

LOPINGIAN (LATE PERMIAN) PALYNOMORPHS FROM THE CADEBY FORMATION, CADEBY QUARRY, YORKSHIRE, UK

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Abstract. Seventeen samples from the Cadeby Formation (Lopingian, Permian, EZ1) of Cadeby Quarry near Doncaster, South Yorkshire, UK, yielded organic residues including phytoclasts, cuticle, unstructured tissue and generally well-preserved palynomorphs. The palynomorph assemblages are dominated by taeniate and non-taeniate bisaccate pollen including *Klausipollenites schaubergeri*, *Limitisporites rectus*, *Lueckisporites virkekiae* and *Taeniaesporites noviaulensis*. The assemblages are generally similar to those from the English Midlands described from Kimberley Railway Cutting and the Haughton Hall Borehole, Nottinghamshire and those from the Marl Slate Formation (lower EZ1) of the Durham Sub-basin at Claxheugh Rock and Crime Rigg Quarry and to the mid EZ1 of the Salterford Farm Borehole and Woolthorpe Bridge Borehole. The excellent preservation of the assemblages allows the recognition that *Dicappipollenites* Tiwari & Vijaya 1995 is a junior synonym of *Lueckisporites* Potonié & Klaus emend. Clarke 1965.

The presence of rare microphytoplankton and microforaminiferal test linings indicate a neashore marine environment. The clastic (and organic) content of the Cadeby Formation, part of a dominantly carbonate succession, may represent erosion and transport of material from the hinterland reflecting a wetter climatic period, though the alternation of clastic and carbonate sedimentation in the section at Cadeby suggests some wet/dry palaeoclimatic cyclicity.

INTRODUCTION

Late Permian (Lopingian) strata of the Zechstein Group crop out in a narrow North-South trending belt across northern England (Fig. 1A). The outcrop consists of strata deposited at the western limit of the Anglo-Dutch Basin, part of the Southern Permian Basin which extended from Britain into Poland (Peryt et al. 2010). The rocks repre-

sent a range of palaeoenvironments from sabkha to shelf with accumulation of carbonates being dominant. In the outcrop from Catterick, North Yorkshire southwards to Nottinghamshire, the lowermost carbonates of the Zechstein Group are assigned to the Cadeby Formation. This formation is correlated with the Raisby and Ford formations in Durham, the Zechsteinkalk Formation in the UK Southern North Sea, and the Z1 Carbonate Formation further East (Johnson et al. 1994; Peryt et al. 2010).

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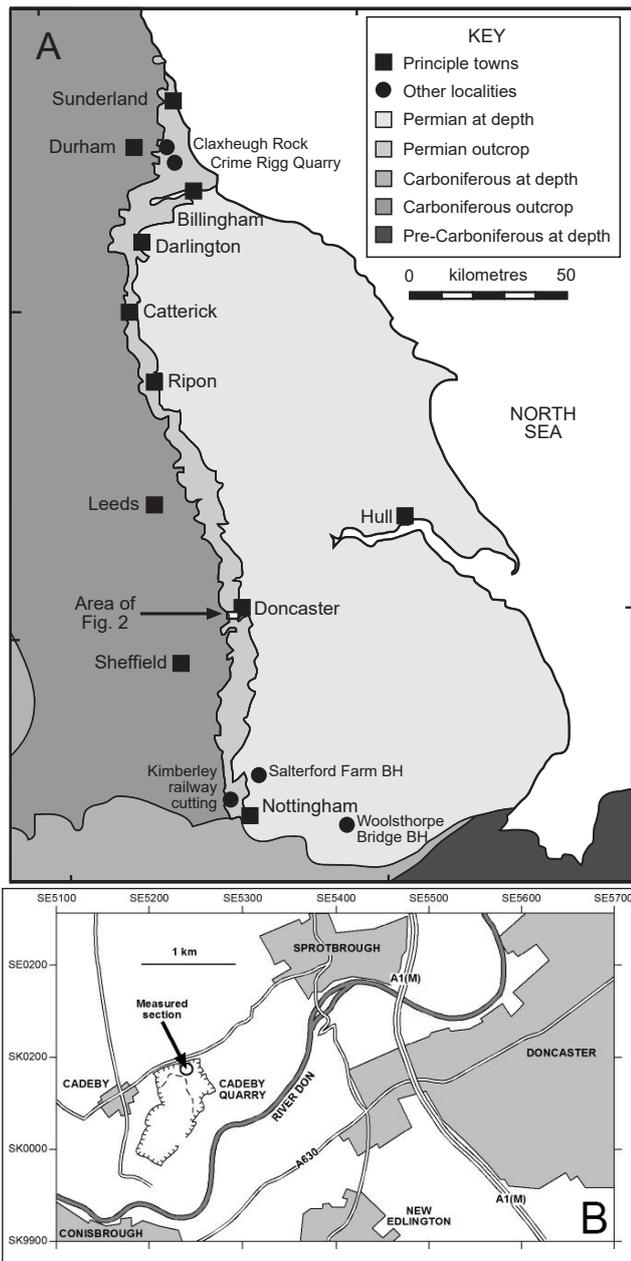


Fig. 1 - A) Distribution of pre-Triassic rocks in central-eastern and north-eastern England showing Carboniferous and Permian outcrop with subcrop below Triassic and younger strata. Also showing location of Figure 1B. B) Location of Cadeby Quarry and measured section.

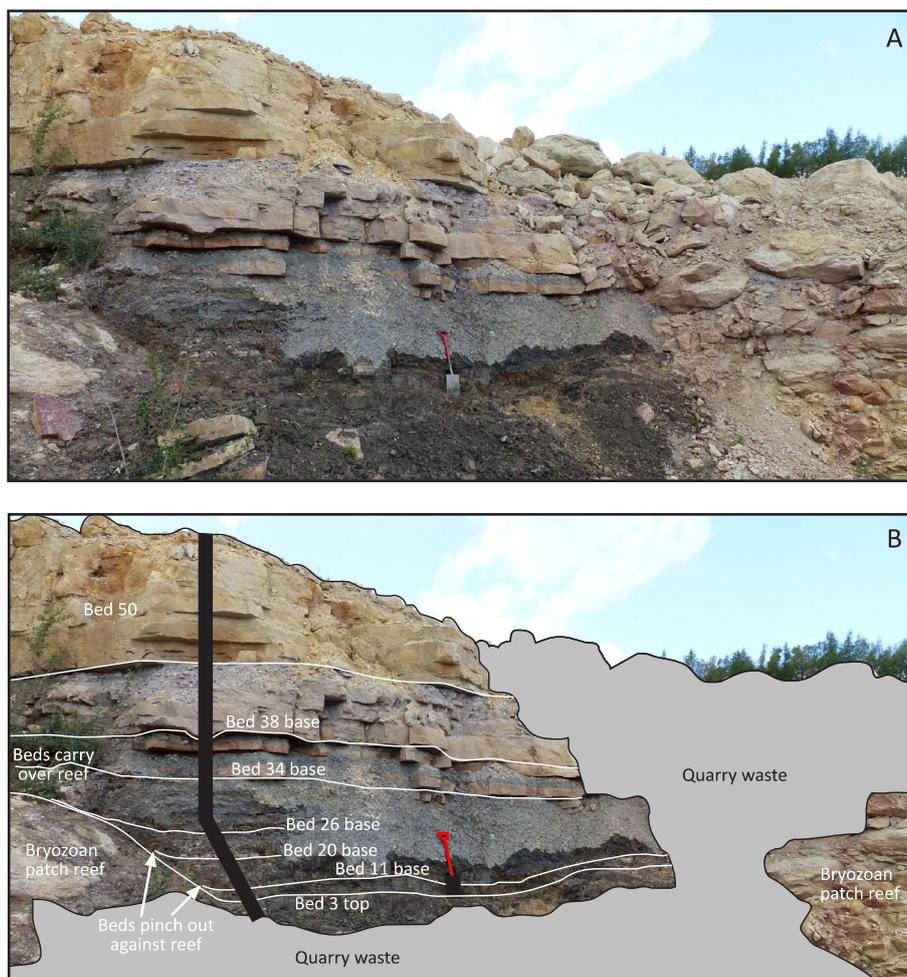
Cadeby Quarry [National grid reference SE 523 008] is located 6 km to the WSW of Doncaster, South Yorkshire, UK. It lies midway between the towns of Sprotbrough and Conisbrough on the North side of the gorge which the River Don cuts through the Permian outcrop (Fig. 1B). The quarry exposes the type section of the Cadeby Formation (Smith et al. 1986). Some rock faces in the older part of the quarry [SE 522 003] make up a designated

LITHOSTRATIGRAPHY				CHRONO-STRAT	
Group	Formation	Member	Beds		
Zechstein Group (15-45 m)	Roxby Formation (15-20 m)			Lopingian (part)	PERMIAN
	Brotherton Formation (15-18 m)				
	Edlington Formation (15-45 m)				
	Cadeby Formation (32-54 m)	Sprotbrough Member (15 m)	Hd / HB (0-3 m)		
	Wetherby Member (17 m)				
VU	YSF (0-5 m)				
Pennine Coal Measures Group (>1900 m) (part)	Pennine Upper Coal Measures Formation (>300 m) (part)			Bolsivian (part)	CARBONIFEROUS

Fig. 2 - Simplified lithostratigraphical log for the Cadeby area. Vertical bar indicates position of the Cadeby Quarry section. Variations in thicknesses of the Permian units reflect thickening of these to the East, i.e. away from the western margin of the Southern Permian Basin. Note that the Variscan Unconformity at the base of the Lopingian strata represents a gap of at least 50 Ma. Abbreviations: HB – Hampole beds (not to scale); Hd – Hampole disconformity; YSF – Yellow Sands Formation; VU – Variscan Unconformity.

Site of Special Scientific Interest (S.S.S.I.) and the whole quarry as it existed at the time was described as a regionally significant Geological Conservation Review site by Smith (1995). Summary descriptions of the sections in the older part of Cadeby Quarry are provided by Smith (1969, 1981) and Smith et al. (1986) with more detail provided by Smith (1995). At the time, most of the higher parts of the exposed stratigraphy were inaccessible due to the height of the rock faces (> 18 m), and were only described as seen from the quarry floor (Smith 1995, p. 166-167). Recent extension of the quarry to the North has produced several benches which allow access to the higher strata, and has, albeit temporarily, exposed a section which includes accessible unweathered siliciclastic claystones and siltstones that yield organic material including recognisable palynomorphs. Although possibly not representing the same or lateral equivalent strata from which Downie (1967) reported walchian conifer fossils (see below), this section represents a similar facies which also contains macroscopic plant remains. There are no published accounts of the sections in the newer parts of the quarry (Ramsdale 2022).

Fig. 3 - A) Field photograph of the measured section looking NNE, showing relationship of the bedded dolostones and silicilastics to the patch-reefs on either side. B) Annotated photograph. Vertical black bar indicates position of measured section.



Permian strata in the area rest unconformably upon Carboniferous rocks, with the oldest preserved Permian assigned to the Yellow Sands Formation. This is not exposed in the quarry but is proven at depth in boreholes and known at outcrop nearby (Hough et al. 2007). The overlying Cadeby Formation dominantly consists of shallow water, marine limestones that are largely dolomitised. The formation is divisible into the Wetherby and Sprotbrough members with an informal unit termed the Hampole beds between (Fig. 2). In the quarry the Wetherby Formation has peloid, skeletal grainstones (with some packstones) that lie within a mosaic of bryozoan-rich boundstone patch-reefs and their overlying, draped stromatolitic laminites. The base of the Hampole beds is identified as an irregular discontinuity surface (the Hampole discontinuity of Smith, 1981) with a local relief of 2.5 to 3.0 m with the Hampole beds infilling depressions between patch-reefs. The Hampole beds consist of interbedded dolomite mudstones and siliciclastic mudstones, although Smith (1995) only observed

these from a distance. The base of the Sprotbrough Member is formally defined within the Hampole beds (Smith et al. 1986), but as this usage contravenes lithostratigraphical practice, the base has more recently been taken at the position of the Hampole discontinuity (Tyman et al. 2017). In this informal usage, the Hampole beds form the lowermost part of the Sprotbrough Member. The remainder of this member consists of well-graded ooid grainstones that display thick, sub-parallel bedding in the lower part and large-scale cross-stratification in the remainder of the unit.

DESCRIPTION OF THE MEASURED SECTION

The logged section (Figs. 3 and 4, Table 1) lies towards the northern edge of Cadeby Quarry at SK 52396 00868. The section was initially exposed by quarrying and subsequently manually cleared to remove large amounts of fallen debris and allow detailed inspection. It consists of 5 m of thinly

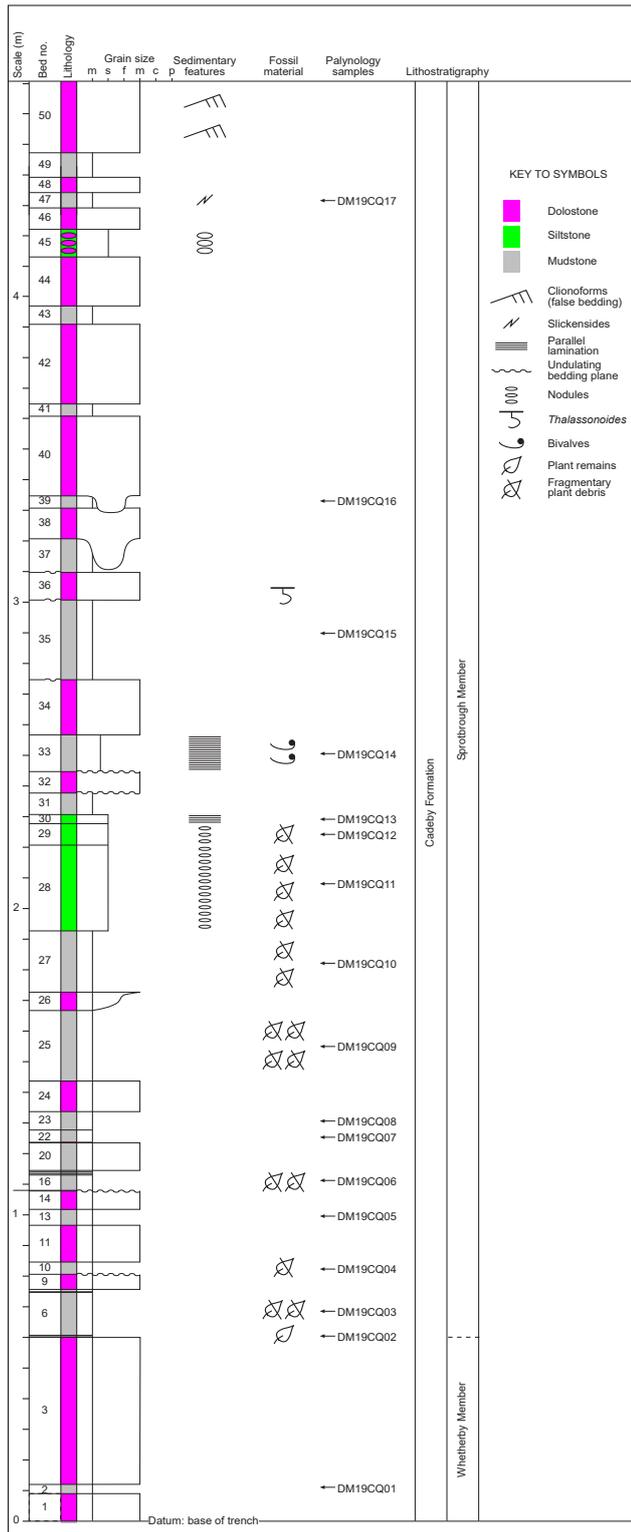


Fig. 4 - Measured lithological log showing the position of palynological samples.

bedded dolostones interbedded with thin, poorly lithified claystones and siltstones. The lower beds occupy a depression between two domed, algal patch-reefs while the upper beds extend over the tops of the reefs.

The bedded dolostones are generally grey-yellow in colour at the base of the section, becoming cream-yellow and pink higher. They weather to a characteristic pink colour. The lowermost beds (Beds 1 to 3, Fig. 4) are a lateral continuation of the base of the patch-reef. The mudstones of Bed 2 laterally develop into a nodular bed within the reef. Higher beds (Beds 4 to 25) pinch out against the patch reef although the uppermost part of bed 25 thins out against but extends over the patch-reef dolomites. Beds 26 and 27 similarly thin but extend across the reef. The siltstones of beds 28 to 30 are the oldest beds to transgress the reef without any apparent thinning. An up-section increase in bed thickness is apparent. Several features amongst the higher bedded dolostones may allow some lateral correlation. These include the development of indurated red “crusts” on the bounding surfaces of beds 35 and 36. That at the base of Bed 36 is associated with abundant *Thalassinoides* burrows. Beds 38 and 40 display conspicuous “load” structures while Bed 45 has a characteristic nodular internal structure. Bed 48 marks the highest of the dolostone beds with conspicuous pink weathering. The presence of slickensiding in the underlying mudstone (Bed 47) suggests some disturbance which is possibly related to movement of quarry vehicles on the ramp above and behind the section. Although thickening of the Cadeby Formation in the area associated with the Don Valley fault structure (Mitchell et al. 1947; Ramsdale 2022) suggests some syndepositional tectonic control, the slickensiding is a small feature, restricted to a single bed and is considered unlikely to be of tectonic origin. The top of the section is occupied by a thickly-bedded (c. 3 m thick), buff-yellow dolostone, weathering to yellow. It has well-developed, small-scale cross-bedding and at the top shows development of fenestrae.

The siliclastic interbeds are variably grey-green, blue-grey and red claystones with an interval of blue-purple micaceous siltstones (Bed 28). Some claystones where they are in contact with the dolostone layers show a few millimeters of bright red colouration. The lower beds between the patch-reefs (siliclastic beds 4 to 27) are characteristically plastic, pliable and very poorly lithified. They are micaceous at the base becoming less micaceous higher. Fine, disseminated plant debris is present throughout and larger, coaly fragments of plant material occur in the 14 cm thick Bed 5. Beds 28 and

Bed Number	Bed Thickness (cm)	Description	Palynological sample	Lithostratigraphy	
				Sprotbrough Member	Cadeby Formation
50	300+	Dolostone, buff-yellow, well-bedded, clinofolds (false bedding), fenestrate at top		Sprotbrough Member	Cadeby Formation
49	8	Siltstone, pale grey-green-pink		Sprotbrough Member	Cadeby Formation
48	5	Dolostone, grey-pink, lenticular. Highest pink-weathering dolomite		Sprotbrough Member	Cadeby Formation
47	5	Mudstone, grey-yellow, slickensided	DM19CQ17	Sprotbrough Member	Cadeby Formation
46	7	Dolostone, pink-green-yellow, tabular		Sprotbrough Member	Cadeby Formation
45	9	Dolostone, pink, nodular, within pink-green siltstones		Sprotbrough Member	Cadeby Formation
44	16	Dolostone, yellow-pink		Sprotbrough Member	Cadeby Formation
43	6	Mudstone, dark grey-pink, rotten - site of seepage		Sprotbrough Member	Cadeby Formation
42	26	Dolostone, cream-yellow		Sprotbrough Member	Cadeby Formation
41	4	Mudstone, medium grey-green, orange-red mottles		Sprotbrough Member	Cadeby Formation
40	26-33	Dolostone, yellow-cream. Base cuts down into underlying dolostone		Sprotbrough Member	Cadeby Formation
39	4	Marly mudstone, pale grey-green. Thins to right-hand side	DM19CQ16	Sprotbrough Member	Cadeby Formation
38	9-19	Dolostone, yellow-cream, pink weathering. Distinctive "loads" on lower surface extend 10 cm below base of bed		Sprotbrough Member	Cadeby Formation
37	7-11	Claystone, pale green with red mottling/staining. Weathered/rotten		Sprotbrough Member	Cadeby Formation
36	9-11	Dolostone, yellow, pink weathering. Upper and lower surfaces undulose. Distinctive red "crust" and <i>Thalassinoides</i> on lower surface		Sprotbrough Member	Cadeby Formation
35	26	Claystone, poorly lithified, blue-grey at base becoming pale green-grey at top. Sample DM19CQ15 at 15 cm from base	DM19CQ15	Sprotbrough Member	Cadeby Formation
34	15-18	Dolostone, cream-yellow, weathering pink, red stained top and base. Undulating upper surface		Sprotbrough Member	Cadeby Formation
33	12	Silty claystone, parallel laminated, grey-green with purple staining. Small, poorly preserved bivalves towards top	DM19CQ14	Sprotbrough Member	Cadeby Formation
32	6-8	Dolostone, cream-green, clean, purple staining at top and base. Undulose upper and lower surfaces		Sprotbrough Member	Cadeby Formation
31	7	Mudstone, grey-green with orange, red and green staining		Sprotbrough Member	Cadeby Formation
30	3	Siltstone, parallel laminated, grey-pale green	DM19CQ13	Sprotbrough Member	Cadeby Formation
29	7	Siltstone, packed nodules 2-10 mm across, pale green, micaceous, plant debris	DM19CQ12	Sprotbrough Member	Cadeby Formation
28	28	Siltstone, packed nodules 2-10 mm across, pale blue-purple, micaceous, plant debris	DM19CQ11	Sprotbrough Member	Cadeby Formation
27	20-30	Claystone, poorly lithified, pliable, micaceous, blue-grey with yellow-green staining	DM19CQ10	Sprotbrough Member	Cadeby Formation
26	0-6	Dolostone, grey-yellow, orange weathering. Thins out to right-hand side to a thin (1 mm) orange stain then red lamina		Sprotbrough Member	Cadeby Formation
25	12-23	Claystone, poorly lithified, pliable, blue-grey, common plant debris. Thickens to right-hand side	DM19CQ09	Sprotbrough Member	Cadeby Formation
24	8-10	Dolostone, grey-yellow, weathers orange, dirty at top, thickens to lefthand side		Sprotbrough Member	Cadeby Formation
23	6	Claystone, poorly lithified, pliable, dark blue-grey	DM19CQ08	Sprotbrough Member	Cadeby Formation
22	4	Claystone, poorly lithified, pliable, grey-green	DM19CQ07	Sprotbrough Member	Cadeby Formation
21	0.2	Claystone, poorly lithified, pliable, red		Sprotbrough Member	Cadeby Formation
20	9	Dolostone, yellow-grey, weathers orange and red. Red upper surface		Sprotbrough Member	Cadeby Formation
19	0.5	Claystone, poorly lithified, pliable, red, mottled		Sprotbrough Member	Cadeby Formation
18	0.5	Claystone, poorly lithified, pliable, green-grey		Sprotbrough Member	Cadeby Formation
17	0.5	Claystone, poorly lithified, pliable, yellow		Sprotbrough Member	Cadeby Formation
16	5	Claystone, poorly lithified, pliable, olive grey-green, rare mica, common plant debris. Red stained upper surface	DM19CQ06	Sprotbrough Member	Cadeby Formation

Tab. 1 - Detailed description of lithological units in the Cadeby Quarry measured section.

29 consist of packed micaceous siltstone nodules with abundant disseminated plant debris. These and higher siliciclastic units are more lithified and often

show parallel lamination, probably indicating internal grain-size heterogeneity. The beds become paler and more pink in colour up-section. Very poorly

preserved shell material, possibly of bivalves, was recorded in Bed 33, but otherwise faunas were not seen.

The boundary between the Wetherby and Sprotbrough members is difficult to establish in the section measured in Cadeby Quarry. The section appears like that shown as ‘unit 3 Hampole Beds’ in Smith (1995, fig. 4.23), but the relationship of the Hampole beds to the Wetherby-Sprotbrough boundary is problematic. The base of the Sprotbrough Member is defined by the “top of the lower dolomite bed of the Hampole beds (Smith 1968), or the Hampole Discontinuity where the lower dolomite bed is absent” (Smith et al. 1986). However, they remarked that the top of the Wetherby Member is “... not readily distinguishable where Hampole Beds are absent or atypical...”, and there are several features of the Cadeby Formation in Cadeby Quarry that are atypical, including the structure and spatial distribution the patch-reefs of the Wetherby Member, the thickness and lithological variation of the Hampole beds, and the unusual high relief on the Hampole discontinuity (Smith 1995). Further, the lower dolomite bed of the Hampole beds is not present at Cadeby, although its position is inferred on the geological section of Smith (1995, fig. 4.23). Despite their importance in subdividing the Cadeby Formation the Hampole beds remain an informal, undefined lithostratigraphical unit. As mentioned above, it is poor practice to have a lithostratigraphical unit (in this case beds) that transcends the boundary of higher status units (members). It may thus seem inadvisable to attempt to identify the position of the Wetherby-Sprotbrough member boundary in the section, although several factors can be considered:

Regionally, patch reefs are restricted to the Wetherby Member suggesting, *de facto*, that the reefs on either side of the section, and the bedded units at the very base of the logged section belong to the Wetherby Member.

Thin and regionally impersistent silicilastic claystones units are known in the upper part of the Wetherby Member below the level of the Hampole beds (Smith 1995), being “abundant” in Cadeby Quarry (Smith 1968). These, though, are described as being in some way readily distinguishable from the mudstones of the Hampole beds (Smith 1968). Ramsdale (2022) recorded two claystone units up to 20 cm thick approximately 2 m below the logged section at Cadeby. These can be traced laterally

for several tens of metres and are associated with prominent rippled surfaces of the underlying carbonate beds. He suggests that the base of these may represent the Hampole discontinuity. However, as these lie below the level of the patch-reefs, it is also possible that these lie within the Wetherby Member below the level of the discontinuity (compare Smith 1995, fig. 4.23);

The Hampole beds can be seen in the western part of the quarry (S.S.S.I. section) abutting against and overlying a patch-reef. Visual correlation into the northern part of the quarry shows that the position of the horizon of the base of these beds lies somewhat deeper than the measured section. This may suggest that there were several periods of mudstone input onto the carbonate shelf which resulted in more than one period of inundation of the patch-reefs by sediment.

At present the base of the Sprotbrough Member in the logged section has been drawn at the top of the patch-reefs, but this is open to revision. This is a purely lithostratigraphical approach, and would indicate marked local diachroneity of the Wetherby-Sprotbrough boundary. It ignores any temporal implications for the presence of the mudstone units or any associated disconformity surface (e.g. regionally synchronous effects of sea level change as suggested by Smith 1974) since it is clear that these cannot be consistently mapped, even over short distances in the quarry. A review of the lithostratigraphical subdivision of the Cadeby Formation is needed and the relationship of the Hampole beds to the boundary between the Wetherby and Sprotbrough members needs clarification. The situation in which Smith et al. (1986) defined lithostratigraphical units in relation to an informal, undefined unit (the Hampole beds) needs to be rectified. It is worth noting that separation of the two members of the Cadeby Formation is not usually made in borehole sections (e.g. Berridge et al. 1999). This may also be the case for Cadeby Quarry.

PREVIOUS BIOSTRATIGRAPHICAL STUDIES

Because of its dolomitised nature, little attention has been paid to the palynological analysis of material from the Cadeby Formation. Published studies are restricted to those by Wall & Downie (1963), Clarke (1965) and Gibson & Wellman

(2021), with very limited data or interpretations of individual samples in, for example Berridge et al. (1999, p. 31). An up to date summary of palynological work on the Lopingian throughout Britain is provided by Gibson & Wellman (2021).

An early Lopingian age for the Cadeby Formation is provided by lithological correlation of dated under- and overlying formations. The conodont *Mesogondolella britannica* is recorded from the underlying Marl Slate Formation (Swift & Aldridge 1986) while the conodont *Merrillina divergens* is known from the Werra Folge which is correlated with the overlying Hayton Anhydrite Formation. Thus the whole of the Don Group belongs in the early Lopingian *Merrillina divergens*-*Mesogondolella britannica* Biozone.

MATERIALS AND METHODS

The section was logged and sampled for palynology. The sampled mudstones are remarkably plastic and poorly lithified. Material was collected using a sharp knife to cut out clean blocks of claystone. For palynological preparation the samples were processed as standard in hydrochloric acid (HCl) and hydrofluoric acid (HF) and oxidised for 10 to 15 min. in Schulze's Reagent followed by treatment with potassium hydroxide (KOH) (Smith & Butterworth 1967; Wood et al. 1996). Residues were sieved between 10 µm and 180 µm, strewn-mounted on cover slips in polyvinyl alcohol (PVA) and mounted on microscope slides in Petropoxy.

Counts of one-hundred specimens were made for each sample and remaining areas of the cover slips were scanned to record accessory taxa. Data were recorded and range charts presented in Stratabugs™. The slides are stored at the British Geological Survey, Keyworth, Nottingham, NG12 5GG.

Palynology

The seventeen samples yielded organic residues including phytoclasts (black equant fragments, varying amounts of yellowish unstructured tissue and elongate woody fragments) and generally well-preserved palynomorphs (Fig. 5). Samples at 0.61 m, 0.68 m, and 1.11 m above the base of the section contain abundant cuticle fragments. Only samples at 0.11 m, 3.33 m and 4.31 m did not yield enough palynomorphs to achieve a count of 100 specimens.

Overall, the assemblages are dominated by taeniate and non-taeniate bisaccate pollen, including indeterminate palynomorphs of both types, *Klausipollenites schaubergeri*, *Limitisporites rectus*, *Lueckisporites virkeiae* and *Taeniaesporites noviaulensis*. The non taeniate bisaccate pollen *Alisporites nuthallensis* is common at the base of the section, as is *Limitisporites moersensis*. The probable spore *Perisaccus granulatus* is common between 1.00 m and 2.29 m. Other spores are extremely rare. A small number of microfossiliferous test linings occur in the lower part of the section at 1.25 m and 1.3 m. *Botryococcus* is recorded from the samples at 2.50 m and 2.89 m. Very rare spores reworked from Carboniferous rocks include *Densosporites sphaerotriangularis* and *Knoxisporites stephanophorus*.

Given the general uniformity of the assemblages through the section, it is not proposed to subdivide the section palynologically. However, the excellent preservation of the assemblages presents an opportunity to describe and illustrate some of the most important palynomorphs in the section, and to comment on matters of nomenclature and morphological variation. Bisaccate pollen are described and measured using the convention shown in Fig. 6.

SYSTEMATIC PALYNOLOGY

Genus *Klausipollenites* Jansonius, 1962

Type Species: *Klausipollenites schaubergeri* (Potonié & Klaus) Jansonius, 1962

Klausipollenites schaubergeri (Potonié & Klaus)
Jansonius, 1962

Plate 4, 3-11

Description. Pollen, bisaccate, bilaterally symmetrical, alete; amb haploxylonoid (although often preserved in lateral or oblique view when it has a phaseolate outline). Corpus distinct, latitudinal oval, large in comparison with the sacci. Cap-pa thick (1-2 µm), indistinctly columellate when viewed in oblique compression; finely reticulate in proximo-distal view; cappa exoexine difficult to distinguish from saccus exoexine. When viewed in lateral or oblique compression it can be seen that the thick columellate exoexine is absent in the cap-pula area and only intexine is present. Cappula oval in outline; width approximately 60% of the width

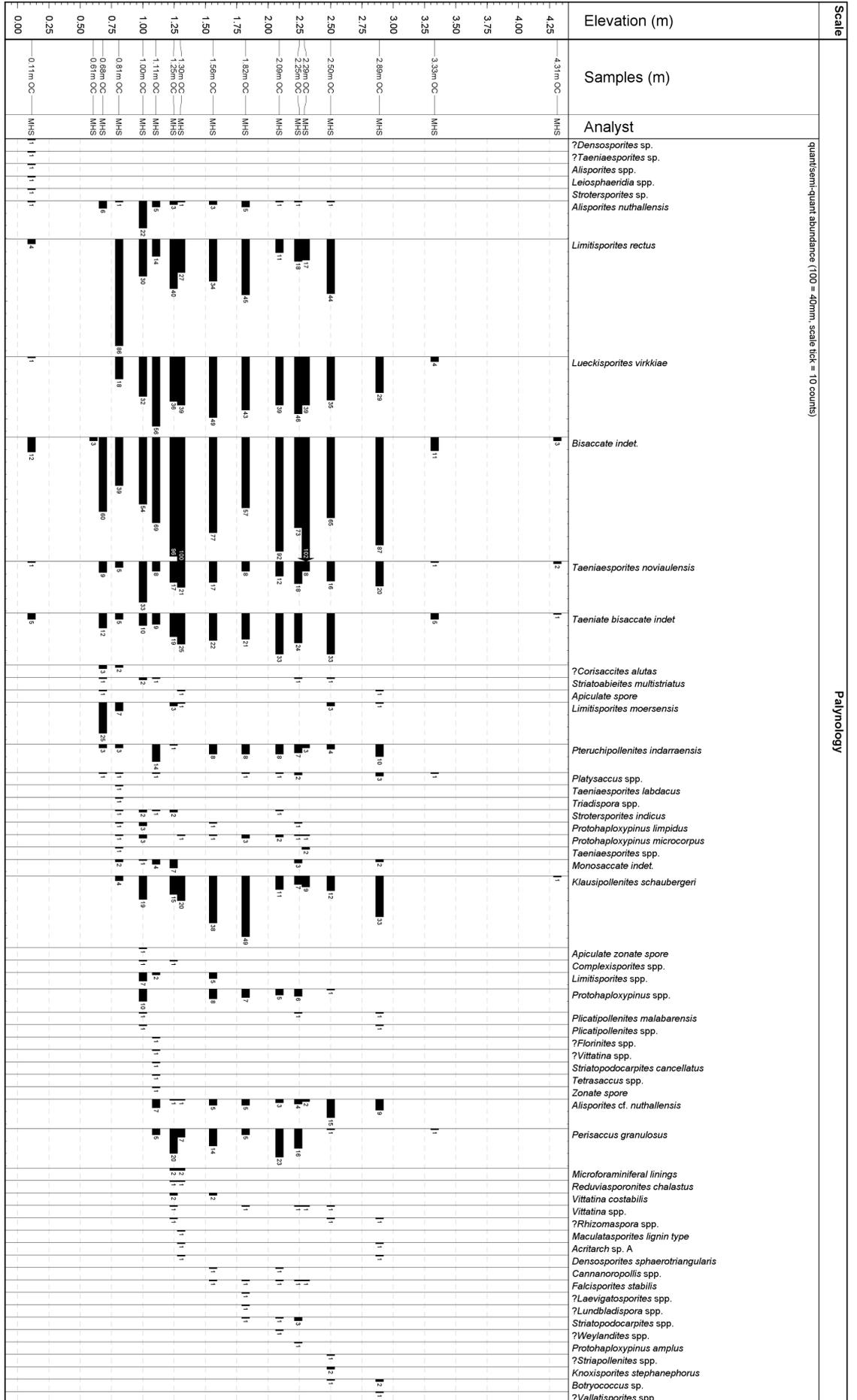
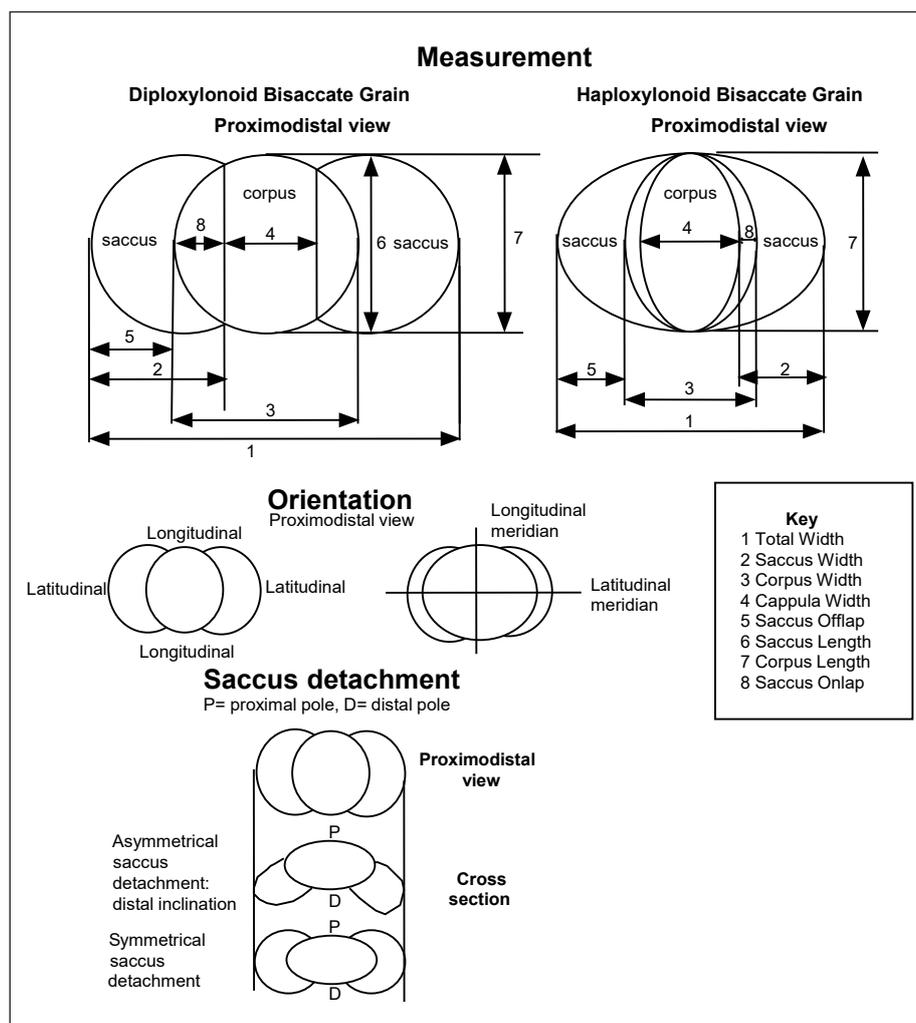


Fig. 5 - Quantitative palynology of the Cadeby section shown in Figure 4. Numbers on columns give the number of palynomorphs counted.

Fig. 6 - Convention for the measurement and description of bisaccate pollen.



of the corpus, extends 80% of the corpus length. Sacci distally inclined, proximal saccus detachment difficult to discern in proximo-distal view due to the indistinct nature of the proximal cappa/saccus boundary, but clearly equatorial in lateral view; distal saccus detachment 4-8 μm in from the distal corpus margin. Sacci small (<40% of the corpus size), outline in lateral view semi-circular; outline in proximo-distal view narrow crescentic. Infrareticulation of the sacci appears to be fine; brochi diameter <1 μm .

Dimensions. Total width 44(49)70 μm ; total length 29(33)45 μm ; sacci length 23(25)27 μm ; corpus width 30(31)33 μm ; saccus offlap 6(7)9 μm ; saccus onlap 4(6)8 μm ; 30 specimens.

Remarks. Amongst non-taeniate bisaccate pollen, *Klausipollenites schanbergeri* is one of the most distinctive forms due to its rigid appearance with a lack of folding, well developed small sacci, and haploxytonoid outline.

The present specimens are comparable in size to those described by Balme (1970) (51(61)72 μm) and Klaus (1963) (25-70 μm). The specimens have a distinctive, slightly columellate cappa similar to those described and figured by Balme (1970, pl. 16, figs. 2-5) and Grebe & Schweitzer (1964; pl. 10, figs. 7-9). Specimens in oblique compression (e.g. Pl. 4, Fig. 6, 11) display this columellate structure particularly well (see also Klaus 1963, pl. 19, fig. 93; Balme 1970, pl. 16, fig. 1).

Klausipollenites staplinii Jansonius, 1962 differs from the present species in lacking connection of the sacci along the equatorial margin of the corpus. Other species of *Klausipollenites* described by Jansonius (1962) are larger than the present species.

Previous records. For Euramerican previous records of this species see Klaus (1963, p. 335) and Gomankov (1992, p. 1016). For a discussion of the occurrence of the species outside Europe see Balme (1970; p. 386).

Taeniaesporites Leschik 1955 emend. Klaus, 1963

Type species: *Taeniaesporites kraeuseli* Leschik, 1955

Limitisporites Leschik, 1955, p. 56-57.

Remarks. The genus *Taeniaesporites* is retained here in agreement with Balme (1970), and is, as Balme suggested, one of the most distinctive of the taeniatae bisaccate pollen having four or five well-developed infrareticulate taeniae with deep clefts between the taeniae revealing smooth thick intexine in the floor of the cleft. The combined thickness of the intexine and exoexine often gives the corpus a rather dark overall colour. The main species recorded in Britain appear to be *Taeniaesporites alatus* Klaus, 1963 (haploxylo-noid, wide clefts between taeniae), *T. albertae* Jansonius, 1962 (haploxylo-noid with large saccus onlap), *T. bilobus* Clarke, 1965 (strongly diploxylo-noid with large sacci), *T. labdacus* Klaus, 1963 (strongly diploxylo-noid with sacci similar in size to the corpus, and with the central pair of taeniae better developed than the outer taeniae), and *T. noviaulensis* Leschik, 1956 (haploxylo-noid to slightly diploxylo-noid with four well-developed, equally spaced taeniae of equal size).

The holotype and other specimens of *T. pel-lucidus* (Goubin) Balme, 1970 figured by Goubin (1965, pl. 2, figs. 4-6) appear to have more than four taeniae and as many as six, as well as a rather light-coloured corpus and thin taeniae more in keeping with *Protobaploxylinus*. A number of other species of *Taeniaesporites* are in common use e.g. *T. angulistriatus* (Klaus) Clarke, 1965, *T. novimundi* Jansonius, 1962, *T. nubilus* (Leschik) Clarke, 1965, *T. ortisei* Klaus, 1963, *T. samoilovichii pantii* Klaus, 1963, and *T. transversundatus* Jansonius, 1962. Differences between these appear rather minor, suggesting that a re-appraisal of *Taeniaesporites* may be required. This would be best achieved by reference to the type material.

Taeniaesporites noviaulensis Leschik, 1956

Plate 1, 1-9; Plate 2, 9-10; Plate 3, 2-6

Description. Pollen, bisaccate, bilaterally symmetrical, taeniatae; amb haploxylo-noid to slightly diploxylo-noid. Corpus distinct, oval, dark in colour; intexine 1-2 μm thick; corpus often with monolete mark. Cappula sometimes indistinct due to opacity of corpus, width approximately 25%-50% of the

width of the corpus. Cappula parallel-sided. Cappa with four taeniae (4-6 μm wide) with clefts 3-10 μm wide in between; clefts floored by intexine. Central cleft sometimes up to 12 μm wide; monolete mark occurs in the intexine in the centre of the cleft. Saccus distally inclined; proximal saccus detachment equatorial, distal saccus detachment 15-30 μm in from the distal margin. Sacci outline semi-circular, similar in size to the corpus; sacci appear rigid.

Dimensions. Total width 60 (87)110 μm ; saccus length 49(56)65 μm ; corpus length 42(45)49 μm ; corpus width 45(58)75 μm ; saccus offlap 9(17)18 μm ; saccus onlap 15(30)31 μm ; 10 specimens.

Previous records. Extensive synonymy and previous records of this species are provided by Foster (1979, p. 83-84).

Lueckisporites Potonié & Klaus, 1954

Type Species: *Lueckisporites virkkiae* Potonié & Klaus, 1954

Synonym: *Dicappipollenites* Tiwari & Vijaya, 1995, p. 84-93, text-fig 12; A, B.

Remarks. Several 'Gondwana' species previously assigned to *Lueckisporites* including *Lueckisporites singhii* Balme, 1970 and *Lueckisporites nyakapendensis* Hart, 1960, were recombined with *Dicappipollenites*

PLATE 1

Specimens indicated first by England Finder code and slide code for which see Fig. 4.

- 1) *Taeniaesporites noviaulensis*, E35, 03, focus on taeniae;
- 2) *Taeniaesporites noviaulensis*, E35, 03, focus on saccus attachment;
- 3) *Alisporites nuthallensis*, D41, 03;
- 4) *Taeniaesporites noviaulensis*, D35, 03, focus on taeniae;
- 5) *Taeniaesporites noviaulensis*, D35, 03, focus on distal folds associated with saccus;
- 6) *Taeniaesporites noviaulensis*, P40, 03;
- 7) *Taeniaesporites noviaulensis*, P41/1, 03, focus on saccus detachment;
- 8) *Taeniaesporites noviaulensis*, P41/1, 03, focus on taeniae;
- 9) *Taeniaesporites noviaulensis*, M39/3, 03;
- 10) *Lueckisporites virkkiae* (variant A), P28/3, 03, corpus intexine focus;
- 11) *Lueckisporites virkkiae* (variant A), P28/3, 03, saccus detachment focus;
- 12) *Lueckisporites virkkiae* (variant A), P28/3, 03, distal focus;
- 13) *Limitisporites rectus*, H41/1, 03;
- 14) *Limitisporites* sp., D27/4, 03;
- 15) *Lueckisporites virkkiae* (variant A), V28/1, 04, focus on taeniae.

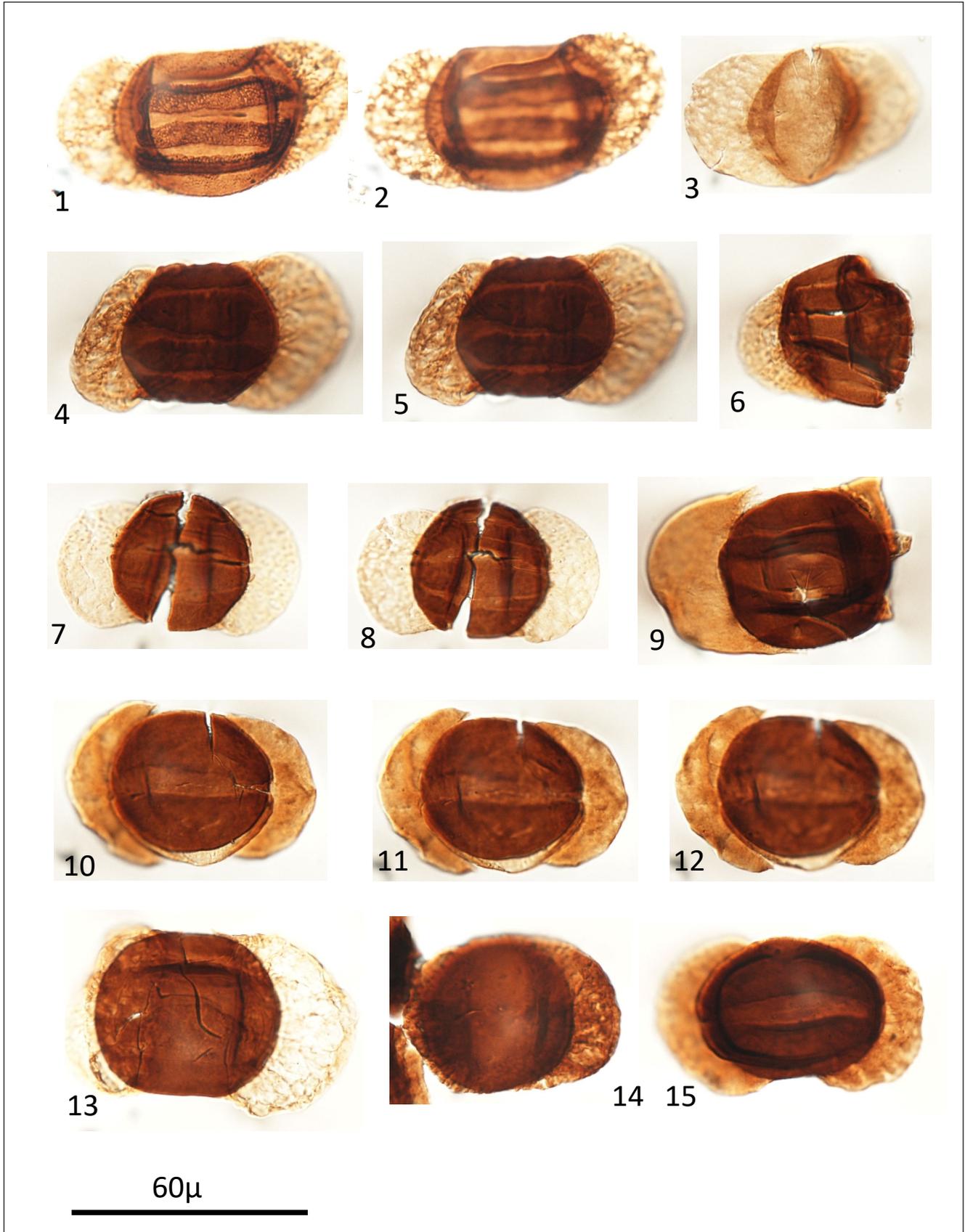


PLATE 1

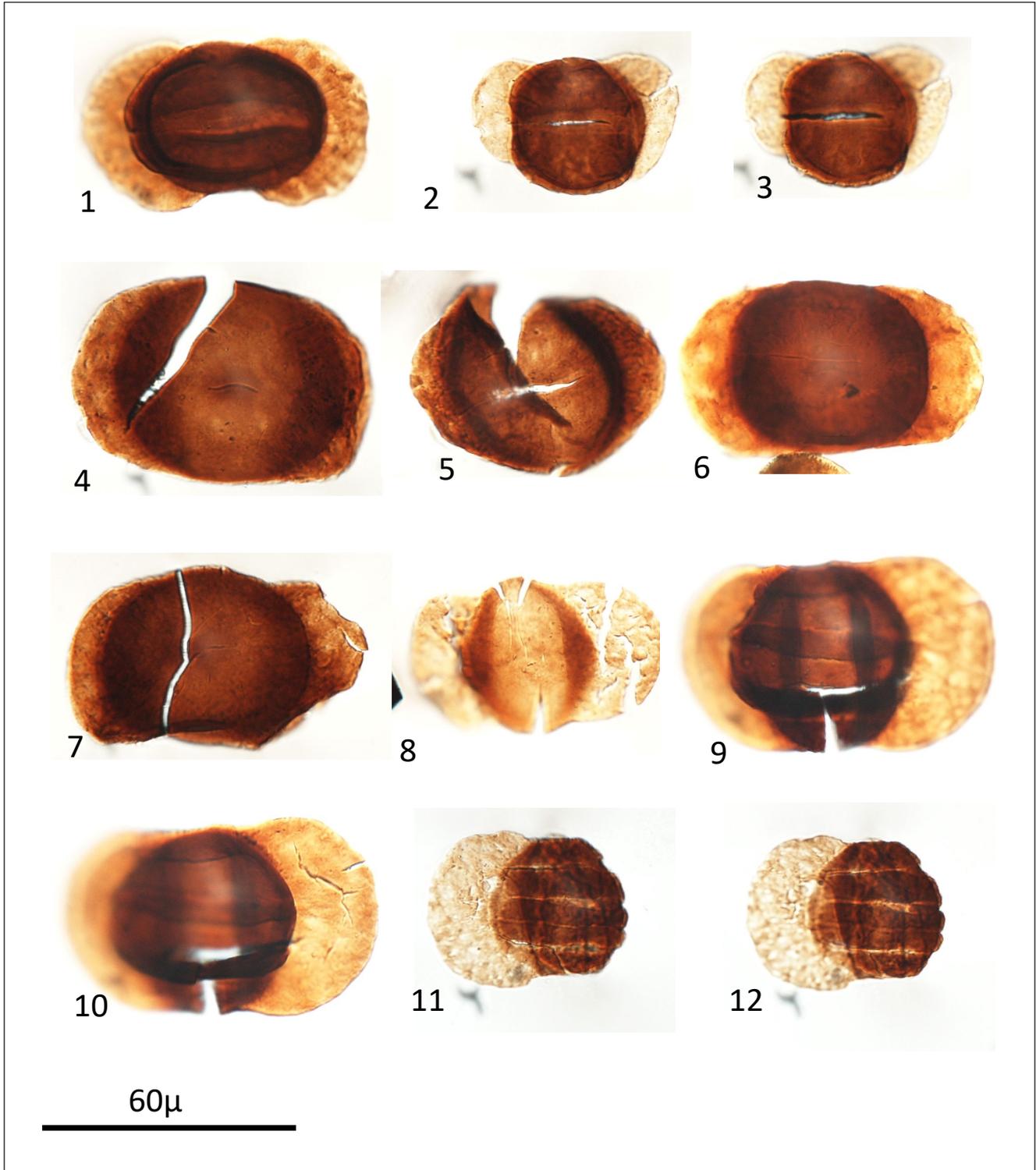


PLATE 2

- 1) *Lueckisporites virkkiaae*, V28/1, 04, distal focus; 2) *Lueckisporites virkkiaae*, R38, 04, distal focus; 3) *Lueckisporites virkkiaae*, R38, 04, focus on taeniae; 4), *Limitisporites rectus* V42/2, 04; 5), *Limitisporites rectus*, R43, 04; 6) *Limitisporites rectus*, L32, 04; 7) *Limitisporites rectus*, L32, 04; 8) *Alisporites nuthalensis*, R44, 04; 9) *Taeniaesporites novianlensis*, R34/1, 04, focus on taeniae; 10) *Taeniaesporites novianlensis*, R34/1, 04, distal focus; 11) *Taeniaesporites labdacus*, P42, 04, distal focus; 12) *Taeniaesporites labdacus*, P42, 04, focus on taeniae.

by Tiwari & Vijaya (1995). The main reason for this was to establish the unique character of certain Gondwana taxa and to stress the inappropriate use of the mainly Euramerican genera to which these taxa had been previously assigned. While it is clearly important to be aware of the phytogeographical influences on taxonomy, the present authors believe that form taxa should not be differentiated on phytogeographical grounds.

Dicappipollenites is purportedly distinguished from *Lueckisporites* by its lack of a monolete mark and its less well-developed and differently structured taeniae. Tiwari & Vijaya (1995) designated *Dicappipollenites crassus* (basonym *Lueckisporites crassus* Sinha, 1972) as the type species of their genus. The holotype of the type species (Sinha 1972. pl. 5, fig. 63) is indeed alete but this appears to be because the intexine is absent (possibly as a result of over-maceration). A paratype of *L. crassus* (Sinha, 1972. pl. 5, fig. 64) seems to display a monolete mark and intact intexine. As other differences advocated by Tiwari & Vijaya (1995) are explicable in terms of differing processing techniques, *Dicappipollenites* is here considered a subjective junior synonym of *Lueckisporites*.

***Lueckisporites virkkiae* Potonié & Klaus emend.**

Clarke, 1965

Plate 1, 1, 10-12, 15; Plate 2, 1-3; Plate 3, 9, 11-13

Description. Pollen, bisaccate, bilaterally symmetrical, monolete, bitaeniate; amb variably diploxylo-noid (variants A and C of Clarke 1965) to haploxylo-noid (variant B of Clarke 1965). Corpus slightly latitudinally oval; intexine thick, smooth; cappa with two reniform taeniae made of expanded exoexine. Cappula distinct, width approximately 25-50% of the width of the corpus; occasionally delimited by poorly developed, subparallel, distal, intexinal folds. Cappa bitaeniate; taeniae with variable internal structure, either infrareticulate, unstructured, or internally columellate with a surface tectum (*sensu* Visscher 1971); taeniae up to 5 µm thick in section (sectional view often apparent at the margin of the corpus), taeniae cover most of the cappa apart from the medial cleft. Medial cleft extends the width of the corpus. Proximal saccus detachment equatorial; distal saccus detachment occurs approximately 10 µm in from the margin of the corpus. Sacci distally inclined; sacci outline

semi-circular; sacci vary in size from approximately half the size of the corpus to equal in size to the corpus. Saccus infrareticulation occasionally obscured by opaque saccus surface; when visible infrareticulation is coarse (brochi diameter 1-2 µm). Monolete mark usually present, occurs in the intexinal floor of the medial cleft; mark extends approximately 50% of the width of the corpus.

Dimensions. Total width 44(60)76 µm; saccus length 23(37)45 µm; corpus width 30(38)45 µm; corpus length 22(33)40 µm; saccus offlap 6(11)17 µm; saccus onlap 7(10)20 µm; 20 specimens.

Remarks. The population of specimens assigned to *L. virkkiae* shows a high degree of variability, mainly in the diploxylo-noid or haploxylo-noid outline and the taeniae thickness in section i.e. how much the taeniae project from the cappa. Nevertheless, the specimens are encompassed by “norms” A and B of Visscher (1971) and variants A, B and C of Clarke (1965). The diploxylo-noid forms (norm A and variants A and C) are by far the most common in the present assemblages while the haploxylo-noid form (norm B, variant B) is rare. Gibson et al. (2020) studied the full range of morphology in *L. virkkiae* from the Cadeby Formation at Kimberley in Nottinghamshire, UK in a sequence that corresponds to sample K5 of Clarke (1965). They found that similarities in gross structure and wall ultrastructure suggest that the taxonomic grouping of variants suggested by Clarke (1965) is correct. The variants represent the range of morphological development within a single species. They also suggested that the differences in morphology are subtle and attributable to harmomegarthy. Thus the name *L. virkkiae* is retained for “norms” A and B of Visscher (1971) and variants A, B and C of Clarke (1965). It also seems likely, as suggested by Clarke (1965), that *L. microgranulatus* Klaus, 1963, *L. globosus* Klaus, 1963 and *L. parvus* Klaus, 1963 fall within the circumscription of *L. virkkiae*.

Specimens of the strongly haploxylo-noid species *Corisaccites alutas* Venkatachala & Kar, 1966 are superficially similar to *L. virkkiae* variant B. *C. alutas* is distinct in having sacci that appear rigid, robust, dark in colour, often ‘leathery’ and structureless. In *C. alutas*, the sacci are similar in structure and appearance to the two halves of the cappa. *C. alutas* appears to lack a medial cleft between the two proximal halves of the cappa, and has a Cisuralian first appearance (see review in Stephenson 2008).

Previous records. For Euramerican records of this species see Molin et al. (1986, p. 2), Ouyang & Utting (1990, p. 95), Utting et al. (1997, p. 5), Koloda & Kanev (1996, p. 20), Visscher (1980, p. 238-239), Visscher & Brugman (1986, p. 126), Warrington (in Smith et al. 1974, p. 37), and Spina et al. (2015)

Lueckisporites virkkiae has a well-established first occurrence in the lower part of the Kazanian (Roadian) in its type area in the Russian Platform and is considered a useful marker for the approximate base of the Guadalupian across Euramerica (e.g. Utting et al. 1997; Warrington 1996; Stephenson 2015, 2016).

Limitisporites Leschik emend. Klaus, 1963

Type Species: *Limitisporites rectus* Leschik, 1956

Remarks. Grebe & Schweitzer (1964) described *in situ* pollen grains from *Ullmania frumentaria* (Schlotheim) Göppert, 1850. These are similar to *Limitisporites* but include monolete, dilete and trilete forms. This finding shows the artificiality of the distinction made by Leschik (1956) between *Limitisporites* (diagnosed as essentially monolete) and *Jugasporites* Leschik, 1956 (essentially dilete). Klaus (1963) showed the two genera to be separable on the basis of the distribution of cappa exoexine rather than haptotypic features. *Limitisporites* Leschik was emended to include grains with intact cappa exoexine. *Jugasporites* was rediagnosed as having a proximal circumpolar area surrounding the haptotypic mark, in which exoexine is strongly reduced to completely lacking. Foster (1983) suggested that a diagnostic feature of *Jugasporites* is an exoexinal operculum covering the proximal intexinal haptotypic mark, and when detached a smooth area of intexine is exposed. Specimens of this type were not observed in the present assemblages. Klaus (1963) used *Illinites* (Kosanke) Potonié & Kremp, 1954 to include forms differentiated from *Jugasporites* and *Limitisporites* largely on the basis of the haptotypic features. However, Foster (1983) retained the original concept of *Illinites* Kosanke, 1950 (based on the nature of the genotype, *I. unicus* Kosanke, 1950) to only include taeniate forms. When applied in this way, *Illinites* is readily distinguished from *Jugasporites* and *Limitisporites*.

Limitisporites rectus Leschik, 1956

Plate 1, 13, Plate 2, 4-7, Plate 3, 7

Description. Pollen bilaterally symmetrical, bisaccate, monolete to dilete; amb slightly diploxylonoid. Intexinal body latitudinally oval, circular or rarely longitudinally oval; intexine 1-2 μm thick and relatively dark coloured; laevigate to very finely microreticulate; occasionally indistinctly striated. Occasional irregularly shaped areas of expanded infrareticulate exoexine occur on the cappa. Cappula distinct; width 60% of corpus width; length equal to that of corpus. Commonly a pair of distal intexinal folds mark the cappula margins. Proximal saccus detachment equatorial, distal saccus detachment subequatorial; sacchi distally inclined. Saccus shape lunate to semicircular, rigid with generally small saccus offlap; sacchi connected via narrow sacchi connections of expanded exoexine at the longitudinal margins of the corpus. Saccus infrareticulation coarse; brochi large, approximately 1-2 μm diameter; brochi radially arranged close to the corpus. Monolete mark distinct, 50-80% of corpus width.

Dimensions. Total width 65(80)96 μm ; total length 50(56)69 μm ; corpus width 52(54)62 μm ; corpus length 44(52)68 μm ; saccus offlap 17(20)22 μm ; saccus onlap 10(15)20 μm ; 6 specimens.

Previous records. Gondwana, Permian (e.g. Foster 1979, Lindström 1995); Euramerica, Late Permian (e.g. Leschik 1956, Klaus 1963); India, Early Permian (Lele & Karim 1971).

PLATE 3

- 1) *Taeniaesporites* cf. *noviaulensis*, K35, 05;
- 2) *Taeniaesporites noviaulensis*, F32/1, 05, focus on cappa intexine;
- 3) *Taeniaesporites noviaulensis*, F32/1, 05, focus on taeniae;
- 4) *Taeniaesporites noviaulensis*, H31, 05;
- 5) *Taeniaesporites noviaulensis*, F37/2, 05;
- 6) *Taeniaesporites noviaulensis*, D46/3, 05;
- 7) *Limitisporites rectus*, S36, 05;
- 8) *Limitisporites moersensis*, F46/2, 05;
- 9) *Lueckisporites virkkiae* (variant A), C36/1, 05;
- 10) *Alisporites nuthallensis*, C37/2, 05;
- 11) *Lueckisporites virkkiae* (variant B), L32, 05;
- 12) *Lueckisporites virkkiae* variant with narrow taeniae, P39, 05;
- 13) *Lueckisporites virkkiae* (variant C), N42, 05;
- 14) *Protobaploxypinus microcorpus*, U45, 05.

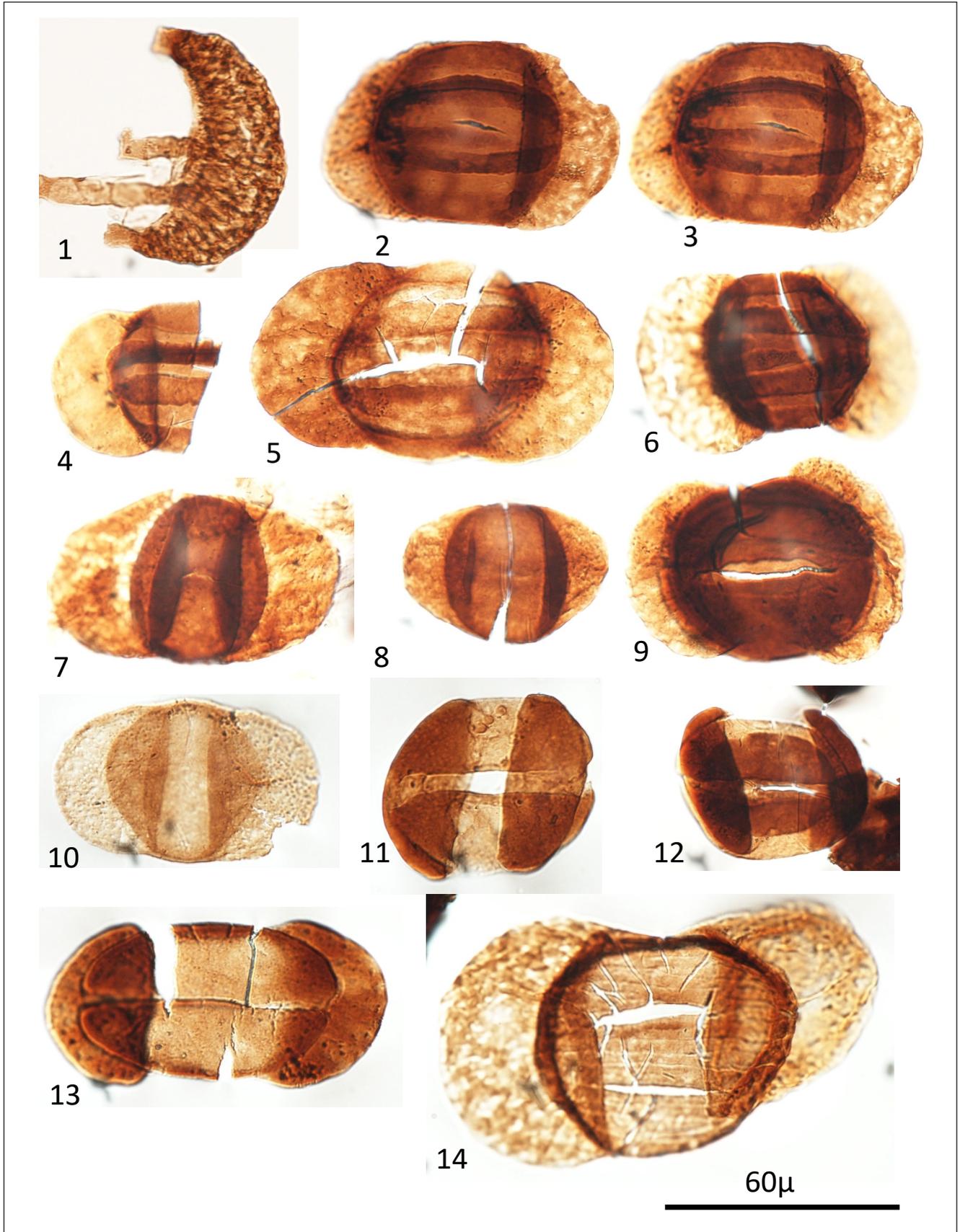


PLATE 3

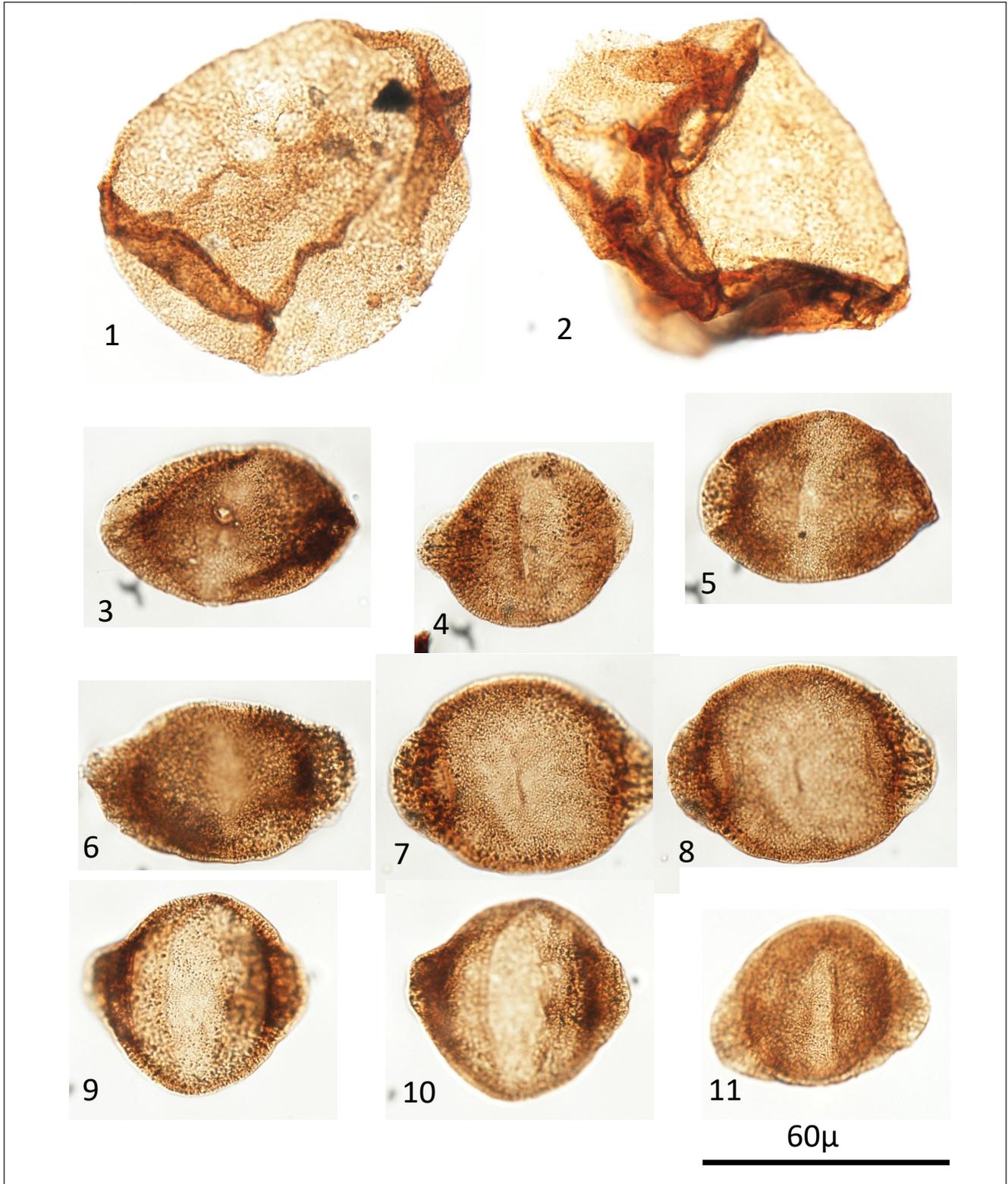


PLATE 4

1) *Perisaccus granulatus*, H39, 07; 2) *Perisaccus granulatus*, E30/3, 07; 3) *Klausipollenites schaubergeri*, H38, 07; 4) *Klausipollenites schaubergeri*, H40, 07; 5) *Klausipollenites schaubergeri*, H43/1, 07; 6) *Klausipollenites schaubergeri*, F42/4, 07; 7) *Klausipollenites schaubergeri*, D34/1, 07, proximal focus; 8) *Klausipollenites schaubergeri*, D34/1, 07, distal focus; 9) *Klausipollenites schaubergeri*, D37/1, 07, proximal focus; 10) *Klausipollenites schaubergeri*, D37/1, 07, distal focus; 11) *Klausipollenites schaubergeri*, C48/3, 07.

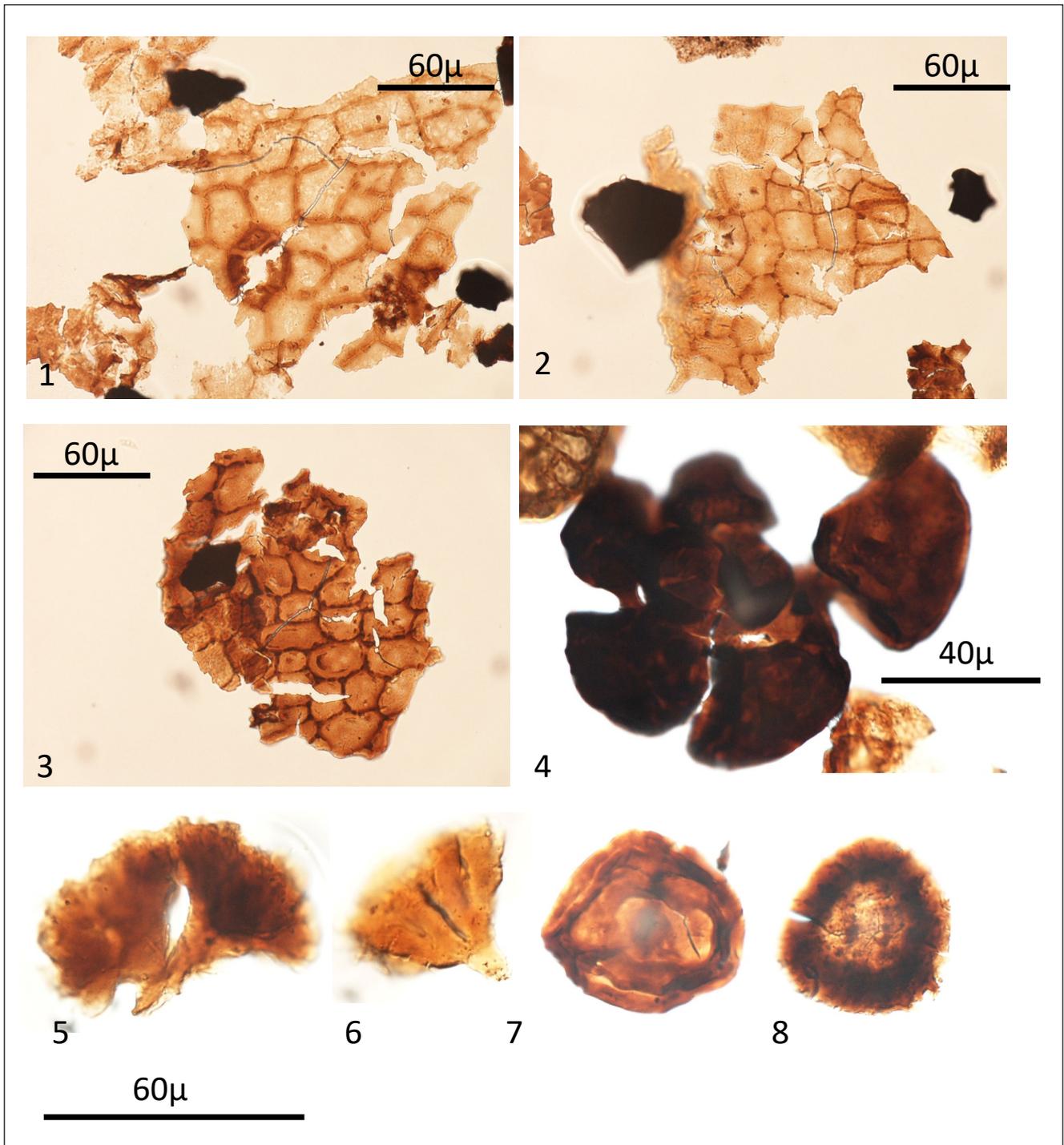


PLATE 5

1-3) cuticle, 1, E31, 03; 2, E26/4, 03; 3, H42, 03; 4) microforaminiferal test lining, D41/1, 07; 5) *Botryococcus* sp. M38/1, 15; 6) *Botryococcus* sp. N32/3, 15; 7) *Knoxisporites* cf. *stephanephorus* Love, 1960, E41/3, 14; 8) *Densosporites sphaerotriangularis* Kosanke, 1950, M32/1, 08.

***Limitisporites moersensis* (Grebe) Klaus, 1963**

Plate 3, 8

Description. Pollen, bilaterally symmetrical, bisaccate tending to monosaccate; amb oval to spindle-shaped haploxytonoid. Corpus longitudinally

oval, dark in colour; intexine relatively thick (1 µm). Cappula 70% of the corpus width. Proximal saccus detachment equatorial; distal saccus detachment subequatorial. Sacci distally inclined; crescentic in outline; smaller than the corpus; relatively rigid; infrareticulation coarse (brochi 1-2 µm in diameter).

Cappa with distinct trilete or dilete mark; length of mark variable.

Dimensions. Total width 55 µm; total length 35 µm; corpus width 35 µm; corpus length 35 µm; saccus offlap 15 µm; saccus onlap 7 µm; saccus length 30 µm; 1 specimen.

Remarks. Similar to *L. rectus* but smaller, with a proportionately larger corpus, and an amb which is oval to spindle-shaped haploxytonoid.

COMPARISON WITH OTHER STUDIES OF THE PERMIAN ZECHSTEIN SUCCESSION

Palynomorph assemblages have been described from the Bakevillia province of north west England and Ireland (Clarke 1965; Warrington 2008; Visscher 1971), from the Zechstein province of the English Midlands and the north east of England (Clarke 1965; Gibson & Wellman 2021), and from south west England (Warrington & Scrivener 1988).

Assemblages from the Hilton plant beds in the Eden Shales Formation contain common *Lueckisporites virkkiae*, *Taeniaesporites* spp., and *Klausipollenites schaubergeri* (Clarke 1965). Warrington (2008) described assemblages from 120 to 230 m depth in the Hilton Borehole within the Penrith Sandstone and Eden Shales formations (including the Hilton plant beds) recording mainly bisaccate pollen, some monosaccate pollen and a few pteridophytic spores. The most common pollen recorded was *Lueckisporites virkkiae*, though species of *Lunatisporites* (= *Taeniaesporites*) and *Klausipollenites schaubergeri* were also common throughout the borehole. *Perisaccus granulatus* was particularly common in the Hilton plant beds. There appeared to be no strong palynological trends through the extent of the studied part of the Hilton Borehole.

In the English Midlands Clarke (1965) described assemblages from the Kimberley Railway Cutting and the Haughton Hall Borehole, Nottinghamshire dominated by *Lueckisporites virkkiae* and species of *Taeniaesporites*, and also containing *Klausipollenites schaubergeri*, *Falcisporites zapfei*, *Labisporites granulatus* and *Illinites delasaucei*. A small number of monosaccate pollen were also recorded including *Potonieisporites novicus* and *Nuskoisporites dulhuntyi*. *Perisaccus granulatus* was also present.

The most comprehensive review of UK Zechstein palynology in the midlands and north east

of England was by Gibson & Wellman (2021). They described palynomorph assemblages from the English Zechstein evaporation-replenishment cycles (EZ1 to EZ5). These assemblages are dominated by pollen grains, with rare trilete spores, and even rarer acritarchs and microforaminiferal test linings. The assemblages of pollen grains reported are of low diversity (up to 35 species) and dominated by taeniate and non-taeniate bisaccate pollen. The composition of assemblages remains little changed, both within and between Zechstein cycles, being dominated throughout by *Lueckisporites virkkiae*, *Taeniaesporites* spp. and *Klausipollenites schaubergeri*. As might be expected given the stratigraphic position of the Cadeby Formation (mid EZ1) at Cadeby Quarry, the present assemblages are similar to those described by Gibson & Wellman (2021) from the Marl Slate Formation (lower EZ1) of the Durham Sub-basin at Claxheugh Rock and Crime Rigg Quarry. Those from Claxheugh Rock were dominated by taeniate bisaccate pollen *Lueckisporites virkkiae* (31.5%), *Protobaploxylinus* sp. (1.0%), *Taeniaesporites* sp. (17.0%), but also contained *Vittatina hiltonensis*, *Alisporites nuthallensis* and *Klausipollenites schaubergeri*. Those from Crime Rigg Quarry were also dominated by *Lueckisporites virkkiae* (43.5%), *Protobaploxylinus* sp. (2.5%), *Taeniaesporites* sp. (28%), *Klausipollenites schaubergeri* (8.0%) and *Illinites* sp. (7.0%). Gibson & Wellman (2021) also reported mid EZ1 Yorkshire Sub-basin assemblages from the Cadeby Formation exposure in Kimberley railway cutting, Salterford Farm Borehole, and Woolsthorpe Bridge Borehole with similar proportions of *Lueckisporites virkkiae*, *Taeniaesporites* spp. and *Klausipollenites schaubergeri* to those in the Marl Slate Formation. Overall there are few differences between the assemblages from Cadeby Quarry and those from elsewhere within cycle EZ1 (Clarke 1965; Warrington 2008; Gibson & Wellman 2021). Apparent differences can be explained by different taxonomic approaches. For example the pollen assigned to *Limitisporites* in this study are likely identical to those assigned to *Illinites* and *Jugasporites* in other studies (see comments on *Limitisporites*). Similarly, specimens assigned by Warrington (2008) to *Lunatisporites* are likely identical to those here assigned to *Taeniaesporites* (see comments on *Taeniaesporites*).

Palynomorphs in Permian rocks of southwest England are sparse and poorly preserved, however

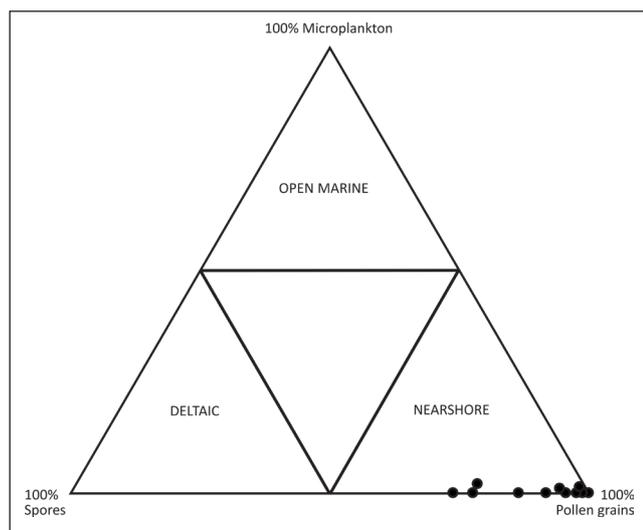


Fig. 7 - Microplankton/spore/pollen ternary plot for the Cadeby assemblages

Warrington & Scrivener (1988) described them from cores from the upper part of the Whipton Formation which yielded poorly preserved bisaccate pollen including *Lueckisporites virkkiae*, *Perisaccus granulatus*, *Klausipollenites schaubergeri*, *Jugasporites delauscei*, *Protobaploxypinus microcorpus* and *Lunatisporites* spp.

PALEOENVIRONMENTS

Palynological assemblages from the sampled clastic material in the Cadeby Formation are dominated by terrestrially derived material: tracheophyte phytoclasts; bisaccate pollen of pteridosperms (seed ferns); and pinophytes (conifers) (see Gibson & Wellman 2021, table 1 for palaeobotanical affinities of palynomorph taxa). However, the presence of rare microphytoplankton and microforaminiferal test linings indicates that this material is allochthonous, deposited in a marine environment. This is in keeping with the general paleoenvironmental interpretation for the formation (Smith 1968, 1974, 1995). The palynomorph assemblages are dominated by bisaccate pollen. Rare (usually <1%) trilete miospores are recorded but several of these are considered to represent material reworked from Carboniferous strata. *Perisaccus granulatus* (of unknown botanical affinity) is the only non-infraticulate saccate Permian form that occurs in any number in the assemblages, reaching 16 to 20% in some samples (Fig. 5). The bisaccate pollen-domi-

nated assemblages plot in the “nearshore” field on the microplankton/spore/pollen ternary plot for marine total palynomorph assemblages of Fedorova (1977) and Düringer & Doubinger (1985) (Fig. 7). The organic component of the samples is thus largely derived along with the clastic load by fluvial transport into a nearshore marine environment. The green alga *Botryococcus* is recorded from samples at 2.50 m and 2.89 m. This is an indicator of oligotrophic freshwater to brackish lake environments (Guy-Ohlsen 1992). Its presence suggests the existence of standing bodies of water in the source area for the allochthonous material. *Reduviasporonites* is recorded from samples at 1.25 m and 1.30 m. The affinity of this form is disputed (e.g. Foster et al. 2002). Warrington (2008) and Gibson & Wellman (2021), who also recovered *Reduviasporonites* from the Cadeby Formation, considered it to represent brackish environments in the British Lopingian.

With the exception of the interval of the Hampole beds, clastic sediment is scarce (but not absent) throughout the sequence of the Cadeby Formation in all parts of northeastern England from the western limit of the Permian outcrop, eastwards into the subsurface. This indicates that there was little clastic sediment supply into the basin and the lack of clastic material cannot be explained by sediment bypass. Stratigraphical intervals with increased clastic (and organic) content thus represent particular periods when erosion and transport of material from the hinterland took place. They most likely represent intervals of higher terrestrial runoff, reflecting wetter climatic periods. In a classic sequence stratigraphic model this would be interpreted as representing a eustatic lowstand reflecting a (palaeoequatorial and palaeotemperate) pluvial period that is time equivalent to a (palaeopolar) glacial period. Models (e.g. Matthews & Perlmutter 1994) implicate increased terrestrial runoff during pluvials in providing increased clastic input during eustatic lowstands. Tucker (1991) identified a type 2 sequence boundary associated with the Hampole Beds. This is consistent with observations in the Cadeby section where the clastic strata are interbedded with carbonates, suggesting that marine conditions suitable for carbonate deposition were not fully interrupted. Cessation of carbonate deposition reflects increased input of fine-grained terrestrial material into a marine system rather than subaerial exposure. Carbonate

beds 1 and 3 at the base of the section (Fig. 4) are laterally continuous with the bryozoan patch reef to the North (right hand side of Fig. 3). The clastic claystone between (Bed 2) runs into nodular dolostones within the reef. Beds 4 to 25 all pinch out against the reef indicating that their formation post-dates the reef. Beds 25 to 27 thin towards the reef but continue over it, and the thicknesses of all higher beds are not affected by the presence of the reef. The bedding plane at the base of Bed 4 is thus time-equivalent to the sides and top of the reef and represents about 110 cm of topography. There is no evidence for erosion or karst associated with this topography and elsewhere in Cadeby Quarry the margins of patch reefs that are abutted by carbonates appear similar. Consequently the margins of the reef are considered to represent an original, non-erosional subaqueous feature that was subsequently infilled with sediment. The implication is that there was either a relatively low fall in sea level with a limited basinward shift in facies (type 2 sequence boundary) and/or that the change in facies represents climatically-driven increased terrestrial runoff with freshwater and clastic input resulting in cut-off of carbonate precipitation. The alternation of clastic and carbonate sedimentation in the section at Cadeby suggests some wet/dry palaeoclimatic cyclicity. Such cyclicity has already been postulated for the British Lopingian (Schweitzer 1986). In detail though, the relative effects of sea-level and climate are hard to disentangle, not least because of the difficulties in identifying the exact position of the Hampole disconformity at Cadeby and the precise relations of this to other, stratigraphically lower clastic intervals within the Wetherby Member.

REWORKED MATERIAL

The presence of Carboniferous miospores in the Cadeby samples indicates that some, at least, of the clastic material is derived from rocks of Carboniferous age. Mapping of regional facies and thickness variations (Peryt et al. 2010) indicates that the Lopingian strata thin rapidly to the West and the shoreline of the Zechstein Sea lay not far from the present day Permian outcrop (Fig. 1). Swift & Aldridge (1982) recorded Carboniferous and Devonian conodonts reworked into the Cadeby Formation in Nottinghamshire.

CONCLUSIONS

Seventeen samples from the Cadeby Formation yielded organic residues including phytoclasts, cuticle, unstructured tissue and generally well-preserved palynomorphs. The palynomorph assemblages are dominated by taeniate and non-taeniate bisaccate pollen including *Klausipollenites schaubergeri*, *Limitisporites rectus*, *Lueckisporites virkkiae* and *Taeniaesporites noviaulensis*. The assemblages are generally similar to those of others from the English Midlands described by Clarke (1965) from the Kimberley Railway Cutting and the Haughton Hall Borehole, Nottinghamshire. They are also similar to those described by Gibson & Wellman (2021) from the Marl Slate Formation (lower EZ1) of the Durham Sub-basin at Claxheugh Rock and Crime Rigg Quarry and to the mid EZ1 of the Salterford Farm Borehole and Woolthorpe Bridge Borehole with similar proportions of *Lueckisporites virkkiae*, *Taeniaesporites* spp. and *Klausipollenites schaubergeri*. The excellent preservation of the assemblages allowed the recognition that *Dicappipollenites* Tiwari & Vijaya 1995 is a junior synonym of *Lueckisporites* Potonié & Klaus emend. Clarke 1965. The palynological assemblages are consistent with an early Lopingian age suggested by conodonts of the *Merrillina divergens-Mesogondolella britannica* Biozone

The presence of rare microphytoplankton and microforaminiferal test linings indicate a near-shore marine environment. The clastic (and organic) content of the Cadeby Formation, part of a dominantly carbonate succession, may represent erosion and transport of material from the hinterland reflecting a wetter climatic period, though the alternation of clastic and carbonate sedimentation in the section at Cadeby suggests some wet/dry palaeoclimatic cyclicity. Such cyclicity has already been postulated for the British Lopingian (Schweitzer 1986).

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APPENDIX

List of species recorded

- Alisporites* cf. *nuthallensis* Clarke, 1965
Alisporites nuthallensis Clarke, 1965
Densosporites sphaerotriangularis Kosanke, 1950
Falcisporites stabilis Balme, 1970
Klausipollenites schanbergi (Potonié & Klaus) Jansonius, 1962
Knoxisporites cf. *stephanephorus* Love, 1960
Limitisporites moersensis (Grebe) Klaus, 1963
Limitisporites rectus Leschik, 1956
Lueckisporites virkkiaae Potonié & Klaus emend. Clarke, 1965
Perisaccus granulatus (Leschik) Clarke, 1965
Plicatipollenites malabarensis (Potonié & Sah) Foster, 1975
Protobaploxypinus amplus (Balme & Hennelly) Hart, 1964
Protobaploxypinus limpidus (Balme & Hennelly) Balme & Playford, 1967
Protobaploxypinus microcorpus (Schaarschmidt) Clarke, 1965
Pteruchipollenites indarraensis (Segroves) Foster, 1979
Reduviasporonites chalastus (Foster) Elsik, 1999
Striatoabieites multistriatus (Balme & Hennelly) Hart, 1964
Striatopodocarpites cancellatus (Balme & Hennelly) Hart, 1964
Strotersporites indicus Tivari, 1965
Taeniaesporites labdacus Klaus, 1963
Taeniaesporites noviaulensis Leschik, 1956
Vittatina costabilis Wilson, 1962

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