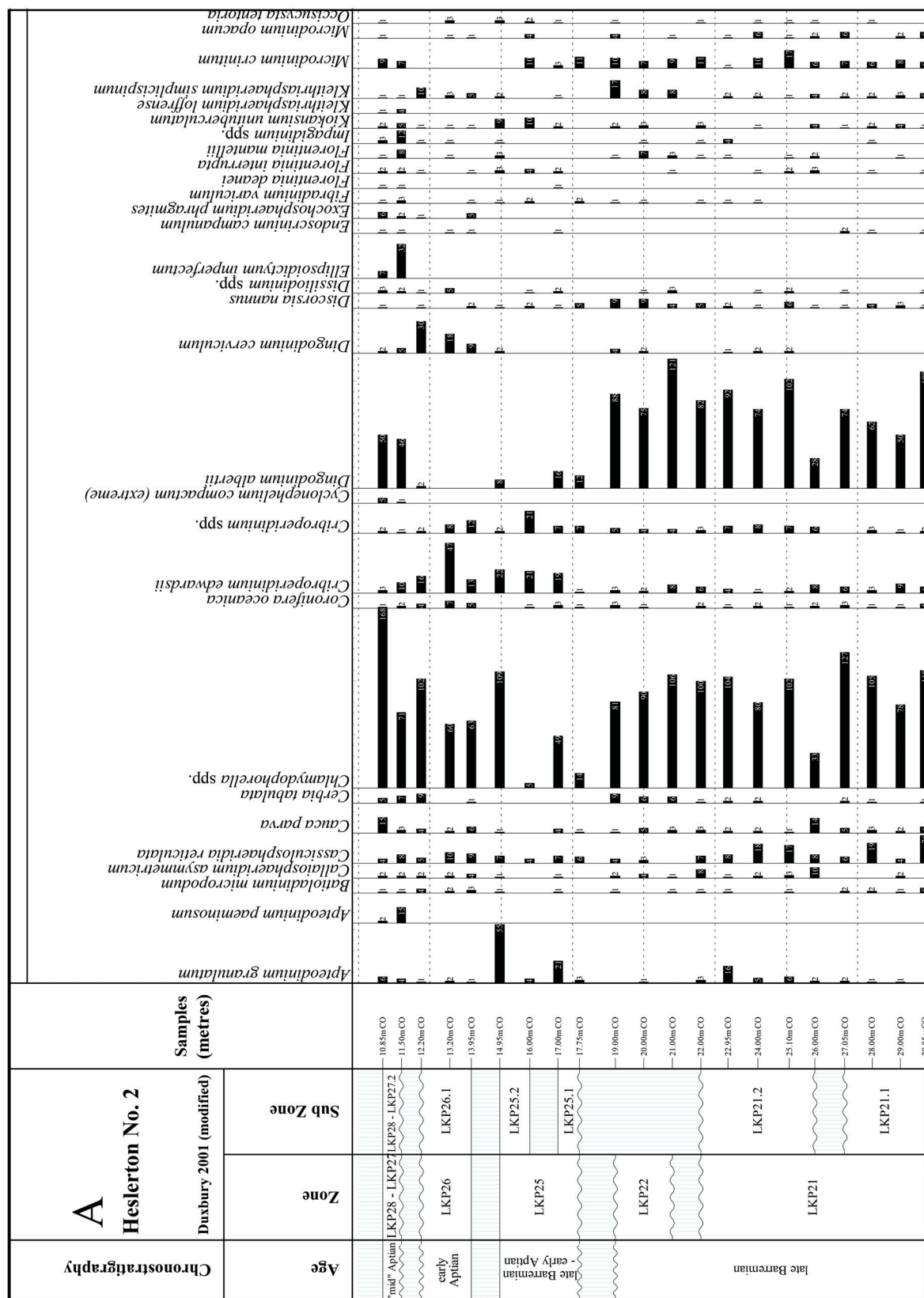


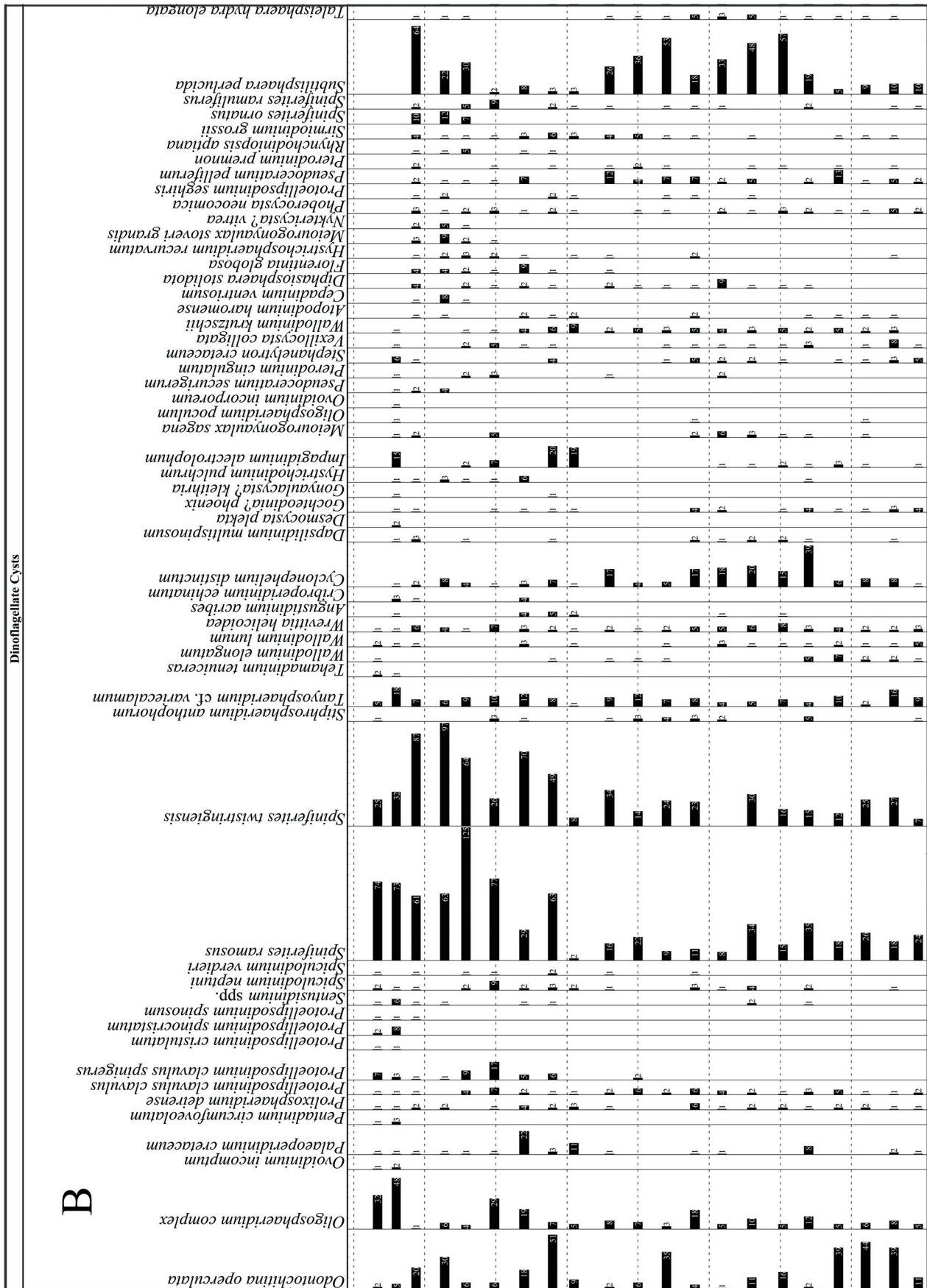
Age	BIOZONES		TOPS	PALYNOLOGICAL EVENTS	BASES
	Ammonites*	Dinocysts			
APTIAN	Late	MARTINIOIDES	LKP28	<i>A. polymorpha</i> (comm.) major influxes <i>Aptecodinium granulatum</i> , <i>Canninginopsis reticulata</i> , <i>Cerbia</i> cf. <i>magna</i> and <i>I. alectrolophum</i>	<i>C. compactum</i> (extreme), <i>K. prolatum</i> , comm. <i>P. distinctum</i>
			LKP27.2	<i>Exiguosphaera plectilis</i> , <i>Pterodinium premon</i>	<i>P. distinctum</i>
	Early	BOWERBANKI	LKP27	<i>Florentinia abijuncta</i> , <i>F. interrupta</i> , <i>Pseudoceratium securigerum</i>	<i>P. spinocristatum</i>
		DESHAYESI	LKP27.1	<i>Ctenidodinium elegantulum</i>	<i>T. tenuiceras</i>
		FORBESI	LKP26.2	<i>Phoberocysta neconomica</i>	
		FISSICOSTATUS	LKP26	<i>Diphasiosphaera stolidota</i> , <i>Heslertonia heslertonensis</i>	
	BARREMIAN	this interval except where discussed in the text	LKP26.1	<i>Avellodinium falsificum</i> influxes <i>Cepaditium variabilis</i> and <i>prasinophyceae</i> . FDO <i>Fromea quadrigata</i>	
			LKP25.2	<i>Batioladinium longicornutum</i> , <i>Hystriochodinium furcatum/ramoides</i>	<i>C. ventriosum</i>
			LKP25	<i>Cribroperidinium episomum</i> , <i>Kleithrasphaeridium fasciatum</i> , <i>Muderongia squirota</i> , common <i>Sirmiodinium grossii</i>	<i>P. hirsutum</i>
			LKP25.1	<i>Chlamydomphorella membranoperforata</i> , <i>Protoellipsodinium hirsutum</i>	<i>C. hadrum</i>
			LKP24	<i>Cribroperidinium hadrum</i>	
			LKP24.2	<i>Cribroperidinium cornutum</i> , <i>Scrinioidinium barremianum</i>	
			LKP24.1	<i>Meiourgonayulax lacunosa</i> <i>Aptecodinium bulla</i> <i>Cerbia magna</i> . Marked increase in <i>Hystriochosphaeridium arborispinum</i>	<i>A. bulla</i>
			LKP23.2	<i>Impagidinium diversum</i>	<i>C. magna</i>
			LKP23	<i>Oligosphaeridium magnum</i> and peak <i>Cerb. magna</i> peak <i>Impagidinium diversum</i>	<i>I. diversum</i>
			LKP23.1	peak <i>O. magnum</i>	<i>O. magnum</i>
Early	BARREMIAN	Ammonite zone equivalence uncertain in the text	LKP22	<i>Hystriochodinium voigtii</i> , common <i>Pseudoceratium peliferum</i> <i>Wrevittia</i> cf. <i>cassidata</i>	<i>M. lacunosa</i> , <i>R. minor</i> , common <i>C. membranoperforata</i>
			LKP21.2	<i>Cassiculosphaeridia calvata</i>	<i>C. cornutum</i> , <i>C. episomum</i> , <i>W. cf. cassidata</i>
			LKP21	<i>Spiniferites caninus</i>	
			LKP21.1	<i>Rhynchodiniopsis fimbriata</i> <i>Cribroperidinium colum</i>	<i>R. fimbriata</i>
			LKP20	<i>S. dentatus</i> (rare), <i>Spiniferites fenestratus</i> <i>Kleithrasphaeridium corrugatum</i>	<i>P. premon</i> , <i>T. quinquestrum</i>
			LKP19	<i>Ascodinium fissilum</i> , comm. <i>K. corrugatum</i> , peaks <i>Dingodinium albertii</i> and <i>H. arborispinum</i>	<i>Achomosphaera ramulifera</i> , <i>Palaeoperidinium cretaceum</i>
Early	APTIAN	ELEGANS	LKP18	<i>Pseudoceratium anaphrissum</i> (comm./ab.), influx <i>Rugubivesiculites rugosus</i> (common)	<i>Cerbia tabulata</i> , <i>Odontochitina operculata</i>
		FISSICOSTATUS	LKP18		

TEXT-FIGURE 9 Revised Duxbury (2001) palynofloral zonation and events, Early Barremian to "mid" Aptian.

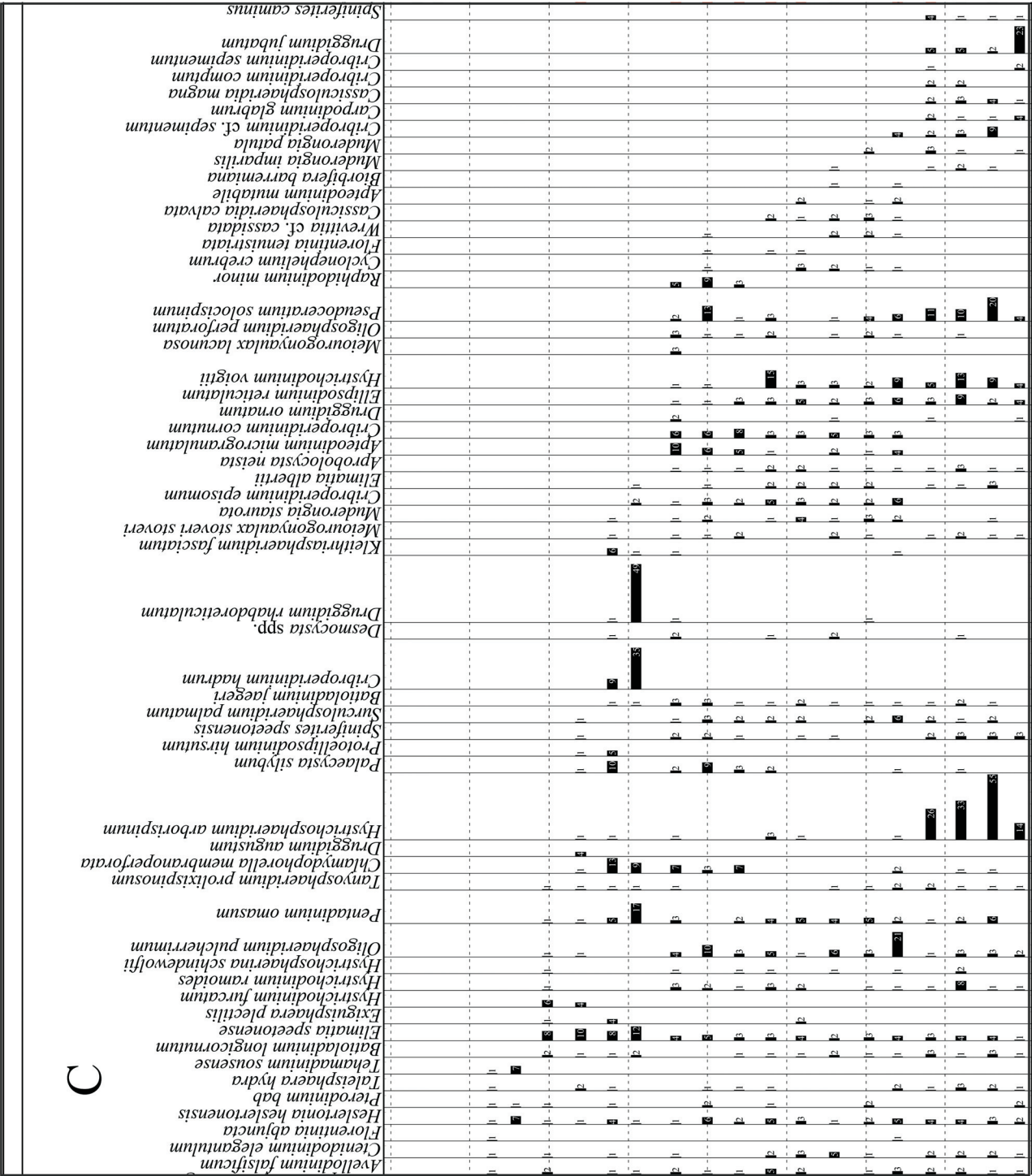


TEXT-FIGURE 10 (parts A - E): Stratigraphic occurrence and absolute abundance of palynomorphs in the Heslerton No. 2 borehole. Species are ordered alphabetically by category, LADs first, following the methodology outlined in the revised Duxbury 2001 zonation scheme.



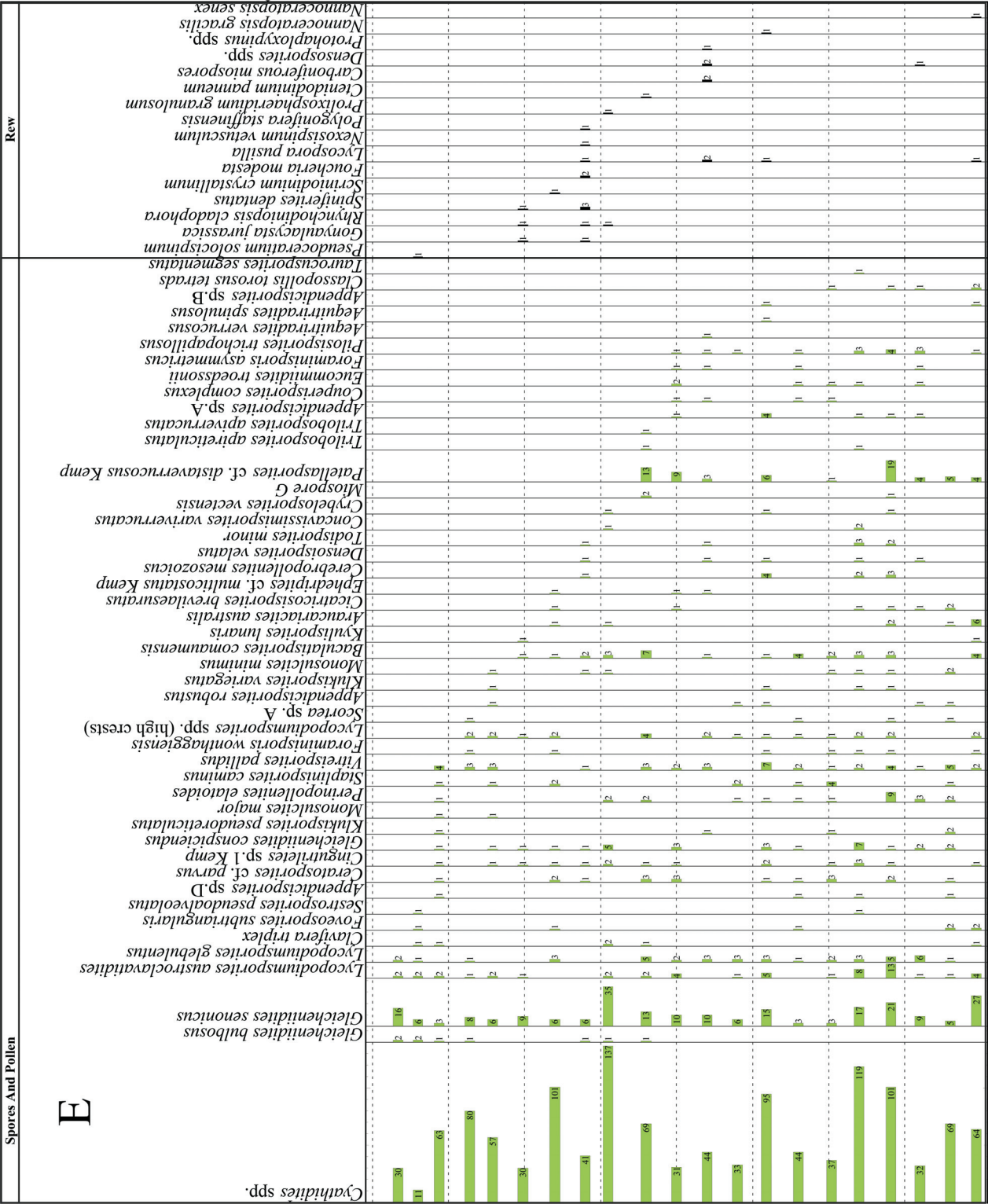


TEXT-FIGURE 10, Part B



TEXT-FIGURE 10, Part C





TEXT-FIGURE 10, Part E



Subzone LKP25.1 therefore encompasses the total range of *C. hadrum*.

The FAD and peak occurrence of *Protoellipsodinium hirsutum* was at 17.00 m in Heslerton No. 2, the same level as the LAD of *C. hadrum*; *P. hirsutum* therefore appears to span the LKP25.1/LKP25.2 subzonal boundary.

#### Zone LKP24

Age: late Barremian

Definition: The interval from the LADs of *Cribroperidinium cornutum* and *Scriniodinium barremianum* to the LAD of *Impagidinium diversum*.

Remarks: This zone may be confidently assigned a late Barremian age (see comments on the Barremian/Aptian boundary, above).

Zone LKP24 can be subdivided into two subzones:

##### Subzone LKP24.2

Definition: The interval from the LADs of *Cribroperidinium cornutum* and *Scriniodinium barremianum* to the LAD of *Cerbia magna* and a marked downhole increase in *Hystrichosphaeridium arborispinum*.

Remarks: The LAD of *Meiourogoniaulax lacunosa* occurs within this subzone, although this species is rare, and the LAD of *Apteodinium bulla* is towards the base.

Late Barremian heteromorph ammonites were noted within this Subzone, at 11,152.00 ft in well 22/26a-2 (Rawson and Jeremiah 2001, Jeremiah 2001), including the genera *Hemihoplites*, *Camereiceras* and *Heteroceras*, indicative of the Tethyan *Hemihoplites feraudinianus* ammonite Subzone (see Reboulet et al. 2014, Table 1b). This is equivalent to the Boreal *stolleyi* Zone (Rawson and Jeremiah 2001; Jeremiah 2001).

##### Subzone LKP24.1

Definition: The interval from the LAD of *Cerbia magna* and a marked downhole increase in *Hystrichosphaeridium arborispinum* to the LAD of *Impagidinium diversum*.

Remarks: A marked downhole increase in *H. arborispinum* has been consistently recorded at the top of this subzone by the present author in the UK Central North Sea, although this event was recorded in well 22/26a-2 only as high as 11,167.00' (top Zone LKP23). Subzone LKP24.1 is interpreted to occur within the sample gap between 11,159.00 ft and 11,167.00 ft in well 22/26a-2 (text-fig. 7).

#### Zone LKP23

Age: late Barremian

Definition: The interval from the LAD of *Impagidinium diversum* to the LADs of *Hystrichodinium voigtii* and common *Pseudoceratium pelliiferum*.

Remarks: This zone is characterised by major influxes of three distinctive species, *Cerbia magna*, *Impagidinium diversum* and *Oligosphaeridium magnum*, in descending sequence. The acme of each of these species is typically represented by very abundant occurrences. *Hystrichosphaeridium arborispinum* is common throughout the zone with the oldest abundant occurrence at the base of Zone LKP23.

Zone LKP23 can be subdivided into two subzones:

##### Subzone LKP23.2

Definition: The interval from the LAD of *Impagidinium diversum* to the peak occurrence of *I. diversum*.

Remarks: *Cerbia magna* occurs throughout this subzone, its peak is within it and its FAD is at its base. The FAD of *Apteodinium bulla* is towards the top of Subzone LKP23.2 and the LAD of *Oligosphaeridium magnum* is within it.

##### Subzone LKP23.1

Definition: The interval from the peak occurrence of *Impagidinium diversum* to the LADs of *Hystrichodinium voigtii* and common *Pseudoceratium pelliiferum*.

Remarks: This subzone is characterised by a major influx of *Oligosphaeridium magnum*, which can be superabundant at a level corresponding with the deepest occurrence of *Impagidinium diversum*. The FAD of *O. magnum* is at the base of this unit, where it is rare.

Occasional *Aprobolocysta neista* were recorded as high as 11,181.33 ft in well 22/26a-2 (i.e., to the base of Zone LKP23 - see comments under Zone LKP21, below).

#### Zone LKP22

Age: late Barremian

Definition: The interval from the LADs of *Hystrichodinium voigtii* and common *Pseudoceratium pelliiferum* to the LAD of *Cassiculosphaeridia calvata*.

Remarks: Isolated specimens of *Hystrichodinium voigtii* were recorded as high as 11,167.00 ft in well 22/26a-2, the same level as the LAD of *I. diversum* (i.e., to the top of Zone LKP23) and some reworking of *H. voigtii* is therefore presumed. Because of this, the top of this zone has been picked at 11,187.00 ft in that well, based on the highest common occurrence of *Pseudoceratium pelliiferum*.

The LAD of *Pseudoceratium solocispinum* also occurs at 11,187.00 ft in well 22/26a-2, suggesting that this event might also prove useful as a top Zone LKP22 marker.

In Duxbury (2001), the LAD of the miospore *Couperisporites complexus* was considered to occur within Zone LKP21, because of its position below the LAD of *Aprobolocysta neista*. However, in the present study, *C. complexus* was observed as high as 20.00 m in Heslerton No. 2, a level assigned to Zone LKP22 here (see notes under Zone LKP21, below).

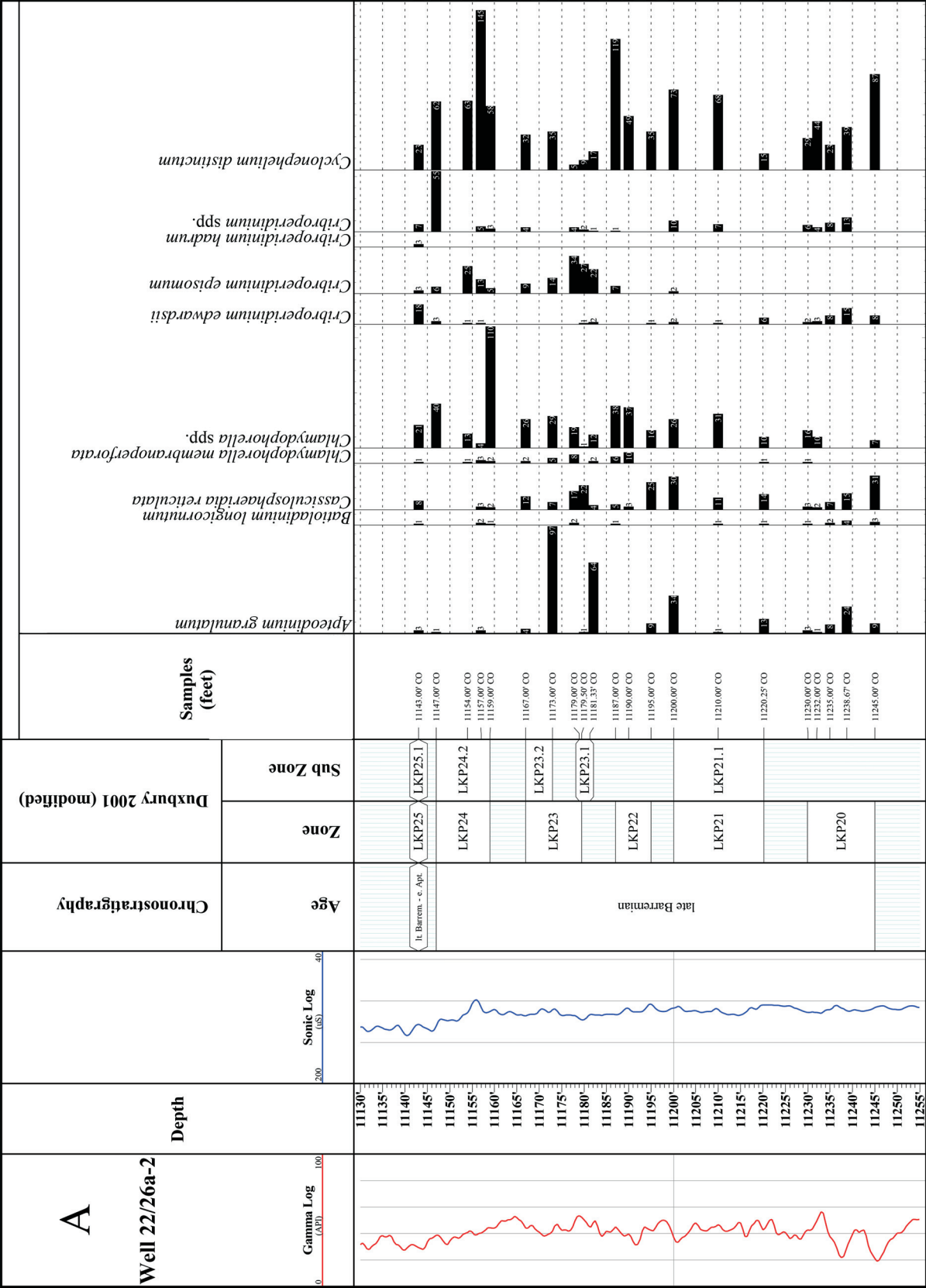
The LAD of *Wrevittia* cf. *cassidata* and the FADs of *Meiourogoniaulax lacunosa* and common *Chlamydothorella membranoperforata* are within this zone. *Raphidodinium minor* appears to be restricted to Zone LKP22, although this requires further confirmation.

#### Zone LKP21

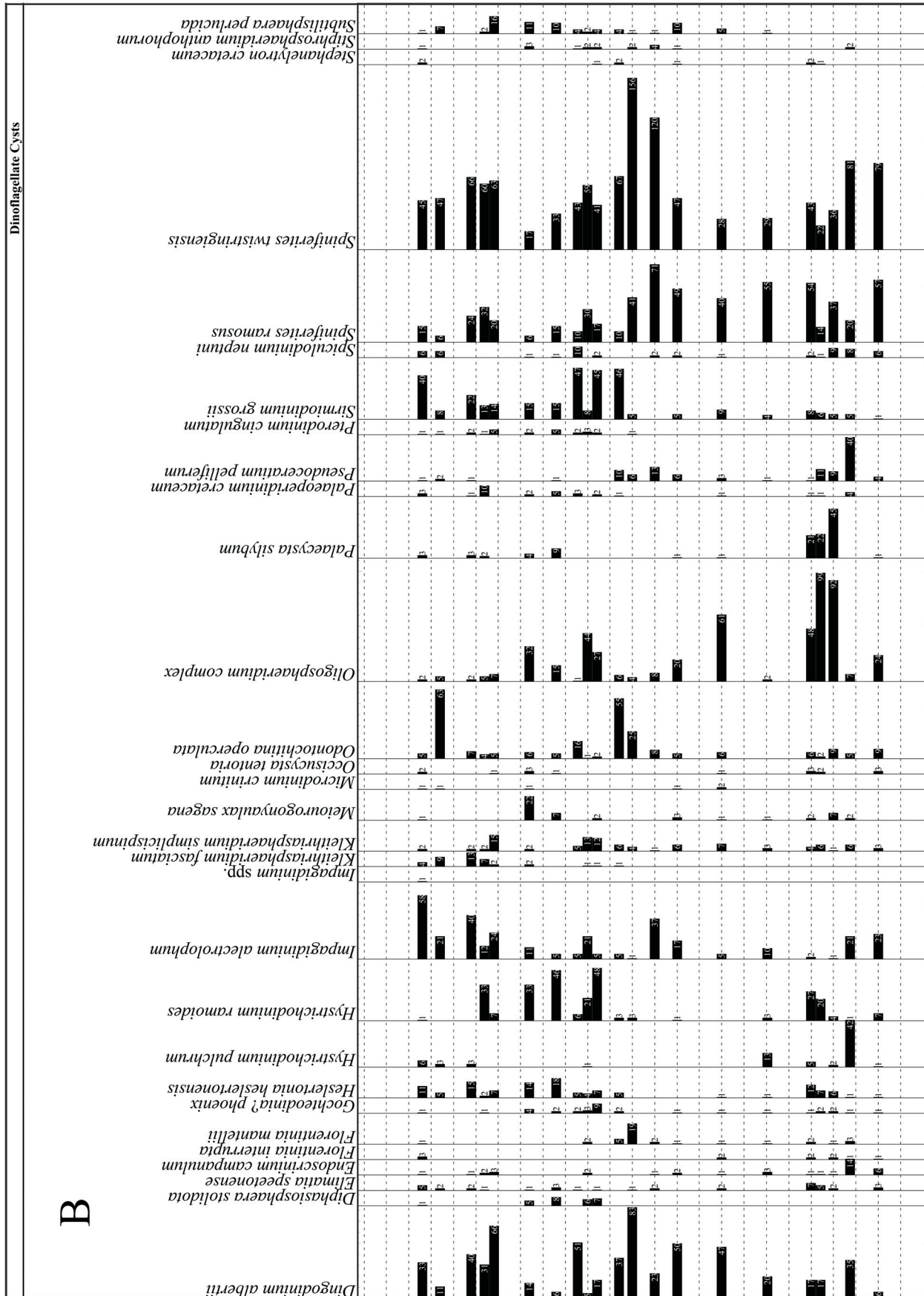
Age: late Barremian

Definition: The interval from the LAD of *Cassiculosphaeridia calvata* to the LAD of *Rhynchodiniopsis fimbriata*.

Remarks: In Duxbury (2001), the top of this zone was defined as, "The interval from the first downhole occurrences of

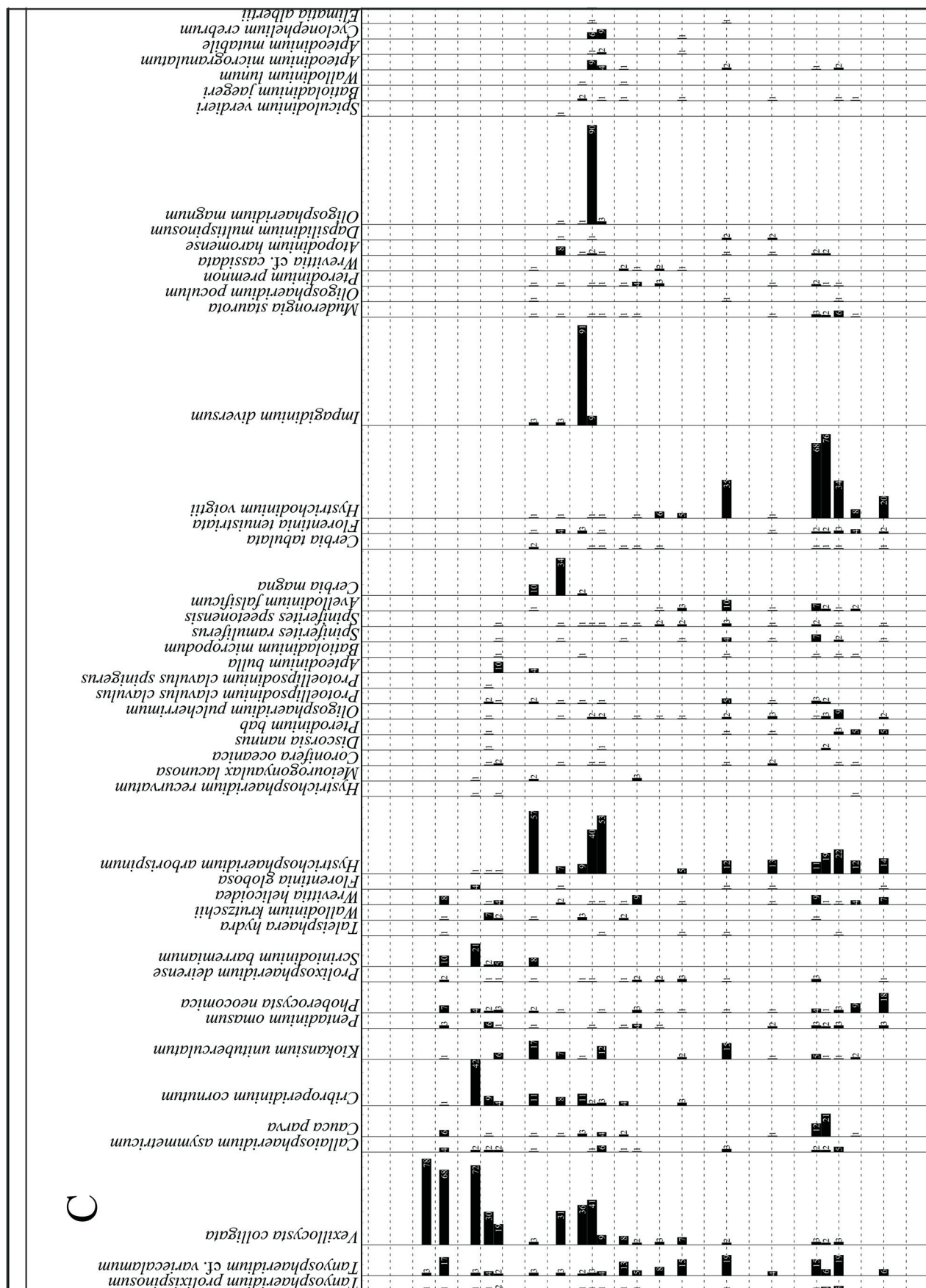


TEXT-FIGURE 11 (parts A - D): Stratigraphic occurrence and absolute abundance of palynomorphs in Gannet well 22/26a-2. Species are ordered as in Text-figure 10.



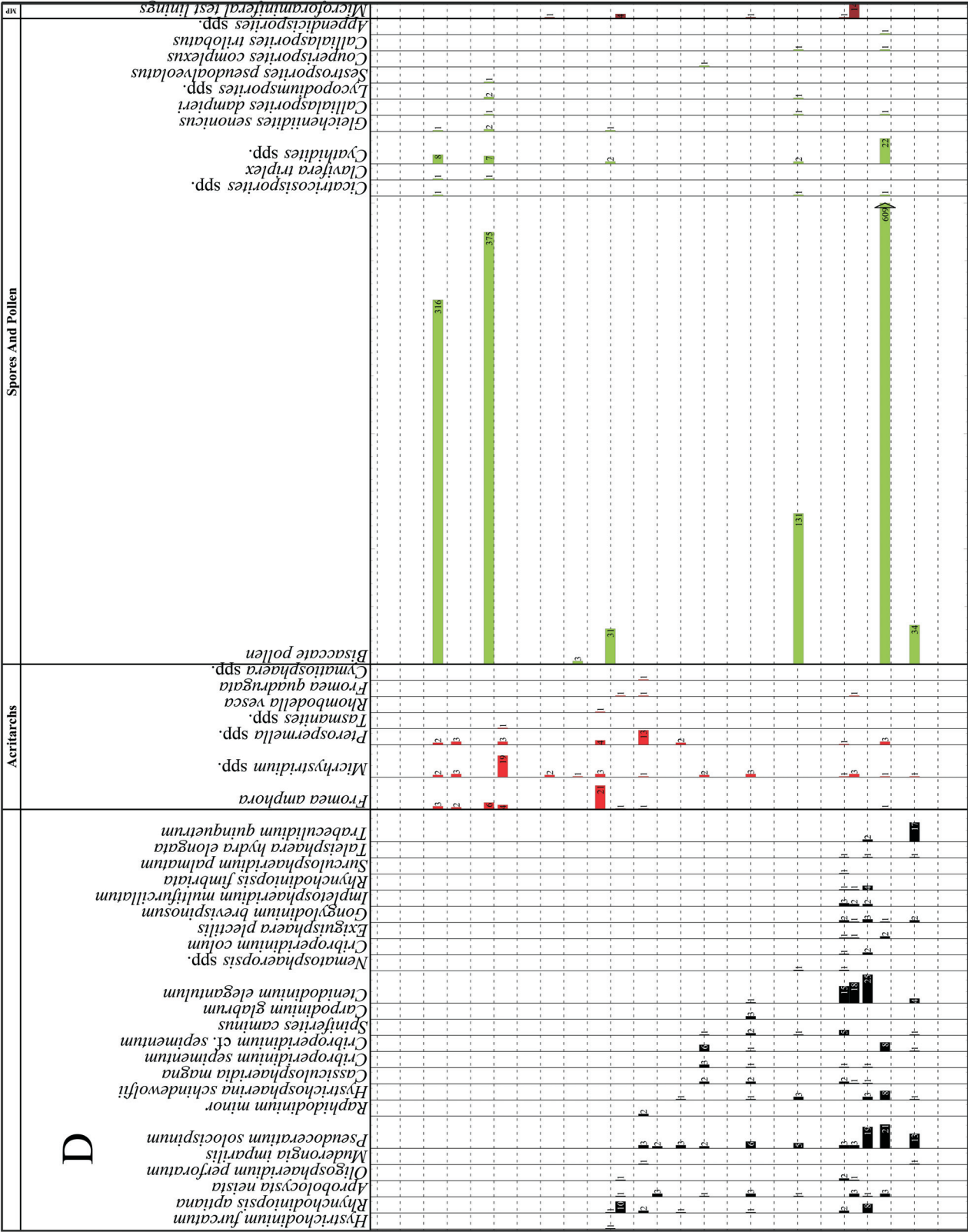
TEXT-FIGURE 11, Part B





TEXT-FIGURE 11, Part C





TEXT-FIGURE 11, Part D

*Cassiculosphaeridia magna* and *Aprobolocysta neistosa*". However, the present study has shown these events not to be isochronous, with *A. neista* ranging consistently higher than *Cassiculosphaeridia calvata* (*C. magna* of Duxbury, op. cit.), in the case of well 22/26a-2 to the base of Zone LKP23. Because of this, the top of this zone has been redefined here. Common to abundant *Hystrichodinium voigtii* occur throughout this and older zones.

Zone LKP21 can be subdivided into two subzones:

#### Subzone LKP21.2

Definition: The interval from the LAD of *Cassiculosphaeridia calvata* to the LAD of *Spiniferites caminus*.

#### Subzone LKP21.1

Definition: The interval from the LAD of *Spiniferites caminus* to the LAD of *Rhynchodiniopsis fimbriata*.

Remarks: The LAD of *Cassiculosphaeridia magna* coincided with the LAD of *Spiniferites caminus* in Heselton No. 2 and in

### Specimen magnification is indicated per plate.

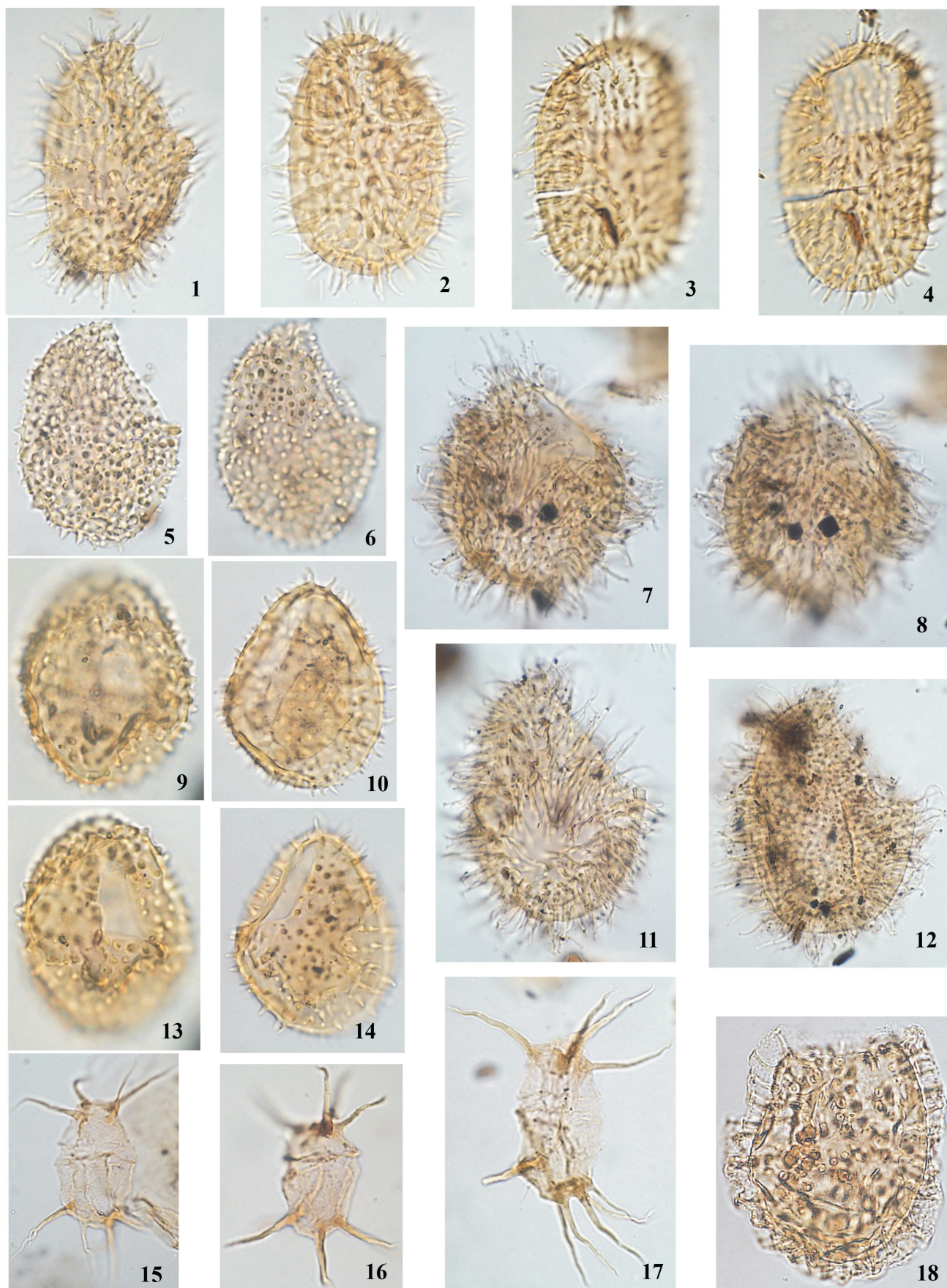
England Finder (E.F.) and Natural History Museum (FD) references are given for all specimens.

#### PLATE 1

All specimens from Heselton No. 2, Speeton Clay Formation. All photographs × 950.

- 1-4 *Protoellipsodinium spinocristatum*. All specimens from the "mid" Aptian. Figure 1 at 10.85 m, a left lateral view with the operculum missing, E.F. J28.1, FD1092(7) and Figures 2, 3 and 4 at 11.50 m. Figure 2 E.F. E30.1, FD1093(14), an oblique lateral view with the operculum partially displaced and Figures 3, 4 E.F. P39.0, FD1093(13), showing the lower (ventral) and upper (dorsal) surfaces respectively. All specimens display the longitudinal ridges and acuminate spines typical of this species.
- 5, 6, 9, 10, 13, 14 *Protoellipsodinium seghire*. Figures 5, 6 at 17.00 m (upper Barremian to lower Aptian), E.F. S27.3, FD1100(6), left-lateral aspect, focused on the archeopyle margin and upper (left) epicyst respectively. Figures 9, 13 at 24.00 m (upper Barremian), E.F. R53.3, FD1110(4), marginal and dorsal views respectively. Figures 10, 14 at 21.00 m (upper Barremian), E.F. W36.3, FD1107(6), Figure 10 focused on the operculum which is retained within the cyst and Figure 14 an oblique dorsal view focused on the archeopyle margin. Significant variations in ornament density and length (although always simple and very short) are well demonstrated by these specimens.
- 7, 8, 11, 12 *Protoellipsodinium hirsutum* n. sp. All specimens from 17.00 m, upper Barremian to lower Aptian. Figures 7, 8, E.F. H49.2, FD1100(3), a left lateral aspect focused on the archeopyle and cyst margin respectively. Figure 11 E.F. E51.4, FD1100(4), and Figure 12 (holotype) E.F. S54.0, FD1100(5), both left lateral aspects. All specimens show the numerous, flexuous spines typical of this species and Figure 12 is focused on the upper (left) surface, showing the very dense arrangement of spine bases, with some alignment.
- 15-17 *Raphidodinium minor* n. sp. All specimens from the upper Barremian. Figure 15 (holotype) and Figure 17 (paratype) both at 21.00 m, E.F. S41.0, FD1107(1) and E.F. G40.2, FD1107(2) respectively. Figure 16 at 20.00 m, E.F. T48.0, FD1106(2). All specimens show a clear, notched cingulum, tabulation marked by low ridges and solid spines, the latter restricted to polar areas.
- 18 *Chlamydophorella membranoperforata*. Upper Barremian at 19.00 m, E.F. L30.4, FD1103(5).





well 22/26a-2, suggesting that *C. magna* might be a useful secondary marker for the top of this subzone, although this species tends to be rare at the top of its range and can be confused with *Cassiculosphaeridia calvata* in poorly-preserved material.

In addition, the FADs of *Cribroperidinium cornutum*, *C. episomum* and *Wrevittia* cf. *cassidata* were at the top of Subzone LKP21.1 in well 22/26a-2 and at the base of Subzone LKP21.2 in Heselton No. 2; these are clearly useful intra-Zone LKP21 markers.

*Carpodinium glabrum* is restricted to this subzone and it again tends to be rare.

#### Zone LKP20

Age: late Barremian

Definition: The interval from the LAD of *Rhynchodiniopsis fimbriata* to the LAD of *Kleithriasphaeridium corrugatum*.

Remarks: This zone was recorded only in well 22/26a-2, proving that the Heselton No. 2 core did not penetrate to this level. The FADs of *Trabeculidium quinquetrum* and *Pterodinium premnon* and the LAD of *Cribroperidinium colum* are within this zone, and *Rhynchodiniopsis fimbriata* is restricted to it.

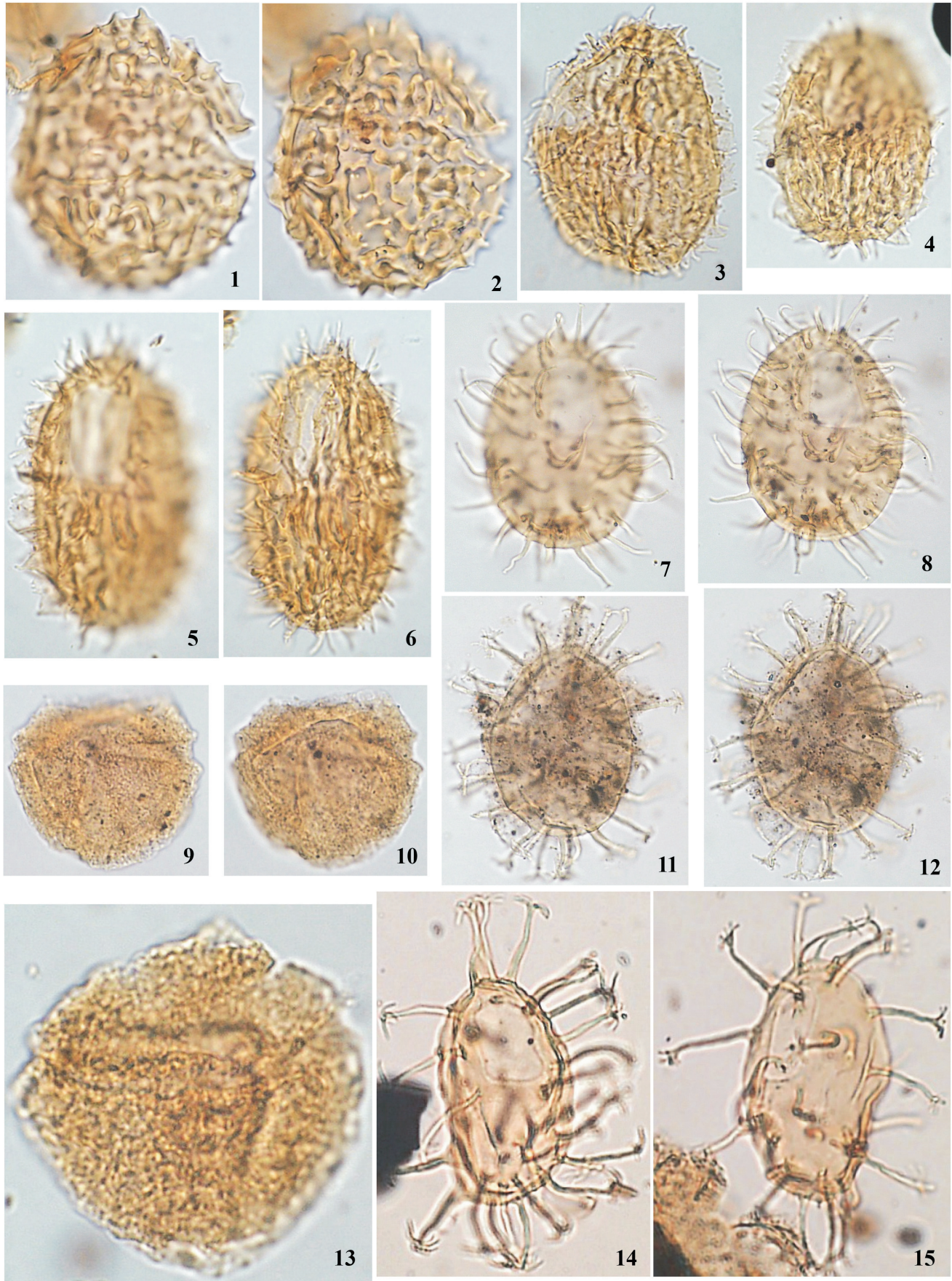
The LAD of *Gongylodinium brevispinosum* was at 11,230.00 ft in well 22/26a-2, and this was not seen in Heselton No. 2, suggesting that this might also be a valuable alternative top LKP20 marker. However, the position of this event relative to the LAD of *Rhynchodiniopsis fimbriata* (i.e., to the top of Zone LKP20) remains unresolved.

## PLATE 2

All specimens from Heselton No. 2, Speeton Clay Formation. All photographs  $\times 950$  except Figure 13, which is  $\times 1900$ .

- 1,2 *Ellipsodinium reticulatum*. A specimen from 21.00 m, upper Barremian, E.F. N38.0, FD1107(5). A left lateral view with Figure 1 focused on the partially-detached operculum (3") and Figure 2 focused on the distinctive, coarse surface reticulum.
- 3-6 *Protoellipsodinium cristulatum* n. sp. All specimens from the "mid" Aptian. Figure 3 (holotype) at 11.50 m, E.F. E39.4, FD1093(1), a right-lateral view focused on the archeopyle and Figure 4 at 10.85 m, E.F. S33.0, FD1092(1), showing the characteristic crests. Figures 5 and 6 a specimen at 11.50 m, E.F. R42.3, FD1093(2), focused on the lower (dorsal) and upper (ventral) surfaces respectively.
- 7,8 *Protoellipsodinium clavulus* subsp. *clavulus*, "mid" Aptian at 11.50 m, E.F. V46.0, FD1093(8). Figure 7 shows the long but relatively simple, capitate spines and Figure 8 is focused on the single-plate (3") precingular archeopyle.
- 9,10,13 *Fibradinium variculum*. Figures 9, 10 from the upper Barremian to lower Aptian, at 17.75 m, E.F. Q42.2, FD1101(1), with Figure 9 showing the thick wall, fibrous texture and sulcal depression and Figure 10 demonstrating the deep cingular notch. Figure 13 "mid" Aptian, at 11.50 m, E.F. X46.2, FD1093(10), a complete specimen with the operculum detaching. The rounded-triangular hypocyst and pronounced cingular and sulcal grooves are clearly shown by this specimen.
- 11,12,14, 15 *Protoellipsodinium clavulus* subsp. *spinigerus* n. stat. Figures 11, 12 from the upper Barremian at 20.00 m, E.F. U30.1, FD1106(5). An oblique right-lateral view with Figure 11 focused on the archeopyle and Figure 12 showing the well-developed distal spines. Figures 14, 15 from the "mid" Aptian, at 11.50 m, E.F. G39.0, FD1093(7) and E.F. G50.1, FD1093(6) respectively, both clearly showing the single-plate (3") archeopyle characteristic of the genus. Figures 14 and 15 both represent the more extreme development of this sub-species, referred to *P. clavulus spinigerus* (extreme) in Text-figure 5.







## DISCUSSION AND CONCLUSIONS

The current study has focused on the stratigraphic distribution of marine microplankton (largely dinocysts) in sediments of an upper Barremian to "mid" Aptian age, using very rich, diverse and well-preserved palynofloras from the Speeton Clay Formation of the Heslerton No. 2 shallow borehole (eastern England) and the Valhall Formation of Gannet Field well 22/26a-2, UKCS Central North Sea.

A two-fold sub-division of the Barremian has been followed here as opposed to the three-fold approach (including a middle Barremian = Middle B or Cement Beds of Speeton), previously used by Duxbury (1977, 1980). Similarly, the Aptian is divided into two substages rather than the three-fold sub-division preferred by Kemper (1995).

The oldest sediments analysed are from well 22/26a-2, and these have been assigned to palynofloral Zone LKP20, older than anything recovered from Heslerton No. 2. Electric log data

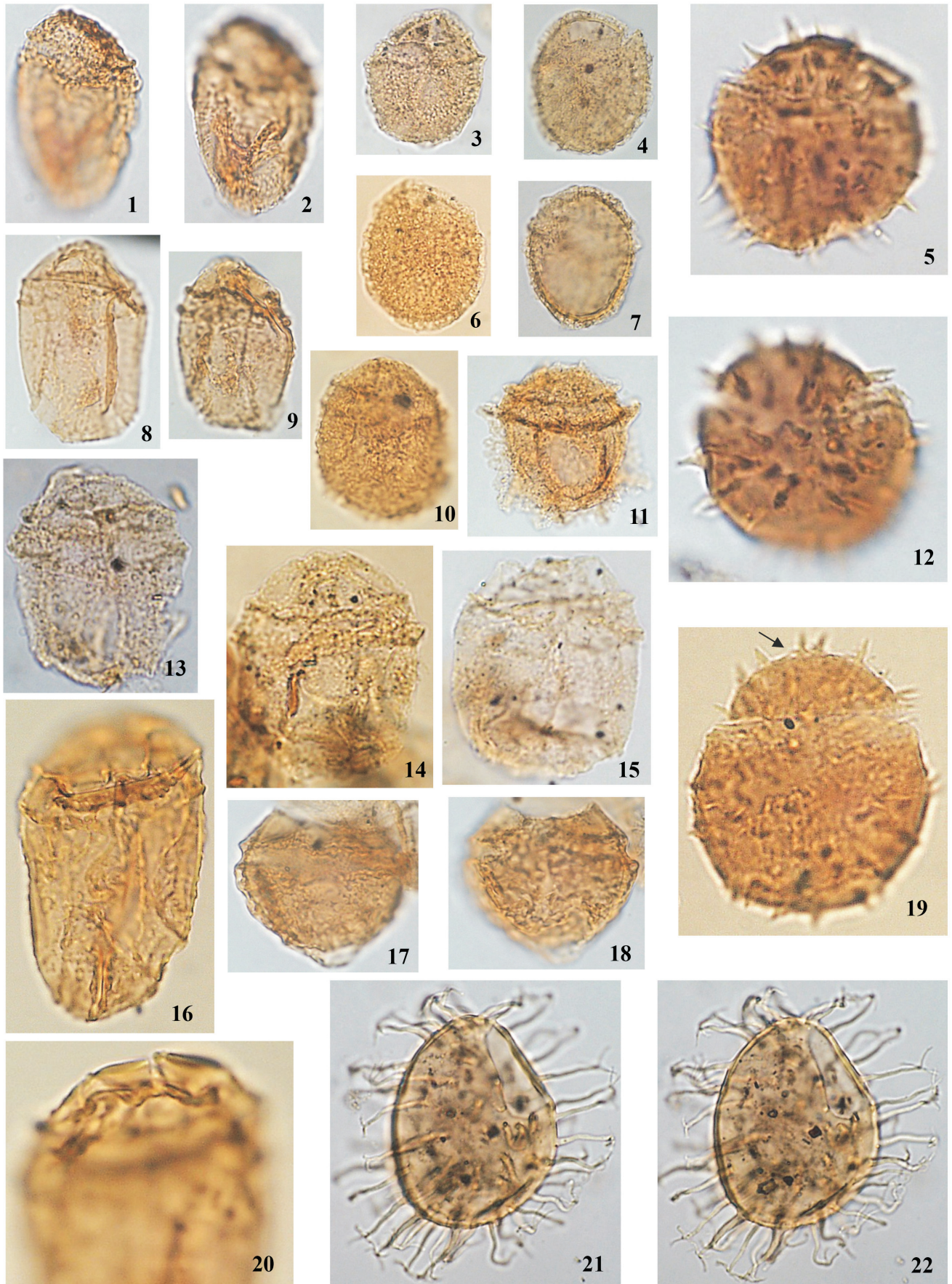
have allowed the lithostratigraphic unit V3/V4 boundary of Johnson and Lott (1993) to be placed at 11,235.00 ft in well 22/26a-2, corresponding to a marked uphole change from a lower-gamma section into higher gamma shales; palynofloral evidence suggests that this is equivalent to the transition from the Middle B (Cement Beds) to Upper B Beds in the Speeton coastal outcrop.

A major hiatus has been demonstrated between the 19.00 m and 17.75 m samples in Heslerton No. 2, highlighted by the absence from that borehole of several key late Barremian taxa, which are otherwise well represented in well 22/26a-2 (text-figs. 6, 7, 10 and 11). The full significance of this Heslerton No. 2 hiatus is currently unclear as the position of the Barremian/Aptian boundary, based on palynology, can not be directly calibrated with ammonite data, as highlighted by Kemper (1995). However this boundary is interpreted, part of the upper Barremian, that is equivalent to a significant portion of the 22/26a-2 core is clearly absent from Heslerton No. 2 (text-figs. 6, 7, 8).

## PLATE 3

All specimens from Heslerton No. 2, Speeton Clay Formation. All photographs  $\times 950$  unless otherwise stated.

- 1,2,8,9, 16,20 *Druggidium ornatum* n. sp. All specimens from the upper Barremian. Figures 1, 2 a specimen with dense granulation over the entire surface from 27.05 m, E.F. C31.2, FD1116(10). Figures 8, 9 specimens from 29.85 m (E.F. O54.0, FD1121(1)) and 19.00 m (E.F. D44.0, FD1103(3)) respectively, both with reduced surface ornament. Figures 16 and 20 (holotype), a specimen with relatively coarse ornament over much of the cyst from 24.00 m, E.F. G46.0, FD1110(1). Figure 16 is  $\times 1400$  and Figure 20 is  $\times 1900$ , with the latter focused to show smooth precingular plates. The indistinct tabulation expressed as low surface ridges, distinct cingulum and long hypocyst typical of this species are observed in all specimens.
- 3,4,6,7, 10 *Druggidium rhabdoreticulatum*. All specimens from the upper Barremian to lower Aptian at 17.75 m, E.F. K51.2, FD1102(1), E.F. D34.1, FD1101(2), E.F. G43.2, FD1101(3), E.F. T40.3, FD1101(4) and E.F. J42.4, FD1101(5) respectively. A typically small, rounded dinocyst covered with a fine reticulum of variable height, largely obscuring the tabulation but with a wide cingulum which is usually clearly seen. Figure 3 has two partially detached precingular plates whereas in Figures 4 and 6 the operculum is lost. Figures 3 and 10 illustrate the broad cingulum and Figure 7 is focused marginally, showing significant variation in ornament height.
- 5,12,19 *Biorbifera barremiana* n. sp.  $\times 1900$ . All specimens from the upper Barremian at 27.05 m (E.F. L48.0, FD1117(3)), 24.00 m (E.F. N53.2, FD1111(1)) and 26.00 m (E.F. N45.4, FD1114(2)) respectively. The epicystal archeopyle and broadly-tapering acuminate spines are clearly shown. In addition, Figure 19 (holotype) has a slightly indented cingulum and lateral connection of some spines by slender "trabeculae" a short distance from the cyst surface (arrowed).
- 11 *Druggidium jubatum* from the upper Barremian, at 29.85 m (E.F. H44.0, FD1121(2)).
- 13-15 *Druggidium augustum*  $\times 1400$ . All specimens from the upper Barremian to lower Aptian at 16.00 m, E.F. S30.0, FD1099(3), E.F. E27.0, FD1099(4) and E.F. F44.4, FD1099(5) respectively. The small, relatively delicate nature of this species is clearly shown, together with the dense cover of small granules, although some areas are devoid of ornament in Figure 15. The cingulum is clear in all specimens and indistinct tabulation is marked in Figures 13 and 15 by low sutural ridges.
- 17,18 *Fibradinium variculum* from the "mid" Aptian at 10.85 m, E.F. V40.0, FD1092(5); operculum missing. The rounded triangular hypocyst and pronounced cingular and sulcal grooves are clearly shown by this specimen. The coarse surface ornament approximates a reticulum in places.
- 21,22 *Protoellipsodinium clavulus* subsp. *spinigerus* n. stat., from the lower Aptian, at 13.95 m, E.F. G53.0, FD1098(8). An oblique left lateral view with 21 focused on the archeopyle (3") and 22 showing the well-developed distal spines.





Two further hiatuses were recognised in Heselton No. 2, one indicating missing section including the Fischschiefer (near base Aptian) and a second representing a significant part of the lower Aptian (text-figs. 6, 8).

The availability of conventional core samples from both Heselton No. 2 and well 22/26a-2 has allowed some insights into morphological variations and trends within and between species and into possible relationships between some genera. As also noted in Duxbury (2018), dinocyst species boundaries were difficult to apply in some cases. The current study suggests that taxonomic changes based on samples far removed from the type material, either geographically or temporally can lead to questionable interpretations, with significant (sometimes unexpected) re-assignments being based on photographic material and/or third-party illustrations.

Although sound taxonomy is undoubtedly the basis of detailed and consistent biostratigraphy, excessively prescriptive definitions, based on characteristics felt particularly important to individual authors can be difficult to sustain and leads to “grey areas” - Helenes (1984, p. 128) assigned *C. cornutum* to his “Provisionally assigned” species because, “all the species here included in *Cribroperidinium* are acavate”. *Cribroperidinium cornutum* is clearly close to *C. sepimentum*, the type species (arguably closer than several species of *Cribroperidinium* accepted without question by Helenes), and an intermediate form, *C. cf. sepimentum*, is very similar to *C. cornutum* but acavate. There appears to be a direct lineage within the late Barremian from *Cribroperidinium sepimentum* to *Scriniodinium barrem-*

*ianum*, involving an initial reduction in size, development of cavation, formation of characteristic apical horn distal perforations and loss of surface features.

In addition, Helenes (op. cit., p. 110) stated that, “Some taxa have been excluded from *Cribroperidinium* and referred to other genera even though they exhibit similar paratabulation patterns, wall structure, general shape, and occasional indications of intratabular ridges”, and he transferred *Gonyaulacysta episoma* (positively) and *Gonyaulacysta hadra* (questionably) to *Leptodinium* Klement 1960.

Helenes’ basis for the transfer of *G. episoma* was presumably because, “Study of published photographs of the types reveal certain characteristics of paratabulation, shape and ornamentation that indicate affinities with ...*Leptodinium*” (Helenes, op. cit., p. 131). His transfer of *G. hadra* was because Sarjeant’s (op. cit.) text-fig. 28, “suggests the presence of quadrate X and Y paraplates”, in spite of Sarjeant’s (1966a, p. 120) statement that text-figure 28, “is unlikely to be accurate in detail”. Neither transfer is accepted here, and both species have been transferred to *Cribroperidinium*. In addition, *Cribroperidinium episomum* is considered here to be a taxonomic senior synonym of *Cribroperidinium boreas*, an unquestionably accepted *Cribroperidinium* in Helenes (op. cit., p. 121).

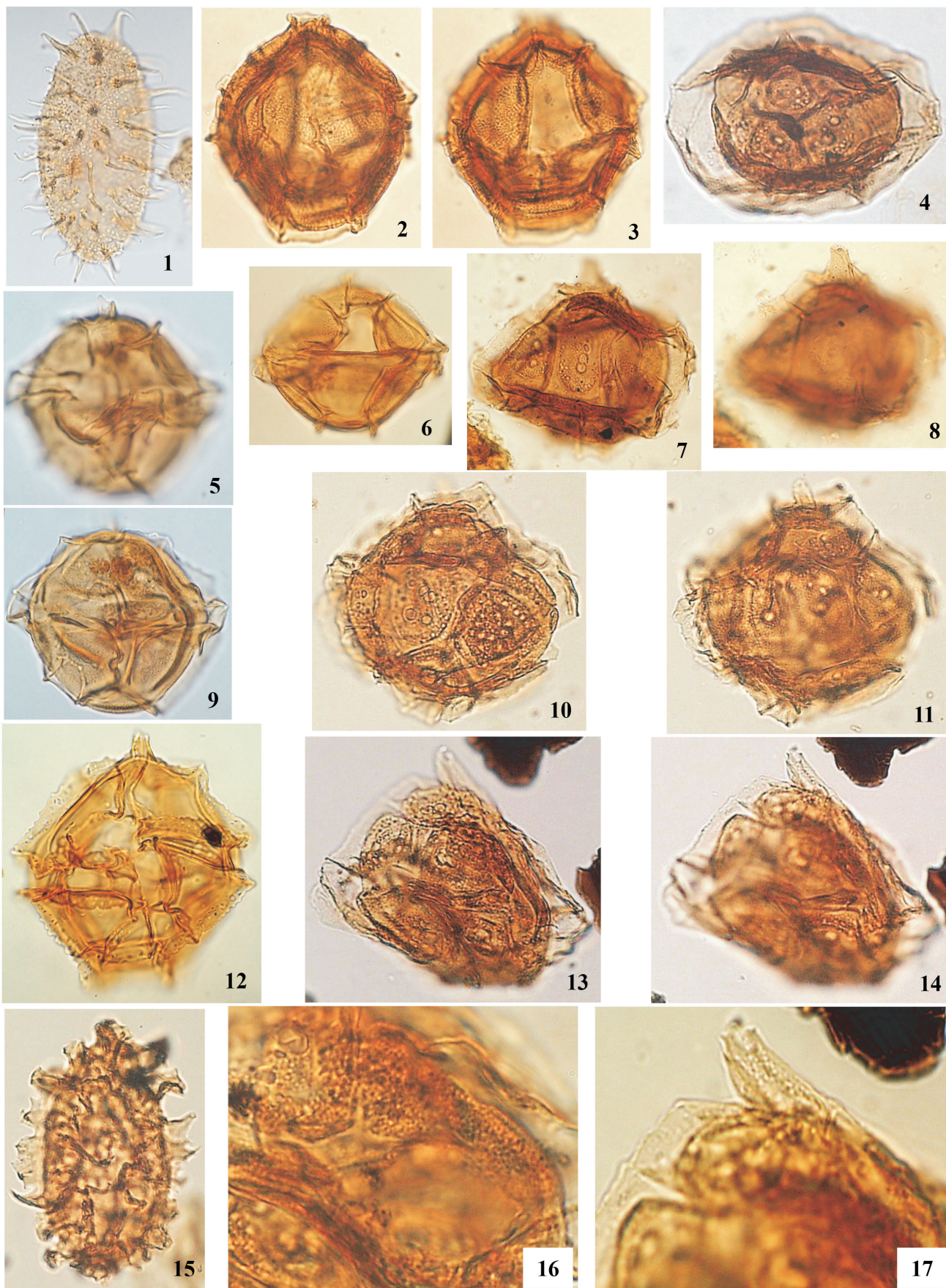
Similarly, assignment of Early Cretaceous taxa to genera originally described from the Jurassic or Tertiary can be problematic; the place of *Cassiculosphaeridia* within this context has been discussed in the text, where taxa essentially similar to the type species, *Cassiculosphaeridia reticulata*, have been assigned to

#### PLATE 4

All specimens from Heselton No. 2, Speeton Clay Formation. All photographs × 700 except Figures 16 and 17, which are × 1400.

- 1 *Prolixosphaeridium deirense* from the upper Barremian, at 27.05 m, E.F. B47.4, FD1116(3).
- 2,3 *Impagidinium alectrolophum* from the “mid”Aptian, at 11.50 m, E.F. J45.2, FD1093(12). Ventral (lower) and dorsal (upper) surfaces respectively. The surface texture appears to be very similar to that of *Pentadinium omasum* in Figures 5, 6 and 9.
- 4,7,8,10, *Pentadinium circumfoveolatum* n. comb. Specimens from the “mid”Aptian; those figured in Figures 4, 7 and 8 are from 11.50 m and the rest are from 10.85 m. Figure 4, E.F. F32.0, FD1093(3), is an oblique polar view showing the cingulocavate nature of this species, and Figures 7 and 8, E.F. U51.4, FD1094(1), are focused to show the characteristic wall structure and well-developed apical horn respectively. These features are also demonstrated by Figures 10 and 11, E.F. M41.4, FD1092(3), although this specimen has a more complex wall structure. Figures 13, 14, 16 and 17 provide a right-lateral view of the same specimen, E.F. J54.0, FD1092(4), with the last two magnified to × 1400 in order to show the “pseudopunctate orange-peel” texture of the endophragm and the well-developed *Gonyaulacysta/Wrevittia*-type apical horn respectively.
- 5,6,9 *Pentadinium omasum*, all at 21.00 m, upper Barremian. Figures 5, 9 (E.F. B41.2, FD1107(3)) focused to show a short apical projection and the characteristic cingulocavation and “pseudopunctate orange-peel” texture, and Figure 6 (E.F. M30.0, FD1107(4)) showing the dorsal (upper) surface and single-plate precingular archeopyle (3”).
- 12 *Pterodinium bab* from the upper Barremian, at 29.85 m, E.F. S42.3, FD1121(3), focused on the ventral (upper) surface and showing clearly the irregularly perforate and distally denticulate sutural crests.
- 15 *Aprobolocysta neista*. A complete specimen from the upper Barremian, at 27.05 m, E.F. S53.1, FD1116(1), showing the typical “holly leaf” outline of this species, due to the irregularly spikey distal crest margins.







*Ellipsoidictyum imperfectum* and *E. sagera*. As Duxbury (2018) placed the FAD of *C. reticulata* in the Valanginian, and as *Ellipsoidictyum cinctum* (the type species) was described from the middle Oxfordian (ranging only into the late Oxfordian - Duxbury et al. 1999), the “*Cassiculosphaeridia*-like” taxa discussed here might bear a much closer relationship to each other than to superficially similar “true” *Ellipsoidictyum* spp.

Depending on usually subjective defining characteristics, therefore, similar taxa are often placed in different genera. Many essentially similar bi-layered proximate dinocysts were recorded in the present study, typically with no wall separation over epiphytic and hypocystal areas and with sutural crests of varying height. They each display a single-plate, mid-dorsal archeopyle (3”), range from taxa with no cavation to suturocavate and pterocavate forms, and have been allocated to the genera *Impagidinium*, *Pentadinium* and *Pterodinium*, all of the Subfamily Gonyaulacoideae (Fensome et al. 1993). All lack processes but some have apical structures of varying types, and the defining differences in practical terms are that *Pterodinium* bears particularly high sutural crests and that *Pentadinium* is pterocavate.

Three representatives of *Impagidinium* and *Pentadinium* recorded here, *I. alectrolophum*, *P. omasum* and *P. circumfoveolatum* appear to have characteristic “orange peel” wall texture (described in Harding 1990). Although there is a stratigraphic gap between the LAD of *P. omasum* and the FAD of *P. circumfoveolatum*, including much of the lower Aptian, the ranges of these species are “connected” by that of *I. alectrolophum*, which could be the origin of both.

The LADs of *I. alectrolophum*, *P. omasum* and *P. circumfoveolatum* are at the top of the lower Albian, top Barremian and “mid” Aptian respectively, whereas the type species of both *Impagidinium* and *Pentadinium* were described with Late

Eocene and Oligocene–Miocene ages respectively. In a necessarily purely morphological classification, however, there can be no differentiation by age of material. In his comments on *Druggidium*, Harding (1986, p. 19) stated, “it is of importance to note that all of the positively identified species of *Druggidium* are restricted to the pre-Aptian Early Cretaceous”, suggesting a possible age-differentiation of genera, although more recently, *Druggidium discretum* and *D. meerensis* have been described from the late Maastrichtian and Danian by Slimani and Louwye (2011). The last two taxa appear to comply fully with Harding’s own criteria for this genus.

Similarly, in their remarks on *Kleithriasphaeridium*, Fensome and Williams (2019, p. 117), state that, “*Kleithriasphaeridium* is similar to *Cordosphaeridium* in being chorate with one process per paraplate, and bearing a precingular archeopyle. However, in *Cordosphaeridium* the processes are fibrous”. However, *Kleithriasphaeridium porosispinum* is listed *per se* in Williams et al. (2017, p. 477), although it has many characteristics distinctly similar to those of *Cordosphaeridium*, including one process per plate, a precingular archeopyle and fibrous processes. Its retention in *Kleithriasphaeridium* by various authors is presumably because of its much older range (early Volgian to late Ryazanian - Duxbury et al. 1999) than “accepted” *Cordosphaeridium* spp.

The effects of palaeoenvironmental changes on palynofloral assemblages are only partially understood and, although assemblage fluctuations observed in the current study were often very marked with some apparently very rapid (text-figs. 10 and 11), no detailed interpretation has been possible here. Some grouping of Early Cretaceous dinocyst taxa according to water depth has been demonstrated elsewhere (Wilpshaar and Leereveld 1994) and some effects of variable salinity have been reported for the “*Muderongia* Complex” (Harding 1990, p. 20). Influxes of Tethyan cephalopod macrofossils were noted in well 22/26a-2, associated with Tethyan nannofossils (Jeremiah 2001,

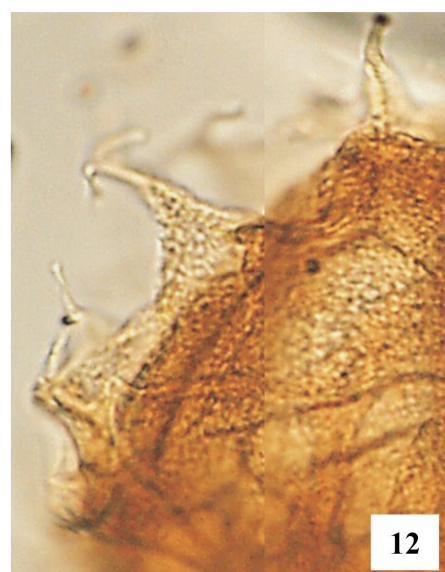
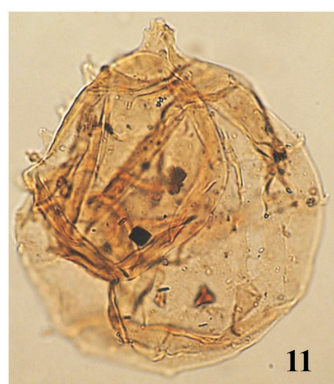
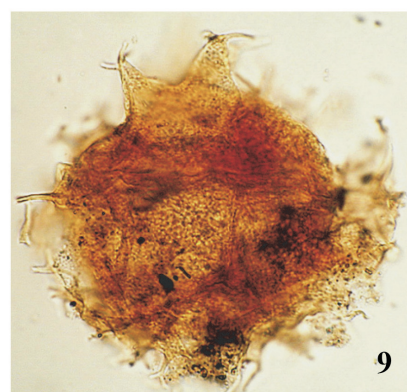
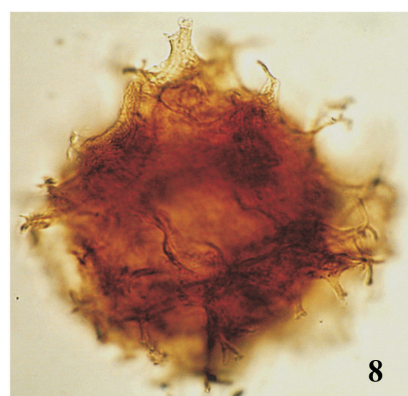
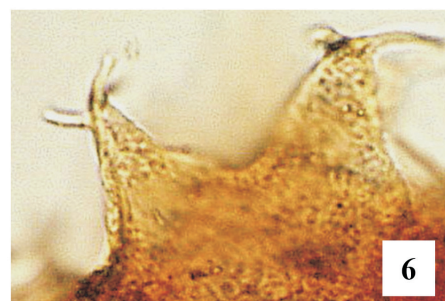
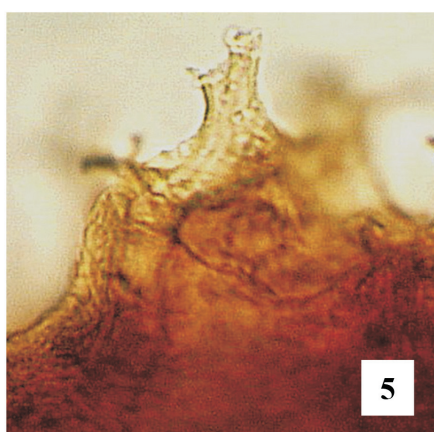
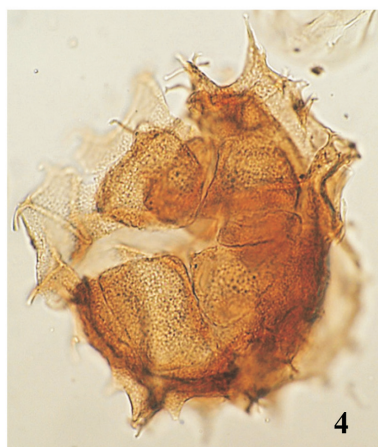
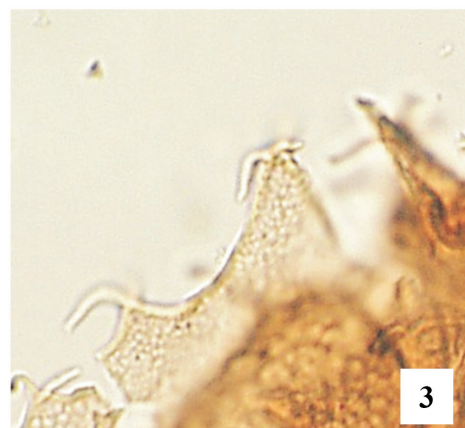
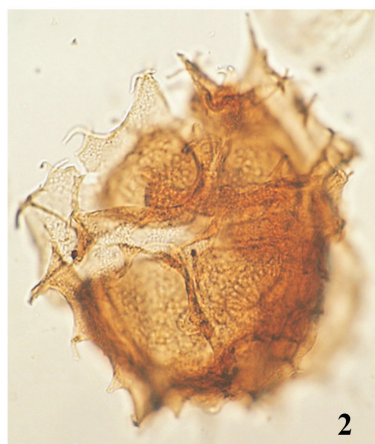
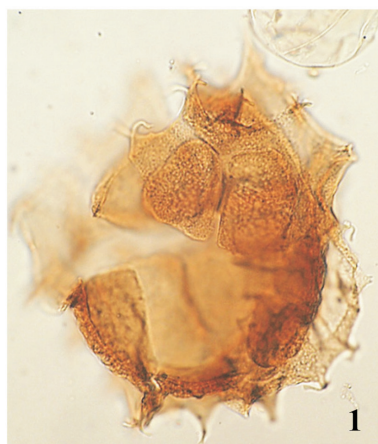
## PLATE 5

All specimens from Heselton No. 2, Speeton Clay Formation.  
All photographs × 700 except Figures 3, 5, 6 and 12, which are × 1900.

1-4, 5, 6, *Spiniferites ornatus* n. sp. from the lower Aptian. Figures 1-4 (holotype) at 13.20 m, E.F. V39.0, FD1097(6) in right-lateral view showing the thick, fibro-perforate endophragm, ventral pericoel with a large claustrum and an apical spike. Figure 3, a detail of the same specimen × 1900 showing the thinner, microperforate pericoel. Figures 5, 6, 8, 9 (paratype) at 13.20 m, E.F. Q28.1, FD1097(5), displaying the characteristic suturocavation of this species, with Figures 5 and 6 enlarged to × 1900 to show details of the apical horn and microperforate pericoel respectively. Figure 12 a specimen at 12.20 m, E.F. L26.1, FD1095(1), a combination of two foci showing the

thick, fibro-perforate endophragm, thinner, microperforate pericoel and suturocavation.

7, 10, 11 *Diphasiosphaera stolidota*. Figures 7, 10 from the lower Aptian, 12.20 m, E.F. J33.3, FD1096(2) in left-lateral aspect and Figure 11, from the upper Barremian, 22.95 m, E.F. X36.0, FD1109(5), is a right-lateral view. The large cavation (with wall attachment restricted to the archeopyle margin and that portion of the paracingulum directly beneath it), and characteristic apical horn are well demonstrated by these specimens.





Rawson and Jeremiah 2001), but the current lack of comparative Tethyan/Boreal dinocyst data for the Barremian precludes any similar palynofloral conclusions.

An empirical approach might allow better assessment of palaeoenvironmental change, particularly where fully quantitative data allows statistical analysis, although in the Early Cretaceous, where diversity is exceptional, specimen counts would need to be particularly high. In this case, the “why” of palynofloral assemblage change must remain unanswered unless closely linked to parallel studies, ideally including sedimentological, micropaleontological, nannofloral, geophysical, geochemical, macrofaunal and isotope analyses.

Evidence from Heselton No. 2 and well 22/26a-2 has allowed some refinement of the Duxbury (2001) zonation scheme, including the addition of a number of subzones. A total of 79 key palynofloral events are now recognised for the late Barremian and early Aptian, including many FADs. Some key events relate to previously undescribed taxa, and 1 new genus, 23 new

species and 2 new subspecies of dinocysts have been described and illustrated to formalise these.

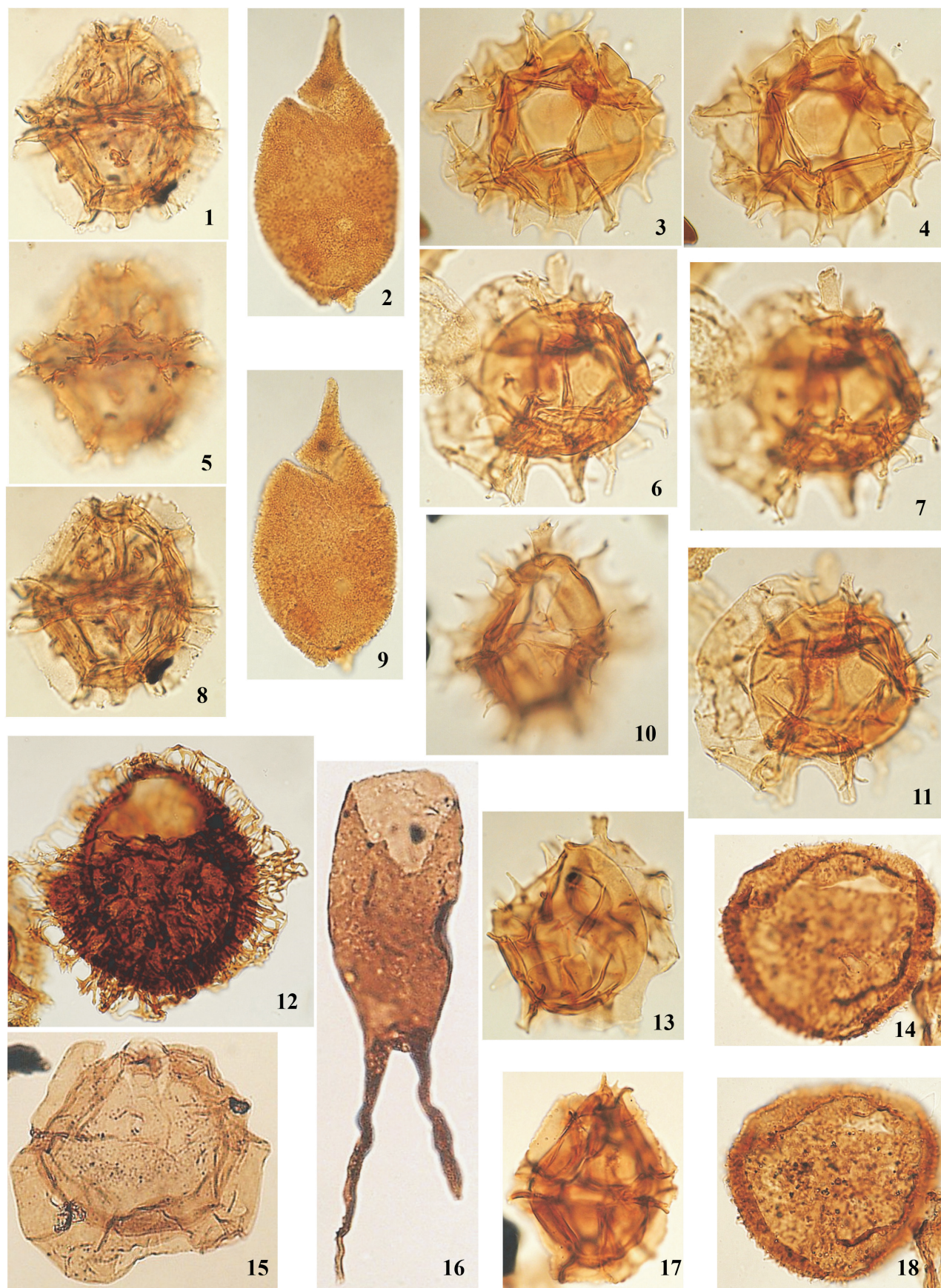
Direct and detailed correlation of first-hand data from well 22/26a-2 and Heselton No. 2 to the Lower Saxony Basin has been possible (text-fig. 8), a distance of about 700km, using palynofloral evidence provided for the Wiechendorf 1/86 borehole in Lister and Batten (1995). However, poor macrofossil control has precluded precise ammonite calibration of palynofloral events.

The position of the Barremian/Aptian boundary tends to be differently interpreted using “standard” palynofloral, foraminiferal and nannofloral events; this was well-illustrated by Kemper (1995) and is summarised for Wiechendorf 1/86 in Figure 8 here. In consequence, the precise position of this boundary remains to be established palynologically, although there are several events which are of potential value (text-fig. 9), and these have been discussed in the text.

## PLATE 6

Specimens from Heselton No. 2, Speeton Clay Formation, except for Figures 12 and 14-18 which are from well 22/26a-2.  
All photographs × 700.

- 1,5,8 *Pterodinium premnon*, upper Barremian at 20.00 m, E.F. O51.0, FD1106(1). Three levels of focus to show (1) the characteristic plate-centred projections, (5) crests marking the cingular series and (8) the absence of plate-centred projections from the apical plates. The high, distally-irregular sutural crests are shown by each illustration.
- 2,9 *Batioladinium micropodum*, upper Barremian at 27.05 m, E.F. U26.0, FD1116(6). The fine, dense ornament typical of this species is clearly shown by this specimen.
- 3,4,6,7, 10,11,13 *Spiniferites caminus* n. sp., of late Barremian age. Figures 3 and 4 a specimen from 29.85 m, E.F. V39.0, FD1121(8), left-lateral view, showing the large ventral cavation and characteristic apical horn. Figures 6, 7, 11 holotype, at 27.05 m, E.F. M52.0, FD1116(9) – a right-lateral view focused to show (6) the partially detached 3" operculum, (7) the characteristic apical horn and (11) the large ventral pericoel and claustrum. Figure 10, at 27.05 m, E.F. M25.4, FD1117(2), a specimen showing an unusually ornate apical horn bearing a ring of distal spines. Figure 13 (paratype), a right-lateral view at 27.05 m, E.F. X41.0, FD1116(8), has a relatively small pericoel, although it still covers the entire ventral surface.
- 12 *Exiguisphaera plectilis*, well 22/26a-2, upper Barremian at 11,235.00 ft, E.F. B31.3, FD1131(2), showing the large two-plate precingular archeopyle and the high, complex enclosing network.
- 14,18 *Gongylodinium brevispinosum*, well 22/26a-2, upper Barremian at 11,235.00 ft, E.F. R28.0, FD1131(6). Figure 14 is focused on the dorsal (lower) surface, showing the large two-plate precingular archeopyle and Figure 18 shows the surface ornament of short spines on the ventral (upper) surface.
- 15 *Sirmiodinium grossii* at 11,181.33 ft, upper Barremian in well 22/26a-2, E.F. J48.1, FD1127(3).
- 16 *Batioladinium longicornutum* at 11,210.00 ft, upper Barremian in well 22/26a-2, E.F. X43.1, FD1128(1).
- 17 *Pterodinium cingulatum* at 11,181.33 ft, upper Barremian in well 22/26a-2, E.F. L37.0, FD1127(5), showing the ornament-free cyst surface and high, distally smooth sutural crests.





## ACKNOWLEDGMENTS

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## PLATE 7

Specimens from Heselton No. 2, Speeton Clay Formation and well 22/26a-2 (as indicated). All photographs × 700.

- 1 *Trabeculidium quinquetrum*, upper Barremian at 11,235.00 ft, well 22/26a-2, E.F. M56.0, FD1131(17). A left-lateral view.
- 2,3,6,7, 10,11 *Impletosphaeridium multifurcillatum* all from the upper Barremian of well 22/26a-2. Figures 2, 7, 10, 11 at 11,235.00 ft, E.F. P42.1, FD1131(8), E.F. S42.0, FD1131(9), E.F. V55.1, FD1131(10) and E.F. V28.0, FD1131(11) respectively. Figures 3 and 6 from 11,230.00 ft (E.F. U37.4, FD1129(4)) and 11,232.00 ft (E.F. Q33.0, FD1130(3)). The small size, spheroidal cyst and numerous (but variable), distally-furcate processes are clearly shown. Figure 2 with a possible single opercular plate retained and Figure 11, upper surface, displays a possible two-plate precingular archeopyle.
- 4,8,12, 14,15,18 *Kiokansium unituberculatum*, all from the “mid” Aptian of Heselton No. 2. Figures 4, 8, 12 at 10.85m, E.F. C53.4, FD1092(8) and Figures 14, 15 and 18 at 11.50m, E.F. U32.0, FD1093(23) (14, 15) and E.F. O31.3, FD1093(24) (18) respectively. Three specimens to illustrate the wide variability in morphology, from smooth, ovoidal specimens with very slender processes showing some alignment (Figures 4, 8, 12) to coarser individuals, spheroidal with a granular surface and broad, stiff, distally-digitate spines (Figures 14, 15, 18). In figure 15, the dorsal (upper) surface is focused to show the two-plate precingular archeopyle.
- 5,9 *Cribroperidinium echinatum* n. sp. (holotype) from the “mid” Aptian of Heselton No. 2 at 11.50m, E.F. T55.4, FD1093(11). Dorsal (upper) and ventral (lower) surfaces respectively, showing the single-plate precingular archeopyle, very spiny surface and clear tabulation, marked by spiny ridges, which are typical of this small species.
- 13,16 *Spiniferites speetonensis* from the upper Barremian of Heselton No. 2 at 27.05m, E.F. O37.3, FD1117(4). Figure 13 focused to show the characteristically fenestrate distal process terminations and Figure 16 showing a ventral pericoel.
- 17 *Phoberocysta neocomica* from the upper Barremian of well 22/26a-2 at 11,235.00 ft, E.F. U52.3, FD1131(18).



