

33. THE BRITO-ARCTIC IGNEOUS PROVINCE FLORA AROUND THE PALEOCENE/EOCENE BOUNDARY¹

M. C. Boulter² and S. B. Manum³

ABSTRACT

Palynological studies of the intrabasaltic sediment layers in the lower volcanic series from ODP Leg 104 outer Vøring Plateau Hole 642E Cores 102 through 109 indicated abundant pollen and rarer dinoflagellate cysts. The dinoflagellates belong to the *Apectodinium hyperacanthum* Zone and indicate an age equivalent to nannoplankton Zones NP9-lower NP10 around the Paleocene/Eocene boundary.

The pollen and spore assemblage found here in 12 of the samples from the lower volcanic series is of well-preserved and distinctive specimens and contains unusual forms of pollen from the Taxodiaceae and the Hamamelidae. It has not been transported far from vegetation that was dominated by conifer forest with some ferns and deciduous arborescent angiosperms. Nearly identical assemblages are found elsewhere in the Brito-Arctic Igneous Province, in intrabasaltic sediments from eastern Greenland, the Faeroe Islands, the Isle of Mull, and Antrim (Northern Ireland), and above basalt at the Rockall Plateau. The assemblage is also present in sediments around the Paleocene/Eocene boundary in Spitsbergen. This pollen and spore flora is also associated with dinoflagellate cysts of the *Apectodinium hyperacanthum* Zone in the deposits from eastern Greenland, the Rockall Plateau, and Spitsbergen, suggesting that these are correlative. Assemblages of the same age from the North Sea, Denmark, and the London and Paris Basins are different.

Paleobotanical evidence suggests a short survival of the intrabasaltic flora, and that all the deposits considered here are of about the same age. We propose that at around the Paleocene/Eocene boundary a distinct flora, named here as the Brito-Arctic Igneous Province (BIP) flora, occurred on the line of volcanicity stretching from Rockall to the Greenland Sea, and even to Spitsbergen. Geophysical evidence supports our view that the Rockall to East Greenland intrabasaltics are more or less contemporaneous, at about the Paleocene/Eocene boundary. However, the comparable pollen and spore assemblage in the Hebridean province, at Mull and Antrim, is from pyroclastics that may be a little older.

INTRODUCTION

The Ocean Drilling Program (ODP) Leg 104 in the Norwegian Sea had as one of its main objectives determination of the nature and age of the seaward-dipping seismic reflector sequences observed below sediments along the margins of the Norwegian Sea (Eldholm, Thiede, Taylor, et al., 1987, pp. 8-12). This was the primary reason for selecting Site 642 at the outer Vøring Plateau (Fig. 1). At this site, Holes 642A through 642E were drilled, of which Holes 642 A through 642D successively penetrated 315 m of Holocene to Eocene sediments. Hole 642E was drilled through approximately 900 m of interbedded basalts and volcanoclastic sediments without reaching the base of the basaltic sequence. The volcanic sequence is divided into two distinct parts separated by a volcanoclastic unit at the base of the dipping reflector sequence (Eldholm, Thiede, Taylor, et al., 1987). The upper sequence is tholeiitic, approximately 760 m thick and consists of 120 flows. The lower series, of which 140 m was drilled, is andesitic in nature. Both appear to have been extruded in subaerial environments and occasionally flowed into water. Marine fossils in the intrabasaltic sediments indicate a near-shore marine environment (Eldholm, Thiede, Taylor, et al., op. cit., p. 146). The upper sequence shows affinity with basalts of the Paleogene North Atlantic Volcanic Province, probably related to the opening of the Norwegian Sea (Eldholm, Thiede, Taylor, et al., op. cit. p. 754). The lower sequence is associated with the transition between rift and drift phases of the incipient ocean basin (Skogseid and Eldholm, 1987).

The palynomorph assemblages that form the basis for this report were obtained from 12 samples of the 6 volcanoclastic layers in the lower basalt series (Cores 104-642E-102, -105, -107, and -109). A radiometric age of 57.8 ± 1.0 Ma is reported for this series by LeHuray and Johnson (this volume). In the absence of other biostratigraphically diagnostic fossils from this series it is the palynological investigations which provide important constraints for the age of these deposits. Preliminary shipboard analysis of the palynomorphs from the intrabasaltic sediments has already been reported (Eldholm, Thiede, Taylor, et al., 1987, pp. 478-479).

Pollen and spores are difficult to use to date Paleogene sediments, though they can give useful indications of paleoenvironment and climate. On the other hand, dinoflagellate cysts are thought to yield reliable information on the age of marine Tertiary and Mesozoic sediments. Fortunately, samples studied by us from the base of Hole 642E contain adequate numbers of biostratigraphically diagnostic dinoflagellate cysts.

As our investigations began it became clear that they impinged on much paleontological and geophysical work that has already been published. This work concerns the nature and origin of what has been called the Brito-Arctic Province (Holmes, 1918) or the Thulean Volcanic Province (Wenk, 1961; Curry et al., 1978). Following the argument by Wenk (1961), we adopt here the term Brito-Arctic Igneous Province (BIP) to describe the region bounded by Greenland, the Rockall Plateau, Ireland, Scotland, Norway, and Spitsbergen (Fig. 1), where early Tertiary volcanic activity was common. The basaltic sequence drilled at Site 642 marks a major episode of volcanic activity at the inception of opening of this northernmost part of the North Atlantic. Biological and geological features recorded in the rocks of this province have a character different from those of coeval rocks elsewhere, such as to the west of Greenland and those formed in the deltas near the northern shores of Tethys. A general geological commentary on the eastern Greenland basaltic

¹ Eldholm, O., Thiede, J., Taylor, E., et al., 1989. *Proc. ODP, Sci. Results*, 104: College Station, TX (Ocean Drilling Program).

² Palynology Research Unit, North East London Polytechnic, Romford Road, London E15 4LZ, U.K.

³ Department of Geology, University of Oslo, PO Box 1047, Blindern, N-0316 Oslo 3, Norway.

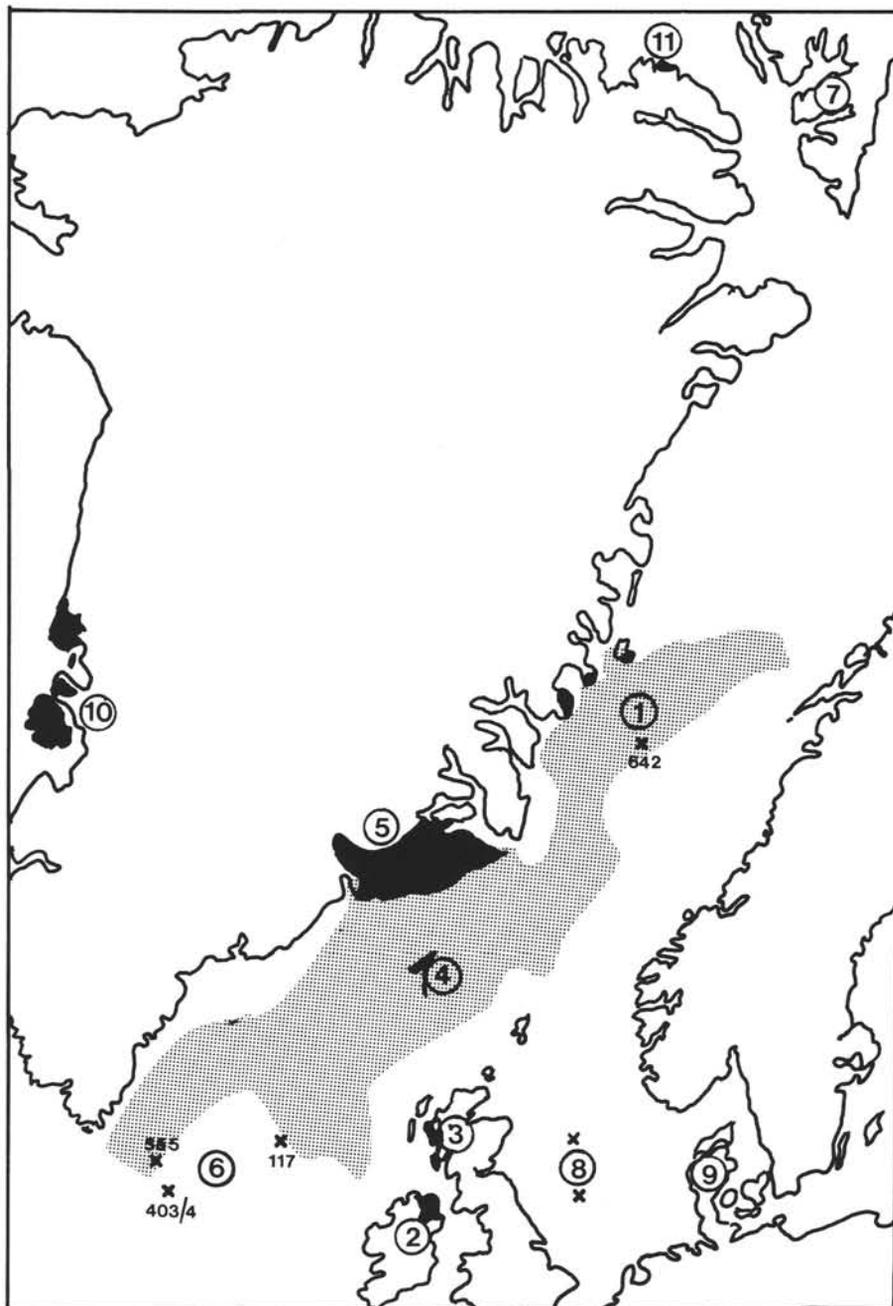


Figure 1. The Brito-Arctic Igneous Province at magnetic anomaly 24-25 time showing the location of ODP Site 642 and other localities referred to in this study. Basalts are indicated by hatching (offshore) and black shading (onshore). 1: ODP Leg 104 Site 642, 2: Antrim, 3: Isle of Mull, 4: Faeroes, 5: eastern Greenland, 6: Rockall Plateau, 7: Spitsbergen, 8: North Sea, 9: Denmark, 10: western Greenland, 11: northern Greenland.

rocks caused Wenk (1961) to suggest a "relation with the geologically related blocks of Greenland, Spitsbergen and Scotland."

SAMPLE PREPARATION AND TAXONOMIC METHODS

Cores 104-642E-102 to -110 were sampled for intrabasaltic sediments by the ODP staff. About 25 samples from volcanics of the upper basalt series (Cores 104-642E-5 to -94) examined by us were all palynologically unproductive. From the lower series (Cores 104-642E-102 to 109) 12 out of 18 samples yielded good assemblages with well-preserved palynomorphs,

the remainder were either palynologically barren or had suffered badly from thermal alteration. The sediments were treated with 40 to 45% hydrofluoric acid at 70°C until all silica dissolved, followed by 10% hydrochloric acid treatment at the same temperature. The washed residue was sieved through a metal sieve with 20-µm circular holes, and then oxidized for 30 to 60 s in fuming nitric acid. The final residues were mounted in glycerine jelly with paraffin-wax seals. Preparations are curated at the Department of Geology, University of Oslo, Norway.

Terrestrial palynomorphs and plant debris dominate in all the productive samples. Dinocysts are always present, although with much lower frequencies, indicating that the basalts were de-

posited in very near-shore environments. The dinocyst assemblages show low taxonomic diversity and represent mostly known forms. A list of the significant species is given in Table 1. There is no significant variation in the occurrence of these taxa within the sequence examined. The names of dinocyst taxa used here are all in accordance with the genera and species index of Lentin and Williams (1985), where the authors' names can be found.

Pollen and spore taxonomy is less clear than that of dinoflagellate cysts and consequently the taxonomy is more confused (Boulter, 1978). To try and resolve these difficulties we have used this opportunity to describe the pollen and spores as biorecords, using Hughes' (1986) guidelines. The full details of the biorecords are available on MS-DOS floppy disk from the authors or from ODP/TAMU. A summary of the preliminary taxonomic descriptions is given in the Appendix.

Five of the new biorecord taxa are particularly characteristic of the pollen assemblage at the base of Hole 642E, and these are briefly discussed in a subsequent section.

INTERPRETATION AND DISCUSSION OF DINOCYST DATA

The stratigraphically most significant element of the dinocyst assemblages are the representatives of the *Apectodinium homomorphum* plexus (Harland, 1979). *A. augustum* is present in 10 of the 12 productive samples studied; *A. parvum* and *A. hyperacanthum* have been recorded from only one sample (Core 642E-107-2, 10–11 cm). The *A. homomorphum* plexus is characteristic of the *A. hyperacanthum* Zone of Costa and Downie (1976) and the three species named above are restricted to this zone. We therefore refer the assemblages from Cores 642E-102-1, 50–51 cm to 642E-109-1, 109–110 cm, to the *A. hyperacanthum* Zone. Some of our specimens of this plexus are shown in Plate 1.

Most authors correlate the *A. hyperacanthum* Zone with the standard nannoplankton Zone NP9 and the lower part of NP10, as indicated here in Figure 2 (Costa and Downie, 1976; Costa et al., 1978; Harland, 1979; Knox, 1984). In the latest Cenozoic geochronology of Berggren et al. (1985), however, the *A. hyperacanthum* Zone is not shown to range into NP10. The discrepancies in correlation between dinocyst and nannoplankton zonation result from insufficient first-order nannofossil control in sections where the dinocyst zonation has been established. This correlation problem is also intimately linked to the discussion of the position of the Paleocene/Eocene boundary in relation to biostratigraphic zonations, magnetostratigraphy, and geochronology. Berggren et al. (1985) have placed the entire *A. hyperacanthum* Zone in the late Paleocene, with its top at the Paleocene/Eocene boundary coinciding with the top of NP9. Knox (1984), on the other hand, studied ash stratigraphy and correlated events around the Paleocene/Eocene boundary in the northwest European basin. He argued that the *A. hyperacanthum* Zone also overlaps with the lower part of NP10, which dates the main ash horizon in the North Sea Basin.

We propose that our material from Cores 104-642E-102 to -109 is correlatable to the upper, i.e., the early Eocene, part of the *A. hyperacanthum* Zone, on the basis of the occurrence of *Hyrtrichokolpoma rigaudiae* and *Lentinia wetzelii* whose earliest known record appears to be from the Eocene. However, we cannot disregard a late upper Paleocene age. *Deflandrea oebisfeldensis* is known to have an acme occurrence in the upper part of the *A. hyperacanthum* Zone (Knox and Harland, 1979). Any such quantitative variation would hardly be detectable in this material, because it appears to be stratigraphically rather restricted and it is not rich in identifiable cysts. It is noted, however, that *D. oebisfeldensis* is among the most regularly occurring cysts in our samples. Most of the species recorded are otherwise known to range across the Paleocene/Eocene boundary,

notably *Areoligera senonensis*, *Caligodinium amiculum*, *Deflandrea oebisfeldensis*, *Glaphyrocysta ordinata*, *Hafinasphaera septata*, and *Thalassiphora delicata*. In addition to the species listed in Table 1, the assemblages include *Spiniferites* spp., *Impagidinium* spp., *Oligosphaeridium* spp., and some apparently new, small peridinioid species. Occasional reworked Cretaceous forms are present (*Alterbia* sp., *Aptea* sp., *Chatangiella* spp., *Isabellidium* spp. and *Odontochitina* sp.).

INTERPRETATION AND DISCUSSION OF POLLEN DATA

The results of semiquantitative counts of the pollen and spores in the 12 samples studied are presented in Figure 3 and the most important taxa are illustrated in Plates 2 to 4. Many of the pollen taxa present in the assemblages are known to occur in other Paleocene and Eocene assemblages from Europe and have been described and discussed at length in the publications listed in the Appendix (in each section headed: OTHER RECORDS). Those mentioned below are less familiar elsewhere and their regular occurrence in the BIP assemblage makes them deserve special comments here. Though they are not unique to our BIP flora they are much more abundant here than in the other assemblages summarized in the section below. See Appendix.

INAP SPLITPAP (Plate 2, 18–22)

Although Krutzsch (1971) has illustrated rare specimens of taxodiaceous pollen with both a split and a papilla, these forms are very rare in the Paleogene deposits from central and southern Europe. In the assemblages from Hole 642E they are common and often abundant, and are present in all the other localities from the BIP which have been studied for palynology. This BIP distribution, in association with the more familiar split or papillate Taxodiaceae pollen (and a matching megafossil record), suggests that the parent plants also favored the swampy or warm environment so characteristic of the Taxodiaceae, both living and extinct. But in the absence of full paleobotanical evidence, there is little room for deduction, despite the records of leaves from plants of that family (which are from extinct taxa of uncertain ecology). What is clear is that these inaperturate pollen with splits and papillae are rare in more southeasterly assemblages.

TRIPROJECT (Plate 4, 1–4)

These rare specimens are sometimes badly preserved and may be reworked from Cretaceous sediments, as are some of the dinocysts. However, many specimens are well preserved and there is no indication that any other pollen is reworked. Triprojectate pollen are well preserved in other BIP localities (Fig. 3).

TRIP SUBEQUAT (Plate 4, 5–10)

These pollen have three subequatorial pores and are common in Hole 642E. They usually have a thinner wall at the face without germinals, a structural weakness that encourages up to three folds at that surface (see Appendix). The form in Hole 642E is very similar to *Caryapollenites simplex* described on Jansonius and Hills (1976) card number 404. Very similar pollen, with the same range of variation in size, pore feature, wall thickening and folding, is found in the comparative material from Mull, Antrim, the Faeroes, the Rockall Plateau, Spitsbergen, and eastern Greenland.

Krutzsch (1966) recorded a "*Caryapollenites triangulus*-Gruppe" in his latest Paleocene Zone 10, from the German Democratic Republic, which is thought to represent a cool climatic cycle (Krutzsch, 1970).

Triplicate pollen with subequatorial pores, referred to as *Subtriporopollenites*, is abundant in the Eocene of the North Sea and of Leg 38 Site 338 of the Norwegian Sea (Boulter, 1986).

Table 1. Dinoflagellates and pollen of the Brito-Arctic Igneous Province flora.

Core, section, interval (cm)	<i>Apectodinium</i> <i>augustum</i>	<i>Apectodinium</i> <i>hyperacanthum</i>	<i>Apectodinium</i> <i>parvum</i>	<i>Areoligera</i> <i>senonensis</i>	<i>Caligodinium</i> <i>amiculum</i>	<i>Deflandrea</i> <i>oebisfeldensis</i>	<i>Diphyes</i> <i>colligerum</i>	<i>Glaphrocysta</i> <i>ordinata</i>	<i>Glaphrocysta</i> <i>pastielsii</i>	<i>Hafniasphaera</i> <i>septata</i>	<i>Hystriocholpoma</i> <i>rigaudiae</i>	<i>Hystriocholpoma</i> <i>tubiferum</i>	<i>Lejeunecysta</i> <i>hyalina</i>	<i>Lentinia</i> <i>wetzeli</i>	<i>Palaecystodinium</i> <i>golzowense</i>	<i>Polysphaeridium</i> <i>subtile</i>	<i>Thalassiphora</i> <i>delicata</i>
102-1, 50-51	X	.	.	.	.	X	X	.	X	.	.	.	.	X	.	.	.
102-1, 70-71	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	X	.
102-1, 89-90	X	.	.	.	X	X	.	X	.	.	.	.	.	.	.	.	X
102-1, 109-110	X	.	.	.	.	X	.	X	.	.	.	.	X	X	.	.	.
105-4, 70-71	X	.	.	.	.	X	.	.	.	.	.	.	.	X	.	.	.
105-5, 19-21	X	.	.	.	.	.	.	X	.	X	.	.	X	X	X	.	X
107-1, 109-110	X	.	.	X	.	X	.	X	.	X	X	X	X	X	.	.	.
107-2, 10-11	X	X	X	X	X	X	.	X	.	X	.	.	X	X	X	.	X
107-2, 15-16	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
109-1, 70-71	.	.	.	X	.	X	.	.	.	.	.	.	X	X	X	.	X
109-1, 90-91	X	.	.	.	X	X	.	.	.	X	.	.	.	X	.	.	X
109-1, 109-110	X	.	.	X	X	.	.	X	.	X	.	.	X	X	.	.	.

These forms are not the same as the TRIP SUBEQUAT specimens from the older intrabasaltics of the dipping reflector sequence (see Appendix).

TRICOLP RETSMALL (Plate 4, 29-32)

These tricolpate pollen are about 25 μm long with lumina about 2 μm in diameter. Very similar forms were described by Simpson (1961) and Srivastava (1975) from the Isle of Mull, and our studies show comparable forms from Antrim, the Rockall Plateau, Spitsbergen, and the Faeroe Islands.

PESAVIS

This multicellular fungal fruiting body is well described on Jansonius and Hills (1976) card 1977. Apparently identical forms are present in Hole 642E (Fig. 3) samples and have been described from the Paleogene intrabasaltics of the Faeroes (Lund, 1983 and in press). Pesavis was originally described from the Eocene/Paleocene of northwest Canada, although new records extend its range into the Oligocene (Wilkinson and Boulter, 1980) of Europe.

COMPARISON TO OTHER LAND FLORAS IN THE BRITO-ARCTIC IGNEOUS PROVINCE

Geographically, the closest locality with Paleogene sediments to compare with the intrabasaltic sediments of the Site 642 dipping reflector sequence is DSDP Leg 38 Site 338. This latter hole reached the top of the dipping reflector basalts (Skogseid and Eldholm, this volume). The deepest sediment samples, from Cores 338-39 to -42, lie just above basalts. The lowest dinocyst zone of Manum (1976) and the lowest pollen zone of Koreneva et al. (1976) both correlate with NP12 at about 54 Ma. These sections from Leg 38 yield pollen assemblages including well-established Eocene taxa (Boulter, 1986) which are absent from the samples from Cores 104-642E-102 through 110 (see the high OTHERS records for these samples in Fig. 3). Site 338 assemblages are more comparable to our new data from cores higher in the Site 642 sequence (see Manum et al., this volume), and are similar to the assemblages described from the bottom of Leg 38 Site 345 (Koreneva et al., 1976).

The distinctive palynological features of the BIP flora in Hole 642E encouraged us to reexamine preparations from other localities we thought might be comparable, and our observations are summarised below.

Rockall Plateau

Paleocene-Eocene tuffaceous sediments of the Rockall Plateau were studied palynologically by Costa and Downie (1979; DSDP Leg 48), and Brown and Downie (1984; Leg 81). Costa and Downie (1979) erected three dinocyst zones, Ia, Ib, and II (Fig. 2) for the tuffaceous sediments of Sites 403 and 404 (Leg 48). These zones were equated to the *Apectodinium hyperacanthum* Zone, the *Wetzeliella meckelfeldensis* Zone, and the *Dracodinium varielongitudum* Zone, respectively, of Costa and Downie (1976). They assumed the Paleocene/Eocene boundary to be close to the top of their Zone Ia. In an appendix to their Leg 48 study, Costa and Downie (1979) presented observations on DSDP Leg 12, Hole 117A where a Zone Ial was added to the zones mentioned above. This zone was equated to the *Wetzeliella astra* Zone of northwest Europe. Morton et al. (1983) reexamined material from Hole 117A and discovered ash bands in the lower part in sediments containing nannoplankton of Zone NP10 and dinocysts of Zone Ial of Costa and Downie (1979); NP11 was reported from sediments yielding cysts from Costa and Downie's dinoflagellate Zone II (Fig. 2).

Brown and Downie (1984) studied material from Site 555 (Leg 81) which penetrated approximately 300 m of basalts and interbedded sediments that produce the dipping seismic reflector signatures there. Brown and Downie recognized dinocysts of Zone Ia of Costa and Downie (1979) from the intrabasaltic sediments and Zones Ia and Ib from sediments above the basalts. Nannoplankton of zone NP9 were recorded from the intrabasaltic sediments, and nondiagnostic assemblages referred to NP10 above the basalts (Roberts, Schnitker, et al., 1984). Brown and Downie (1984) compared their findings with the dinocyst stratigraphy of Soper et al. (1976) for the east Greenland intrabasaltic sediments around the Paleocene/Eocene boundary (Fig. 2).

Costa and Downie (1979) reported high frequencies of pollen and terrestrial debris which encouraged us to reexamine their preparations from sediments around the Paleocene/Eocene bound-

Initiation Norw. Sea spreading	MAGN. ANOM.	MILL. YR.	EPOCHS	NP ZONES	DINOFLAGELLATE ZONES Costa and Downie 1976 Costa et al. 1978	NORWEGIAN SEA Vøring Plateau Lower basalts Site 642 this study	ROCKALL PLATEAU DSDP SITES			NORTH SEA Knox and Morton 1983; Knox 1984	DENMARK Heilmann-Clausen 1985 and this study	FAEROES Lund unpubl. and this study	HEBRIDEAN VOLCANICS		EAST GREENLAND Kap Dalton Soper et al. 1976 and this study	SPITSBERGEN Manum and Thronsen 1988 and this study				
							Site 555 Brown and Downie 1984: Zonation =Sites 403/404	Site 117A Morton et al.1983	Sites 403/404 Costa and Downie 1979 and this study				Isle of Mull this study	Antrim this study						
|	23	54	Eocene EARLY	12	<i>Kisselovia coleothrypta</i>															
					11	<i>Dracodinium varielongitudum</i>														
						<i>Wetzeliella similis</i>														
					10	<i>Wetzeliella meckelfeldensis</i>														
						<i>Wetzeliella astra</i>														
					58	9	<i>Apectodinium hyperacanthum</i>	BDF	642E-102-1 642E-109-1	B	D Ia1	555-67-3	AD Ia1 NP10	117A-3-3 117A-3-6	404-12-1 404-14-1					
					25	8	<i>Deflandrea speciosa</i>													
26	6																			
62	E.	4	<i>Palaeoperidinium pyrophorum</i>																	

Figure 2. Proposed palynological correlation of basalts and ash-bearing sediments within the BIP and neighboring areas. Geochronology follows Berggren et al. (1985) except for minor adjustments of nannoplankton and dinoflagellate zones at the Paleocene/Eocene boundary. B: basalt or intrabasaltic sediment, A: ash/tuffaceous sediments, D: dinocysts, F: pollen of the BIP flora).

	MONOL SMOOTH	TRIL SMOOTH	TRIL GEMMAE	TRIL RIDGE	INAP SPLITPAP	INAP SPLIT	INAP PAP	MONOCOLP VERRUC	MONOCOLP SMOOTH	MONOSAC FRILL	BISAC STRAIGHT	BISAC ROUND	BISAC THICKEDGE	BISAC LARGE	BISAC SMALLBODY	TRIPROJECT	TRIP SUBEQUAT	TRICOLPOR SMALL	TRICOLPOR LARGE	TRICOLP RETSMALL	TRICOLP LARGE	MULTIP RETIC	MULTIP ARCI	TETRAD SMALL	TRIP EQUATLARGE	TRIP EQUATSMALL	PESAVIS	OTHERS	
Leg 104, 642E																													
642 102/1 50	■	□	□	.	□	.	□	□	□	□	□
642 102/1 70	■	□	□	.	□	.	□	□	□	□	□	
642 102/1 90	■	□	□	.	□	.	□	□	□	□	□	
642 102/1 110	■	□	□	.	□	.	□	□	□	□	□	
642 105/4 70	■	□	□	.	□	.	□	□	□	□	□	
642 105/5 20	■	□	□	.	□	.	□	□	□	□	□	
642 107/1 110	■	□	□	.	□	.	□	□	□	□	□	
642 107/2 15	■	□	□	.	□	.	□	□	□	□	□	
642 107/2 20	■	□	□	.	□	.	□	□	□	□	□	
642 109/1 70	■	□	□	.	□	.	□	□	□	□	□	
642 109/1 90	■	□	□	.	□	.	□	□	□	□	□	
642 109/1 110	■	□	□	.	□	.	□	□	□	□	□	
Leg 38, 338																													
338 39/2 25	.	.	□	■
338 40/1 90	■
338 41/2 104	■
338 42/2 10	■
Isle of Mull																													
Ardtun MCB	□	.	■	■	□
Bremanoir JBS	□	□	□	□
Shiaba JBS	□	□	□	□
Simpson 1961	?	?	?	?	⊗	⊗	⊗	.	⊗	.	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Srivastava 1975	⊗	⊗	.	.	⊗	⊗	⊗	.	⊗	.	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Antrim																													
Ballypala WAW	□	.	□	□	□	□	□	□
Ballypala JSG	□	.	■	■	■	□	□
Glenarm JSG	□	□	□	□	□	□
Craigah NIGS	■	.	.	□	□
Spitzbergen																													
Sarkofagen FM	.	?	■	□	□
Basilika FM	.	?	■	□	□
Manum 1962	⊗	⊗	⊗	.	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗
Fardes																													
Sudero JL	■	□	.	.	?	□	□	□	.	.	□	□	□	□	□
Lund Thesis	⊗	⊗	⊗	.	?	⊗	⊗	⊗	.	.	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗

□ = Rare; ⊗ = Literature; □ = Common; ■ = Abundant; ? = Questionably Present; . = Not Present

Figure 3. Semiquantitative range chart of pollen and spore taxa at ODP Hole 642E and at other localities used for comparison (DSDP Site 338 Norwegian Sea; Isle of Mull; County Antrim; Spitsbergen; the Faeroe Islands; DSDP Sites 112 and 555, Rockall Plateau; East Greenland). Unpublished material by MCB (M. C. Boulter), JBS (J. B. Simpson), WAW (W. A. Watts), JSG (J. S. Gardner), NIGS (Northern Ireland Geological Survey) and JL (J. Lund).

ary at Site 403. This preliminary study shows that the BIP flora is present between DSDP Cores 403-39-1 and -46-1. More work needs to be done to assess its precise composition and extent in the Rockall Plateau sediments.

Faeroe Islands

The only plant megafossil described from the intrabasaltics of the Faeroes is *Metasequoia occidentalis* (Rasmussen and Koch, 1963). The pollen and spores have been studied in detail by Lund (in press) and briefly reviewed by her (Lund, 1983). She concludes that the pollen and spores indicate a Landenian age. There are no records of marine microfossils within these Faeroe sediments.

Radiometric dating of the surrounding basalts shows considerable age ranges (Tarling and Gale, 1968) dating the Faeroes

rocks at between 49 and 62 Ma. Recent magnetostratigraphic work on deep core material correlates the Faeroes basalts with the magnetic anomalies 22 to 24, i.e., early Eocene (Abrahamson et al., 1984).

Figure 3 shows the results from our reexamination of some of Lund's material and some of the records from her personal communication. There are very few of her taxa which are absent from the Hole 642E assemblage.

Isle of Mull

Over the last century, paleobotanical studies of the intrabasaltic coals and other nonmarine sediments on the Isle of Mull have created a confused and conflicting story. Leaf megafossil studies were published by Gardner (1886) who interpreted conifer and angiosperm remains to be of early Eocene age. Pollen

work published in the 1960's and 1970's is reviewed in Curry et al. (1978); the age of the deposits was controversial and varied from Maastrichtian (Srivastava, 1975) to as late as the Miocene (Simpson, 1961).

Figure 3 shows the results of our semiquantitative comparison with the Hole 642E samples. The sample from Ardtun was collected by one of us (M.C.B.) in 1970 from the cliff ledge north of Bunessan. The samples from Bremanoir and Shiaba are new palynological preparations from the J. B. Simpson collection at the British Museum (Natural History). The samples have Simpson's labels: "Bremanoir 5" and "Shiaba 22", respectively.

All the biorecord taxa present in these two Simpson samples also occur in Hole 642E, and the M. C. B. "Ardtun" sample shows a very similar assemblage with a few additional taxa (and more that are absent from Hole 642E—see Fig. 3). Despite the new data presented here there is a need to make new studies on the pollen and spore assemblage at Mull. Work is in progress (Boulter and Kvacek, in press) to incorporate detailed results of pollen and spores from samples collected in 1987, with detailed descriptions of the fossil leaves available in extensive collections in British museums. This monographic study will provide an up-to-date account of the fossilized plant parts that have been found from the remains of the BIP flora at Mull as well as Antrim, Spitsbergen, and East Greenland.

Antrim

Plant megafossils were first described from the intrabasaltic sediments in northeast Ireland by Gardner (1886). Subsequent work on the plant fossils was reviewed by Watts (1970). He deduced a Paleocene-early Eocene age from the pollen assemblages. The palynology of these sediments has never been fully studied, although we analyzed pollen and spores semiquantitatively from four samples (dinocysts are absent). Two of the samples are from the J. S. Gardner collection in the British Museum (Natural History), Ballypallady V.15153 and Glenarm V.14856, and show a very similar assemblage to our Hole 642E slides (Fig. 3). However, the two other samples show a very different assemblage of pollen and spores. This difference is compatible with the range of radiometric dates of Evans et al. (1973), which suggest that volcanicity in Northern Ireland lasted as long as 20 m.y. up to the middle Eocene.

East Greenland

Mathiesen (1932) described several species of conifer and angiosperm leaf megafossils from Kap Dalton and other localities, and deduced "an Early Tertiary (Palaeocene-Eocene) age of these deposits." This dating is confirmed loosely by Tarling and Gale's (1968) 49–62 Ma radiometric dating of surrounding basalts, and more closely by the dinoflagellate cysts (Soper and Costa, 1976; Soper et al., 1976). This suggests an age ranging through no more than 3 m.y. from the latest Paleocene to the earliest Eocene. Soper et al. (1976, p. 153) report that: "shales from the upper part of the sequence [Kap Dalton, Eocene] yielded only remains of terrestrial vegetation." We have reexamined the material from Kap Dalton (Soper and Costa, 1976) to compare with the Hole 642E assemblages. Two of their samples from the intrabasaltic horizons (GGU 116342 and 179232) show a very similar pollen and spore assemblage to that from the intrabasaltics of Hole 642E, and the *Apectodinium* plexus is present in the latter sample. The major differences between the pollen of this assemblage and that at the base of Hole 642E are the rarity of taxodiaceous pollen and the common occurrence of a triporate pollen type with thickened pores more reminiscent of the Bombacaceae than the Tiliaceae.

Spitsbergen

Megafossil plant remains were first described by Heer (1868, 1870, and 1876) and it is now generally accepted that the floras of the various formations range in age from Paleocene to early Oligocene (Manum and Thronsen, 1986). Pollen and spores there were first described by Manum (1962) who also compared the palynological and megafossil evidence for the flora. Vaku-lenko and Livshits (1970) confirmed Manum's evaluation of the assemblages and their ages.

Manum and Thronsen (1986) reviewed previously available biostratigraphic evidence for the age of the Tertiary formations on Spitsbergen and supplied new dates for certain formations based on dinocysts. Of particular interest in this connection is their report of an *Apectodinium hyperacanthum* Zone assemblage including *A. augustum*, from ash layers in the lower part of the Gilsonryggen Formation (Fig. 2). Matthiessen (1986) subsequently described rich *Apectodinium* assemblages from other horizons of the same formation. These horizons are considered to be of an age close to the Paleocene/Eocene boundary. Pollen are rare in the Gilsonryggen Formation, but more common in the upper part of the underlying Sarkofagen Formation. *Apectodinium* is absent there, but other uppermost Paleocene dinocysts are present; the pollen assemblage is similar to that in our Hole 642E samples. The underlying Basilika Formation (Fig. 2) is dated by dinocysts to the early/late Paleocene transition, and has a different pollen assemblage (Fig. 3). There are no published radiometric or magnetic datings of these formations.

NEIGHBORING DEPOSITS OUTSIDE THE BIP

Palynological work has been published on assemblages from many other Paleocene and Eocene localities adjacent to the BIP. The most important are from northeast arctic Canada (Rouse, 1977; Hickey et al., 1983; Norris and Miall, 1986), west Greenland (Croxtan, 1980), north Greenland (Batten et al., 1981), the London and Paris basins around the northern shores of Tethys (reviews in Allen, 1982; Schumacker-Lambrey, 1978), the North Sea Basin, and Denmark. From the often meager data publicly available it appears that the pollen assemblages in these sediments are largely different from those of the Norwegian Sea ODP Leg 104 and other localities in the Brito-Arctic Igneous Province.

North Sea Basin

No plant megafossils have been described recently from Paleogene deposits in the North Sea and Denmark, though there are extensive collections from the MoClay in northern Jutland (Larsson, 1975). Equally, few palynological studies are published despite the intense commercial investigations in the area over the last decade. Harland (1979) described details of the stratigraphically important *Apectodinium homomorphum* plexus from the Paleocene-lowermost Eocene. This plexus is a characteristic component of *Apectodinium hyperacanthum* Zone assemblages (Costa and Downie, 1976); *A. augustum*, the distinctive dinocyst that we found in the lower basalt series of Hole 642E, is restricted to this zone. The *A. hyperacanthum* Zone has been calibrated to the nannoplankton Zones NP9 and the lower part of NP10 (Costa and Downie, 1976; Knox, 1984; Williams and Bujak, 1985). The *A. hyperacanthum* Zone therefore ranges into the lowermost Eocene.

Pollen and spores from the lower Eocene marine sediments of the North Sea and Norwegian Sea (Boulter, 1986) show an important increase in the numbers of *Subtripropollenites*. These forms, however, are not the same as the similar subequatorial triporate pollen described from Hole 642E as TRIP SUBEQUAT which occur in older strata.

Another marine section in the North Sea, the Sele Formation, includes the Paleocene/Eocene boundary and shows abundant pollen and spores and palynodebris (Boulter and Riddick, 1986) all thought to have been transported from the northwest. *Apectodinium* species are present in this assemblage, although the pollen and spores are largely different from those of the BIP flora. More work is needed for detailed comparisons of the pollen from these marine deposits with those of the more autochthonous BIP intrabasaltic sediments.

Denmark

Hansen (1979) identified the *A. hyperacanthum* Zone in the ash-bearing MoClay and Heilmann-Clausen (1985), studying a borehole (Viborg 1) that penetrated the ash-bearing sequence (Ølst Formation), confirmed the presence of this zone in the ash layers. Heilmann-Clausen found *A. augustum* to be restricted to the ash-bearing formation. He kindly made some of his preparations available to us for pollen analysis: the assemblage is from a marine facies and resembles that of the Sele Formation of the Forties Field (see above) rather than the BIP.

West Greenland and Ellesmere Island

Hickey et al. (1983) detailed part of their rich palynological assemblage from near the Cretaceous/Tertiary boundary in the Eureka Sound Formation. There are few conifers, and many angiosperms, quite unlike the younger material from the east of Greenland.

We have made preparations from British Museum samples from the Vaigat Strait (V.1545), Trifail (V.14250) and Disco Island (V.6497 and 7794), all thought to be Paleocene, and find very different pollen assemblages from those of the BIP Flora. Croxton (1980) has found *Aquilapollenites* from deposits near the "Cretaceous/Palaeocene (?)" of the Nugssuaq peninsula, central west Greenland.

North Greenland

Batten et al. (1981) reported angiosperm leaf fragments and triprojectate pollen from sediments associated with the Kap Washington Group volcanics. The palynodebris (Batten, 1982, p. 15) suggests that the environment of deposition was either marginal or nonmarine; both the palynology and "Rb-Sr age determinations based on rhyolites suggest that the volcanicity occurred at, or just prior to, the Cretaceous/Tertiary boundary."

Northern Ireland

As mentioned above, Evans et al. (1973) obtained radiometric dates for these lavas ranging from 44.6 to 65.7 Ma. One of the reference slides used in our study is from Craighullier, near Portrush (N. Ireland Geological Survey) and shows a different pollen assemblage from that of the BIP flora (Fig. 3). These data may mean that the Craighullier sample is older than the others from Northern Ireland (Fig. 3). Watts (1970) studied the pollen of this Craighullier sample and confirmed differences with the Ballypalady assemblage.

London Basin (NW Shores of Tethys)

The palynological assemblages described by Schumacker-Lambry (1973) and Allen (1982) are much in line with those of a similar age from mainland western Europe. Though some taxa are the same as those in the Hole 642E assemblage, many of the more southern species are absent from the latter. Indeed, the southern assemblages are usually much more diverse than our BIP one, as can be expected from climatic differences in the two regions. The North Sea Basin climate was determined by the warm influences from the Tethys Ocean (Ziegler, 1982) while that of the BIP was more likely influenced by the young Atlantic Ocean or systems from the Arctic. To the north, barriers pre-

vented the warmer waters of the Tethys from influencing the colder Arctic area (Fig. 1). The lowland on either side of the shallow seaway that began to penetrate these barriers formed the margin of the proto-northernmost Atlantic, and was the site of our BIP Flora.

THE OVERALL PALYNOLOGICAL CHARACTER OF THE BRITO-ARCTIC IGNEOUS PROVINCE FLORA

We believe that the palynological assemblage from the intrabasaltic sediments of Hole 642E represents the remains of a distinct Flora that survived for between 1 and 3.5 m.y. along the entire BIP.

From our present knowledge of the fossil leaves, pollen, and spores at different localities within the Province, it is clear that the Flora was of a mixed woodland type, dominated by conifers of the Pinaceae and Taxodiaceae, and with deciduous angiosperms of the Fagales, Juglandales, and other groups. In the more open swamps of the lower slopes we have evidence of the growth of extinct swamp-cypress-like trees with ferns. The fungus remains such as PESAVIS may have been associated with rotting vegetation in these lowlands. The shorelines of the shallow seaway from Rockall to Spitsbergen were the sites of deposition of remarkably consistent pollen and spore assemblages associated with dinoflagellate cysts of the *Apectodinium homomorphum* plexus and others.

The angiosperm fossils of the BIP flora are mostly members of the Hamamelidae whose modern representatives are classified in families such as the Cercidiphyllaceae, Platanaceae, Hamamelidaceae, Eucommiaceae, Myricaceae, Betulaceae, and the Fagaceae. Of other groups, the Juglandales, Salicales, and Ericales were also represented. In uppermost Cretaceous and lowermost Tertiary deposits at middle latitudes, where nonseasonal evergreen plants were dominant world-wide, ancestors of these groups are rare (Wolfe, 1987). However, at high latitudes such as Alaska, plants of the Hamamelidae became abundant, firstly on unstable substrates, and then as climax forest (Spicer et al., 1987). Together with deciduous conifers, these early hamamelids adapted quickly to winter darkness (Wolfe, 1987).

It was from this Arctic center that many of the BIP Flora's constituents originated. During the Paleocene, deciduousness is thought (Wolfe, 1987) to have become an established feature of physiological efficiency and the Arctic Hamamelidae, being among the first plants to adopt this feature, were the most important part of the BIP angiosperm vegetation (there may have been many deciduous gymnosperms as well). Plants from other groups, such as the Coniferales, Juglandales, Salicales, and Ericales, may also have developed a deciduous habit, though we have little knowledge that it was an exclusive feature within these groups.

Intrabasaltic sedimentation can be expected to preserve plant megafossil remains more or less autochthonously (Burnham and Spicer, 1986). The pollen and spores, on the other hand, would have been transported not only by wind, but by water, to their site of deposition, perhaps over several tens of kilometers. The consistently abundant palynodebris from Cores 104-642E-102 to -109 is well preserved and includes tracheids and cuticle which suggest shallow-water deposition. There is an absence of debris such as amorphous matter which is usually associated with deeper offshore facies. The palynological preparations from the other BIP localities contain similar material, implying equally shallow conditions. *Pediastrum* is present in several samples from Cores 104-642E-102 to -109, suggesting that freshwater conditions were close by.

The palynological assemblage of the BIP is not restricted to intrabasaltic sediments. At the Rockall Plateau intrabasaltic deposits were not cored during DSDP Leg 48, but the same microspore assemblage occurs in clays just above the upper Paleocene

basalts. At Spitsbergen, the beds around the Paleocene/Eocene boundary are associated with ash layers presumed to be derived from volcanicity to the south (Faleide et al., 1988). The Spitsbergen material from the top of the Sarkofagen Formation as well as from the base of the Gilsonryggen Formation is from a distal deltaic facies. Thus the same palynological assemblage is found in a variety of depositional environments, ranging from those producing relatively thin intrabasaltic sediments, through tuffaceous deltaic sediments, to distal deltaic facies. In the Hebridean and Faeroes deposits there is no evidence of marine influence. The consistency of the assemblage shows that we are dealing with a real flora and not just an assemblage associated with a particular kind of intrabasaltic facies.

The BIP flora inhabited the broad area of lava flows and other lowland territory in the vicinity of the line of opening of the northern Atlantic, extending north from the Rockall Plateau to Spitsbergen. No volcanically influenced environment of this scale in both space and time exists in the modern world and so our interpretation of the ecosystem is speculative.

Evidence from Hole 642E (Eldholm, Thiede, Taylor, et al., 1987) shows that there were 120 flows in the upper volcanic series and 17 in the lower volcanic series, and the bulk of this magmatism is thought to have occurred in 2 to 3 m.y. or less (White, 1987). It is conceivable that this regular volcanic ash fall would have had an effect on the composition of the BIP flora, and that once the peculiar environment ceased many of its vegetational elements became extinct. Furthermore, if magmatism occurred every few thousand years, pioneer vegetation conditions would have been created repeatedly, preventing the establishment of the climax forests so familiar in coeval deposits outside the BIP.

We also suggest that there were climatic differences between the BIP and the region to the southeast, as reflected by the greatly contrasting pollen and spore assemblages. For example, in the BIP samples there is a distinct lack of certain pollen types which are usually present in uppermost Paleocene and lowermost Eocene assemblages in northwest Europe. Normapolles, in particular, are apparently absent from Hole 642E, the Faeroes, and Antrim deposits, and they occur only very rarely at Mull and Spitsbergen. Lund (1983 and in press) suggested that the absence of the normapolles from the Faeroes intrabasaltic sediments may be correlated with Krutzsch's (1966) pollen Zone 10 in which the group is poorly represented. This zone is thought by Krutzsch to be Thanetian and to indicate a cooler climatic cycle. The presence of small quantities of these normapolles at Mull and Spitsbergen may suggest that these localities were bordering on the BIP, where the climate was different.

There is evidence from a quite different source, oxygen isotope studies on Paleogene oceans from Antarctica (Shackleton, 1986), which suggests that there was a global climatic cooling around the Paleocene/Eocene boundary.

Other pollen and spores that are common in the northwest European Tertiary basin are either absent at the base of Hole 642E or present in unusually small numbers. Most of the pollen missing are triporate and tricolpate angiosperms usually thought to come from deciduous angiosperms. Also, pollen such as that from the Sparganiaceae, associated with shallow marine deltaic facies, are absent in the BIP flora. Most of the pollen and spore assemblages of the northwest European basin deposited at around this time are of shallow marine facies, as Ziegler's (1982) paleogeographic map suggests.

BIOSTRATIGRAPHIC IMPLICATIONS FOR THE EVOLUTION OF THE BRITO-ARCTIC IGNEOUS PROVINCE

Our biostratigraphic interpretation of Cores 104-642E-102 to -109 based on dinocyst ranges within northwest Europe, and

their correlation with other localities within the BIP are shown in Figure 2. The associated pollen and spore assemblage has the same age, namely earliest Eocene or latest Paleocene.

Because the pollen and spore assemblage from these Hole 642E intrabasaltics is so similar to those from the pyroclastics of eastern Greenland, the Faeroes, the Isle of Mull, and Antrim, and are all different from coeval assemblages outside this area, we call this the BIP flora. At Spitsbergen the same assemblage is associated with ash layers rather than intrabasaltics. Dinocysts are absent from the nonmarine sediments at the Faeroes, Mull, and Antrim. From paleobotanical evidence (reviewed in Boulter et al., 1987), we know that during the Paleocene and early Eocene angiosperm evolution was radiating at the species level, taking advantage of new niches and responding to climatic and environmental changes. This suggests that the BIP flora changed quite quickly, particularly over at least part of the large area from Rockall to Spitsbergen. We know that the climate was cooling across the Paleocene/Eocene boundary and that would have encouraged evolution and/or migration. However, the assemblage over about 25 degrees latitude is very similar. This similarity and distribution suggests a very close age for all the deposits.

Much of the radiometric and geomagnetic work has been summarized for each appropriate locality above, and there seems to be increasing agreement that the peak of volcanic activity lasted for about 3.5 m.y. or less at about 58 Ma (Mussett et al., 1980; LeHuray and Johnson, this volume). Studies of the volcanic ash layers in the Rockall Plateau and North Sea Basin (Knox, 1984; Knox and Morton, 1983) give similar conclusions.

Knox and Morton (1983) discussed the correlation and age of pyroclastic sediments in the North Sea Basin. They identified two main phases of which the younger includes the so-called ash marker which can be correlated with the Mo-clay Formation in Denmark. Biostratigraphically it lies within the *Apectodinium hyperacanthum* dinocyst Zone of Costa and Downie (1976), around the Paleocene/Eocene boundary. The older ash phase, about 2 to 3 m.y. older (at 57-58 Ma on the time scale used by Knox and Morton loc. cit.) is correlated with the Hebridean volcanic province. However, their evidence for this is circumstantial. Our correlation for the Mull volcanics would preferably be with the younger phase of ash, based on the principle of coevality between the intrabasaltic floras of Mull and of the Vøring Plateau, which we have referred to the *A. hyperacanthum* Zone. To what extent this fits in with the radiometric age depends on both the selected estimate from scattered radiometric ages and on the geochronological scale used. Based on Berggren et al. (1985), which we use for Figure 2, the 58-Ma estimate places the Mull basalts at the Paleocene/Eocene boundary, while the scale of Lowrie (1982) has this boundary at 55 Ma and thus would place the Mull basalts in the upper Paleocene. Berggren et al. (1985) place the boundary at 57.8 Ma. This kind of argument becomes tautological, and our contribution cannot assist.

Whether the Mull basalts correlate better to the first or the second pulse of igneous activity as represented by the pyroclastic phases in the North Sea Basin seems still to be an open question, although we would favor the latter. The difference in age between these two alternatives appears to be on the order of 3 m.y. The resolution of available data does not seem to be high enough to settle this question at the moment. We have no objection to the view that the intrabasaltic sediments of the British Isles were somewhat older than those from the Norwegian Sea. The question is by how much.

There seems to be some agreement that the peaks of North Atlantic volcanism lasted only about 3 to 3.5 m.y. (Soper et al., 1976; Mussett et al., 1980; Knox and Morton, 1983; Skogseid and Eldholm, 1987). The associated pyroclastics contain our distinctive BIP flora and, where there was marine influence, di-

nocysts of the *Apectodinium hyperacanthum* Zone. This zone appears to be restricted to the uppermost Paleocene–lowermost Eocene, being equivalent to nannoplankton Zones NP9 and lower part of NP10 (Harland, 1979). The numerical age varies according to different authors' time scales.

Volcanism in the province was not restricted to this time interval; many of the basalts are much younger or older (Evans et al., 1973). Our evidence shows, however, that a land flora of remarkably consistent composition existed in the BIP at this time and that coeval marine sediments in the North Sea and Spitsbergen associated with ash deposits contain more long-distance transported plant material of about the same age.

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APPENDIX

Because this is one of the first times that the Hughes (1986) Palaeo-Data Handling Code (PDHC) has been used publicly, some introductory comments are appropriate. We have several reasons for using this new taxonomic method:

1. It has no formal reliance on practically unobtainable type specimens and on inadequate or ambiguous descriptions which are difficult to match with the specimens being investigated.
2. The PDHC forces statements about variation, the number of specimens counted and synonyms. We feel these data are essential in accurate palynological investigations and we enjoy the rigor of the PDHC system.
3. A biorecord taxon is unique and can be ignored by others if it is shown to be inadequate for any particular purpose.
4. These biorecord-format data are easily stored in personal computer software for sorting and retrieval. This is not so easy with form genera and species whose descriptions lack the forced headings which structure the biorecords, and which are useful for searching and encouraging full descriptions. Micropro's *Wordstar Professional Release 4* Shorthand Default enables Record Forms A and B (Hughes, 1986) to be constructed very easily and gives simple search and selected printout facilities.
5. Some of our biorecords will no doubt soon be shown to have been badly conceived. Certainly, Hughes envisages more concise details. More thought would produce more and different taxa.

Another reason for our crude brevity is that within the 12 samples from ODP Leg 104, Hole 642E, intrabasaltics there is no sign of change in the assemblage upon which to base biostratigraphic divisions. When comparative studies are made with assemblages from elsewhere in the BIP, splitting of our often highly varied (entry N on Hughes's Record Form B), biorecords may stimulate their replacement. We believe it is important at this stage to follow Hughes's (1986) guidelines as closely as possible, and so the data in this appendix are straight expressions of his recommendations. We are not uncritical of the 1986 guidelines for the PDHC, and plan to improve their application to personal computer database software to aid storage, search, and retrieval which many of the 1986 headings do inefficiently.

We hope to have time for more work on these BIP pollen and spores, to give more detailed descriptions, and to investigate more fully the Comparison Records (to be prefixed by cf. A, B, and C) from the other localities in the Province (entry K on PDHC Multi-Purpose Record: Record Form A). Our brief analysis of the morphological variations within each biorecord has detected some variation, described within entry N. Further study will elaborate these details. At present we feel that a more precise biostratigraphy cannot be achieved by using these degrees of variation to establish more biorecords. When more detailed comparisons

are made with the pollen and spores of other localities in the BIP, then comparison entries (K on Hughes's Record Form A) may develop these variation entries (N on Hughes's Record Form B) into new Biorecords. The following biorecords use field *VARIATION N* as a guide to variation in Comparison Records that can be made from specimens in these samples. Many of the biorecord descriptions refer to the detailed descriptions quoted on the relevant cards of Jansonius and Hills' (1976) index. Some space has been saved here by bringing Common Data, entries characteristic of all the biorecords we have made, into one section at the beginning of this appendix, to avoid repetition. We have not done this with entries A (originator) and B (date) as Hughes (1986) advises that these be reserved as the unique identifiers of each taxon.

ODP LEG 104 NORWEGIAN SEA, HOLE 642E

Common Data

Locality	C ODP Leg 104, Norwegian Sea, Hole 642E-102 to 109
Formation	D Lower basalt series
Lithology	F Intrabasaltic volcanoclastics
Age	G Tertiary, e.Eocene/Palaeocene, NP10/11
Numeric Age	H 57 Ma (Berggren et al., 1985)
Preservation	P Thermal alteration index 3-5. Mostly well preserved and compressed
Facies	Q Shallow marine very near shore basaltic lava flows
Repository	R Geological Institute, University of Oslo

Reference Taxon Descriptions

Group	J Monolete
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 December 10, 15.30
Taxon Name	K MONOL SMOOTH
Description	M about 15 × 30 μm, walls about 3 μm thick, often with one fold, wall smooth. Jansonius and Hills (1976) card 1436
Variation	N cf. B: walls thinner, about 1 μm thick. Cf. C: a few specimens have a finely punctate ornament
Number	L 50 counted
Sample	E Core 107-2, 20 cm
Other Record	S Manum, 1962: <i>Laevigatosporites haardt</i> Srivastava, 1975: <i>L. ovatus</i> Lund, 1983: <i>Laevigatosporites haardt</i>

Group	J Monolete
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 December 15, 11.30
Taxon Name	K MONOL SPINES
Description	M about 15 × 30 μm, walls about 3 μm thick, covered with spines up to 2 μm in length. Plate 2, item 7.
Variation	N nothing apparently significant
Number	L 25 counted
Sample	E Core 109-1, 70 cm
Other Record	S none

Group	J Trilete
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 November 5, 9.20
Taxon Name	K TRIL RIDGE
Description	M Amb rounded to triangular with convex sides; ribs 1 to 1.5 μm wide, sinuous with crenate outlines. Equatorial diameter about 35 μm. Plate 2, 6. Jansonius and Hills (1976) card 468.
Variation	N nothing apparently significant
Number	L 22 counted
Sample	E Core 109-1, 90 cm
Other Record	S Wilkinson and Boulter, 1980: <i>Cicatricosporites</i> Group C

Group	J Trilete
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 November 5, 11.30
Taxon Name	K TRIL SMOOTH
Description	M Amb triangular, sides convex-concave, laesurae long, exine smooth-punctate, may have folds and/or distal ridges most commonly 25 to 33 μm in diameter. Plate 2, 8-10. Jansonius and Hills (1976) card 1472.
Variation	N Cf. B: up to 40 μm in diameter
Number	L 49 counted
Sample	E Core 107-1, 110 cm
Other Record	S Manum, 1962: <i>Leiotriletes cf. adriennis</i> Srivastava, 1975: <i>Cyathidites minor</i> , <i>Obtusisporis junctus</i> Lund, 1983: <i>Deltoidospora diaphana</i> Wils. and Webst.

Group	J Trilete
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 November 1, 15.50
Taxon Name	K TRIL BAC
Description	M 50 to 70 μm in diameter, often broken and usually folded. Exine less than 1 μm thick, baculae 1 to 3 μm high and the shorter ones look like gemmae. The trilete mark is about 3/4 the diameter of the spore. Plate 2, 2-5. Jansonius and Hills card 219.
Variation	N nothing apparently significant
Number	L 50 counted
Other Record	S Manum, 1962: <i>Baculatisporites cf. gemmatus</i> Krutzsch, 1969: <i>Baculatisporites gemmatus</i> Lund, 1983: <i>B. gemmatus</i>

Group	J Inaperturate
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 November 4, 12.10
Taxon Name	K INAP SPLITPAP
Description	M about 25 to 35 μm in diameter, round; wall smooth, 1.5 μm thick; prominent split with papilla usually at its edge. Plate 2, 18-22.
Variation	N nothing apparently significant
Number	L 100 counted
Sample	E Core 102-1, 50 cm
Other Record	S Simpson, 1961: <i>Taxodium distichiforme</i> Srivastava, 1975: <i>Taxodiaceapollenites distichiforme</i> Lund, 1983: <i>Inaperturopollenites hiatus</i>

Group	J Inaperturate
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 November 5, 12.00
Taxon Name	K INAP SPLIT
Description	M about 30 × 20 μm, oval, wall smooth, 0.5 μm thick, often folded prominent split with no papilla. Plate 2, 16-17. Jansonius and Hills (1976) card 1308?
Variation	N cf. B: about 30 μm round, rarely folded
Number	L 100 counted
Sample	E Core 107-2, 20 cm
Other Record	S Simpson, 1961: <i>Cunninghamia rugosa</i> Manum, 1962: <i>Inaperturopollenites</i> sp. A Srivastava, 1975: <i>Taxodiaceapollenites distichiforme</i> Lund, 1983: <i>Inaperturopollenites hiatus</i>

Group	J Inaperturate
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 November 4, 13.30
Taxon Name	K INAP PAP
Description	M about 25 μm diameter, round, wall smooth, 1.5 μm thick, papilla up to 3 μm long, with no split. Plate 2, 23-5. Jansonius and Hills (1976) card 2582.
Variation	N cf. B: scabrate, often with a fold and often oriented with the papilla central to appear as a pore.
Number	L 200 counted
Sample	E Core 102-1, 50 cm
Other Record	S Simpson, 1961: <i>Metasequoia shiabensis</i> Manum, 1962: <i>Sequoiapollenites</i> sp. Srivastava, 1975: <i>Sequoiapollenites shiabensis</i> Lund, 1983: <i>Sequoiapollenites paleocenicus</i>

Group	J Monocolpate
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 November 3, 14.00
Taxon Name	K MONOCOLP VERRUC
Description	M Round — oval, about 40 to 50 μm in diameter. Verrucae up to 4 μm high and wide. Plate 2, 1. Jansonius and Hills (1976) card 2547.
Variation	N nothing apparently significant
Number	L 23 counted
Sample	E Core 102-1, 70 cm
Other Record	S Manum, 1962: <i>Sciadopityspollenites serratus</i> Lund, 1983: <i>Sciadopityspollenites serratus</i>

Group	J Monocolpate
Originator	A M.C. Boulter, North East London Polytechnic
Date	B 1986 December 10, 13.00
Taxon Name	K MONOCOLP SMOOTH
Description	M Colpus does not extend to poles, ending about 2 μm short, pollen about 30 μm long. Plate 2, 11-15. Jansonius and Hills (1976) card 1691.
Variation	N cf. B: colpus extend to poles, which have pointed ends (Jansonius and Hills (1976) card 703: <i>Cycadopites</i>). Distinction between these two (at least) forms has not been made here be-

cause there is no stratigraphic significance: both forms occur in the same samples and the distinguishing features are often obscured.

Number L 48
 Sample E Core 102-1, 90 cm
 Other Record S Simpson, 1961: *Liriodendron sewardii*, *Magnolia scotica* Manum, 1962: *Monocolpopenites* sp.

Group J Bisaccates
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 1, 11.00
 Taxon Name K BISAC STRAIGHT
 Description M Size varies from about $30 \times 50 \mu\text{m}$ to about $40 \times 70 \mu\text{m}$. Lines of attachment of the sacchi to the body are straight. Similar to *Pityosporites* haploxyton-type (Rudolph). Plate 3, 5, 11, 14.
 Variation N nothing apparently significant
 Number L 100 counted
 Sample E Core 102-1, 70 cm
 Other Record S Simpson, 1961: *Picea scotica*, *Cedrus hebridica* Srivastava, 1975: *Cycadopites shiabensis* Lund, 1983: *Pityosporites labdacus*

Group J Bisaccates
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 1, 10.30
 Taxon Name K BISAC ROUND
 Description M Size varies from about $35 \times 60 \mu\text{m}$ to about $50 \times 75 \mu\text{m}$. Lines of attachment of the sacchi to the body are curved. Similar to *Pityosporites* sylvestris-type (Rudolph). Varies in size, ornament, and of course is compressed in a variety of planes. Plate 3, 2-4, 6.
 Variation N nothing apparently significant
 Number L 100 counted
 Sample E Core 102-1, 50 cm
 Other Record S Simpson, 1961: *Pinus hebridica* Manum, 1962: *Pityosporites cf. labdacus* Srivastava, 1975: *Cedripites hebridicus* Lund, 1983: *Pityosporites cf. alatus*

Group J Bisaccates
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 1, 10.45
 Taxon Name K BISAC THICKEDGE
 Description M Similar to BISAC ROUND but the edges of the sacchi have a distinctive thickening. In less well-preserved forms this remains as a particularly prominent feature. Plate 3, 10, 12-13.
 Variation N nothing apparently significant
 Number L 100 counted
 Sample E
 Other Record S Simpson, 1961: *Pinus pre-excelsa*, *Pseudolarix bremanoirensis* Srivastava, 1975: *Pinuspollenites pretabuliformis* Lund, 1983: cf. *Pityosporites* type A, *Pityosporites cf. pacitovae*

Group J Bisaccates
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 2, 12.15
 Taxon Name K BISAC LARGE
 Description M Size varies from about $45 \times 80 \mu\text{m}$ to about $60 \times 120 \mu\text{m}$. The body usually has a thickly (5 to $8 \mu\text{m}$) ornamented edge and the edges of the sacchi have a characteristic structure. Plate 3, 8.
 Variation N cf. B: the surface ornament of the sacchi is often coarser
 Number L 25 counted
 Sample E Core 102-1, 90 cm
 Other Record S Simpson, 1961: *Picea scotica* Manum, 1962: *Abiespollenites* sp., *Abietinaepollenites* sp. Lund, 1983: *Piceapollenites* sp.

Group J Bisaccates
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 3, 14.55
 Taxon Name K BISAC SMALLBODY
 Description M The diameter of the body is less than the height of the sacchi. The body usually has a thickened edge and the ornamentation of the sacchi tends to radiate from the centre. Plate 3, 1, 7, 9.
 Variation N cf. B: The size ranges from about $35 \times 55 \mu\text{m}$ to $55 \times 70 \mu\text{m}$
 Number L 25 counted
 Sample E Core 107-1, 110 cm
 Other Record S Simpson, 1961: *Podocarpus magna*

Group J Triprojectorates
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 December 20, 12.00
 Taxon Name K TRIPROJECT
 Description M These badly preserved specimens measure about $30 \mu\text{m}$ at the polar axis and about $20 \mu\text{m}$ at the equatorial axis. Spines are usually preserved but the structure of the pores remain elusive; Plate 4, 3.
 Variation N cf. B: spines are absent. Plate 4, 4.
 Number L 16 counted
 Sample E Core 109-1, 90 cm
 Preservation P often poor (no other reworked forms are found in these Hole 642E samples). Boulter's sample 249 from Ardtun, Mull, and that from DSDP Leg 38, 338-41-2, 104 cm, both contain well-preserved specimens of what appear to be the same taxon.
 Other Record S Simpson, 1961: *Taurocephalus proteus* Manum, 1962: Incertae sedis Type A (similar forms to this TRIPROJECT are found in the material studied here from the Sarkofagen Formation of Spitzbergen, Table 1).
 Martin, 1968: *Aquilapollenites pachypolus* Srivastava, 1975: *Aquilapollenites ?subtilis* Boulter, 1986: Eocene triprojectates

Group J Triporates
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 22, 16.40
 Taxon Name K TRIP SUBEQUAT
 Description M The greatest diameter varies from about $30 \mu\text{m}$ to about $50 \mu\text{m}$, the three pores are slightly subequatorial and have about a $2\text{-}\mu\text{m}$ thickening at the margin. Usually there is a labrum at the center and a fold between one or more of the pores. These folds occasionally make it difficult to distinguish specimens from *Interpollis*; Plate 4, 5-10.
 Variation N cf. B: The shape varies from round to more or less triangular. For example, the sample with the most abundant specimens (Core 642E-107-1, 110 cm) may show that this single (and simply defined) biorecord should be split into at least two additional biorecords, one for cf. *Interpollis* and another for thicker walled pollen with pores more deeply subequatorial [compare Jansonius and Hills (1976) cards 404 and 1730].
 Number L 50 counted (these account for about 20% of the assemblage at the base of Hole 642E (Table 2).
 Sample E Core 102-1, 90 cm
 Other Record S cf. ? *Interpollis* Lund, 1983: *Momipites/Caryapollenites, Caryapollenites triangulus* Simpson, 1961: *Corylus mullensis* Srivastava, 1975: *Triporopollenites mullensis* Frederiksen and Christopher, 1978: *Casuarinidites convexus?*

Group J Triporate
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 December 3, 12.45
 Taxon Name K TRIP EQUATLARGE
 Description M Triporate pollen 35 to $45 \mu\text{m}$ in diameter, usually with folded proximal and distal faces, with a more or less triangular shape; Plate 4, 11-12.
 Variation N cf. B: Pores vary in structure and protrusion and some specimens have no folds. More work may show reason to establish other taxa from specimens in these deposits.
 Number L 30
 Sample E Core 105-4, 70 cm
 Other Record S none

Group J Triporate
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1987 February 22, 11.45
 Taxon Name K TRIP EQUATSMALL
 Description M Triporate pollen 20 to $35 \mu\text{m}$ in diameter; pores usually not thickened; Plate 4, 13-16.
 Variation N cf. B: pore thickening and surface ornament vary: no apparent stratigraphic significance; rare.
 Number L 17 counted
 Sample E Core 102-1, 90 cm
 Other Record S Simpson, 1961: *Engelhardtia granulata*

Group J Tricolporate
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 2, 10.00
 Taxon Name K TRICOLPOR SMALL

Description M Tricolporate pollen 25- to 35- μm polar length; Plate 4, 13-16.
 Variation N cf. B: various ornament and pore structure
 Number L 10 counted
 Sample E Core 102-1, 90 cm
 Other Record S cf. B, Lund, 1983: *Tricolporopollenites baculoferus*
 cf. C, Lund, 1983: *T. villensis*
 cf. C, Lund, 1983: *T. sp.*

Group J Tripolporate
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 3, 9.45
 Taxon Name K TRICOLPOR LARGE
 Description M Tricolporate pollen 35- to 45- μm polar length; Plate 4, 33-34.
 Variation N cf. B: ornamentation and pore structure vary but without apparent stratigraphic significance.
 Number L 6 counted
 Sample E Core 102-1, 90 cm
 Other Record S Simpson, 1961: *Cornus scotica*
Cornus bremanoirensis

Group J Tricolporate
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 4, 13.00
 Taxon Name K TRICOLP LARGE
 Description M Tricolporate pollen 25- to 40- μm polar length, smooth exine
 Variation N nothing apparently significant
 Number L 29 counted
 Sample E Core 102-1, 90 cm
 Other Record S Simpson, 1961: cf. *Tricolpites parvus*

Group J Tricolporate
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 November 2, 20.00
 Taxon Name K TRICOLP RETSMALL
 Description M reticulate, nearly spherical, prolate or oblate, 25 to 40 μm ;
 Plate 4, 29-31.
 Variation N cf. B: larger forms, up to about 45 μm occur very rarely (Plate 4, 32). They are preserved in the polar plane with the reticulum up to 4 μm . These rare forms are most common at Mull.
 Number L 50
 Sample E Core 102-1, 90 cm
 Other Record S Simpson, 1961: *Hamamelis scotica*
 Srivastava, 1975: *Tricolpites dubhensis*
 Lund, 1983: *Tricolpopollenites sp. 2*

Group J Multiporate
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 October 30, 13.45
 Taxon Name K MULTIP RETIC
 Description M 35- μm diameter, about 20 pores, finely reticulate, (Jansonius and Hills, card 1373) Plate 4, 25-26.
 Variation N cf. B: size and compression angle, some having smaller (less than 5 μm) pores; Plate 4, 22-24 and others with fewer pores

(Plate 4, 20-21) cf. C: folded with fewer (6-10) pores of varying structure; variable surface ornament.

Number L 20 counted
 Sample E Core 102-1, 50 cm
 Other Record S Chenopodiaceae-types
 Simpson, 1961: *Juglandipites magniforamina*

Group J Multiporate
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 October 12, 18.00
 Taxon Name K MULTIP ARCI
 Description M 25- to 30- μm diameter, five pores, arci about 5 μm wide;
 Plate 4, 17-19.
 Variation N cf. B: size varies from 20- to 35- μm diameter
 Number L 20 counted
 Sample E Core 102-1, 50 cm
 Other Record S Simpson, 1961: *Alnus pre-cordata*
Alnus pre-japonica
Alnus alternipora
Alnus rubrifformis
Alnus scotica
Alnus bremanoirensis
 Manum, 1962: *Alnipollenites* spp.
 Srivastava, 1975: *Polyvestibulopollenites vs. P. scoticus*
 Lund, 1983: *Polyvestibulopollenites* spp.

Group J Tetrad
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 October 23, 10.00
 Taxon Name K TETRAD SMALL
 Description M Tetrahedral tetrads 25 to 35 μm across
 Variation N cf. B: some are more loosely attached than others
 Number L 29 counted
 Sample E Core 102-1, 90 cm
 Other Record S none

Group J Fungi
 Originator A M.C. Boulter, North East London Polytechnic
 Date B 1986 December 1, 15.00
 Taxon Name K PESAVIS
 Description M Multicellular fungal fruiting body; stalked central cell and two arms with 9 cells, about 40 μm in diameter. Jansonius and Hills (1976) card 1977
 Variation N cf. B: smaller, 30- μm diameter with contracted arms
 Number L 15 counted
 Sample E Core 102-1, 50 cm
 Other Record S Lund, 1983: *Pesavis tagluensis*

Specimens of other taxa are present in some preparations from Hole 642E samples, as indicated in Figure 3. They are present in small quantities, usually as single specimens, and therefore do not qualify for biorecord status in these data. The most distinctive specimens in this category are triporate pollen.

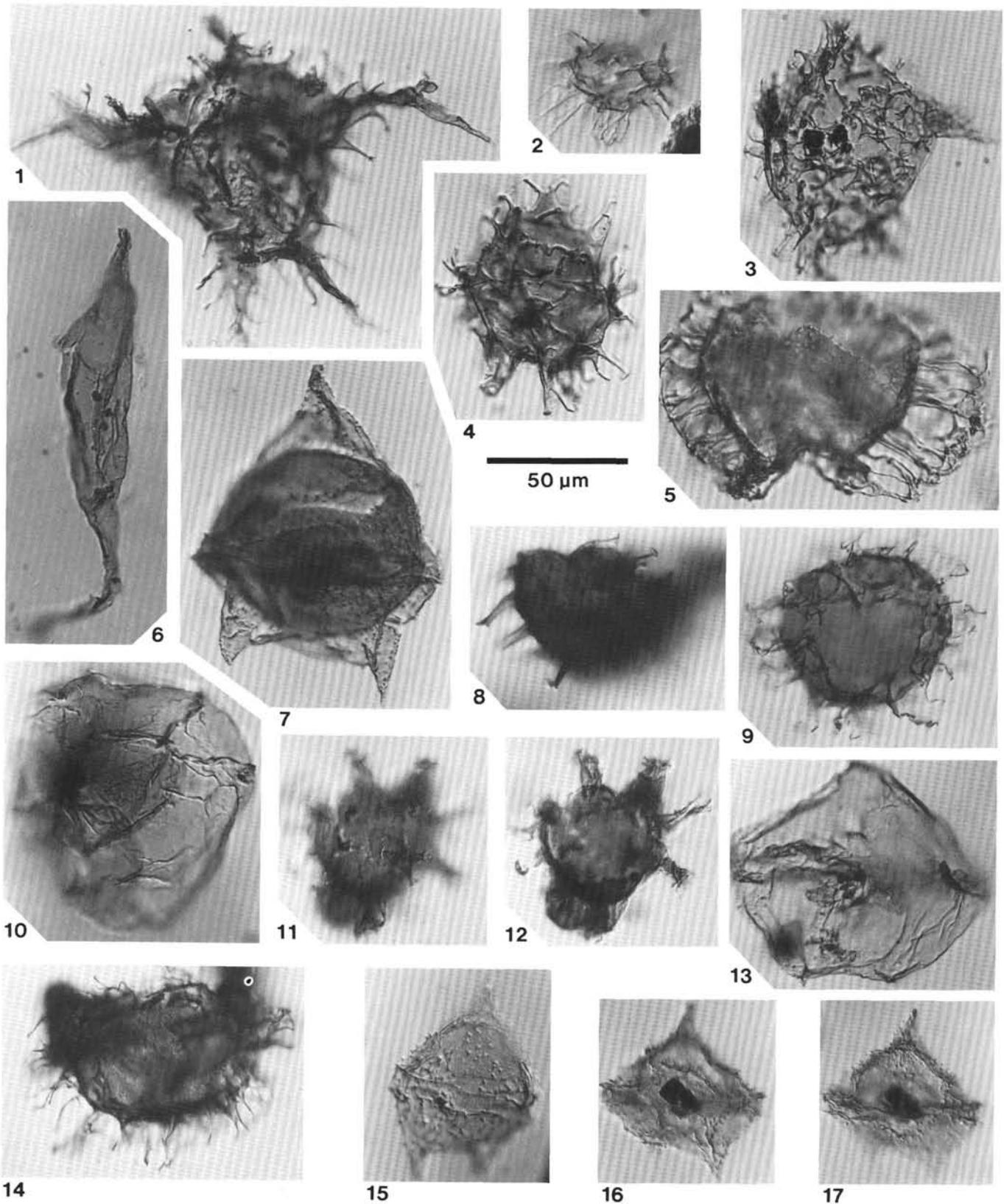


Plate 1. Scale bar 50 μm ; all Sample references are to ODP Leg 104, Hole 642E. 1. *Apectodinium augustum*; -102-1, 109–110 cm. 2. *Diphyes colligerum*; -102-1, 50–51 cm. 3. *Apectodinium hyperacanthum*; -107-2, 10–11 cm. 4. *A. parvum*; -107-2, 10–11 cm. 5. *Glaphyrocysta pastielsii*; -102-1, 50–51 cm. 6. *Palaeocystodinium golzowense*; -107-2, 10–11 cm. 7. *Deflandrea oebisfeldensis*; -102-1, 109–110 cm. 8. *Polysphaeridium subtile*; -102-1, 70–71 cm. 9. *Glaphyrocysta ordinata*; -107-1, 109–110 cm. 10. *Thalassiphora delicata*; -102-1, 89–90 cm. 11–12. *Hystrihokolpoma rigaudiae*; 107-1, 109–110 cm. 13. *Lejeunecysta hyalina*; -102-1, 109–110 cm. 14. *Areoligera senonensis*; -109-1, 109–110 cm. 15. *Lentinia wetzeli*; -109-1, 90–91 cm. 16–17. *L. wetzeli*; -102-1, 109–110 cm.

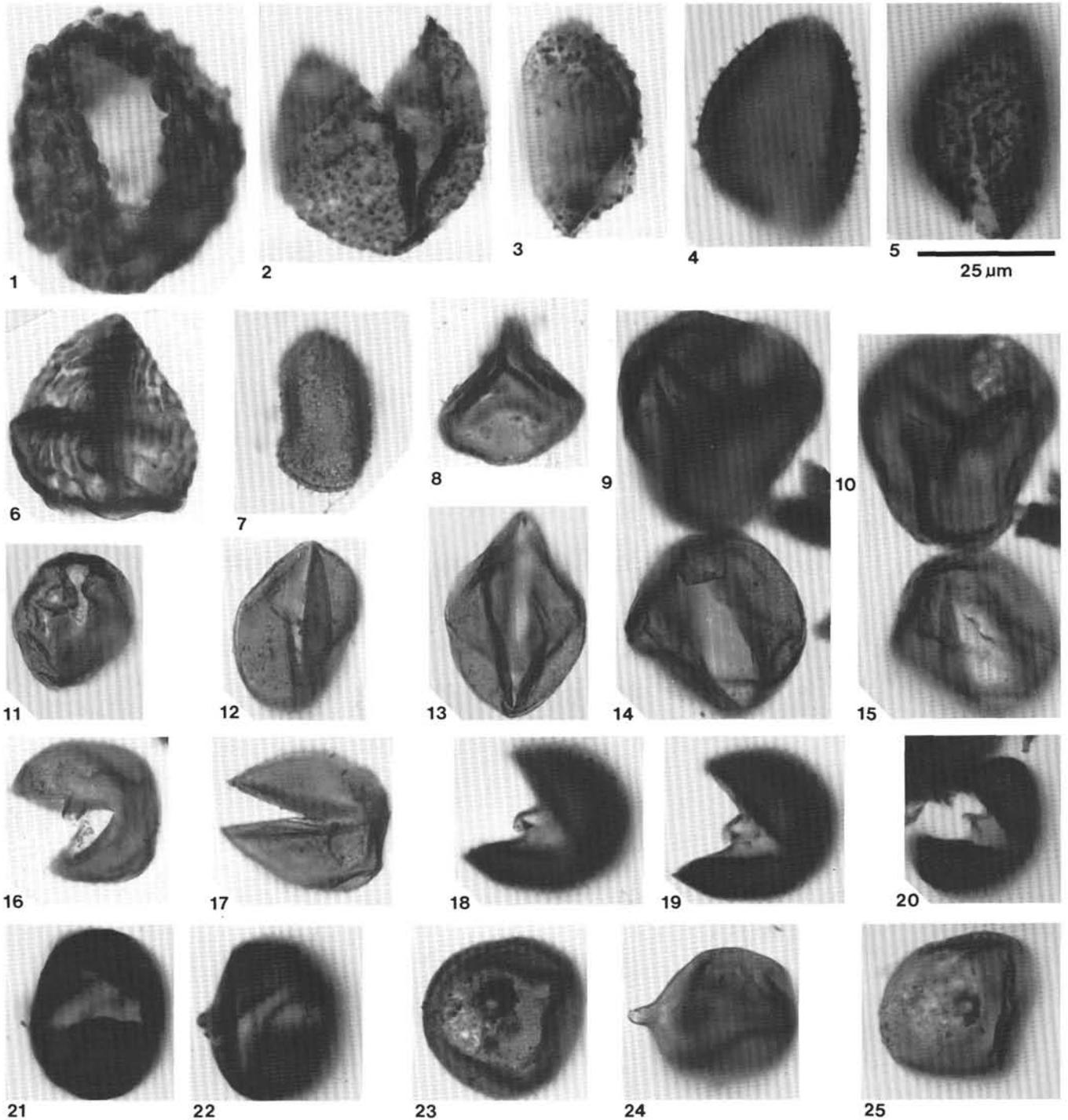


Plate 2. Scale bar 25 μm . All specimens are from ODP Leg 104, Hole 642E. Biorecord descriptions are listed in the Appendix. 1. *MONOCOLP VERRUC.* 2-5. *TRIL BAC.* 6. *TRIL RIDGE.* 7. *MONOL SPINES.* 8-10. *TRIL SMOOTH.* 11-15. *MONOCOLP SMOOTH.* 16-17. *INAP SPLIT.* 18-22. *INAP SPLITPAR.* 23-25. *INAP PAR.*



Plate 3. Scale bar 25 μm (except 50 μm for 3.8). All specimens are from ODP Leg 104, Hole 642E. Biorecord descriptions are listed in the Appendix. 1, 4, and 10. *BISAC STRAIGHT*. 2, 3, and 5. *BISAC THICKEDGE*. 6, 8. *BISAC SMALLBODY*. 7. *BISAC LARGE*. 9-14. *BISAC ROUND*.

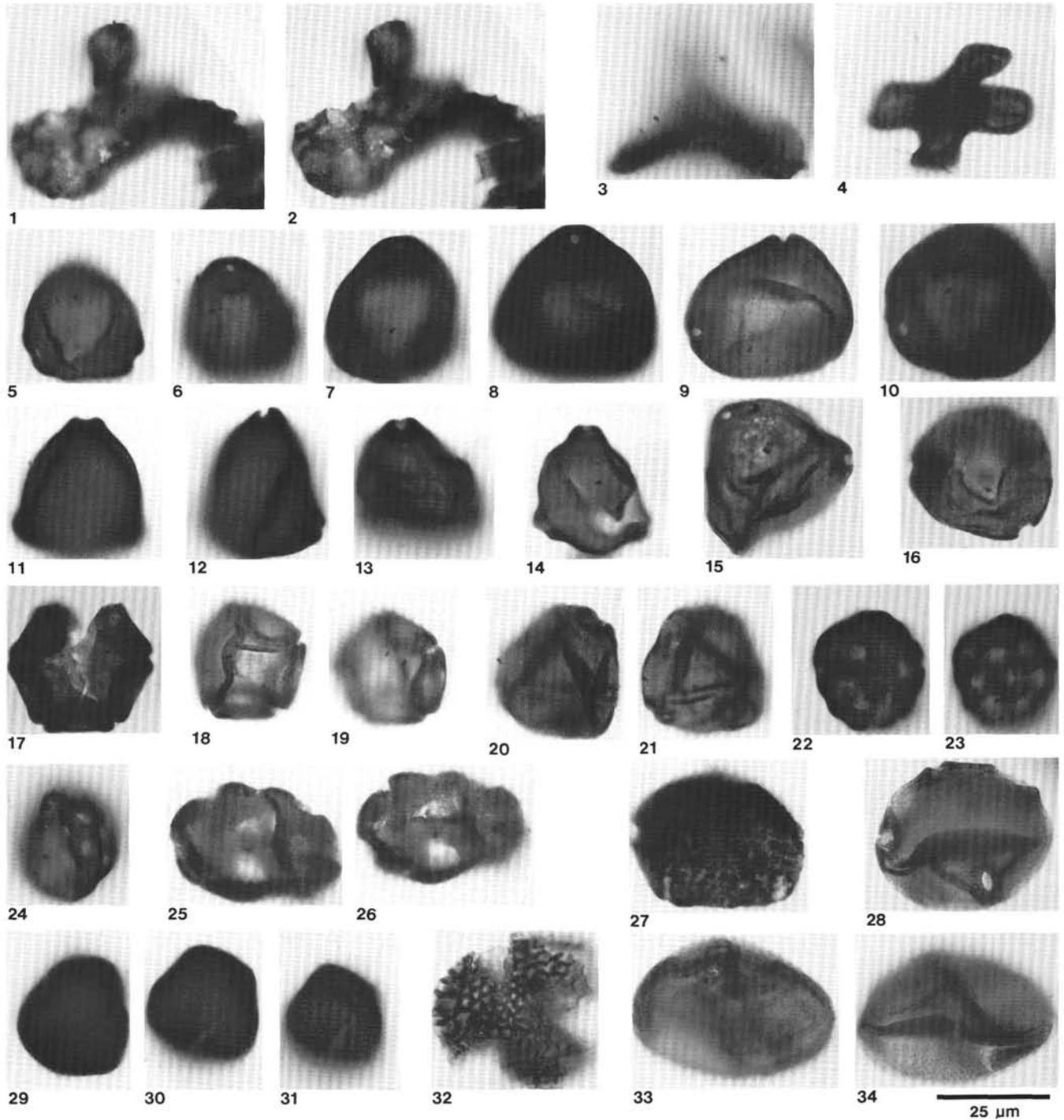


Plate 4. Scale bar 25 μ m. All specimens are from ODP Leg 104, Hole 642E. Biorecord descriptions are listed in the Appendix. **1 and 4.** *TRIPROJECT*. **5-10.** *TRIP SUBEQUAT*. **11-12 and 15-16.** *TRIP EQUATLARGE*. **13-14.** *TRIP EQUATSMALL*. **17-19.** *MULTIP ARCI*. **20-21.** *MULTIP RETIC cfC*. **22-24.** *MULTIP RETIC cfB*. **25-26.** *MULTIP RETIC*. **27-28.** *MULTIP RETIC cfC*. **29-31.** *TRICOLP RETSMALL*. **32.** *TRICOLP RETSMALL cfB*. **33-34.** *TRICOLPOR LARGE*.