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PALYNOLOGY REPORT: THE HILTON BOREHOLE, CUMBRIA

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1. D. Millward (Project leader, ESB7190002601)
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3. British Geological Survey, biostratigraphy records

PALYNOLOGY REPORT: THE HILTON BOREHOLE, CUMBRIA

Requested by: D. Millward
Examination and determinations by: G. Warrington

Purpose:
Documentation of the palynomorph succession in the Hilton Borehole, Cumbria, to investigate its suitability as a local palynostratigraphic reference section and its relationship with other sections in the Bakevellia Province and elsewhere.

Summary:

Palynomorphs indicative of a Wuchiapingian, or possibly Changhsingian, (Late Permian, Lopingian) age have been recovered through a c.108m section comprising the highest beds currently assigned to the Penrith Sandstone, and the succeeding Eden Shales, from the Hilton Plant Beds to the Belah Dolomite, inclusive. The palynomorphs consist largely of miospores, principally bisaccate pollen; some monosaccate pollen and a few pteridophytic spores occur. Algal(?) remains occur, mainly in the Hilton Plant Beds and the Belah Dolomite.

Palynomorph assemblages similar to those from the Hilton Plant Beds have been recovered from samples from the highest part of the sequence currently assigned to the Penrith Sandstone Formation. The boundary of this formation with the overlying Eden Shales may have been placed too high in the borehole, or a passage may exist between these formations.

Poor recovery of palynomorphs through some 63m of beds between the Hilton Plant Beds and the top of Eden Shales unit (vi) may limit the usefulness of the Hilton Borehole record as a reference for the palynostratigraphy of the region.

Previous work

Miospores were reported from samples from exposures of the Eden Shales in Hilton Beck by Jansonius (1962), Chaloner & Clarke (1962), Clarke (1965) and Visscher (1971, 1972). In the most comprehensive of these accounts, Clarke (1965) reported assemblages recovered from discontinuous exposures of the 'Hilton Plant Series', 'Magnesian Limestone' and 'St Bees Shales'. The majority of his samples (35) were from the Hilton Plant Beds. However, 16 were from higher units, including the 'Magnesian Limestone' (Belah Dolomite) and overlying beds, but only six of these, probably from beds equivalent to parts of units (vi) and (vii) of Burgess & Holliday (1974), were productive; no palynomorphs were recovered from the 'Magnesian Limestone' or higher beds.

Sample details and results:

Slides prepared from samples collected by G. Warrington in 1974 were used in this study of the Eden Shales and Penrith Sandstone formations proved in the Hilton Borehole (NY 72 SW/1), sited at [NY 7285 2056], in Hilton Beck,Cumbria. Sample details are as follows:

Preparation (MPA) number	Depth (m) in borehole	Formation and subdivision (after Burgess & Holliday, 1974)
38451	121.92-122.07	Eden Shales (viii): Belah Dolomite
38455	124.89	Eden Shales (vii)
38458	127.86	Eden Shales (vii)
38460	130.79-130.86	Eden Shales (vii)
38462	133.02	Eden Shales (vii)
38465	136.17	Eden Shales (vii)
38466	138.99	Eden Shales (vii)
38468	144.17	Eden Shales (vi)
38469	149.53-149.56	Eden Shales (vi)
38473	152.07	Eden Shales (vi)
38474	159.72	Eden Shales (vi)
38475	165.67	Eden Shales (vi)
38476	170.99	Eden Shales (vi)
38478	172.44-172.52	Eden Shales (v): C-Bed
38479	178.31-178.33	Eden Shales (iv)
38480	181.56	Eden Shales (iii): B-Bed
38483	185.37	Eden Shales (ii)
38487	188.37	Eden Shales (ii)
38488	191.80-191.85	Eden Shales (ii)
38489	198.1	Eden Shales (ii)
38490	201.70-201.75	Eden Shales (ii)
38491	204.56	Eden Shales (ii)
38495	207.87	Eden Shales (ii)
38502	210.92	Eden Shales (i): Hilton Plant Beds
38506	213.72	Eden Shales (i): Hilton Plant Beds
38509	216.43	Eden Shales (i): Hilton Plant Beds
38512	219.45	Eden Shales (i): Hilton Plant Beds
38520	225.08	Eden Shales (i): Hilton Plant Beds

38522	226.44	Penrith Sandstone
38523	227.69	Penrith Sandstone
38524	230.20	Penrith Sandstone

The majority of the 31 preparations examined contain palynomorphs, though in some the assemblages are very sparse; preparations MPA 38476, 38478 and 38488 proved barren. Where sufficient palynomorphs were recovered, counts of 200 specimens were made to supplement the stratigraphic distribution with trends in relative abundance (Fig. 1).

Penrith Sandstone

The lowest 6.66m of the core from Hilton Borehole was assigned to the Penrith Sandstone (Burgess & Holliday, 1974). Palynology preparations were made from samples from three levels in this unit; all proved productive (Fig. 1), though the lowest (MPA 38524) contained only a solitary monosaccate pollen (*Perisaccus granulosus*). The others, from the upper 1.81m of the beds assigned to the Penrith Sandstone, yielded palynomorph assemblages that are comparable with, but less diverse than, those recovered from the overlying Hilton Plant Beds (Eden Shales unit (i); Fig. 1). These assemblages are dominated by pollen, principally bisaccates, but may include algal remains (*Reduviasporonites chalastus*). Most of the pollen taxa present (*Falcisporites zapfei*, *Jugasporites delasaucei*, *Labiisporites granulatus*, *Lueckisporites virkkiae*, *Lunatisporites* sp., *L. labdacus*, *Perisaccus granulosus*. *Protohaploxypinus* sp., *P. chaloneri* and *P. microcorpus*) also occur in assemblages throughout the section examined in the overlying Eden Shales, from the Hilton Plant Beds to the Belah Dolomite (Fig. 1). Exceptions are *Crucisaccites* cf. *variosulcatus*, recorded higher only at the base of the Hilton Plant Beds, and *Protohaploxypinus diagonalis* and *P. jacobi?*, which are recorded in the Hilton Plant Beds and unit (vii) only. The occurrences of *C.* cf. *variosulcatus* constitute the first record of this taxon in the British Permian.

Recovery of palynomorphs from the Penrith Sandstone was unexpected. The remaining unprepared rock samples have been compared with the curated slabbed core to verify the levels sampled. The remaining fragments of unprepared sample material correspond with that at the sample depths and could, in all cases, be physically fitted to the curated core. The samples prepared are, therefore, definitely from beds assigned to the Penrith Sandstone by Burgess & Holliday (1974). Whilst checking the positions of these samples plant remains were observed in beds below the level assigned to the base of the Hilton Plant Beds. Together with the palynological results, this suggests that the base of the Eden Shales, and of the Hilton Plant Beds, in the Hilton Borehole may be lower than previously thought, or that there is an upward transition into the Eden Shales from the Penrith Sandstone in the lowest part of that section.

Eden Shales

In this formation palynomorphs were found to be most abundant in the Hilton Plant Beds (unit (i)), and at the top of unit (vi), in the lower half of unit (vii) and in the Belah Dolomite (unit viii). Preparations from unit (ii), the B-Bed (unit iii), unit (iv), the C-Bed (unit v), most of unit (vi) and the upper half of unit (vii) proved virtually barren or were, in three cases, barren (Fig. 1).

The majority of the palynomorph assemblages consist entirely of miospores; some, from the Hilton Plant Beds (unit i), the base of unit (vii), and the Belah Dolomite (unit viii) also contain possible algal remains (*Reduviasporonites chalastus*). The miospore associations consist largely of bisaccate pollen, with smaller numbers of monosaccate pollen and, very sporadically, trilete spores and monosulcate pollen. The standard of preservation varies considerably between and within preparations, and the counts of 200 specimens include many pollen that are recognisable only as bisaccates or are, at best, determinable only at generic level (Fig. 1).

Many taxa present in the Hilton Plant Beds range up through the Eden Shales to the Belah Dolomite. These comprise the monosaccate *Perisaccus granulosus*, the taeniate bisaccates *Lueckisporites virkkiae*, *Lunatisporites* sp., *L. labdacus*, *Protohaploxypinus* sp., *P. chaloneri*, *P. microcorpus* and *Vittatina* sp., and the non-taeniate bisaccates *Falcisporites zapfei*, *Jugasporites delasaucei*, *Klausipollenites schaubergeri* and *Labiisporites granulatus*. The majority of these also occur in the highest beds assigned to the underlying Penrith Sandstone (see above).

Within this group of miospores some stratigraphic differences in relative abundance within the assemblages are apparent.

Perisaccus granulosus is generally more abundant in assemblages from the Hilton Plant Beds than at higher levels, in units (vi), (vii) and the Belah Dolomite. In the Hilton Plant Beds it typically constitutes >22.5% of the palynomorphs present in an assemblage, and in one instance (MPA 38520) constitutes 33%. At higher levels in the formation relative abundances range from 13%, in unit (vii) to as little as 2%, in the Belah Dolomite.

Lueckisporites virkkiae comprises between 6.5 and 15% of the palynomorphs present in assemblages from the Hilton Plant Beds, but is more common at the top of unit (vi) and in unit (vii) where it forms between 15.5 and 27.5% of the palynomorphs present. It is relatively scarce (3%) in the Belah Dolomite. The majority of the *L. virkkiae* morphotypes observed are those described by Clarke (1965) as A and C. Morphotype B forms no more than c.20%, and usually considerably less, of the total population of *L. virkkiae*. It is slightly more abundant in assemblages from units (vi) and (vii) (1-3.5%) than in those from the Hilton Plant Beds (0.5-1.5%) but was not observed in that from the Belah Dolomite.

Falcisporites zapfei, *Jugasporites delasaucei* and *Klausipollenites schaubergeri* display similar trends to *Lueckisporites virkkiae. Labiisporites granulatus* shows no stratigraphic trend in abundance and comprises between 0.5 and 5% of the palynomorphs present in the Eden Shales assemblages (Fig. 1).

Protohaploxypinus spp. are more abundant (2.5-14.5%) in assemblages from the Hilton Plant Beds than from higher levels, in units (vi) to (viii) (2-5%). In the Hilton Plant Beds larger morphotypes of this genus (*P. jacobi*, *P. microcorpus*) are prominent in the assemblages. *Protohaploxypinus limpidus* has been observed only in the Hilton Plant Beds assemblages and *P. samoilovichi* only in those from unit (vii); *P. diagonalis* occurs sporadically at both these levels. *Protohaploxypinus chaloneri* occurs sporadically in the Hilton Plant Beds assemblages and in some from units (vi) and (vii) and the Belah Dolomite; it is commoner in unit (vii) and the Belah Dolomite.

Specimens referable to *Lunatisporites* are more abundant in assemblages from the Hilton Plant Beds (11-18%) than in those from higher levels where they generally constitute <10% of the palynomorphs present. However, many specimens of *Lunatisporites* are not determinable at specific level, because of their state of preservation. No objective stratigraphic trends can be discerned in the species recognised in both the lower and higher productive samples (*L. albertae*, *L. labdacus*, *L. noviaulensis*), though *L. labdacus* may be slightly commoner in the Hilton Plant Beds. *Lunatisporites bilobus* has been observed only in the Hilton Plant Beds and *L. alatus* only in unit (vii).

Crucisaccites cf. *variosulcatus* is recorded only from the lowest Hilton Plant Beds sample; its occurrences here and at the top of the underlying Penrith Sandstone (see above, and Fig. 1) constitute the first record of this taxon in the British Permian. Other taxa which have not been observed to range above the Hilton Plant Beds in this section include trilete spores (?*Converrucosisporites* sp., *Granulatisporites* sp.), possible specimens of *Endosporites*, the non-taeniate bisaccate pollen *Alisporites nuthallensis*, *Illinites parvus*, *Jugasporites paradelasaucei* and *Limitisporites leschiki?*, the taeniates *Crustaesporites globosus* and *Striatopodocarpites. fusus*, and the monosulcate *Cycadopites* sp. (Fig. 1).

A number of taxa occur in small numbers in some assemblages from the Hilton Plant Beds and from units (vi) and (vii), higher in the Eden Shales but below the Belah Dolomite. These include *Alisporites* sp., *Illinites* sp., *Jugasporites* sp., *J. perspicuus*, *J. schaubergeroides*, *Paravesicaspora splendens*, *Vestigisporites minutus*, ?cf. *Corisaccites alutas*, *Lunatisporites pellucidus*, *Striatoabieites richteri*, *Striatopodocarpites antiquus*, *Vittatina* sp. and *V. hiltonensis* (Fig. 1).

A few taxa are recorded only from Eden Shales unit (vii) or the Belah Dolomite, and occur mostly as single specimens. In addition to *Lunatisporites alatus* and *Protohaploxypinus samoilovichi*, noted above, these include *Proprisporites pococki*, *Potonieisporites* sp., *?Nuskoisporites* sp,, ?cf. *Gardenasporites oberrauchi*, *Paravesicaspora* sp., *Platysaccus* sp., *Striatoabieites* sp., *Striatopodocarpites cancellatus* and *Vittatina ovalis?* The occurrence of the trilete spore *Proprisporites pococki* at the base of unit (vii) constitutes the first record of this taxon in the British Permian.

Specimens of *Reduviasporonites chalastus* occur sporadically in some Hilton Plant Beds samples but constitute 13% of the palynomorphs present in preparation MPA 38512 (Fig. 1). They may occur in some preparations from Eden Shales unit (vi) but occur sporadically in that from the base of unit (vii) and are more abundant in the Belah Dolomite, where they constitute 7.5% of the palynomorphs present (Fig. 1). This palynomorph is considered by Foster et al. (2001) to be probably algal rather than fungal in origin.

The record of palynomorphs from Hilton Borehole (Fig. 1) covers c.108m of beds and is the most extensive, stratigraphically, available from the upper Permian succession in Britain. It is, however, is largely incomplete between the Hilton Plant Beds and the highest part of unit (vi). This probably reflects poor preservation rather than an absence of a parent flora, as palynomorphs occur sporadically in most samples from units (ii) to (vi). The microfloras from the Hilton Plant Beds, together with those from the highest beds currently assigned to the Penrith Sandstone, appear distinct from those from the higher productive levels (units (vi), (vii) and the Belah Dolomite). However, the validity of this distinction remains to be tested by the study of an additional section, or sections, of comparable length in the Vale of Eden.

Regional comparison

The assemblages recovered by Clarke (1965, fig.16), from exposures of the Hilton Plant Beds and higher strata, possibly above the C-Bed, are similar, in composition and character, to those reported here from the Hilton Borehole (Fig. 1). Detailed comparison is hampered by differences in the presentation of the data, and the incompletness of Clarke's section, resulting from near-surface solution of evaporites and discontinuous exposure.

There are no other records of palynomorphs from the Permian succession in the Vale of Eden. Assemblages have, however, been recorded from boreholes at a few sites elsewhere in Cumbria and to the north of the Solway Firth, in Dumfries & Galloway, and elsewhere in the Bakevellia Province. Warrington (in Arthurton & Hemingway, 1972) reported miospores from a sample from the basal part of the Saltom Siltstone, at the base of the St Bees Evaporites Formation of the Cumbrian Coast Group in a borehole near St Bees Head, west Cumbria. This preparation also contains acritarchs and the alga(?) *Reduviasporonites* (Warrington, 1969; BGS unpublished record). Similar assemblages, one including *Reduviasporonites*, were recovered from the same formation in Borehole 13A, at Sellafield, west Cumbria (Warrington, 1995; BGS unpublished record). The 'Grey Beds' at the base of the Cumbrian Coast Group succession in Roosecote borehole, southwest Cumbria (Rose & Dunham, 1977) have yielded assemblages comprising miospores and acritarchs (Warrington, 1971; BGS unpublished record). Warrington (in Holliday et al., 2001) documented palynomorph successions in boreholes at the Chapelcross power station site near Annan, Dumfries & Galloway. Some assemblages from this site included the alga(?) *Reduviasporonites*, the colonial alga *Plaesiodictyon* and, in one instance, test linings of foraminifera. The miospore associations from these sites are comparable in composition with those recorded from Hilton Borehole. However, they provide only limited stratigraphic information, from a single sample level at St Bees and spanning sequences of only 5m at Roosecote, <15m at Chapelcross and <21m at

Sellafield. Comparable associations have been recovered offshore, in the East Irish Sea Basin (Jackson et al., 1987; Warrington *in* Jackson & Johnson, 1996) and the Solway and Peel basins (Newman, 1999; Chadwick et al., 2001), and from the Larne No.2 Borehole, Northern Ireland (Warrington *in* British Geological Survey, 1995), but details of these assemblages have not been published. The fullest account from elsewhere in the Bakevellia Province is from Kingscourt, Co. Cavan, Ireland, where microfloras comparable with those from Cumbria are succeeded, uniquely in the British Isles, by one of earliest Triassic age (Visscher, 1971).

The absence of another palynological record comparable in length to that from Hilton Borehole is not confined to the Bakevellia Province. Records from the Zechstein succession in eastern England (e.g. Clarke, 1965, *in* Gaunt, 1994; Warrington *in* Smith et al., 1973) cover only small parts of that sequence.

Macropalaeontology and other evidence provides some independent stratigraphic control on the sequence in the Bakevellia Province and its relationship to the Zechstein succession (Holliday et al., 2001). The Saltom Siltstone of west Cumbria and the lower part of the Eden Shales are correlated with the lower part of the Don Group (Smith et al., 1986) or EZ1 cycle in the upper Permian of northeast England; the Belah Dolomite is correlated with the carbonate phase of the EZ3 cycle, now the Seaham Formation of the Teesside Group (Smith et al., 1986) in that area.

The miospores originated from the contemporary land flora and provide evidence for dating and correlation but not about the depositional environment. They reflect a parent flora dominated by conifers and known partly from material from the Hilton Plant Beds (Stoneley, 1956, 1958). The acritarchs and organic linings of foraminifera recorded elsewhere in the Bakevellia Province provide no evidence of age but are indicative of marine influence. Sparse colonial algae indicate subaqueous environments but may reflect brackish water rather than fully marine conditions; the more widely occurring *Reduviasporonites*, a possible alga, may indicate similar environments.

Age of the miospore assemblages

The miospores recorded from the Hilton Borehole and exposures in Hilton Beck include characteristic components of microfloras from the Euramerian palaeobotanical province (Warrington, 1996). Similar microfloras have been recorded from sites elsewhere in the Bakevellia Province (see above) and occur widely in the Late Permian Zechstein succession that extends from eastern England and the North Sea to Poland (Warrington *in* Smith et al., 1974; Johnson et al. 1994).

A correlation with rocks in the Kazanian and Tatarian stages of the classical type Permian succession in Russia is indicated by the presence of the bisaccate pollen *Lueckisporites virkkiae*. This distinctive pollen appears first in the Kazanian in its type region (Utting *et al*. 1997) and ranges to the top of the Permian sequence there and elsewhere (Utting & Piasecki 1995; Warrington 1996; Koloda & Kanev 1996; Gomankov *et al*. 1998).

Therefore, it characterises the Kazanian and younger Permian succession. In terms of the new stage and series nomenclature for the Permian System (Jin Yugan *et al*. 1997), this corresponds with the upper Roadian, Wordian and Capitanian stages, which comprise most of the Guadalupian Series, or Middle Permian, and the Wuchiapingian and Changhsingian stages which comprise the overlying Lopingian Series, or Upper Permian.

Magnetostratigraphy aids more precise age assignment. The Illawara Reversal, between the Carboniferous-Permian Reversed and the Permian-Triassic Mixed magneto-stratigraphic megazones, which is dated at about 265 Ma (Menning 1995), is placed in the Wordian Stage of the Middle Permian (Jin Yugan *et al*. 1998), and is recognised in the Tatarian in Russia (Burov *et al*. 1997). In Germany it occurs below the Zechstein sequence, within the Parchim Formation of the Havel Subgroup (Upper Rotliegend) (Menning 2000). Therefore, the Zechstein succession and its correlatives, such as the Eden Shales, in the Bakevellia Province, are post-Wordian in age. This stratigraphical assignment is compatible with the suggestion (Gomankov *et al*. 1998) that the Tatarian sequence is older than much of the Zechstein and its Bakevellia Province correlatives. The latter are, therefore, considered to be Late Permian, Wuchiapingian or possibly Changhsingian, in age, i.e. between *c*. 260 and 251.4Ma according to current timescale information (Wardlaw & Schiappa, 2001).

Conclusions

Palynomorph assemblages dominated by miospores, but including possible algal remains, have been recovered through a sequence of c.108m of beds in Hilton Borehole, ranging from the top of the Penrith Sandstone to the Belah Dolomite in the Eden Shales.

The miospores indicate that the productive sequence is of Wuchiapingian or possibly Changhsingian (Late Permian, Lopingian) age.

The poor recovery of palynomorphs through some 64m of the Eden Shales, between the Hilton Plant Beds and the highest beds in unit (vi) may limit the usefulness of the Hilton Borehole as a reference section for the Late Permian palynostratigraphy of the region. Other long sections in the Vale of Eden should be studied to further assess the palynostratigraphy of the Eden Shales and contiguous formations in that area.

G. Warrington

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Figure caption

Fig. 1. Distribution and relative abundances* of palynomorphs observed in preparations from the Eden Shales and Penrith Sandstone in the Hilton Borehole.
(* - expressed as number present in a count of 200 specimens (numbers in bold); where fewer than 200 specimens were present the numbers are in italic)

Author citations for species recorded:

Miospores

Alisporites nuthallensis Clarke 1965
Corisaccites alutas Venkatachala & Kar 1966
Crucisaccites variosulcatus Djupina 1971
Crustaesporites globosus Leschik 1956
Falcisporites zapfei (Potonié & Klaus) Leschik 1956
Gardenasporites oberrauchi Klaus 1963
Illinites parvus Klaus 1963
Jugasporites delasaucei (Potonié & Klaus) Leschik 1956
Jugasporites paradelasaucei Klaus 1963
Jugasporites perspicuus Leschik 1956
Jugasporites schaubergeroides Klaus 1963
Klausipollenites schaubergeri (Potonié & Klaus) Jansonius 1962
Labiisporites granulatus Leschik 1956
Limitisporites leschiki Klaus 1963
Lueckisporites virkkiae Potonié & Klaus emend. Clarke 1965
Lunatisporites alatus (Klaus)
Lunatisporites albertae (Jansonius)
Lunatisporites bilobus (Clarke)
Lunatisporites labdacus (Klaus)
Lunatisporites noviaulensis (Leschik) Foster 1979
Lunatisporites pellucidus (Goubin) Helby ex. de Jersey 1972
Paravesicaspora splendens (Leschik) Klaus 1963
Perisaccus granulosus (Leschik) Clarke 1965
Proprisporites pococki Jansonius 1962
Protohaploxypinus chaloneri Clarke 1965
Protohaploxypinus diagonalis Balme 1970
Protohaploxypinus jacobii Jansonius emend. Hart 1964
Protohaploxypinus limpidus (Balme & Hennelly) Balme & Playford 1968
Protohaploxypinus microcorpus (Schaarschmidt) Clarke 1965
Protohaploxypinus samoilovichi (Jansonius) Hart 1964
Striatoabieites richteri (Klaus) Hart 1964
Striatopodocarpites antiquus (Leschik) Potonié 1958
Striatopodocarpites cancellatus (Balme & Hennelly) Hart 1964
Striatopodocarpites fusus (Balme & Hennelly) Clarke 1965
Vestigisporites minutus Clarke 1965
Vittatina hiltonensis Chaloner & Clarke 1962
Vittatina ovalis Klaus 1963

Alga(?)

Reduviasporonites chalastus (Foster) Elsik 1999

PALYNOMORPHS

FORMATION	Units	DEPTH (M) IN BOREHOLE	PREPARATION (MPA) NUMBER	*Perisaccus granulosus*	*Protohaploxypinus diagonalis*	*Protohaploxypinus jacobii*	*Lueckisporites virkkiae*	*Lunatisporites* sp.	*Lunatisporites labdacus*	*Protohaploxypinus chaloneri*	*Protohaploxypinus microcorpus*	*Jugasporites delasaucei*	*Falcisporites zapfei*	*Crucisaccites* cf. *variosulcatus*	*Labiisporites granulatus*	*Protohaploxypinus* sp.	*Granulatisporites* sp.	*Jugasporites paradelasaucei*	*Alisporites nuthallensis*	*Endosporites* sp.	*Protohaploxypinus limpidus*
EDEN SHALES	viii	121.92-122.07	38451	4			6	18	1	5	3?	7?	3?		10?	2					
	vii	124.89	38455																		
		127.86	38458					*1*				*1*									
		130.79-130.86	38460	20			38	11	2	7	1	11	11		5	1					
		133.02	38462					*1*					*1?*		*1*						
		136.17	38465	26	2	1	39	11	1	1	1	11	9		4						
		138.99	38466	15			31	18	1		1	5	5		8	2					
	vi	144.17	38468	8			55	36		1		1?	4?			5?					
		149.53-149.56	38469																		
		152.07	38473	*3?*																	
		159.72	38474				*2*														
		165.67	38475					*1?*													
		170.99	38476	Barren																	
	v	172.44-172.52	38478	Barren																	
	iv	178.31-178.33	38479				*1?*														
	iii	181.56	38480																		
	ii	185.37	38483																		
		188.37	38487																		
		191.80-191.85	38488	Barren																	
		198.1	38489																		
		201.70-201.75	38490																		
		204.56	38491																		
		207.87	38495				*5*		*2*						*1?*						
	Hilton Plant Beds	210.92	38502	45		4	13	20	1	1	4		5		9						1
		213.72	38506	46	1?	5	15	21	7	1	2	3	5		4	6				1?	1
		216.43	38509	53		1	29	34	1	2	2		5		7	4					
		219.45	38512	14	1?	12	22	20	4			1?	4		4	15			1		1
		225.08	38520	66	1	1	30	24	2	1			3	2	1	1	1	2	3	1?	1 cf.
PENRITH SANDSTONE		226.44	38522	25			3	79	1?	1?			1	1	1?	1					
		227.69	38523	10	1	1?	55	43	6	2?	1?	1	1								
		230.2	38524	*1*																	

DEPTH (M) IN BOREHOLE	PREPARATION (MPA) NUMBER	*Lunatisporites pellucidus*	*Illinites* sp.	*Vittatina* sp.	*Limitisporites leschiki*	*Lunatisporites bilobus*	*Crustaesporites globosus*	*Striatopodocarpites antiquus*	*Striatoabieites richteri*	*Lunatisporites noviaulensis*	*Vittatina hiltonensis*	*Paravesicaspora splendens*	*Klausipollenites schaubergeri*	*Jugasporites perspicuus*	*Vestigisporites minutus*	*Alisporites* sp.	*Converrucosisporites* sp.	*Cycadopites* sp.	*Striatopodocarpites fusus*
121.92-122.07	38451			2?									1?						
124.89	38455																		
127.86	38458												*1?*						
130.79-130.86	38460		1								2	1?	5			1			
133.02	38462															*1*			
136.17	38465	1 cf.		1					1	2 cf.	1	1	10	1	1	6			
138.99	38466							1			1		14		1	1			
144.17	38468			1?									2			5?			
149.53-149.56	38469																		
152.07	38473																		
159.72	38474												*1?*						
165.67	38475																		
170.99	38476																		
172.44-172.52	38478																		
178.31-178.33	38479																		
181.56	38480																		
185.37	38483																		
188.37	38487																		
191.80-191.85	38488																		
198.1	38489																		
201.70-201.75	38490																		
204.56	38491																		
207.87	38495															*1?*			
210.92	38502								1		1	2	3						
213.72	38506						1?		1		1		3			4	2?	1	1
216.43	38509							1	2	1	1	1?	1	1?	1	2			
219.45	38512	2			1?	1	1	1	1	1	1	1 cf.	3						
225.08	38520	2	7	1															
226.44	38522																		
227.69	38523																		
230.2	38524																		

DEPTH (M) IN BOREHOLE	PREPARATION (MPA) NUMBER	*Illinites parvus*	*Jugasporites schaubergeroides*	*Lunatisporites albertae*	cf. *Corisaccites alutas*	*Jugasporites* sp.	*Proprisporites pococki*	*Platysaccus* sp.	*Paravesicaspora* sp.	cf. *Gardenasporites oberrauchi*	*Striatopodocarpites cancellatus*	*Vittatina ovalis*	*Striatoabieites* sp.	*Protohaploxypinus samoilovichii*	*Potonieisporites* sp.	*Lunatisporites alatus*	*Nuskoisporites* sp.	indeterminate bisaccate pollen	*Reduviasporonites chalastus*
121.92-122.07	38451																1?	115	15
124.89	38455																	*3*	
127.86	38458																	*4*	
130.79-130.86	38460			1?	1?	2								1 cf.				78	
133.02	38462																	*4*	
136.17	38465				1?								1	2?	1	1		63	
138.99	38466		1			8	1	1	2	1?	1	1?	1	1				76	2
144.17	38468			1?														80	1?
149.53-149.56	38469																	*1*	
152.07	38473																		*1?*
159.72	38474																		*1?*
165.67	38475																		
170.99	38476																		
172.44-172.52	38478																		
178.31-178.33	38479																		
181.56	38480																	*4*	
185.37	38483																	*1*	
188.37	38487																	*2*	
191.80-191.85	38488																		
198.1	38489																	*2*	
201.70-201.75	38490																	*1*	
204.56	38491																	*3*	
207.87	38495																	*11*	
210.92	38502	1		1	1?	2												85	
213.72	38506	2	1	1 cf.														62	1
216.43	38509																	50	1
219.45	38512																	62	26
225.08	38520																	49	1
226.44	38522																	86	1?
227.69	38523																	59	1?
230.2	38524																		

Fig. 1. Hilton Borehole palynology