumulation relatively close to fluvial sources in anoxic-dysoxic sediments.

Stratigraphic distribution: Lower part of the Sycharham Member.

Major assemblage-type 5A:2 (F/VC22-VF/VC36)

Number of samples: 8 (4, 8, 37, 48, 112, 122, 162, 177)

Key characters: Very-frequent to very-common transparent-yellow, fluorescent, fibrous SOM and frequent to very-common brown-equidimensional, non-fluorescent, non-cellular fragments. Black-equidimensional very-occasional to frequent.

Minor associations: Occasional brown-bladed and black-equidimensional, non-fluorescent, non-cellular fragments. Sporomorphs are absent to very-occasional, except for 122 which contains frequent sporomorphs. The other components are not crucial in the identification of this assemblage-type. However, variation in the minor characters *e.g.*, occurrence of other types of SOM reflect minor variations in the prevailing redox potential and hydrodynamism.

Lithological distribution: 122 is from a clay rich unit. 4, 8 and 162 are from muds. 37 and 112 are from silty units. 177 is from fine-grained sand. 48 is from a fine- to medium-grained, laterally accreted sandstone.

Palyno-lithofacies distribution: 4, 8, 37, 122 and 162 are from poorly-drained flood-plain deposits rich in macroscopic plant matter. The higher relative proportions of fragments suggest that these samples accumulated in an environment which was closer to fluvio-deltaic activities than 2A. 48 is from a minor, rooted, crevasse splay and 112 is from a brackish IDB [Morgans, 1997] rich in plant matter. The palynofacies data for 48 and 112 suggests that the prevailing redox potential was low. 177 is interpreted as an estuarine deposit [Morgans, 1997]. The combination of fragments and well-preserved organic matter is very unusual. Fragments are indicative of a high-energy, and/or oxic environment, whilst SOM is indicative of a low-energy, anoxic-dysoxic setting. It is possible that the fragments were introduced with the sediments, whilst the SOM entered the system during a period when sedimentation was negligible

Stratigraphic distribution: 4, 8, 37 and 48 are from the Saltwick Formation; 112 is from the Yons Nab Member, Lebberton Formation, 122 is from the Gristhorpe Member and 162 is from the Scalby Formation. 177 is from the Gristhorpe Member, Osgodby Nab

Major assemblage-type 5A:3 (VF/VC36-F/C30-O/F22-VO/035/39-VO/O2-5)

Number of samples: 5 (54, 55, 111, 132, 203)

Key characters: Very-frequent to very-common transparent-yellow, fluorescent, non-fibrous SOM; frequent to common black-equidimensional, non-fluorescent, non-cellular fragments; occasional to

frequent brown-equidimensional, non-fluorescent, non-cellular fragments; very-occasional to occasional brown-black, non-fluorescent, fibrous SOM, and very-occasional abundance of transparent-yellow, fluorescent, fibrous SOM.

Minor associations: 111 and 203 contain occasional spores; this category is very-occasional in 54 and 55. 111 contains frequent black-brown, fluorescent, non-fibrous SOM. Fractions of yellow-brown SOM are very-occasional in 111 and 203 and occasional in 54 and 55.

Lithological distribution : 54 and 55 are from medium-grained sandstone units. 111 is from a clay plant-rich unit, 132 is from an organic-rich, medium-grained, laterally-accreted sandstone and 203 is from a fine-grained, bioturbated sandstone.

Remarks: The higher quantities of fragments, in particular black-fragments, than the previous assemblage-types suggests that these samples were deposited in closer proximity to active fluvio-deltaic sources, or the nature and/or source of the organic matter was different. Both 54 and 55 contain evidence of bioturbation and are rooted, thin, laterally-accreted sandstones.

Palyno-lithofacies distribution: Morgans [1997] interpreted the environment of deposition of 111 and 203 as brackish IDBs. On the basis of the similarity between this assemblage-type and 1C the palynofacies results support her proposal and suggests the setting was anoxic-dysoxic, and was deposited near to fluvio-deltaic sources. A similar environment of deposition is envisaged for 54 and 55. 132 is interpreted as a crevasse splay deposit which was relatively anoxic-dysoxic.

Stratigraphic distribution: 54 and 55 are from the mid-upper part of the Saltwick Formation. Sample 111 is from the Yons Nab Bed, Lebberston Member, Cloughton Wyke. 203 is from the Gristhorpe Plant Bed, Yons Nab.

Minor assemblage-type 5A:4 (O/F3/5-F/C36-VO/F35-F/VF22 and/or F21-O30)

Number of samples: 3 (109, 110, 163)

Key characters: Frequent to common transparent-yellow, fluorescent, non-fibrous SOM; frequent to very-frequent brown-equidimensional, fluorescent or non-fluorescent, non-cellular fragments and occasional to frequent sporomorphs.

Lithological distribution: 109 is from a clay-rich unit; 110 is from a mud, and 163 is from a very-fine-grained sandstone.

Palyno-lithofacies distribution: Morgans [1997] suggested that the sediments, from which 109 and 110, were collected were deposited in brackish IDBs. 163 is interpreted as a poorly-drained flood-plain deposits, and thus was not subject to fluctuation in the water table associated with the tides. All

these sediments were deposited relatively closely to fluvio-deltaic sources and the post-depositional conditions were probably anoxic-dysoxic.

Stratigraphic distribution: 109 and 110 are from the Yons Nab Bed, Lebberston Member. 163 is from the Scalby Formation.

E.6.2 Assemblage Group 5B: Transparent-Yellow and Yellow-Brown, Fluorescent, Non-Fibrous SOM and Non-Vita Fragments

Minor assemblage-type 5B:1 (VF/VC36-F/C39-F/VF21& 22-VO/O5)

Number of samples: 4 (81, 87, 88, 243)

Key associations: Very-frequent to very-common transparent-yellow, fluorescent, non-fibrous; frequent to common yellow-brown, fluorescent, fibrous SOM, and frequent to very-frequent brown-equidimensional, non-fluorescent or fluorescent, non-cellular fragments. Very-occasional to occasional spores.

Minor associations: All samples contain very-occasional to occasional brown-black, fluorescent, fibrous SOM. 243 has frequent transparent-yellow, fluorescent, fibrous SOM.

Lithological distribution: 87 is from a mud and 88 from a very-fine-grained sandstone. 81 is from a fine-grained sandstone and 243 from a silty unit.

Palyno-lithofacies distribution: Ichron [1996] postulated that the sediments from which 243 was collected accumulated in a IDB (mouthbar) setting. 81 and 87 are from minor, rooted, laterally-accreted sandstones which are interpreted as crevasse-splay deposits. 88 is from weakly-bioturbated IDB deposit. The association of fragments and transparent-yellow, fluorescent, non-fibrous and yellow-brown, fluorescent, fibrous SOM suggests that these sediments were deposited in close proximity to fluvio-deltaic activities (moderate velocity) and the post-depositional conditions were partially anoxic-dysoxic.

Stratigraphic distribution: 81, 87 and 88 are from the uppermost part of the Sycarham Member. 243 is from the lower Ness Formation, Brent Group.

E.6.3 Assemblage Group 5C: Transparent-Yellow and Brown-Black Fluorescent, Non-Fibrous SOM and Non-Vita Fragments

Minor assemblage-type 5C:1(VF22-C30-F36-F44)

Number of samples: 1 (126)

Key associations: Very-frequent brown-equidimensional, non-fluorescent, non-cellular fragments; common black-equidimensional, non-fluorescent, non-cellular fragments, and frequent transparent-yellow and brown-black, fluorescent, non-fibrous SOM.

Grain-size distribution: Very-fine-grained sand.

Palyno-lithofacies distribution: Rooted flood-plain deposits. The organic matter indicates that the sediments accumulated near a fluvial source and the sediments were partially oxic, possibly through changes in the level of water-saturation.

Stratigraphic distribution: Gristhorpe Member, Cloughton Wyke.

Minor assemblage-type 5C:2 (VF22-VF30-F36-F45)

Number of samples: 1 (155)

Key associations: Very-frequent brown-equidimensional, non-fluorescent, non-cellular fragments; very-frequent black-equidimensional, non-fluorescent, non-cellular fragments, and frequent transparent-yellow and brown-black, non-fluorescent, non-fibrous SOM.

Grain-size distribution: Very-fine-grained sand.

Stratigraphic distribution: White Nab Member, Scarborough Formation.

Palyno-lithofacies distribution: Morgans [1997] classified this member as a sideritic sandstone which was deposited in a nearshore setting. The organic matter is indicative of deposition close to fluvio-deltaic activities in a partially oxic setting. The darker SOM may be terrestrial sourced, whilst the paler SOM may be locally produced.

E.6.4 Assemblage Group 5D: Transparent-Yellow, Yellow-Brown, Brown-Black SOM and Non-Vita Fragments

Minor assemblage-type 5D:1 (VF22-F36-O35/39/43)

Number of samples: 1 (89)

Key characters: Very-frequent brown-equidimensional, non-fluorescent, non-cellular fragments; frequent yellow-brown, fluorescent, non-fibrous SOM, and occasional yellow-brown and brown-black fluorescent, fibrous SOM.

Grain-size distribution: Medium-grained sand.

Palyno-lithofacies distribution: Morgans [1997] interpreted the sediments as a tidal sand belt. The organic matter indicates that the sediments accumulated in a moderate to high-energy environment which was partially anoxic-dysoxic.

Stratigraphic distribution: Millepore Bed, Cloughton Wyke.

E.6.5 Assemblage Group 5E: Brown-Black, Fluorescent, Fibrous SOM and Non-Vita Fragments

Minor assemblage-type 5E:1 (C43-VF22-O/VF39-O36)

Number of samples: 2 (30, 52)

Key characters: Common brown-black, fluorescent, fibrous SOM; very frequent brown-equidimensional, non-fluorescent, non-cellular fragments, and occasional to very frequent, yellow-brown, fluorescent, fibrous SOM.

Minor associations: 52 contains occasional brown-equidimensional, fluorescent, non-cellular fragments and only occasional yellow-brown, fluorescent, fibrous SOM.

Grain-size distribution: 30 is from a very-fine-grained sandstone and 52 is from a silty unit.

Palyno-lithofacies distribution: Both samples are classified as being deposited in relatively well-drained flood-plain sediments open to fluvio-deltaic influences.

Stratigraphic distribution: 30 is from the Saltwick Formation, High Hawsker and 52 is from the the Saltwick Formation, Blea Wyke.

E.7 Assemblage Group 6: Fragments, Fluorescent SOM and Sporomorphs

E.7.1 Assemblage Group 6A: Transparent-Yellow Fluorescent, Non-Fibrous SOM and Equidimensional, Non-Fluorescent, Non-Cellular Fragments and Sporomorphs

Minor assemblage-type 6A:2 (F4/5-VF36-F22-O39)

Number of samples: 1 (92)

Key characters: Very-frequent transparent-yellow, fluorescent, non-fibrous SOM; frequent brown-equidimensional, non-fluorescent, non-cellular fragments, occasional brown-bladed, non-fluorescent, non-cellular fragment, and frequent sporomorphs.

Minor associations: Occasional *Classopollis* pollen. Occasional brown-bladed, non-fluorescent, non-cellular fragments. Occasional yellow-brown, fluorescent, non-fibrous and brown-black, fluorescent, fibrous SOM.

Grain-size distribution: Mud.

Palyno-lithofacies distribution: The increase in darker SOM in comparison with 6A:1 suggests that the organic matter in this sample was subject to more transportation, and/or the prevailing conditions were more oxic, possibly through bioturbation. 92 is from a bioturbated, anoxic-dysoxic IDB.

Stratigraphic distribution: 92 is from the Millepore Bed.

Minor assemblage-type 6A:2 (F/C36-F/C4/5-F/VF30)

Number of samples 3 (59, 140, 210)

Key characters: Frequent to common transparent-yellow, fluorescent, non-fibrous SOM; frequent to very-frequent black-equidimensional, and non-fluorescent, non-cellular fragments.

Minor Associations: Acritarchs, which are indicative of shallow water marginal marine conditions [Scull *et al.*, 1966; Williams & Sarjeant, 1967] are rare/very-occasional in 140. Acritarchs are absent in the 59 and 210. 140 and 210 were collected from coeval deposits just below the Scarborough Formation. 140 contains common *Classopollis* pollen and 59 and 210 contain very-occasional levels.

Grain-size distribution: 140 and 210 are from mud units and 59 is from a silty unit

Remarks: The association of *Classopollis* pollen, well-preserved transparent-yellow, fluorescent, fibrous SOM and fragments in 140 suggests two possible scenarios, 1) the concentration of *Classopollis*

pollen was caused by hydrodynamically equivalence, and/or 2) the parent plant grow close to the site of deposition (which was anoxic-dysoxic). The abundances of other components reflect localized variations in the redox potential, source of material and hydrodynamics of the system.

Palyno-lithofacies distribution: 59 is interpreted as accumulating near to fluvio-deltaic sources in a poorly-drained IDB. Morgans [1997] interpreted the environment of deposition of 140 and 210 as poorly-drained areas of the flood-plain (with intermittent development of crevasse splays for 139 and 140). On the basis of the palynofacies data it is postulated that 140 and 210 were deposited in sub-aqueous IDB deposits.

Stratigraphic distribution: 59 was collected from the mid-upper part of the Saltwick Formation. 140 and 210 are from the uppermost portion of the Gristhorpe Member. 210 is from Yons Nab.

E.7.2 Assemblage Group 6B: Transparent-Yellow Fluorescent, Non-Fibrous SOM, Equidimensional and -Bladed, Non-Fluorescent, Non-Cellular Fragments and Sporomorphs

Minor assemblage-type 6B:1 (F36-F5-F22-F26)

Number of samples 1 (60)

Key characters: Frequent transparent-yellow, fluorescent, non-fibrous SOM; frequent brown-equidimensional and -bladed, non-fluorescent, non-cellular fragments and frequent spores and occasional *Classopollis* pollen.

Grain-size distribution: Mud.

Palyno-lithofacies distribution: This sample is interpreted as accumulating near to fluvio-deltaic sources in a poorly-drained flood-plain.

Stratigraphic distribution: 60 was collected from the mid-upper part of the Saltwick Formation.

E.8 Assemblage Group 7: Non-Fluorescent and Fluorescent SOM and Non-Vita Fragments

E.8.1 Assemblage Group 7A: Transparent-Yellow, Non-Fluorescent, Non-Fibrous SOM and Non-Vita Fragments

Minor assemblage-type 7A:1 (F/VF22-F38-O30/36/41/45)

Number of samples: 1 (11)

Key characters: Very-frequent brown-equidimensional, non-fluorescent, non-cellular fragments; frequent transparent-yellow, non-fluorescent, non-fibrous SOM; occasional transparent-yellow, fluorescent, non-fibrous SOM and occasional brown-black non-fluorescent, fibrous SOM.

Minor associations: 11 contains very-occasional levels. Occasional to frequent black-equidimensional, non-fluorescent, non-cellular fragments.

Grain-size distribution: Very-fine-grained sand.

Palyno-lithofacies distribution: 11 is from flood-plain deposits which accumulated near fluvio-deltaic sources and were probably partially anoxic-dysoxic. Fluctuations in the water table may have caused the SOM to degrade and/or an increased palaeotemperature [Tarutis, 1992].

Stratigraphic distribution: Lower part of the Saltwick Formation.

E.8.2 Assemblage Group 7B:1 Transparent-Yellow, Non-Fluorescent, Non-Fibrous, Yellow-Brown, Fluorescent, Fibrous SOM and Black-Equidimensional, Non-Fluorescent, Non-Cellular Fragments

Minor assemblage-type (7B:1 VF30-VF38-VF39)

Number of samples: 1 (136)

Key characters: Very frequent black-equidimensional, non-fluorescent, non-cellular fragments; transparent-yellow, non-fluorescent, non-fibrous SOM, and yellow-brown, fluorescent fibrous SOM.

Minor associations: Rare sporomorphs and occasional and very-occasional brown-equidimensional, fluorescent, non-cellular fragments and brown-equidimensional, non-fluorescent, non-cellular fragments respectively.

Grain-size distribution: Fine-grained sand.

Palyno-lithofacies distribution: Morgans [1997] interpreted the sediments as well-drained vegetated

delta plain with a saline influence.

Stratigraphic distribution: Uppermost portion of the Gristhorpe Member.

E.9 Assemblage Group 8: Non-Fluorescent SOM and Fragments

E.9.1 Assemblage Group 8A: Transparent-Yellow, Non-Fluorescent, Non-Fibrous SOM and Non-Vita Fragments

Major assemblage-type: 8A:1 (VF/AB38-VF/VC22)

Number of samples: 10 (5, 6, 13, 14, 18, 38, 47, 51, 57, 86)

Key characters: Common to abundant non-fluorescent, transparent-yellow, non-fibrous SOM; very frequent to very-common brown-equidimensional, non-fluorescent, non-cellular fragments, and absent to occasional sporomorphs. Bladed fragments are absent to rare.

Minor associations: All samples contain a maximum of occasional brown-black, non-fluorescent, fibrous SOM, a presence of yellow-brown, non-fluorescent, non-fibrous SOM, and a maximum of frequent black-equidimensional, non-fluorescent, non-cellular fragments.

Lithological distribution: No clear lithological aspect: 38 is from a silt; 6 is from silt to very-fine-grained sandstone; 18, 51, 57 and 86 are from very-fine-grained sandstone; 13 is from a very-fine to fine sandstone; 14 is from a fine to medium sandstone, and 5 and 47 are from medium-grained sandstones.

Palyno-lithofacies distribution: All samples are alluvial. All samples except samples 47 are rooted. Sample 47 is from the base of a large multistorey channel sandstone. The high concentrations, however, of non-fluorescent, non-fibrous organic matter indicates that the sediments were well aerated. This may have been caused by a fluctuating water table. 86 is from minor laterally-accreted sandstone interpreted as a crevasse splay deposit.

Stratigraphic distribution: All samples, except 86 are from the Saltwick Formation. 86 is from the Sycarham Member

E.9.2 Assemblage Group 8B:1 Transparent-Yellow, Non-Fluorescent and Fluorescent, Non-Fibrous SOM, Brown-Black, Non-Fluorescent, Non-Fibrous SOM and Non-Vita Fragments

Minor assemblage-type 8B:1 (VF22-F36-O38-F45)

Number of samples: 2 (32, 90)

Key characters: Very-frequent brown-equidimensional non-fluorescent, non-cellular fragments, frequent transparent-yellow, fluorescent, non-fibrous SOM, occasional transparent-yellow, non-fluorescent, non-fibrous and frequent brown-black, non-fluorescent, fibrous SOM.

Grain-size distribution: 32 is fine- to medium-grained sand and 90 is medium-grained sand.

Palyno-lithofacies distribution: 32 is from a nearshore setting which was relatively anoxic-dysoxic and influenced by fluvio-deltaic activities. 90 is from an anoxic-dysoxic tidal sand belt. It is possible that the degraded SOM was terrestrially sourced, whilst the well-preserved SOM was produced locally.

Stratigraphic distribution: 32 is from the base of the Dogger Formation and 90 is from the Millpore Bed, Cloughton Wyke.

Minor assemblage-type 8B:2 (C22-F38-VF45)

Number of samples: 1 (179)

Key characters: Common brown-equidimensional non-fluorescent, non-cellular fragments, frequent transparent-yellow, non-fluorescent, non-fibrous SOM, and very-frequent brown-black, non-fluorescent, fibrous SOM.

Grain-size distribution: Medium-grained sand.

Palyno-lithofacies distribution: Morgans [1997] classified the sediments as estuarine deposits. The organic matter is indicative of a high-energy, partially oxic deposit.

Stratigraphic distribution: Gristhorpe Member, Osgodby Nab.

Minor assemblage-type 8B:3 (VF/C22-F30-F38-F/VC45)

Number of samples: 4 (58, 126, 131, 180)

Key characters: Very-frequent to common brown-equidimensional non-fluorescent, non-cellular

fragments, frequent black-equidimensional, non-fluorescent, non-cellular fragments, frequent to very-frequent transparent-yellow, fluorescent, non-fibrous SOM and frequent to common brown-black, non-fluorescent, fibrous SOM.

Grain-size distribution: 58 is very-fine- to fine-grained, 126 is fine-grained sand and 180 is medium-grained.

Palyno-lithofacies distribution: 58 and 126 are from a rooted crevasse splays which were slightly oxic. The organic matter implies that this was the 'distal' part of the deposit. 180 is from a host sediment classified as estuarine by Morgans [1997], which was oxic. The high levels of degraded SOM may be a result of changes in the saturation of the sediments through tidal fluctuations.

Stratigraphic distribution: 58 is from the Saltwick Formation and 180 is from the Gristhorpe Member, Osgodby Nab.

E.9.3 Assemblage Group 8C: Brown-Black, Non-Fluorescent, Non-Fibrous SOM and Non-Vita Fragments

Minor assemblage-type 8C:1 (F45-F/VF22)

Number of samples: 2 (49, 116)

Key characters: Frequent brown-black, non-fluorescent, fibrous SOM and frequent to very-frequent brown-equidimensional, non-fluorescent, non-cellular fragments.

Grain-size distribution: Both 49 and 116 are very-fine-grained.

Palyno-lithofacies distribution: 49 is from a laterally-accreted sandstone which is interpreted as a crevasse-splay. Morgans [1997] interpreted the sediments from which 116 was collected as high-energy IDB deposits. The palynofacies evidence concurs with Morgans [1997] and indicates that the sediments were oxic and deposited in close proximity to fluvial activities.

Stratigraphic distribution: 49 is from the mid-part of the Saltwick Formation, Blea Wyke and 116 is from the Yons Nab Bed, Lebberston Member, Cloughton Wyke.

Minor assemblage-type 8C:2 (C22-VF30-VC45)

Number of samples: 1 (76)

Key characters: Common brown-black, non-fluorescent, fibrous SOM; very-common brown-equidimensional, non-fluorescent, non-cellular fragments very-frequent black-equidimensional, non-fluo-

rescent, cellular fragments.

Lithological distribution: Fine-grained sand

Palyno-lithofacies distribution: Host sediments classified as high-energy IDB. Organic matter is typical of a high-energy oxic setting.

Stratigraphic distribution: Upper part of the Sycharham Member.

Minor assemblage-type 8C:3 (VC45-VC30)

Number of samples: 1 (133)

Key characters: Very-common black-equidimensional, non-fluorescent, cellular fragments and brown-black, non-fluorescent, fibrous SOM.

Lithological distribution: Fine-grained laterally-accreted sandstone.

Palyno-lithofacies distribution: In contrast, to assemblage-type 8C:1 this assemblage-type has abundant black-equidimensional, non-fluorescent, non-cellular fragments. This implies that the primary source material may have been slightly different. It is envisaged that these sediments accumulated close to fluvial activities and that post-depositional conditions were oxic.

Stratigraphic distribution: Gristhorpe Member, Cloughton Wyke.

E.10 Assemblage Group 9: Discrete Non-Vita Fragments and Fluorescent SOM

E.10.1 Assemblage Group 9A: Fragment Dominated and Fluorescent SOM

Minor assemblage-type 9A:1 (VC22-F26-O30-O35-O39)

Number of samples: 2 (42, 43)

Key characters: Very-common brown-equidimensional, non-fluorescent, non-cellular fragments; frequent brown-bladed, non-fluorescent, non-cellular fragments; occasional black-bladed, non-fluorescent, non-fibrous fragments, and occasional transparent-yellow and yellow-brown, fluorescent, fibrous SOM.

Grain-size distribution: 42 is fine-grained sand and 43 is very-fine-grained sand.

Palyno-lithofacies distribution: High-energy, 'distal', in comparison to 5B:1, crevasse splays. The

presence of delicate fluorescent SOM may be related to the colonisation of vegetation after deposition and/or accumulation during low sediment input.

Stratigraphic distribution: Lower part of the Saltwick Formation, Blea Wyke.

Minor assemblage-type 9A:2 (VF/C22-VF/C36-VO/F38-VO/F30-O26)

Number of samples: 3 (17, 25, 176)

Key characters: Very-frequent brown-equidimensional, non-fluorescent, non-cellular fragments and very-frequent transparent-yellow, fluorescent, non-fibrous SOM.

Minor associations: Very-occasional to frequent black-equidimensional, non-fluorescent, non-cellular fragments, very-occasional to frequent yellow-brown, fluorescent, non-fibrous SOM, and occasional brown-bladed, non-fluorescent, non-fibrous fragments.

Grain-size distribution: 17 is from a mud; 25 from a silty unit and 176 from a medium-grained sand unit.

Remarks: 17 and 25 are rooted.

Palyno-lithofacies distribution: 17 and 25 are interpreted as flood-plain deposits which have been colonised following deposition. *i.e.*, moderately well-drained, partially anoxic-dysoxic deposits. 176 is a tidal sand belt [Morgans, 1997]. It is likely that 176 is very similar to 7A:1.

Stratigraphic distribution: 17 and 25 are from the Saltwick Formation and 176 is from the Millepore Bed, Osgodby Nab.

Minor assemblage-type 9A:3 (C/VC30-VF/C36-O/VF22)

Number of samples: 3 (187, 250, 251)

Key characters: Common to very-common black-equidimensional, non-fluorescent, non-cellular fragments, very-frequent to common transparent-yellow, fluorescent, non-fibrous SOM.

Minor associations: 250 and 251 contain occasional yellow-brown, fluorescent, fibrous SOM. Brown-equidimensional, non-fluorescent, non-fibrous fragments are occasional in 251, very-frequent in 250 and common in 187.

Grain-size distribution: 187 is from a silty unit, 250 is very-fine-grained sand and 251 is fine-grained sand.

Palyno-lithofacies distribution: 187 is interpreted as a estuarine deposit [Morgans, 1997]. 250 and

251 are from flood-plain deposits [Ichron, 1996]. The SOM elements indicate that the sediments were poorly-drained and accumulated close to source. The fragments suggest that the sediments accumulated close to fluvial activities. This, therefore, probably indicates that the organic matter comprises two sources: one from the fluvial activities and one produced close to source.

Stratigraphic distribution: 187 is from the Gristhorpe Member, Osgodby Nab. 250 and 251 are from the upper Ness Formation, Brent Group.

E.11 Assemblage Group 10: Discrete Non-Vita Fragments, Fluorescent and Non-Fluorescent SOM

E.11.1 Assemblage Group 10A: Fragment Dominated and Fluorescent and Non-Fluorescent SOM

Minor assemblage-type 10A:1 (VC22-F36-F45-O30)

Number of samples: 1 (166)

Key characters: Very-common brown-equidimensional, non-fluorescent, non-cellular fragments; frequent transparent-yellow, fluorescent, non-fibrous SOM and frequent brown-black, non-fluorescent SOM.

Grain-size distribution: Very-fine-grained sand.

Palyno-lithofacies distribution: The sediments and organic matter indicate accumulation in a relatively poorly-drained flood-plain environment close to fluvial activities.

Stratigraphic distribution: Scalby Formation.

Major assemblage-type 10A:2 (VF/VC22-F/C30-F/VF36-VO/O45)

Number of samples: 6 (120, 182, 183, 185, 186, 188)

Key characters: Very-frequent to very-common brown-equidimensional, non-fluorescent, non-cellular fragments and frequent to common black-equidimensional, non-fluorescent, non-cellular fragments.

Minor associations: Frequent to very-frequent transparent-yellow, fluorescent, fibrous SOM; very-occasional to occasional brown-black, non-fluorescent, fibrous SOM.

Grain-size distribution: 182 is mud, 183 is silty and 120, 185, 186 and 188 are very-fine-grained sand.

Palyno-lithofacies distribution: High-energy, partially anoxic-dysoxic conditions. The host sediments of 120 are interpreted as a crevasse splay and the host sediments of 182, 183, 185, 186, 188 are interpreted as estuarine deposits.

Stratigraphic distribution: 120 is from the Gristhorpe Member, Cloughton Wyke and 182, 183, 186, and 188 are from the Gristhorpe Member, Osgodby Nab.

Minor assemblage-type 10A:3 (VF/C22-VO/O26-VF/C30-VO/O34)

Number of samples: 4 (75, 125, 170, 209)

Key characters: Very-frequent to common brown-equidimensional, non-fluorescent, non-cellular fragments; very-occasional to occasional brown-bladed, non-fluorescent, non-cellular fragments; very-frequent to common black-equidimensional non-fluorescent, non-cellular fragments, and very-occasional to occasional black-bladed non-fluorescent, non-cellular fragments.

Grain-size distribution: 170 is from a mud, 75 and 125 is very-fine-grained sand and 209 is medium-grained sand.

Palyno-lithofacies distribution: High-energy, partially oxic. The host sediments of 75 are interpreted as a high-energy IDB deposit. 125, 170 and 209 are interpreted as accumulating in well-drained areas of the flood-plain close to fluvial activities.

Stratigraphic distribution: 75 is from the upper part of the Sycharham Member. 125 is from the Gristhorpe Member, Cloughton Wyke, 170 is from the Scalby Formation and 209 is from the Gristhorpe Member, Yons Nab.

Minor assemblage-type 10A:4 (C/VC22-VF/C30)

Number of samples: 3 (115, 157, 184)

Key characters: Common to very-common brown-equidimensional, non-fluorescent, non-cellular fragments; occasional to frequent brown-bladed, non-fluorescent, non-cellular fragments and occasional to very-frequent black-equidimensional non-fluorescent, non-cellular fragments.

Minor associations: The SOM elements are present in very-low abundances except for brown-black, non-fluorescent, fibrous SOM which is frequent in 115 and 184. This component is very-occasional in 157.

Grain-size distribution: 184 is silty. 115 and 157 are medium-grained sand.

Palyno-lithofacies distribution: High-energy setting where oxic conditions prevailed. The host sediments for 115 are interpreted as shore-face deposits. 157 is from the base of a large channel sandstone. 184 is from estuarine sediments.

Stratigraphic distribution: 157 is from the base of the Scalby Formation, Hundale Point. 115 is from the Yons Nab Bed, Cloughton Wyke and 184 is from the Gristhorpe Member, Osgodby Nab.

Minor assemblage-type 10A:4 (VC30-VF/C22)

Number of samples: 2 (143, 204)

Key characters: Common to very-common black-equidimensional, non-fluorescent, non-fibrous fragments; very-frequent to common brown-equidimensional, non-fluorescent, non-fibrous fragments; occasional to frequent brown-bladed, non-fluorescent, non-fibrous fragments, and occasional to frequent black-bladed, non-fluorescent, non-fibrous fragments.

Grain-size distribution: Fine-grained sand.

Palyno-lithofacies distribution: The organic matter indicates deposition in a very-high-energy, oxic environment near to fluvio-deltaic sources. 143 is from a siliclastic embayment and 204 from a brackish IDB [Morgans, 1997].

Stratigraphic distribution: 143 is from the base of the Scarborough Formation and 204 is from the Gristhorpe Member, Yons Nab.

Minor assemblage-type 10A:5 (VF20-C22-F24-F26-C30)

Number of samples: 1 (62)

Key characters: Very-frequent, brown-equidimensional, fluorescent, non-cellular fragments; common brown-equidimensional, non-fluorescent, non-cellular fragments; frequent brown-bladed, fluorescent, non-cellular fragments; frequent brown-bladed, non-fluorescent, non-cellular fragments and common black-equidimensional, non-fluorescent, non-cellular, fragments.

Grain-size distribution: Very-fine- to fine-grained sand.

Palyno-lithofacies distribution: Very-high-energy, oxic conditions. Sediments interpreted as shore-face deposits [Morgans, 1997].

Stratigraphic distribution: Eller Beck Formation.

E.12 Assemblage Group 11: Discrete Non-Vita Fragments and Non-Fluorescent SOM

E.12.1 Assemblage Group 11: Fragment Dominated: Fluorescent and Non-Fluorescent SOM

Minor assemblage-type 11A:1 (VF22-VF30-VF38-O35-O36)

Number of samples: 1 (12)

Key characters: Very-frequent, brown-equidimensional, non-fluorescent, non-cellular fragments; very-frequent, black-equidimensional, non-fluorescent, non-cellular fragments; very-frequent transparent-yellow, non-fluorescent, non-fibrous SOM; occasional transparent-yellow, fluorescent, fibrous and non-fibrous SOM.

Grain-size distribution: Mud.

Palyno-lithofacies distribution: High-energy, oxic setting. Well-drained crevasse splay/flood-plain deposit.

Stratigraphic distribution: Saltwick Formation, West Cliff, Whitby.

Minor assemblage-type 11A:2 (VC30-C38-F22)

Number of samples: 1 (142)

Key characters: Very-common black-equidimensional, non-fluorescent, non-cellular fragments; common transparent-yellow, non-fluorescent, non-fibrous SOM, and frequent brown-equidimensional, non-fluorescent, non-cellular fragments.

Grain-size distribution distribution: Very-fine- to fine-grained sand.

Palyno-lithofacies: High-energy, oxic environment of deposition close to a fluvio-deltaic source. The sediments are interpreted as a siliclastic embayment [Morgans, 1997].

Stratigraphic distribution: Base of the Scarborough Formation, Cloughton Wyke.

Minor assemblage-type 11A:3 (C/VC22-VF/VC30-F38 or F45)

Number of samples: 2 (40, 138)

Key characters: Common to very-common brown-equidimensional, non-fluorescent, non-cellular

fragments and frequent to very-frequent black-equidimensional, non-fluorescent, non-cellular fragments.

Grain-size distribution: 40 is from a mud and 138 is from a fine-grained sand unit.

Remarks: 40 contains frequent, transparent-yellow, non-fluorescent, non-fibrous SOM and 138 contains frequent brown-black non-fluorescent, fibrous SOM. 138 contains more black than brown fragments, whilst 40 contains less black than brown fragments.

Palyno-lithofacies distribution: High-energy, oxic conditions. The host sediments from 40 and 138 are interpreted as well-drained areas of the flood-plain.

Stratigraphic distribution: 40 is from the lower part of the Saltwick, Blea Wyke point and 138 is from the upper part of the Gristhorpe Member, Cloughton Wyke.

Minor assemblage-type 11A:4 (C/VC22-O/F30-O/C38)

Number of samples: 2 (83, 181)

Key characters: Common to very-common brown-equidimensional, non-fluorescent, non-cellular fragments; occasional to frequent black-equidimensional, non-fluorescent, non-cellular fragments and occasional to common transparent-yellow, non-fluorescent, non-fibrous SOM.

Remarks: This assemblage-type is very similar to 8A:1.

Grain-size distribution: 83 is medium-grained sand and 181 is fine-grained sand.

Palyno-lithofacies distribution: High-energy, oxic environment. 83 is interpreted as a crevasse splay deposit and 181 is interpreted as an estuarine deposit.

Stratigraphic distribution: 83 is from the upper part of the Sycharham Member and 181 is from the Gristhorpe Member, Osgodby Nab.

E.13 Assemblage Group 12: Discrete Non-Vita Fragments and Sporomorphs

E.13.1 Assemblage group 12A: Discrete Non-Vita Fragments, Sporomorphs and Fluorescent SOM

Minor assemblage-type 12A:1 (C22-O/F30-O3/5-VF35)

Number of samples: 2 (63, 64)

Key characters: Common brown-equidimensional, non-fluorescent, non-cellular fragments; very-frequent transparent-yellow, fluorescent, fibrous SOM; occasional sporomorphs, and occasional black-equidimensional, non-fluorescent, non-cellular fragments.

Grain-size distribution: 63 is from a very-fine- to fine-grained unit. 64 is from a mud.

Palyno-lithofacies distribution: Morgans [1997] interpreted the setting for 63 as a shore-face deposit and 64 as a brackish IDB. The organic matter is indicative of an anoxic-dysoxic setting close to fluvial activities.

Stratigraphic distribution: Eller Beck Formation.

Minor assemblage-type 12A:2 (F22-O/F26-F/VF30-O/F3/5-VO/O35-F36)

Number of samples: 2 (39, 124)

Key characters: Frequent brown-equidimensional, non-fluorescent, non-cellular fragments; frequent transparent-yellow, fluorescent, non-fibrous SOM; frequent to very-frequent black-equidimensional, non-fluorescent, non-cellular fragments and occasional to frequent sporomorphs.

Grain-size distribution: Silty units.

Palyno-lithofacies distribution: The host sediments of 39 and 124 are rooted, flood-plain deposits. The organic matter suggests that the environment of deposition was relatively close to fluvial activities in poorly-drained sediments.

Stratigraphic distribution: 39 is from the lower part of the Saltwick Formation, Blea Wyke Point and 124 is from the Gristhorpe Member, Cloughton Wyke.

Minor assemblage-type 12A:3 (VC22-O36-O35-F3/5)

Number of samples: 1 (85)

Key characters: Very-common brown-equidimensional, non-fluorescent, non-cellular fragments; frequent sporomorphs (occasional *Classopollis* pollen), and occasional transparent-yellow, fluorescent, fibrous and non-fibrous SOM.

Grain-size distribution: Silt to very-fine-grained sand.

Palyno-lithofacies distribution: Rooted, flood-plain deposit. This is very similar to 12A:2. The lower levels of fluorescent SOM indicate that the energy levels were higher and/or the environment of deposition was more oxic.

Stratigraphic distribution: Upper part of the Sycarham Member.

Minor assemblage-type 12A:4 (C22-F36-VF3/5-C30)

Number of samples: 2 (123, 248)

Key characters: Common brown-equidimensional, non-fluorescent, non-cellular fragments; common black-equidimensional, non-fluorescent, non-cellular fragments; very-frequent sporomorphs and frequent transparent-yellow, fluorescent, fibrous and non-fibrous SOM.

Grain-size distribution: Clay and mud respectively.

Palyno-lithofacies distribution: Both the host sediments are rooted, flood-plain deposits. The increase in black fragments, in comparison with 12A:2 indicates that the source of material may be different.

Stratigraphic distribution: 123 is from the Gristhorpe Member and 248 is from the upper Ness Member, Ness Formation.

Minor assemblage-type 12A:5 (F22-VF36-VF3/5-C30)

Number of samples: 1 (137)

Key characters: Frequent brown-equidimensional, non-fluorescent, non-cellular fragments; common black-equidimensional, non-fluorescent, non-cellular fragments; very-frequent sporomorphs and very-frequent transparent-yellow, fluorescent, fibrous and non-fibrous SOM.

Grain-size distribution: Mud.

Palyno-lithofacies distribution: Rooted, flood-plain deposit. A environment of deposition very sim-

ilar to 12A:4 is envisaged.

Stratigraphic distribution: Gristhorpe Member

E.13.2 Assemblage Group 12B: Discrete Non-Vita Fragments, Sporomorphs and Fluorescent and Non-Fluorescent SOM

Minor assemblage-type 12B:1 (C22-O26-O30-O3/5)

Number of samples: 1 (20)

Key characters: Common brown-equidimensional, non-fluorescent, non-cellular fragments; occasional brown-bladed, non-fluorescent, non-cellular fragments; occasional brown-equidimensional, non-fluorescent, non-cellular fragments, and occasional sporomorphs.

Remarks: Both non-fluorescent and fluorescent SOM are present in approximately equal quantities. 20 was collected from the base of the raffle-rich, multi-storey channel sandstone.

Grain-size distribution: Medium-grained sand.

Palyno-lithofacies distribution: High-energy, oxic channel sandstone.

Stratigraphic distribution: Lower part of the Saltwick Formation.

E.14 Assemblage Group 13: Transparent-Yellow, Fluorescent SOM & $\geq$ Very-Occasional Dinoflagellate Cysts

E.14.1 Assemblage Group 13A: Transparent-Yellow, Fluorescent, Fibrous and Non-Fibrous SOM and Occasional dinoflagellates cysts

Minor assemblage-type 13A:1 (VC35-C36-O10)

Number of samples: 3 (22, 36, 230)

Key character: Very-common transparent-yellow, fluorescent, fibrous SOM; common transparent-yellow fluorescent, non-fibrous, and occasional dinoflagellate cysts.

Minor associations: 22 and 36 contain very-occasional acritarchs which are rare in the 230. 36 and 230 comprises occasional, and 22 occasional amounts of, when combined, spores and non-bisaccate pollen. Rare and occasional levels of brown-equidimensional, non-fluorescent, non-cellular fragments. All samples only contain rare/very-occasional black-equidimensional fragments. Rare levels

of black-bladed, non-fluorescent, non-fibrous fragments are also recorded. Index of organic matter contents are: 1.05, 0.04 and 0.21 respectively.

Grain-size distribution: 22 and 36 are medium grained; 230 is from a mud.

Palyno-lithofacies distribution: All samples occur in the marine lithofacies which were probably anoxic-dysoxic.

Stratigraphic distribution: 22, 36 are from the Dogger Formation. 230 is from the Broom Formation, Brent Group.

E.14.2 Assemblage Group 13B: Transparent-Yellow, Fluorescent, Non-Fibrous SOM and Occasional Dinoflagellates Cysts

Minor assemblage-type 13B:1 (AB36-O10-R3/4/5)

Number of samples: 1 (173)

Key Characters: Abundant transparent-yellow, fluorescent, non-fibrous SOM; occasional dinoflagellate cysts, and rare relative abundance of sporomorphs.

Minor Associations: Other types of SOM are rare to absent and leiospheres are very-occasional.

Lithology: Fine- to medium-grained sand.

Palyno-lithofacies: Marine; anoxic-dysoxic tidal sand belt with limited input from fluvio-deltaic sources during accumulation of the organic matter.

Stratigraphic distribution: Millepore Bed, Lebberston Member, Osgodby Nab.

Major assemblage-type 13B:2 (AB36-O3-VO/O9 and VO/O10)

Number of samples: 6 (150, 151, 214, 215, 216, 217)

Key characters: Abundant transparent-yellow, fluorescent, non-fibrous SOM; occasional to very-occasional dinoflagellate cysts; very-occasional to occasional non-bisaccate pollen, and presence of greater than rare acritarchs and dinoflagellates cysts.

Minor associations: Brown-equidimensional and -bladed fragments are very-occasional, whilst black-equidimensional fragments are occasional except for 150 and 151. Black-bladed fragments are very-occasional in all samples. The relative abundance of black fragments is greater than brown-equidimensional fragments in all samples in this assemblage-type except 151. All samples contain

transparent-yellow, fluorescent, fibrous SOM: minimum level is very-occasional in 32 and 33 and the maximum is frequent in 150. Rare to absent yellow-brown and brown-black SOM; except 215 and 216 that comprise very-occasional yellow-brown, fluorescent, fibrous SOM, and 214 which contains occasional yellow-brown, fluorescent, non-fibrous and brown-black fluorescent, non-fibrous SOM. Index of particulate organic matter per gram ranges from 0.62 to 2.78. The average is 1.14.

Grain-size distribution: 216 and 217 are from silty units. 151 and 214, 215 are very-fine-grained sand. 150 is from a fine- to medium-grained sandy unit.

Remarks: The organic matter content probably reflects the grain-size. The silty samples: 216 and 217 contain 2.7 and 1.7 respectively. 151 and 215 contain 1.39 and 0.93 respectively, whilst 214 contains 0.62. No weight data is available for 150.

Palyno-lithofacies distribution: All are marine; 215, 216 and 217 are from a nearshore environment [Morgans, 1997]. 150 is from shore-face deposits and 151 from a mixed siliclastic/carbonate shelf [Morgans, 1997]. The palynofacies data suggests that the sediments accumulated in a fully marine environment which was anoxic or temporarily dysoxic and where there was limited influence from fluvio-deltaic activities. The slightly higher levels of black fragments than brown may be due to increased transportation and/or increased production of black fragments.

Stratigraphic distribution: All samples are from the Scarborough Formation *humphriesianum* Zone. 215, 216 and 217 are from the White Nab Member of the Scarborough Formation, Northern Yons Nab. 150 and 151 are from the Hundale Sandstone and Spindle Thorn Members of the Scarborough Formation respectively.

Major assemblage-type 13B:3 (AB36-F22-VO10)

Number of samples: 1 (108)

Key characters: Abundant transparent-yellow, fluorescent, non-fibrous SOM; frequent brown-equidimensional, non-fluorescent, non-cellular fragments, and very-occasional dinoflagellate cysts.

Grain-size distribution: Clay.

Palyno-lithofacies distribution: Morgans [1997] interpreted that these sediments accumulated in a high-energy IDB. The organic matter is indicative of a relatively low-energy anoxic-dysoxic setting.

Stratigraphic distribution: Yons Nab Bed, Lebberston Member, Cloughton Wyke.

E.15 Assemblage Group 14: Trans.-Yellow, Fluorescent, Non-Fibrous SOM, Yellow-Brown, Fluorescent, Fibrous SOM

Major assemblage-type 14A:1 (C/VC36-O10-F/VF39)

Number of samples: 12 (66, 100, 107, 156, 190, 191, 192, 193, 194, 196, 201, 232)

Key characters: Common to very-common transparent-yellow, fluorescent, non-fibrous SOM; occasional to common yellow-brown, fluorescent, non-fibrous SOM, and very-occasional dinoflagellate cysts.

Minor associations: Discrete equidimensional fragments usually range from occasional to frequent. 107 contains no discrete fragments. 156, 191, 193 and 232 contain occasional to frequent brown-equidimensional, fluorescent, non-cellular fragments. Bladed fragments are typically absent to rare. Only 193 and 232, and 194 and 201 contain occasional black- and brown-bladed fragments respectively. Sporomorphs range from occasional to very-occasional.

Grain-size distribution: 107 and 201 are from clay units. 194 is a mud. 100, 190, 191, 192 and 193 are siltstones. 196 is from a very-fine sandstone. 232 is from fine-grained sandstone. 66 is from a fine- to medium-grained sandstone.

Lithofacies associations: The palynofacies data suggests that the organic matter accumulated in low-energy anoxic-dysoxic or temporarily dysoxic setting close to source with limited fluvial input. The presence of dinoflagellate cysts indicates that there was a saline influence during deposition.

Stratigraphic distribution: 66 is from the Eller Beck Formation. 100, 107, 191, 193 and 194 are all from the Yons Nab Member. 156 is from the Bogmire Gill Member of the Scarborough Formation. 201 is from the Gristhorpe plant bed, Gristhorpe Member. 232 is from the Rannoch Formation.

Minor assemblage-type 14A:2 (F/VF35-F/VF36-F/VF39-VO10-O/F43-O22)

Number of samples: 2 (93, 198)

Key characters: Frequent to very-frequent transparent-yellow, fluorescent, fibrous SOM; frequent to very-frequent transparent-yellow, fluorescent, non-fibrous SOM; frequent brown-equidimensional, non-fluorescent, non-cellular fragments, and occasional to very-frequent yellow-brown and brown-black, fluorescent, fibrous SOM, and very-occasional dinoflagellate cysts.

Grain-size distribution: 93 is from a fine-grained sandstone. 198 is from a very-fine-grained sand-

stone. 93 displays some evidence of burrowing

Palyno-lithofacies distribution: 93 and 198 are from burrowed IDB deposits which were partially anoxic-dysoxic, *i.e.*, less anoxic-dysoxic than the previous assemblage-types. The darker material is either a result of oxidisation after deposition due to burrowing and/or changes in the water-level, or alteration prior to deposition.

Stratigraphic distribution: 93 is from the Millepore beds exposed north of Cloughton Wyke. 198 is from Yons Nab Bed, Yons Nab.

Minor assemblage-type 14A:3 (VF43-F39-O/F36-O10)

Number of samples: 2 (103, 195)

Key characters: Very-frequent brown-black, fluorescent, fibrous SOM; frequent yellow-brown fluorescent, fibrous SOM; occasional to frequent transparent-yellow fluorescent, non-fibrous SOM, and occasional dinoflagellate cysts.

Grain-size distribution: 103 is fine-grained sand. 195 is from a silty unit.

Palyno-lithofacies distribution: IDB often sub-aerially exposed or bioturbated.

Stratigraphic distribution: Yons Nab Bed: 103 is from Northern Yons Nab and 195 is from Cloughton Wyke.

E.16 Assemblage Group 15 : Trans.-Yellow, Yellow-Brown & Brown-Black, Fluorescent SOM, Fragments & Sporomorphs

Minor assemblage-type 15A:1 (F22-F35-O36-F39-F43-VO10)

Number of samples: 1 (73)

Key characters: Frequent brown-equidimensional, non-fluorescent, non-cellular fragments; frequent transparent-yellow, fluorescent, fibrous SOM; frequent yellow-brown, fluorescent, fibrous SOM, and frequent black-brown, fluorescent, fibrous SOM.

Grain-size distribution: Very-fine- to fine-grained sand.

Palyno-lithofacies distribution: The sediments are interpreted as a minor crevasse splay. The combination of fragments and SOM suggests that the deposit was formed in a moderate energy setting

which was partially anoxic-dysoxic.

Stratigraphic distribution: Lower part of the Sycharham Member.

E.17 Assemblage Group 16: Trans.-Yellow, Fluorescent and Non-Fluorescent SOM and $\geq$ V.O. dinoflagellate cysts

Minor assemblage-type 16A:1 (VF/F36-VF/F38-O/F22)

Number of samples: 2 (197)

Key characters: Very frequent, transparent-yellow, non-fluorescent, non-fibrous SOM and occasional transparent-yellow fluorescent, non-fibrous SOM. Frequent brown-equidimensional, non-fluorescent, non-cellular discrete fragments.

Lithology distribution: Iron-rich, rooted, fine-grained sandstone.

Palyno-lithofacies distribution: This combination of fluorescent and non-fluorescent material indicates that the organic matter was exposed to partially oxic conditions and/or consists of two or more sources. The dominance of delicate material indicates that the organic matter accumulated in a low-energy setting. It is feasible that the sediments were deposited and were subsequently colonised by vegetation like 31.

Stratigraphic distribution: Yons Nab Bed, Lebberston Member, Yons Nab.

Assemblage-type 16A:2: (AB/VC38-O/F36-VO10)

Number of samples: 2 (33, 35)

Key characters: Abundant to very-common transparent-yellow, non-fluorescent, non-fibrous SOM; occasional to frequent transparent-yellow, fluorescent, non-fibrous SOM, and very-occasional to occasional yellow-brown, non-fluorescent, non-fibrous SOM. Very-occasional dinoflagellate cysts.

Minor associations: Minor presence of brown-equidimensional, non-fluorescent, non-cellular fragments in 33 and 35.

Grain-size distribution: 33 is fine-grained sand and 35 is medium-grained sand.

Palyno-lithofacies distribution: All samples from a marine setting, which was probably partially

anoxic-dysoxic.

Stratigraphic distribution: 33 and 35 are from the Dogger Formation at Blea Wyke Point.

E.18 Assemblage Group 17: Transparent-Yellow, Fluorescent, Non-Fibrous SOM and Non-Vita Fragments

Minor assemblage-type 17A:1 (VF22-VF35-O39-VO10)

Number of samples: 1 (174)

Key characters: Very-frequent brown-equidimensional, non-fluorescent, non-cellular fragments; very-frequent transparent-yellow, fluorescent, fibrous SOM; occasional yellow-brown, fluorescent, fibrous SOM, and very-occasional dinoflagellate cysts.

Grain-size distribution: Medium-grained sandstone.

Palyno-lithofacies distribution: Tidal sand belt [Morgans, 1997]. The palynofacies data provides evidence that the sediments accumulated close to fluvio-deltaic sources and/or near the shoreline in an anoxic-dysoxic setting.

Stratigraphic distribution: Millepore Bed, Lebberston Member, Osgodby Nab.

Major assemblage-type 17A:2 (VC36-O/F22/21-VO/O30/39-VO/O10)

Number of samples: 8 (1, 2, 3, 10, 21, 189, 199, 200)

Key characters: Very-common transparent-yellow, fluorescent, non-fibrous SOM; occasional to frequent brown-equidimensional, fluorescent or non-fluorescent, non-cellular fragments; occasional to very-occasional dinoflagellate cysts; occasional to very-occasional black-equidimensional, non-fluorescent, non-cellular fragments; very-occasional to frequent transparent-yellow, fluorescent, fibrous SOM, and occasional to very-occasional yellow-brown, fluorescent, fibrous SOM, except in sample 21. Other fractions of SOM are rare to absent.

Grain-size distribution: 1, 189, 199, and 200 are from clay rich units. 3, 10 and 21 are from mud 2 is from a very-fine- to fine-grained sandstone.

Palyno-lithofacies distribution: Morgans [1997] suggested that 189 was deposited in a brackish IDB, and 199 and 200 accumulated in a poorly-drained flood-plain or abandonment channel. The palynofacies data suggests that latter sediments were deposited in a poorly-drained flood-plain open to saline influences. A similar environment is envisaged for 3 and 10. 1 and 2 are from marine settings.

1 is from a marine mudstone and 2 from a sideritic silty sandstone (nearshore environment).

Stratigraphic distribution: 1 and 21 are from the Whitby Mudstone Formation. 2 is from the Dogger Formation, and 3 and 10 are from the Saltwick Formation. 189 is from the Yons Nab Member of the Lebberston Member. 199 and 200 are from the Gristhorpe Plant Bed, Gristhorpe Member, Yons Nab.

Minor assemblage-type 17A:3 (C36-VF/C22-VO10)

Number of samples: 2 (67, 175)

Key characters: Common transparent-yellow, fluorescent, non-fibrous SOM; very-frequent to common brown-equidimensional, non-fluorescent, non-cellular fragments and very-occasional dinoflagellate cysts.

Lithological distributions: 67 is very-fine- to fine-grained sand. 175 is fine-grained sandstone.

Palyno-lithofacies distribution: Morgans [1997] proposed the following environments of deposition: a high-energy IDB for 67 and a tidal sand belt for 175. The nature of the organic matter partially concurs with this interpretation, and indicates that the sediments accumulated near to fluvio-deltaic activities/shoreline in post-depositional anoxic-dysoxic conditions.

Stratigraphic distribution: 67 is from the Eller Beck Formation and 175 is from the Millepore Bed, Osgodby Nab.

Major assemblage-type 17A:4 (F/C22-VO/F30-VO/O10-O/F36/35/45)

Number of samples: 7 (23, 70, 94, 99, 101, 102, 129, 178)

Key characters: Frequent to common brown-equidimensional, non-fluorescent, non-cellular fragments; very-occasional to frequent black-equidimensional, non-fluorescent, non-cellular fragments and very-occasional to occasional dinoflagellate cysts.

Minor association: Occasional to frequent transparent-yellow, fluorescent, fibrous SOM. Occasional to very-frequent transparent-yellow, fluorescent, fibrous SOM, and very-occasional to frequent yellow-brown, fluorescent, fibrous SOM.

Grain-size distribution: 23 and 101 are from silty units; 70 and 129 are from very-fine grained units, and 94, 99, 102, 101 and 178 are from fine-grained host sediments.

Palyno-lithofacies distribution: The presence of transparent-yellow, fluorescent, fibrous SOM which

is sourced from terrestrial organic matter, [Lewis, 1995], brown-black SOM and dominance of fragments would suggest that these sediments were deposited in an partially oxic saline influenced IDB close to a fluvial source, *e.g.*, relatively high-energy environment.

Stratigraphic distribution: 23 is from the Saltwick Formation; 94 is from the Millepore Bed; 99, 101, 102 is from the Yons Nab Bed; 129 is from the Gristhorpe Member and 178 is from the Millepore Bed.

Major assemblage-type 17A:5 (F/C36-F30-O/F10)

Number of samples: 11 (141, 144, 145, 146, 148, 147, 149, 152, 153, 154, 211)

Key characters: The key components in this assemblage are very similar to assemblage-type 16A:4. The principal differences are lower levels of transparent-yellow, fluorescent, non-fibrous SOM and higher relative abundances of black-equidimensional and black-bladed fragments.

Minor associations: Very-occasional to occasional sporomorphs, and very-occasional to occasional brown-equidimensional, non-fluorescent fragments. Increased content of black fragments, indicates that the production and/or transportation of these fragments may have increased.

Grain-size distribution: 147, 152, 153, and 154 are from clay. 149 is from a mud. 145, 146 and 148 are from a silty units; 141 is silt to very-fine-grained sand and 144 is very-fine-grained sand.

Palyno-lithofacies distribution: All samples are marine except 141 and 211 which were deposited just below the base of the Scarborough Formation. This would suggest that these sediments accumulated in an environment open to marine influences.

Stratigraphic distribution: All samples from the Scarborough Formation.

Minor assemblage-type 17A:6 (VF/C36-F30-O/F39-VO10)

Number of samples: (128, 205, 206)

Key characters: Very-frequent to common transparent-yellow, fluorescent, non-fibrous SOM; frequent black-equidimensional, non-fluorescent, non-cellular fragments; occasional to frequent yellow-brown, fluorescent, fibrous SOM and very-occasional to occasional dinoflagellate cysts.

Lithological distribution: 205 silt. 206 very-fine-grained sand. 128 is from a bioturbated heterolithic silt to very-fine-grained unit.

Palyno-lithofacies distribution: These samples are interpreted as being deposited in medium-energy

interdistributary bays/swamps which were anoxic-dysoxic.

Stratigraphic distribution: 128 is from the Gristhorpe Member, Cloughton, and 205 and 206 are from the Gristhorpe Member, Yons Nab.

Assemblage-type 17A:7 (VC30-F36-F34-F22)

Number of samples: 1 (212)

Key characters: Very-common black-equidimensional, non-fluorescent, non-cellular fragments, frequent brown-equidimensional, non-fluorescent, non-cellular fragments and frequent black-bladed, non-fluorescent, non-cellular fragments.

Minor associations: Frequent transparent-yellow, fluorescent, non-fibrous SOM.

Grain-size distribution: Fine- to medium-grained sand.

Palyno-lithofacies distribution: Marine: siliclastic embayment, very-close to fluvial source. The dominance of black, non-fluorescent fragments may be related to the primary nature of the material, *e.g.*, charcoal.

E.19 Assemblage Group 18: Transparent-Yellow, Fluorescent SOM, Fragments and Sporomorphs

Minor assemblage-type 18A:1 (F35-VF36-F22-F5-AS/O21-O/26-VO/O30)

Number of samples: 1 (77)

Key characters: Frequent transparent-yellow, fluorescent, fibrous SOM; very frequent transparent-yellow, fluorescent, non-fibrous SOM; frequent brown-equidimensional, non-fluorescent, non-cellular fragments, and frequent sporomorphs.

Grain-size distribution: 77 is from a silty unit.

Palyno-lithofacies distribution: The palynofacies data suggests that the environment was anoxic-dysoxic. The fragments suggest an environment close to fluvio-deltaic activities. A relatively high-energy IDB is envisaged.

Stratigraphic distribution: 77 from the mid-upper portion of the Sycarham Member.

Minor assemblage-type 18A:2 (O/F3/5-F/VF36-VO/F35-F/VF22 and/or F21-O30-VO/O10)

Number of samples: 3 (71, 95)

Key characters: Occasional to frequent spores; frequent to very-frequent transparent-yellow, fluorescent, non-fibrous SOM and frequent to very-frequent brown-equidimensional, fluorescent or non-fluorescent, non-cellular fragments.

Grain-size distribution: 71 is from a silty unit. 95 is fine- to medium-grained sand.

Palyno-lithofacies distribution: 95 is a tidal-sand belt [Morgans, 1997]. 71 is interpreted as a poorly-drained flood-plain deposits open to saline influences. All the sediments were deposited relatively closely to fluvio-deltaic sources and the post-depositional conditions were probably anoxic-dysoxic.

Stratigraphic distribution: 71 was collected from the base of the Sycharham Member and 95 from the Millepore Bed, Lebberston Member.

Minor assemblage-type 18A:3: (VF/VC(3/4/5)-F/C36 and/or O/VF22-O/VF30)

Number of samples: 4 (82, 113, 139, 164)

Key characters: Very-frequent to very-common sporomorphs and frequent to common transparent-yellow, fluorescent, non-fibrous SOM.

Minor associations: 113 contains very-occasional leisospheres which are considered to indicate brackish and shallow marine conditions [Scull *et al.*, 1966]. Acritarchs, which are indicative of shallow water marginal marine conditions [Williams & Sarjeant, 1967] are rare/very-occasional in 139. Acritarchs are absent in the 82 and 164.

Grain-size distribution: 139 is from a clay unit. 113 is from a mud. 164 is from a silty unit. 82 is from a very-fine-grained sandstone.

Remarks: The association of sporomorphs, well-preserved transparent-yellow, fluorescent, fibrous SOM indicate two possible scenarios for the environment of deposition, which are described in Section E.7. The abundances of other components reflect localized variations in the redox potential, source of material and hydrodynamics of the system.

Palyno-lithofacies distribution: Morgans [1997] interpreted the environment of deposition of 113 as a brackish IDB, and 139 as a well-drained areas of the flood-plain (with intermittent development of crevasse splays for 139). On the basis of the palynofacies data it is postulated that 139 was deposited in a poorly-drained IDB. A similar setting is postulated for 82 and 164.

Stratigraphic distribution: 82 is from the Sycharham Member. 113 is from the upper part of the

(Ginkgoalean) plant bed, Yons Nab Bed, Lebberston Member, Cloughton Wyke. 139 is from the uppermost portion of the Gristhorpe Member. 164 is from the Scalby Formation.

E.20 Assemblage Group 19: Non-Vita Fragments and $\geq$ very-occasional dinoflagellate cysts

Minor assemblage-type 19A:1 (C22-VF30)

Number of samples: 1 (114)

Key characters: Common brown-equidimensional, non-fluorescent, non-cellular fragments and very-frequent black-equidimensional, non-fluorescent, non-cellular fragments.

Grain-size distribution: Fine-grained sand.

Palyno-lithofacies distribution: The sediments were classified as brackish IDB deposits [Morgans, 1997]. The organic matter is typical of a high-energy, either through bioturbation or transportation, oxic environment.

Stratigraphic distribution: Yons Nab, Lebberston Member.

Appendix F

Sedimentary Logs

F.1 Lithological descriptions

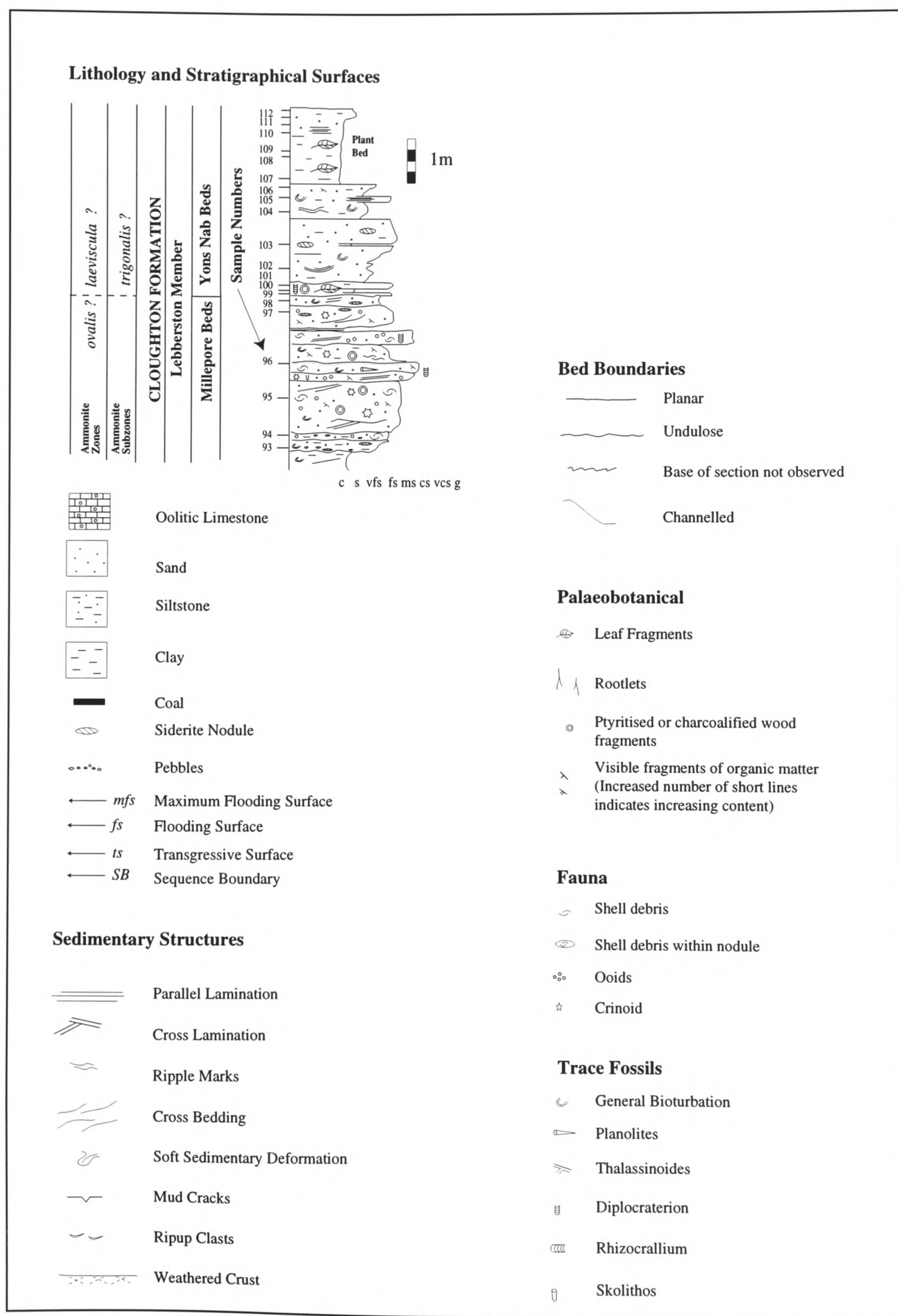


Figure F.1: Key to sedimentary descriptions.

1:Core RV18 drilled into the Ravenscar area

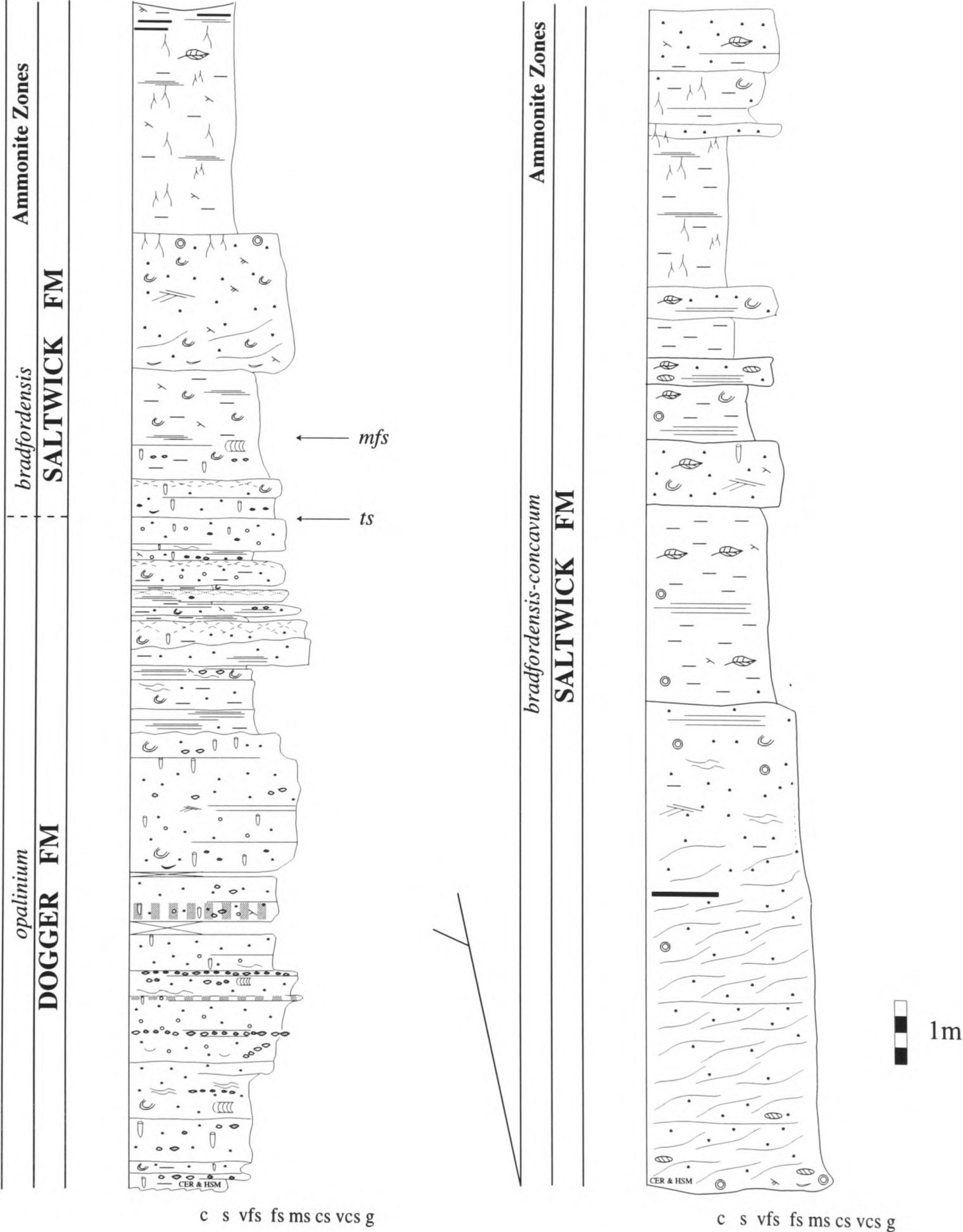


Figure F.2: Core RV18 drilled into the Ravenscar area.

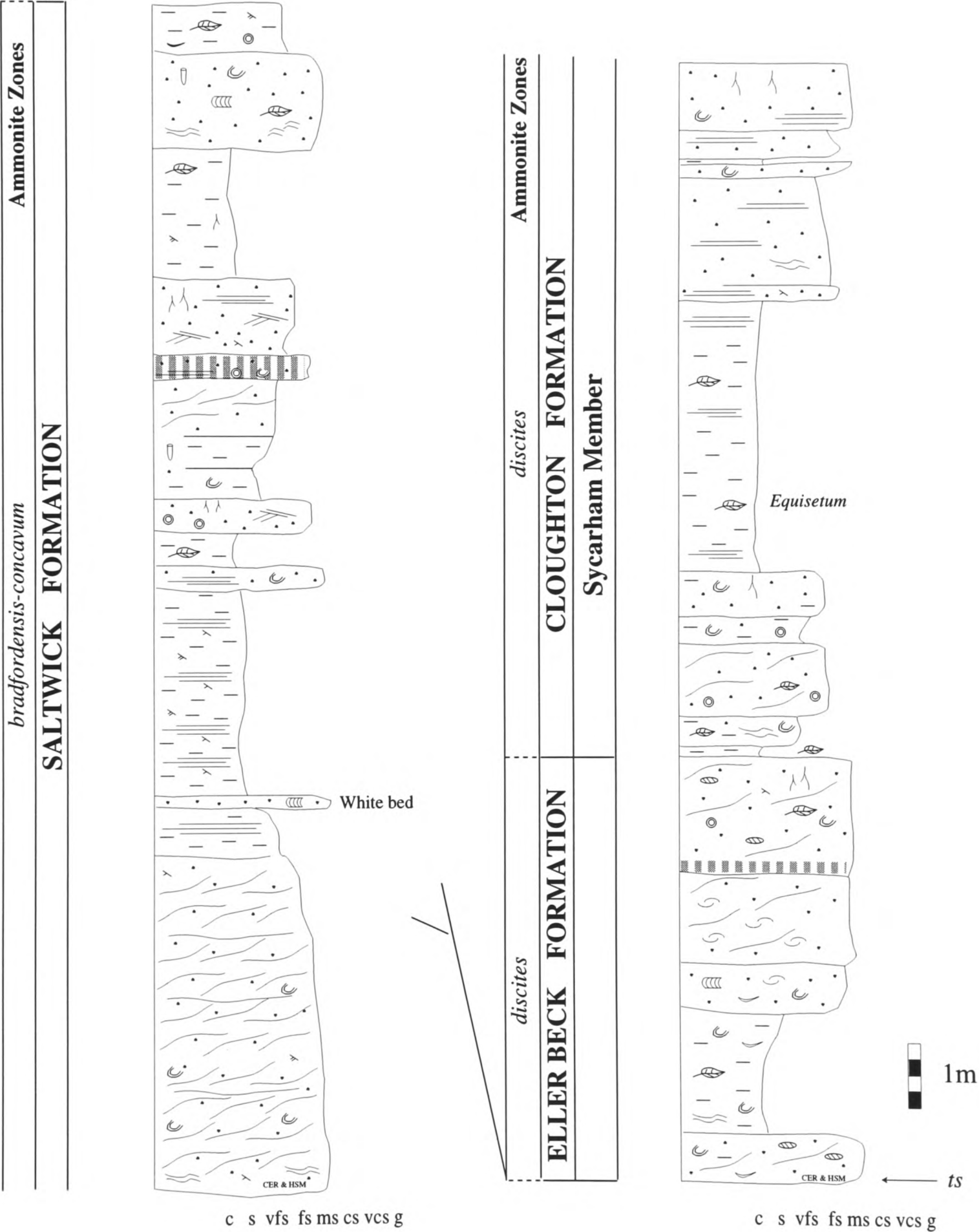
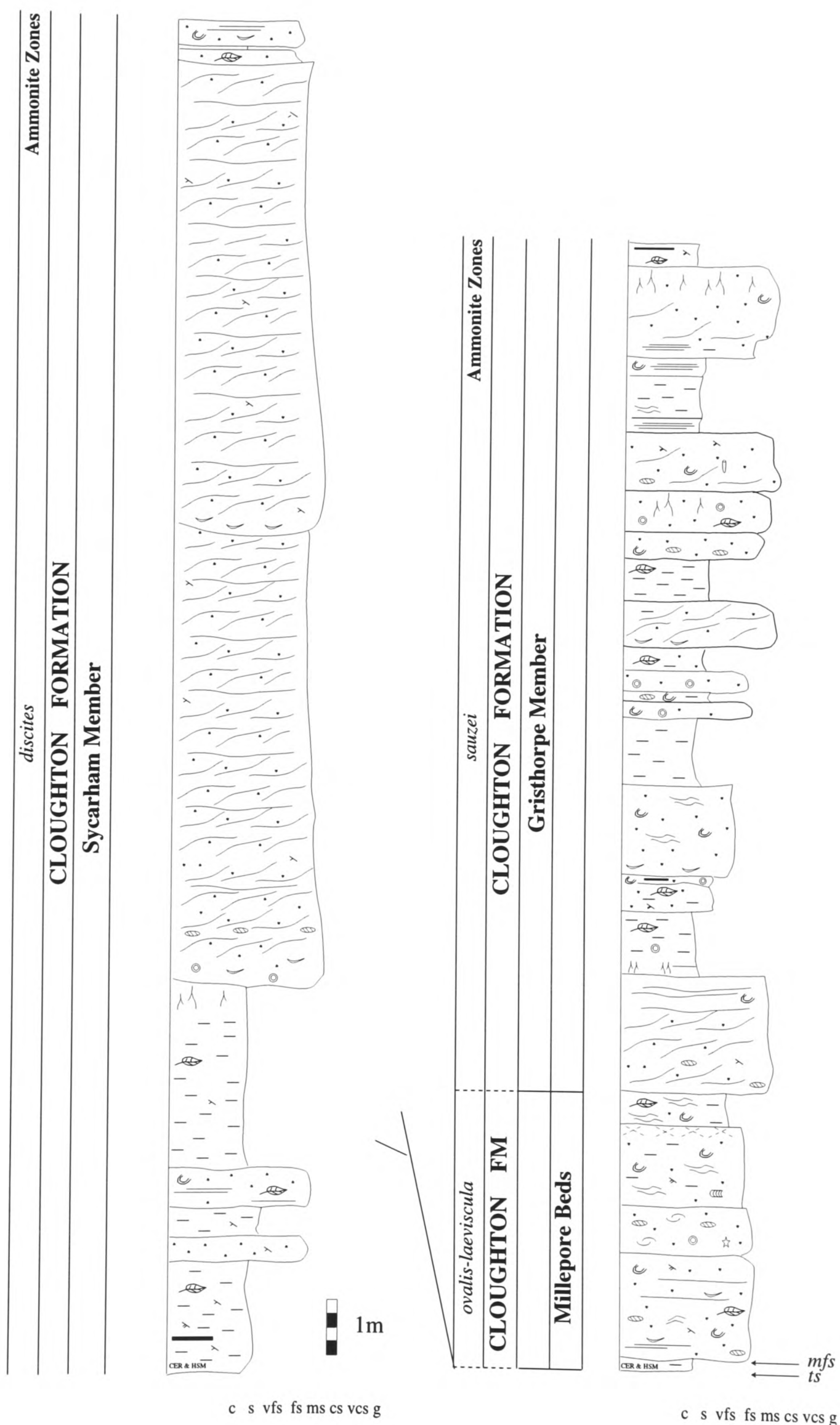


Figure F.3: Continuation of Core RV18 drilled into the Ravenscar area.



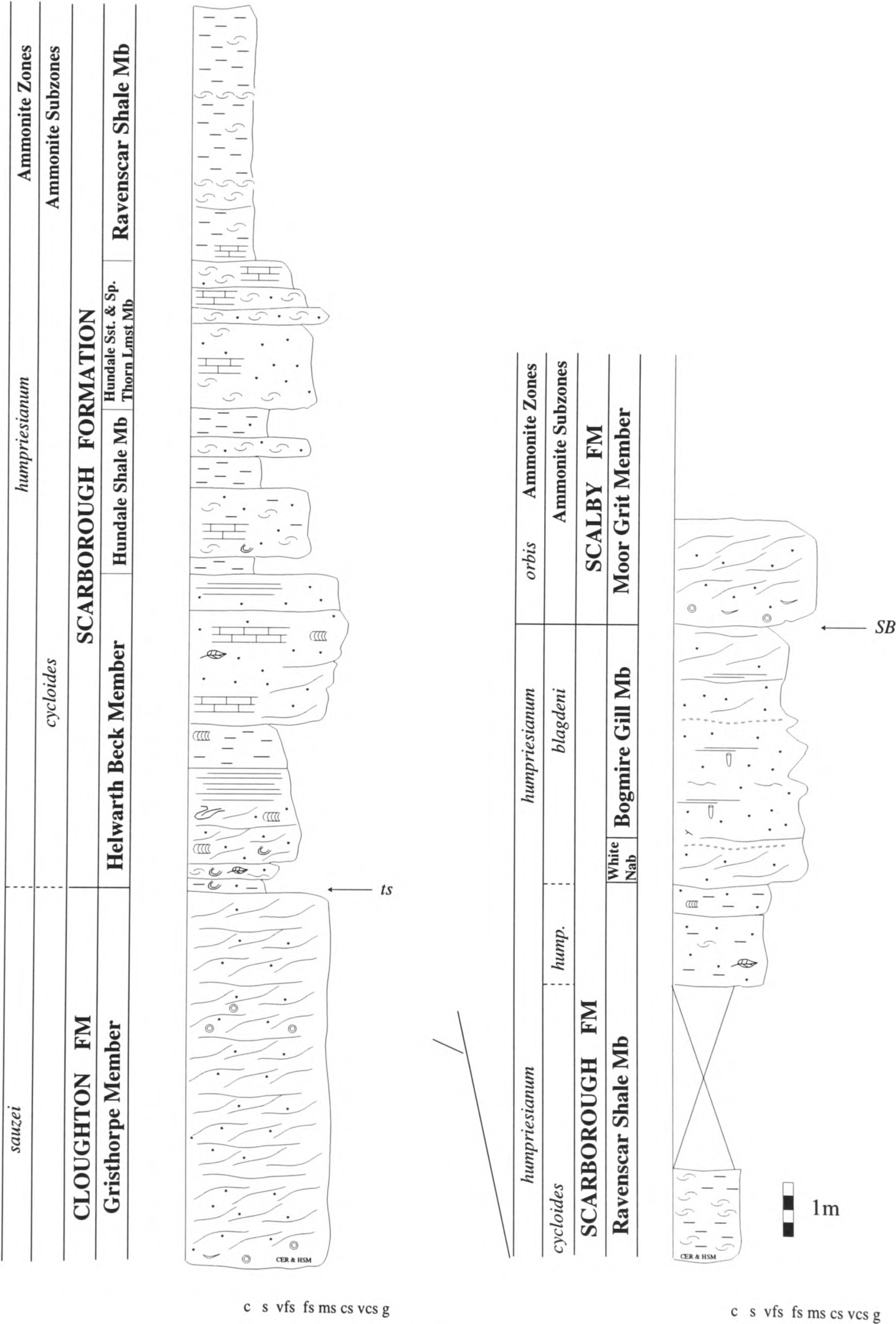


Figure F.5: Continuation of Core RV18 drilled into the Ravenscar area.

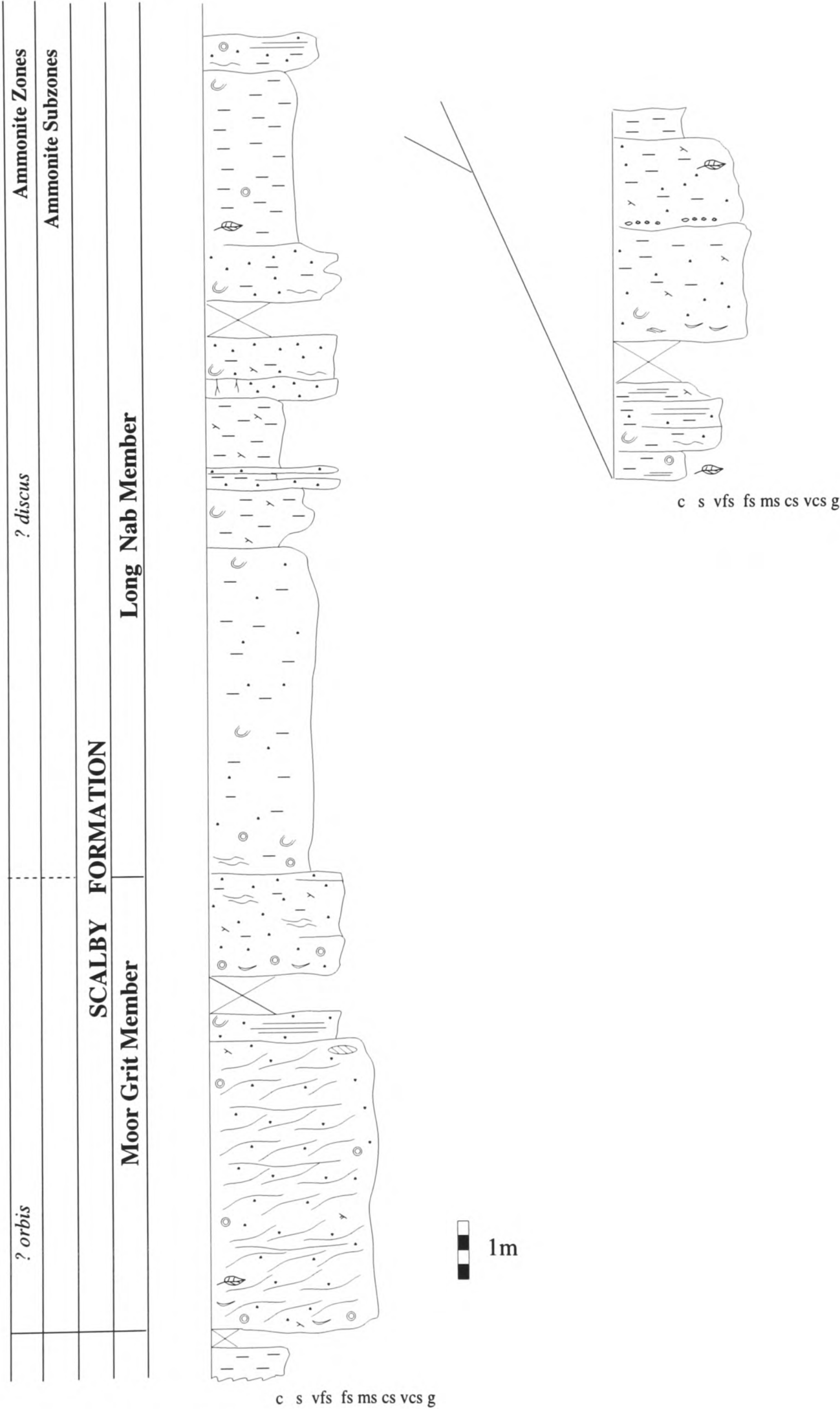


Figure F.6: Core LN16 drilled into the Long Nab/Burniston Wyke area.

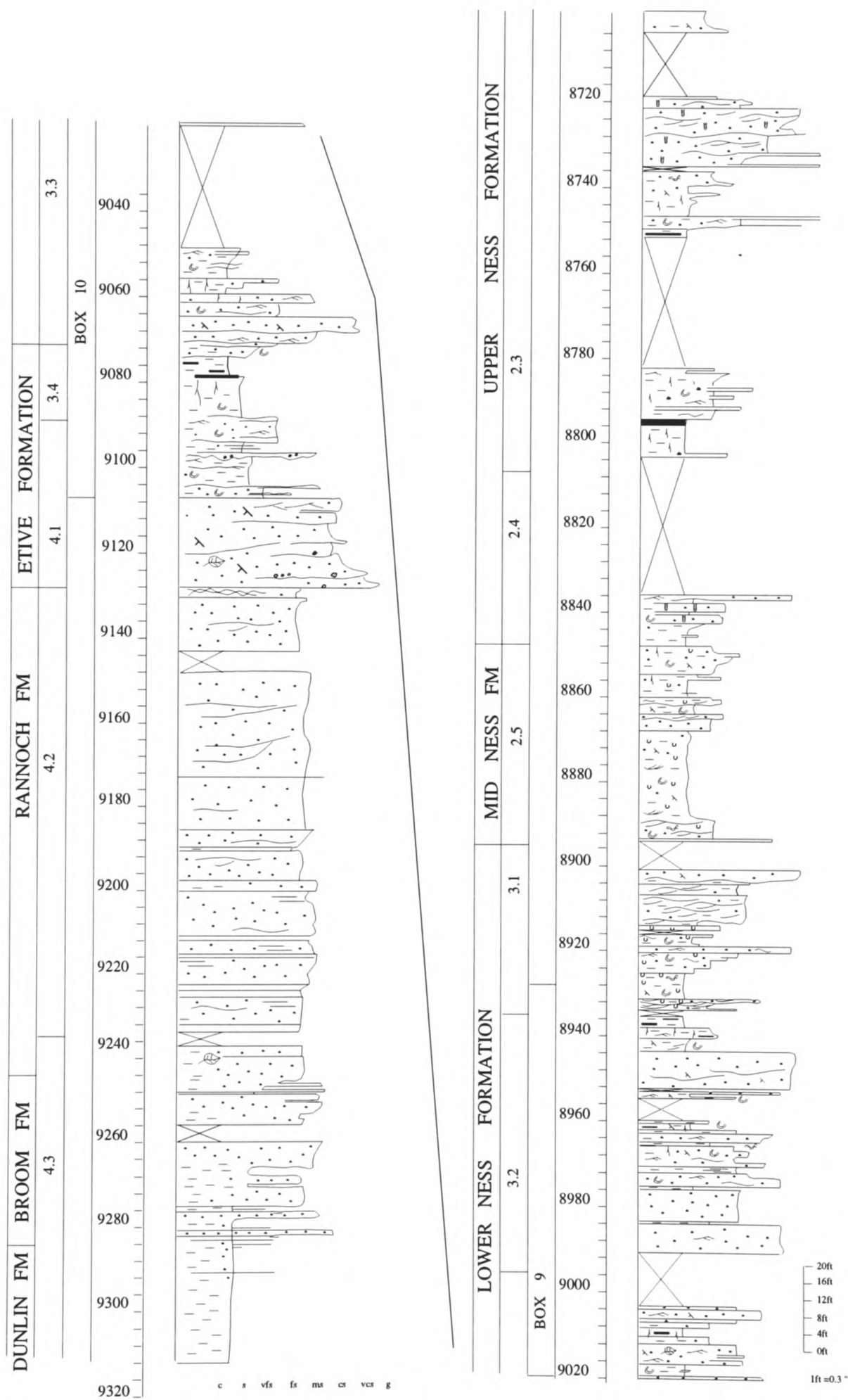
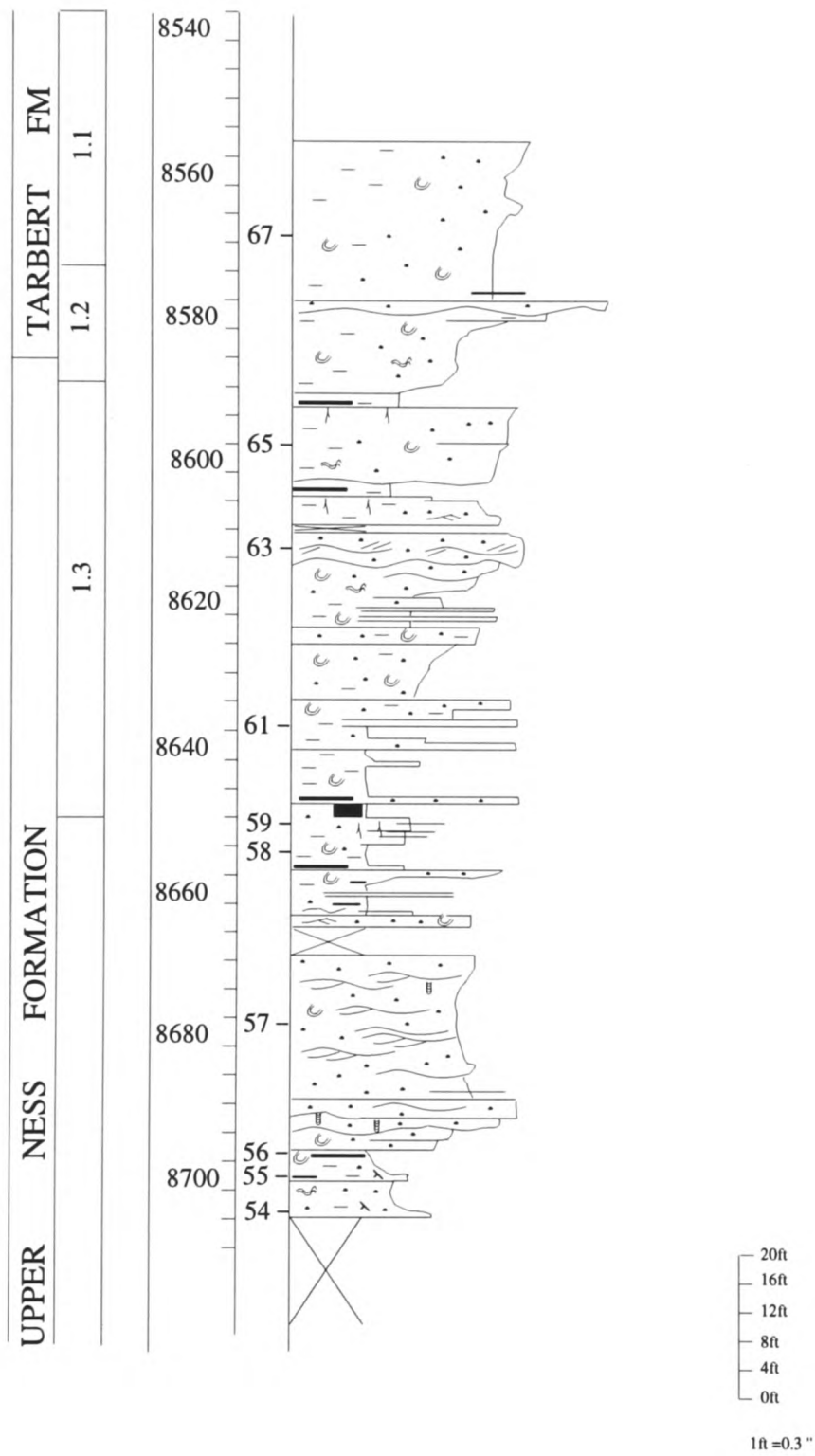


Figure F.7: Brent Core 211/29-3. Description [from Ichron, 1996].



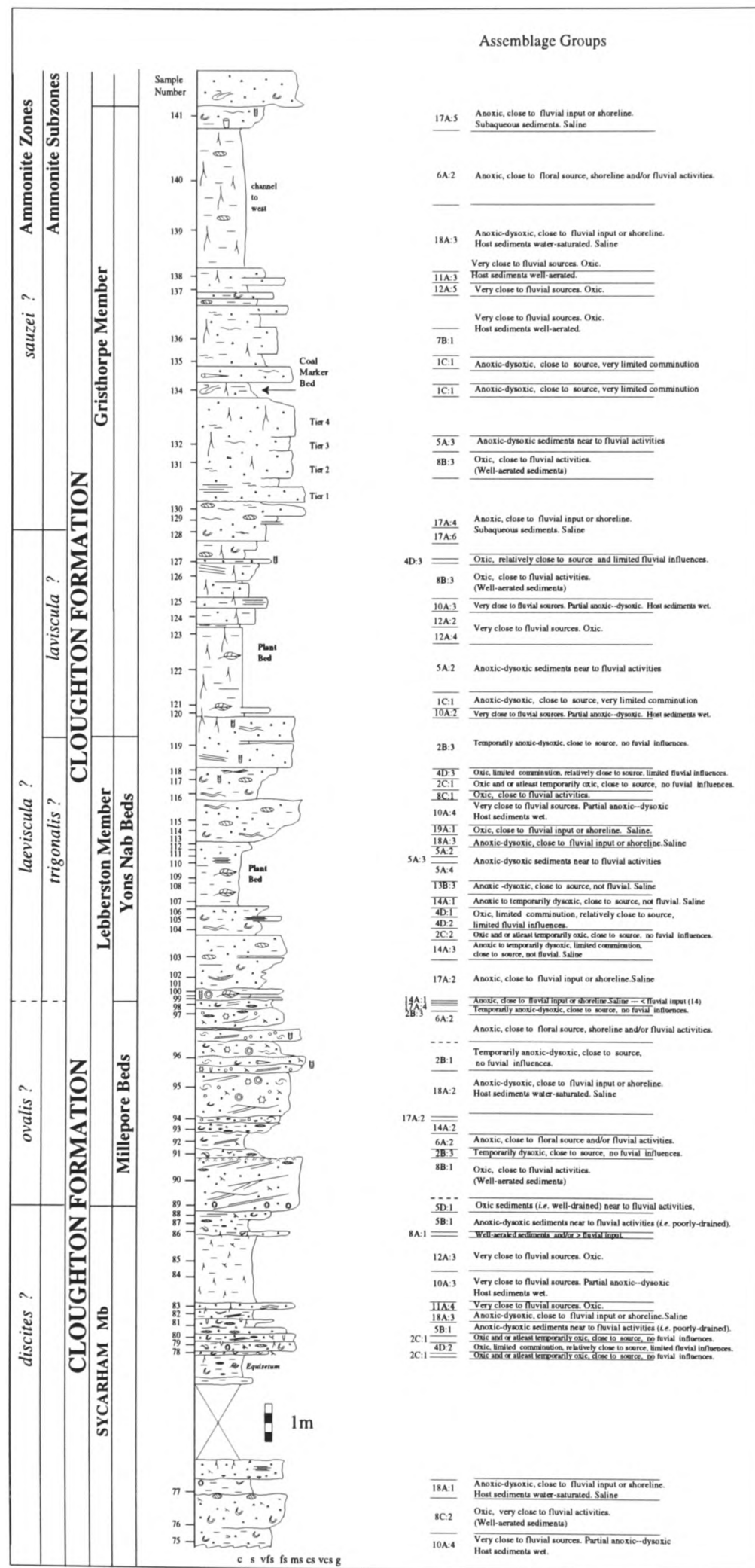


Figure F.9: Sedimentary description of the upper Sycharham Member to base of the Scarborough Formation, Cloughton Wyke [after Morgans, 1997] and list of the Assemblage groups.

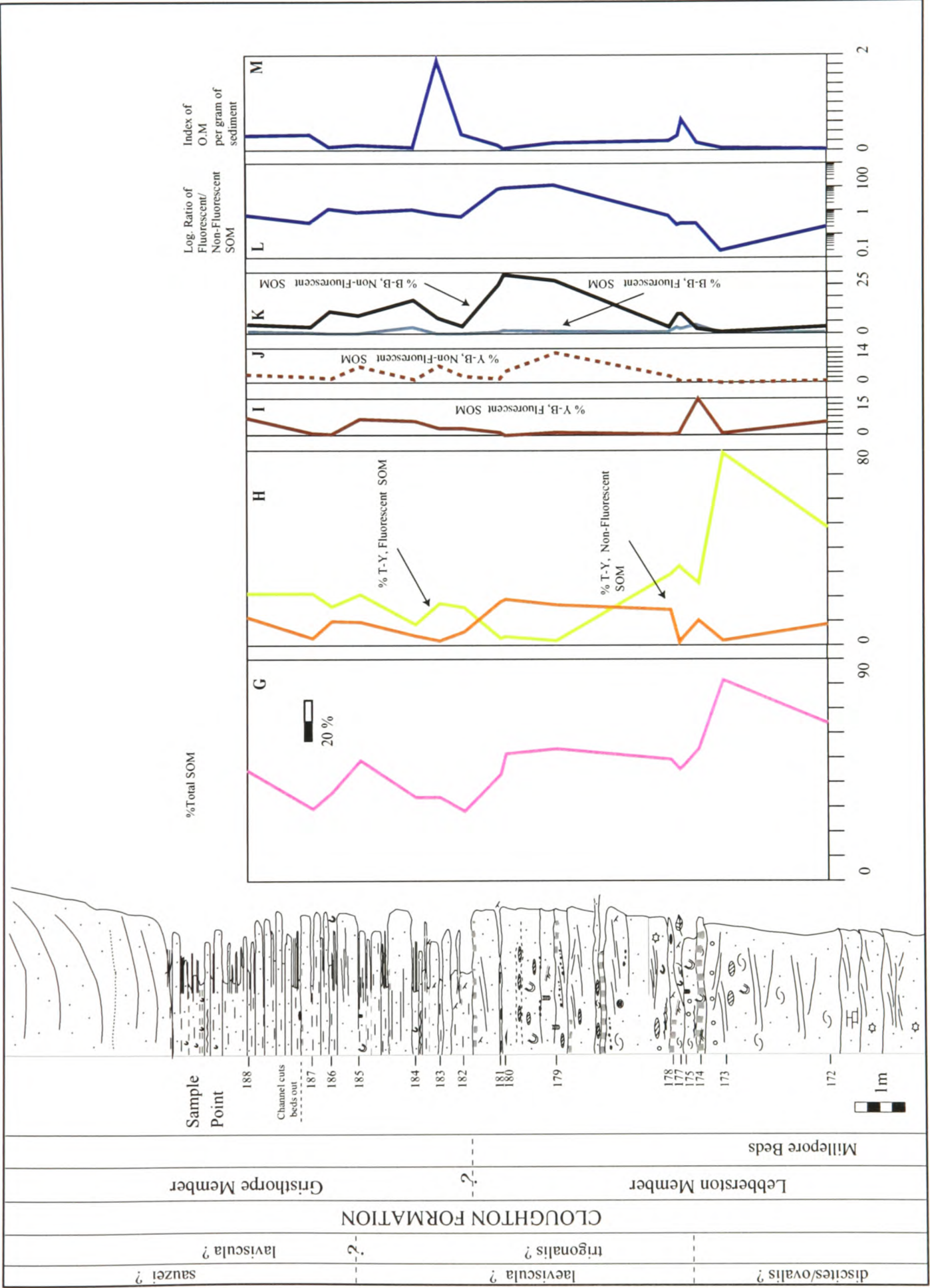


Figure F.10: Sedimentary description of the Millepore Bed, Leberston Member and Gristhorpe Member, Osgodby Nab [after Morgans, 1997]. This diagram shows columns G to M. These contain relative percentage change in total SOM; transparent-yellow, fibrous and non-fibrous SOM and non-fibrous SOM; yellow-brown, fibrous and non-fibrous SOM; yellow-brown, non-fibrous SOM; brown-black, fibrous and non-fibrous SOM; brown-black, non-fibrous SOM; fibrous and non-fibrous SOM; logarithmic ratio of fluorescent/non-fluorescent SOM, and index of organic matter per gram of sediment respectively.