A SURVEY OF THE NEOGENE FLORA FROM TWO DERBYSHIRE POCKET DEPOSITS

by

M.C. Boulter

Summary

The fossil plants which occur in the uppermost beds of clay in two of the pocket deposits in the Derbyshire Carboniferous Limestone have been shown to be of an Upper Miocene - Lower Pliocene age. The fossils that have been identified from the deposits consist of 63 pollen and spore taxa, three species of conifer wood, five species of conifer leaves, three types of angiosperm leaves, five species of seeds or fruits, three species of fungi and one species of moss. The pollen and spores are attributed to woody and herbaceous angiosperms, conifers, pteridophytes and several form species probably assignable to *Sphagnum* spp. Most of the macrofossils have been identified as modern genera, though none are assigned to modern species. The entire flora is interpreted in terms of European floral history during the Cainozoic era, and comparison is made to other European fossil floras of a similar age. Reference to the modern distribution of the constituent genera suggests that during the L. Pliocene, Derbyshire was experiencing a warm, oceanic climate.

Introduction

The Carboniferous Limestone which outcrops in the north western part of Derbyshire has been comprehensively studied by geologists over the last century; in Ford and Mason's (1967) bibliography of the writings on the region up until 1965, 123 references are listed. It is surprising, therefore, that the fossil plants which for many years have been known to occur in the pocket deposits within the limestone have not been the subject of detailed study before now.

Ten years ago, the then Geological Survey passed specimens of the fossil wood and plant bearing clay from one of the pocket deposits to Dr. W.G. Chaloner, who published a brief note on his initial observations (Chaloner, 1961). He concluded from identifications of fossil wood, small conifer leaf fragments, and pollen, that the deposits are probably of late Tertiary age - a conclusion which is confirmed by more detailed study (Boulter, 1970).

The two pocket deposits which have been found to bear fossil plants, Kenslow Top pit (SK 180615) and Bee's Nest pit (SK 240545), have both been visited by the author on about 20 occasions over the past four years. Accurately sampled clay specimens have been obtained from both localities for pollen analysis, fossil wood has been collected, and other macrofossils have been obtained by sieving large samples of the clay. On one occasion small blocks of lignite, consisting of compressed shoots, seeds and wood, were collected from the Bee's Nest pit.

As the investigation of this newly collected material progressed, it became clear that there were four major centres of interest: a contribution to the macro- and microfossil record; the determination of the age of the flora; an increase in the understanding of the structure of fossil leaf cuticles; and lastly, elucidation of the methods by which the pocket deposits originated. Of paramount importance to each of these phenomena has been the unique age (within the British Isles) of the Derbyshire flora, at the Upper Miocene - Lower Pliocene. Not only does this mean that the Derbyshire fossils give the first known indication of the Flora of north west Europe during this time, but they also add significantly to our understanding of the origins of the Flora of the British Isles.

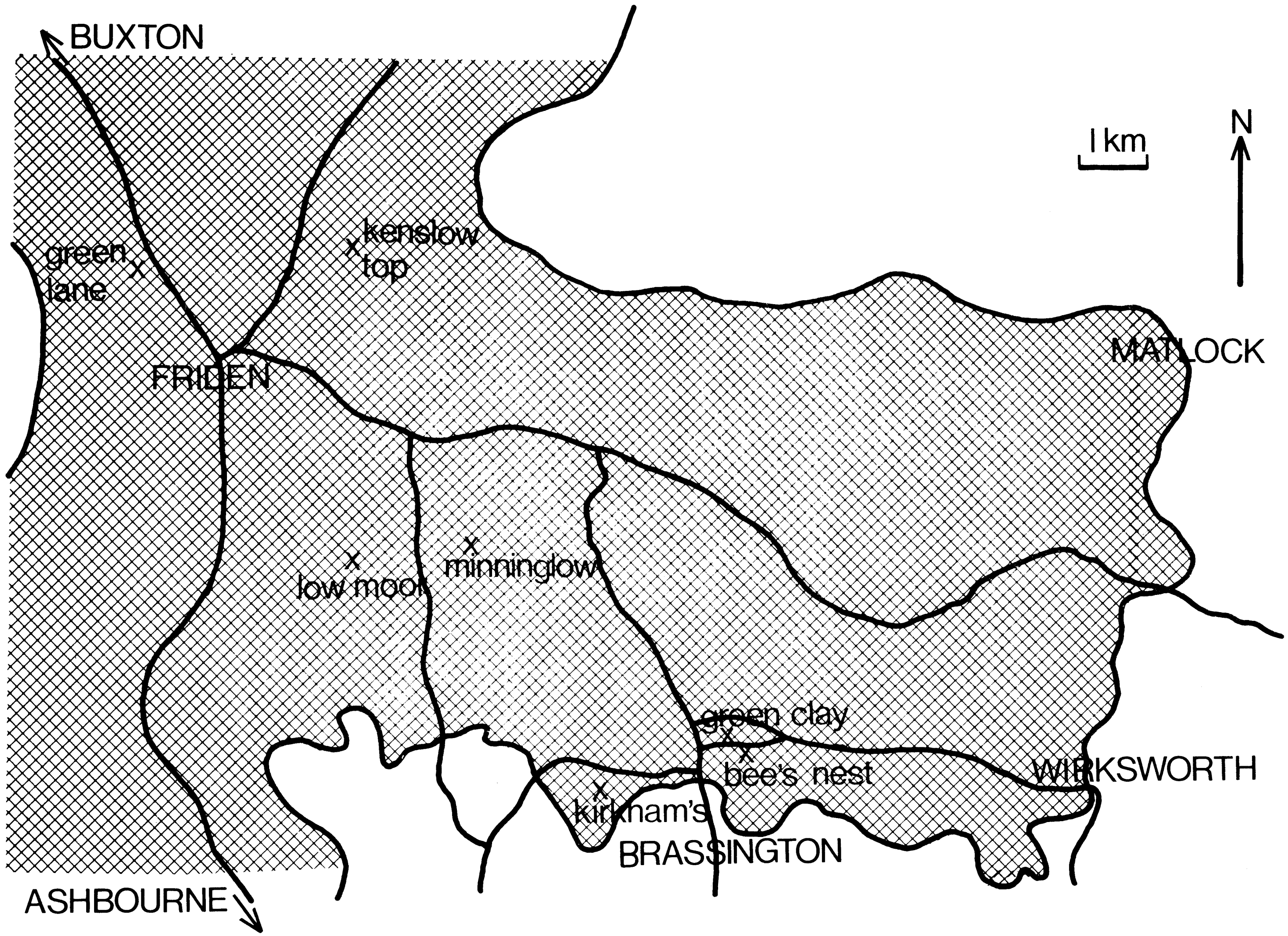

Figure 1. The outcrop of Carboniferous Limestone (diagonal shading) in Derbyshire, showing the location of those Pocket Deposits mentioned in this investigation.

It was during the Tertiary period that many modern plant genera first made their appearance, floras became increasingly provincialised, and there was evolutionary development of a very large number of herbaceous plants. These processes increase the problems confronting the Tertiary palaeobotanist - especially the palynologist - when attempting identifications of fossil plants; they result in a confluence of traditionally palaeobotanical practices with the methods of the Quaternary botanist and the neobotanist. Tertiary plant remains, usually found as isolated plant fragments, can in most cases be assigned to a modern genus (pollen from herbaceous plants forms the largest single exception to this), but changes in modern generic distribution, and the evolutionary changes that have occurred within most plant genera since the Middle Tertiary, make specific identification very difficult. Ideally, the fossil plant organ should be compared with the same part from all extant species; though very few modern species were represented in Europe during the Lower Pliocene. So although comparison of pollen, wood, foliage and seeds to modern reference material is useful in identification at generic level, its value at the more concise specific level is severely limited.

The Derbyshire Pocket Deposits

The outcrop of Carboniferous Limestone in north western Derbyshire (Figure 1) preserves about 60 known pocket deposits which are filled with silica sand, clay and pebble bands. They were first mentioned in the literature by Pilkington (1789) who described pottery clay workings in some of the deposits, though an individual description did not appear until the end of the 19th century when the deposits were more fully exposed by excavations for the silica sands (Howe, 1897). In recent times, debate on the pocket deposits has mainly centred on their age and method of origin (Ford & King 1969; Boulter & Chaloner, 1970).

The occurence of fossil plants in some of the clay infillings was first recognised by Howe (1897) who reported a "bed of lignified wood and carboniferous matter at the northern end of Minning Low pit (SK 202574), near the top". Subsequent references to fossil wood have been made, though only from Bee's Nest pit, Brassington (Kent, 1957, Yorke, 1961) and Kenslow Top Pit, Friden (Yorke, 1961); it is only from the uppermost clays of these two sink holes that plant remains have been discovered during the present investigation (Figure 2). Reconnaisance of the exposed deposits at several other pits (Figure 1), including Green Clay pit (SK 241548), Kirkham's pit (SK 217540), Green Lane pit (SK 174628), Low Moor pit (SK 187566) and Minning Low pit, have not revealed fossil plants, or infillings higher than the coloured clays figured in Boulter & Chaloner (1970). In the light of Howe's record of plants from Minning Low it would perhaps be fruitful to clear off the vegetation cover from the sides of the pit; a search there during October 1968 was frustrated by the absence of exposed sands or clays. A local farmer explained then that the pit has not been used for about 70 years; this suggests that the plant bed described by Howe may not have been removed.

As explained by Boulter & Chaloner (1970) the Neogene plant beds at Brassington and Friden are the youngest preserved sediments in the succession of the infilled material. If these two deposits are the remnants of what was once a substantial cover of plant bearing sediment, most other pocket deposit do not possess the upper strata either because the sink holes are too shallow or because the plant beds have been removed by glacial action.

Since the plant beds at both deposits are the only infilling sediments with Tertiary fossil remains, their relationship to the underlying strata is pertinent to the estimation of the age of the sediments. In a study of the pollen and spores from the plant beds, Boulter (1971, a) has explained how the pollen bearing grey clay at both Bee's Nest pit and Kenslow Top pit becomes blended with non-pollen bearing paler grey clay at the base of each plant bed. This phenomenon is consistent both with the suggestion that there is no unconformity between the plant bed and the underlying sediment (Walsh & Brown, 1971) and with Kent's (1957) proposed sequence of Tertiary deposition on the older underlying silica sands and clays.

Workings at a limestone quarry on Hind Low (SK 083693), some 15 Kms. north east of Kenslow Top pit during November 1969 exposed a pocket deposit which was only about 100 m. in diameter and 6 m. deep. Fossil wood, similar to that badly preserved from the Bee's

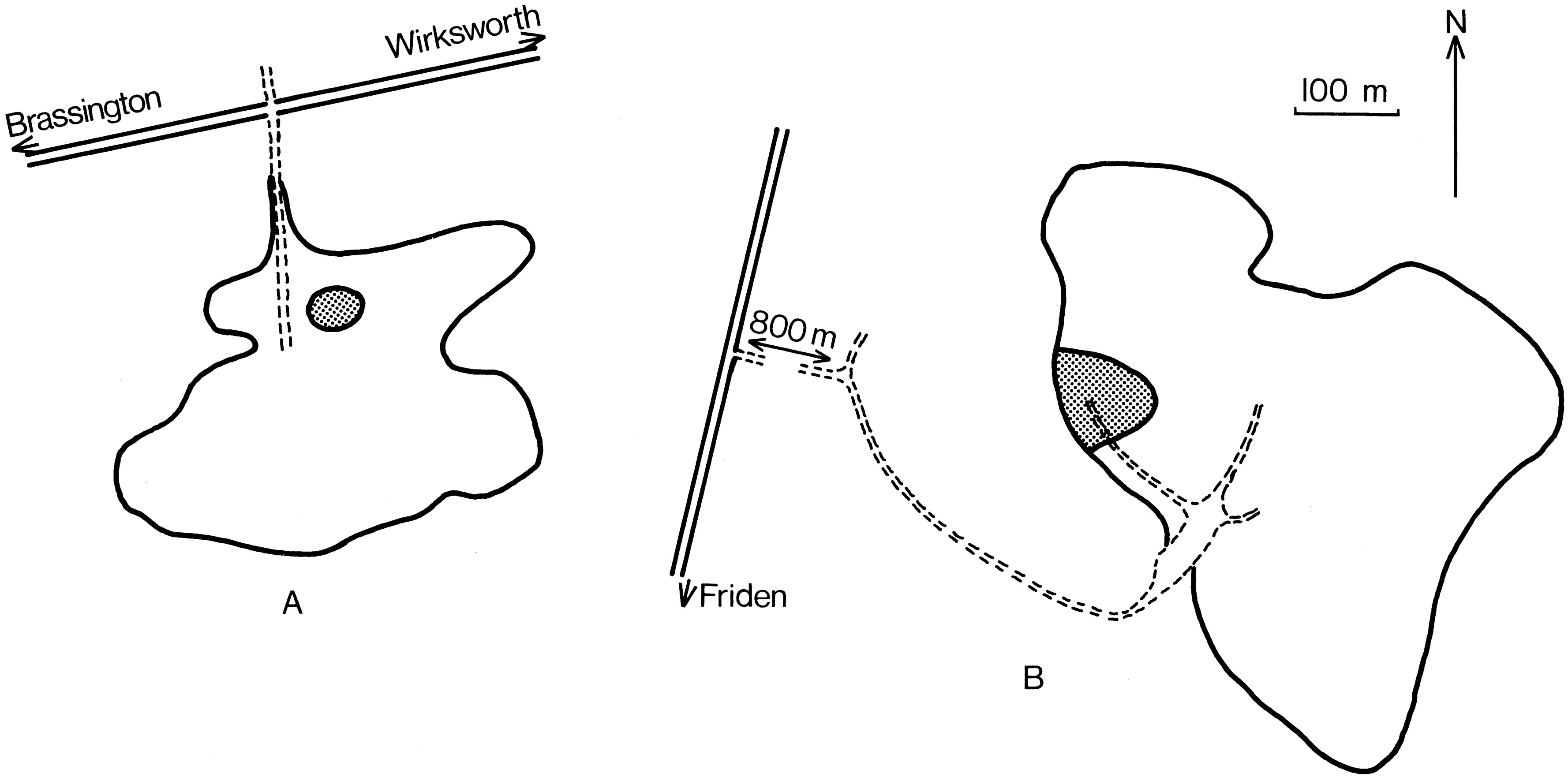

Figure 2. The excavated margins of Bee's Nest pit (A) and Kenslow Top pit (B) showing the position within each of the plant bearing bed (dotted shading, The roads and access tracks to each pit can be compared to the map in figure 1.

Nest pit, was found in the infilling clay by Dr. N. Aitkenhead of the Institute of Geological Sciences (personal communication), though subsequent visits by the author did not yield any wood at all. Palynological studies of the infilling show it to be Namurian Shale (Walsh et al., *in litt*); Tertiary pollen-bearing clays, as well as the sands and pebble bands found underlying them in the more southern pits, were completely absent. One possible explanation to this is that the small pocket deposit was too shallow to allow these sands and clays (which, according to Walsh et al., overlay a cover of Namurian Shale) to infill it during collapse.

Relationships to other British and European Plant Bearing Deposits

The Derbyshire pocket deposits have often been compared to the smaller pocket deposits in the Carboniferous limestone of N.E. Wales, 80 kms. to the west. These have recently been reinvestigated by Walsh & Brown (1971) who attribute a Tertiary, probably Neogene, age to them as a result of geomorphological studies. Although no plant remains have been found from any of the N. Wales deposits, the nature of their infillings, their size, and their relation to the surrounding landscape, suggest an origin similar to that of the Derbyshire deposits.

Another group of just four supposed pocket deposits occur in the Carboniferous Limestone in Co. Tipperary, at Ballymacadam. Watts (1957) published a preliminary account of a pollen assemblage from the clays of the larger of these deposits and reported that it suggests a Lower Tertiary age for the clays. At the beginning of this present investigation it was hoped to undertake a more detailed analysis of the fossil plant remains from Ballymacadam, but when the deposit was visited in June 1968 it was found to be flooded and very much overgrown. Maceration of a piece of the clay which was sampled showed a high percentage of modern grass pollen grains, suggesting that there was a high degree of contamination. The other palynomorphs corresponded well with those identified by Watts to suggest an Oligocene age.

The well known Lower Pleistocene (West, 1968) fissure deposits on the Co. Durham coast near Castle Eden (Trechmann, 1915) bear less geological resemblance to the Derbyshire sink hole deposits than do the deposits mentioned above from Ballymacadam and N.E. Wales. The flora which was described from the fissure clays (Reid, 1920a) is one of the few (if not the only-) British floras closely related in age to the Derbyshire Neogene flora. Reid's list of species from the deposit is based on the identification of seeds and fruits, and it was hoped to compare her results, and those from the Derbyshire deposits, with new identifications from a palynological analysis of the Castle Eden deposits. However, in July 1969, the coastal section from which Reid's material was obtained (Trechmann, 1914) was found to be completely covered with industrial waste, and so no such comparison has been possible.

Badly preserved fossil wood has been discovered recently in the dark transported residuum of the Tynagh residual ore body in Co. Galway, Eire (Morrissey & Whitehead, 1969). Their geomorphological evidence suggests that the deposit originated by the weathering of heavily mineralised limestones sometime during the Tertiary. The wood represents the sole palaeontological record from the deposit and is thought to have been transported into the deposit by fluvial action.

Other Tertiary plant bearing deposits within the British Isles that have been described are of Paleocene and Palaeogene age. The most fully described of these floras are those from the London and Hampshire basins, and current knowledge has been summarised by Chandler (1964). Macrofossils from the lake deposits at Bovey Tracey in Devonshire give an Oligocene age (Chandler, 1957); no work has yet been published on the palynology of these deposits, nor on the entire palaeobotany of the neighbouring Petrockstow basin deposits (SS 5210). Fenning & Freshney (1968) have used geological evidence to suggest that both these basins have deposits of similar age. A comparable age has been given to the 400 m. thick sediments of the Lough Neagh basin in N. Ireland, from a cursory study of the macrofossils (Johnson, 1941) and the pollen (Watts, 1962). A borehole at Mochras on the coast of Cardigan Bay (SH 553259) has recently shown a thickness of 600 m. of supposed Tertiary sediment. Wood & Woodland (1968) point out that there is a superficial similarity between this lignitic clayey sequence and the Bovey and Petrockstow deposits which are of a similar thickness. The implication is that the

Figure 3. The distribution of some of the more important Upper Tertiary plant bearing localities in Europe.

Mochras Tertiary sediments are of similar age to the Devonshire ones. Miss M. Herbert-Smith, however, has reached a provisional conclusion, from her palynological analysis of the Mochras lignite bands, that they are of a Neogene rather than a Palaeogene age (pers. comm.) Although this age determination is consistent with the view that there was a region of deposition passing from Derbyshire to N. Wales during Neogene times (Walsh & Brown, 1971), it conflicts with Wood and Woodland's (1968) tentative comparison of the Mochras Tertiary sediments with those from Devonshire and Lough Neagh. The Tertiary basalts which occur in Co. Antrim, N. Ireland, and on the west coast of Scotland, contain interbedded sediments which are made up of an impure coal, leaf beds, sandstones and conglomerates. Some of the macrofossils from N. Ireland and Mull have been described by Gardner (1886) and Seward & Holttum (1924) respectively, whilst Simpson (1961) has given the only palynological description of the whole assemblage from Mull and Ardnamurchan. Both Gardner and Seward & Holttum conclude that the flora is of Eocene age, whilst Simpson suggests an Oligocene, Miocene or even a Pliocene age, on the basis of his comparison of the pollen assemblage with those from other European Tertiary deposits. Simpson's conclusions should be treated with caution however, firstly because some of his identifications have been challenged (Martin, 1969), and secondly because the uppermost series of basalt in the region has since been dated by K - Ar techniques as being of Paleocene age (Harland, 1963). Montford (1970) has pointed out that Simpson's determination is incorrect and the flora is more likely to be of a Lower Tertiary age. The Derbyshire palynological assemblage (Boulter, 1971a) has little in common with that described by Simpson from Mull; less than would be expected if the Mull flora were of Neogene age.

There is a far more pertinent similarity between the Derbyshire flora and the Neogene floras of Europe, some of which are shown in Figure 3. The deposits in Holland and Germany were formed mainly from coastal swamps at the edge of the Neogene North sea (Teichmuller & Teichmuller, 1968) whilst discontinuous coastal swamps formed the Polish deposits. The Bohemian freshwater Neogene deposits in the Cheb, Sokolov and N. Bohemian basins are the result of supposedly separate lake deposition (Svoboda, 1966). Neogene deposits in southern Europe are the result of swamp development at the borders of the diminishing Tethys and Paratethys Seas, though their structure has been complicated by Alpine uplift sometime during the Miocene and probably the Pliocene too.

Analysis of the Entire Flora

A complete list of the fossils making up the Derbyshire Tertiary Flora is given in Table 1, which indicates the fossilized plant parts that have been identified - either pollen, spores, wood, leaves, reproductive structures, or, in the case of the three fungi, the entire organism. 40 of the 62 palynomorphs have been identified (Boulter 1971a) as established form genera and species, whilst the other 22 palynomorphs, and all the macrofossils have been identified as modern genera. Three of the modern genera which are represented as macrofossils are referred to fossil form species (*Sphaerites areolatus*, *Cryptomeria anglica*, and cf. *Cyrilla thompsoni*) while here the other 15 macrofossil types are given no specific name.

As pointed out elsewhere (Boulter, 1971a), most authors of systematic works on palynological assemblages from the European Neogene do not use a morphograhic system of classification, despite the work of Thompson and Pflug (1953). These authors undertook a study of Tertiary palynology from many European (mainly German) localities and presented a system of naming palynomorphs after a rigid morphographic system which they proposed for use throughout the Tertiary. Many of the taxa that they created have become well established within the literature, and because of this and their loose definition, some have been used in this study (Boulter, 1971a). When the affinity of a palynomorph to a modern genus is well recognized, that name has been used in preference to that of a form taxon.

The Derbyshire pollen assemblage (and the entire Flora) consists of taxa which can be placed in botanical families. Of the 40 form taxa, all but four have well recognised botanical affinity. This affinity has been determined from results of other works (see for example, Potoniê, 1967), occasionally by identifications *in situ* from fossil material or else, more especially, by comparison with modern material. The four taxa within the Derbyshire assemblage which are exceptions to this are *Podocarpoidites libellus*, *Tricolpopollenites ipilensis*,

TABLE 1 **Complete list of fossil plants that have been identified in the Derbyshire Flora Pollen, which may be from the parent plants of *Cryptomeria* sp. *Pinus* sp., *Tsuga* sp., and *Smilax* sp. - all found as macrofossils, has been given form species names which are listed separately.**

E: entire macrofossil, S: spores, P: pollen, W: wood, L: leaves, F: reproductive structures.

Pollen marked on slides V55639-55644. Numbers refer to specimens in the Palaeontology Department collection, British Museum (Natural History).

Microthyriaceae	*Microthallites* sp.	E	V56201
	Callimothallus sp.	E	V53980
(Sphaeriales)	*Sphaerites areolatus*	E	
Hypnodendraceae	*Hypnodendron* sp.	L	V56214.
Sphagnaceae	*Stereisporites minor microstereis*	S	
	S. stereoides stereoides	S	
	S. crucis	S	
	S. wehningensis	S	
	S. germanicus rhenanus	S	
	S. pliocenicus pliocenicus	S	
	S. minimoides	S	
	S. granisteroides	S	
	S. semigranulus	S	
	S. magnoides	S	
	S. microzonales	S	
Lycopodiaceae	*Lycopodium* sp.	S	
Gleicheniaceae	*Gleicheniidites senonicus*	S	
Osmundaceae	*Osmunda* sp.	S	
Polypodiaceae	*Laevitisporites haardti*	S	
	Verrucatosporites favus	S	
Schizaeaceae?	*Leiotrilites wolffi wolffi*	S	
Polypodiaceae?	*L. wolffi brevis*	S	
	Triplanosporites microsinuosus	S	
Taxodiaceae	*Inaperturopollenites hiatus*	P	
	I. dubius	P	
	Cryptomeria anglica	L	V53980
	Cryptomeria sp.	W F	V56173-8
	Sciadopitys sp.	P L	V56197-9
Pinaceae	*Abies* sp.	P L	V56187-90
	Cedrus sp.	P	
	Keteleeria sp.	P	
	Picea sp.	P W	
	Pinus sylvestris-type	P	
	P. haploxylon-type	P	
	Pinus sp.	L W	V56171-2

	Tsuga canadensis-type	P	
	T. diversifolia-type	P	
	Tsuga sp.	L	V56200
Podocarpaceae?	*Podocarpoidites libellus*	P	
Papilionaceae?	*Tricolpopollenites ipilenses*	P	
	T. liblarensis fallax	P	
	T. liblarensis liblarensis	P	
Symplocaceae	*Porocolpopollenites rotundus*	P	
	P. vestibulum	P	
Nyssaceae	*Nyssa* sp.	P	
Araliaceae	*Hedera* sp.	P	
	Tricolporopollenites edumundi	P	
Hamamelidaceae	*Liquidambar* sp.	P	
Salicaceae	*Salix* sp.	P	
	Tricolpopollenites retiformis	P	
Myricaceae	*Myrica* sp.	F	V56186
Betulaceae	*Alnus* sp.	P	
	Trivestibulopollenites betuloides	P	
Fagaceae	*Tricolpopollenites microhenrici*	P	
Corylaceae	*Corylus* sp.	P	
	Carpinus sp.	P	
Juglandaceae	*Juglans* sp.	P	
	Carya sp.	P	
Ulmaceae	*Ulmus* sp.	P	
Theaceae	*Eurya* sp.	F	V56184
Actinidiaceae	*Actinidia* sp.	F	V56183
Ericaceae	*Empetrum* sp.	P	
	Calluna sp.	P	
	Erica sp.	P	
	Rhododendron sp.	P	
Aquifoliaceae	*Tricolporopollenites iliacus*	P	
	T. margaritatus	P	
Cyrillaceae	cf. *Cyrilla thompsoni*	L	V56208-10
Sapotaceae	*Tetracolporopollenites sapotoides*	P	
Onagraceae	*Corsinipollenites maii*	P	
Hydrocaryaceae	cf. *Trapa* sp.	F	V56185
Compositae	*Compositoipollenites rizophorus*	P	
Liliaceae	*Periporopollenites echinatus*	P	
	Smilax sp.	L	V56201-3
Graminae	*Graminidites media*	P	

T. liblarensis fallax and *T. liblarensis liblarensis*. The uncertainties concerning their botanical affinity are explained by Boulter (1971a) and the families to which they are provisionally assigned (Podocarpaceae and Papilionaceae) are designated with a question mark. Consequently it has been possible to classify the components of the Derbyshire Flora under the heading of botanical families as designated and ordered by Hutchinson (1959). It is hoped that this method will be more widely understood than would either an entirely artificial system such as Thompson and Pflug's (into which macrofossils could not be incorporated), or two separate lists, one based on a morphographic system and the other (for macrofossils and some palynomorphs) on a botanical system.

It has been realised throughout this work that modern specific identifications cannot reasonably be made either of the pollen or of the macrofossils. Although an exhaustive (and exhausting) comparative study of the fossils to modern material may elucidate the specific identity of some forms, it is thought to be unlikely that indubitably positive results would be obtained. Preliminary comparisons of fossil pollen with that in a small pollen reference collection (Boulter, 1971a), as well as a comparison of fossil conifer leaf cuticles with those from modern species (Boulter, 1971b) suggest that there are differences, if only in fine structure, and it is at present debatable at which level such differences can be used for specific separation. In summary, modern specific identifications of micro- and macrofossils found in the European Neogene cannot be made with confidence.

An apparent discrepancy with the view that few modern plant species existed in Europe during the Lower Pliocene can be seen in the seed floras of Holland (Pont de Gail and Reuver; Reid, 1920b) and Poland (Kroscienko; Szafer, 1946). These floras have been described by Reid and Szafer as being made up more or less entirely of modern plant species (most often with a present tropical distribution), and were assigned by them to a Lower or Middle Pliocene age. More recently, Leopold (1967) has used these determinations of age and species to demonstrate patterns of plant extinction. Analysis of the pollen assemblages from these classical strata (Florschutz & Someren, 1950; Zagwijn, 1960) have shown widely distributed plant forms, especially conifers, which have significantly changed our understanding of the fossil floras and have revised the estimation of the deposits' age to somewhere about the U.Pliocene/Pleistocene boundary. The exclusive study of seed remains presents a different aspect of a fossil flora than the leaves or pollen, especially if their identification (during the Upper Pliocene of Europe) as modern species was made without reference to other plant parts such as leaves or pollen which are so often present in the same deposit. Stebbins (1947) has pointed out that some plants of this age could have evolved "within the framework of the existing floral organisation, with the principal innovations in the structure of the fruit and seed, but would produce many new and more reduced types of plant as to habit". Although fossil seeds may seem to be identical with those from modern species, the leaves or pollen may not be. On the other hand, other plants may show an opposite trend with newly evolved characters only in the female reproductive structures.

Geographical Analysis

Current theories concerning the migration of European Tertiary floras have been reviewed by Takhtajan (1969). Briefly, Upper Cretaceous and Lower Tertiary floras extended across Central and Northern Europe up to the present Arctic regions. The cooling of the Arctic regions began sometime about the beginning of Tertiary and caused the so called Arcto-Tertiary geoflora to begin a movement south. As a result of cimatic variations and differing rates of evolution of members of the European Tertiary floras, provincialisation is thought to have gradually increased throughout the period.

Many authors have separated Tertiary floras into a number of distinct components on the basis of their similarity with floras of various modern geographical regions. Reid (1920b) was the first to stress this system of analysis: she separated a "Chinese-North American association" and "other exotics" from exclusively temperate species. Szafer (1946) separated the components of his flora from Kroscienko in Poland into eight geographical elements including species that are now present in the Arctic, Euroasia, Central Europe, East Asia and America. Reid's (1920b) initial concept that European Pliocene floras were derived from two sources - one passing from polar regions down to Europe, N. America and Siberia, and another lowland

	1. Present distribution	2. Climate		1. Present distribution	2. Climate
Sphagnum	C	T	*Myrica*	NEM	T
Hypnodendron	SA	S	*Alnus*	NEH	T
Lycopodium	C	T	*Betula*	ANEH	T
Gleichenia	S	S	*Quercus*	ANEM	T
Osmunda	C	T	*Corylus*	NE	T
Polypodiaceae	C	T	*Carpinus*	AE	T
Schizaea	S	S	*Juglans*	NE	T
Cryptomeria	A	T	*Carya*	N	T
Sciadopitys	A	T	*Ulmus*	NE	T
Abies	AE	T	*Ilex*	ANEM	T
Cedrus	EM	T	Sapotaceae	SA	S
Keteleeria	SA	T	*Eurya*	SN	S
Picea	AEH	T	*Actinidia*	SA	S
Pinus	C	T	*Empetrum*	ME	T
Tsuga	AN	T	*Calluna*	NE	T
Podocarpaceae	SA	T	*Erica*	EM	T
Papilionaceae	C	T	*Rhododendron*	C	T
Symplocos	SA	S	*Cyrilla*	SN	S
Nyssa	AN	T	*Oenothera*	NE	T
Hedera	E	T	*Trapa*	SAE	T
Aralia	SA	S	Compositae	C	T
Liquidambar	SANM	S	*Smilax*	S	S
Salix	C	T	Graminae	C	T

TABLE 2. The estimated modern generic or family equivalents to members of the Derbyshire Tertiary flora are related to their present distribution and climatic conditions.

S: subtropical and tropical (exclusively so in column 2);

M: Mediterranean; N: North American; A: East Asian;

H: Holarctic; T: temperate; C: cosmopolitan.

Data from Szafer (1961) and Willis (1960).

element from East Asia through the Middle East and Mediterranean, has been accepted with little criticism by many authors (e.g. Mädler, 1939; Szafer, 1946). Rather, these latter authors have elaborated upon Mrs. Reid's concepts by further subdividing the geographical zones, though they do not elaborate upon the relationship between these zones and the possible centres of origin of the floral constitutents.

In the present study where only modern generic identifications have been made, few major deductions can be drawn from the kind of geographical analysis instigated by Reid. The current views on the history of European Tertiary floras make such analysis less significant than was previously thought. These theories, reviewed recently by Takhtajan (1969), suggest that Tertiary migrations from distant areas such as East Asia took place only rarely, and that what has been referred to as the East Asian component of European Tertiary floras, originated like the North American ones, more or less entirely from the Arcto Tertiary geoflora. Most movements from Asia to the Arctic are thought to have occured by the beginning of the Tertiary, at which time it is unlikely that modern vascular plant species existed. Provincialisation and evolution took place in such complex ways during the Tertiary that a simple comparison between taxa of a single Tertiary fossil flora and those of modern regions is unlikely to show much similarity at the specific level.

Since modern specific identifications have not been made in this study of the Derbyshire flora, reference to the regions of present distribution for each taxon is not particularly fruitful. The geographical ranges of most of the genera overlap many of the regions that were nominated by Mädler and Szafer for geographical comparisons (Table 2, column 1). It can be seen, however, that the present distribution of the genera making up the Derbyshire flora is very broadly scattered over the northern hemisphere and many individual genera are distributed over more than one of the regions that are referred to in Table 2. From the evidence at present available through our knowledge of Tertiary floras in Europe and of modern plant distribution, no firm conclusions can be drawn concerning the direction and speed of the plant migrations to which the fossil floras bear partial witness. Far more information, obtained from analysis of fossil floras all over the northern hemisphere, is needed before the movements of individual genera can be accurately recognised.

If present day climatic conditions for each genus that was present in the Derbyshire Tertiary flora are used for analysis, disregarding more precise information on geographical location, some meaningful conclusions can be considered. Of the 46 modern genera identified in the Derbyshire flora, about 30% are now restricted to tropical or sub-tropical environments (Table 2, column 2). Although the L. Pliocene forms of each of these genera may have been characteristic of climates different from those which they inhabit at the present, it is unlikely that evolutionary rates over the last 10 million years have been fast enough to bring about dramatic changes in the climatic requirements of closely related groups of plants, such as members of the same genus (Stebbins, 1950). Extinction of the subtropical elements rather than other kinds of evolutionary change is the major effect of such climatic variations in Europe over this time range.

Zagwijn (1960) has interpreted palynological evidence from the Dutch Upper Pliocene to suggest that the mean annual temperature range in Europe during this time was of a warm temperate type. His conclusions are supported by other authors (e.g. Chandler, 1964; Dorf, 1955; Cousminer, 1961) who used floral evidence to support the view that the maximum tropical temperatures (van Steenis, 1962) which occurred in Europe during the late Eocene epoch became progressively cooler through the remainder of the Tertiary period. Studies of marine invertebrates and vertebrates give support to these views.

The proposed Upper Miocene/Lower Pliocene age of the Derbyshire flora, and the existence within it of 30% characteristically sub-tropical/tropical genera do not, taken on their own, make the estimation of the nature of the Derbyshire Neogene climate an easy task. A brief analysis (Table 2, column 2) of the present climatic requirements of some individual components of the flora (Boulter & Chaloner, 1970; Boulter, 1971 a) suggests that the Lower Pliocene climate was a good deal warmer than at present, with smaller seasonal fluctuations in temperature. The genera which we now regard as being sub-tropical/tropical in character are unlikely to have survived sub-zero temperatures. There is evidence from a quite different source to add support to a subtropical type of climate. M. Ijtaba (verbal commn.) has analysed the mineral composition of the plant bearing clay at the Bee's Nest pit by X-ray analysis, and has detected a significant amount of the mineral gibbsite. This is known to form as the result of extreme tropical weathering such as that which occurs today in Cuba. This is a rather extreme factor to reconcile fully with the floristic evidence, though some kind of warm oceanic climate does seem to be suggested by all the data. The same conclusion on the climate is reached by Montford (1970) in his recent review of the Tertiary terrestrial environment. Leopold (1969) reviews the methods that have been used to make more precise estimates of Tertiary climate from floristic data. These all rely on comparisons with the distributions of modern species and so cannot be undertaken for the Derbyshire flora.

Age of the Flora

The Upper Miocene - Lower Pliocene boundary age for the Derbyshire flora has been calculated chiefly from results of palynological analysis (Boulter, 1971 a). The genera of vascular plants in the flora which occur solely as macrofossils - *Hypnodendron* sp., *Eurya* sp., *Actinidia* sp., cf *Cyrilla* sp. and *Trapa* sp.- have not been taken into account directly in this determination of the age. Since none of these five genera is extant in Europe (the fossil species of *Trapa* is thought to be extinct) their presence could mean that the flora is older than that suggested from pollen analysis. It is thought to be unlikely that this is the case however, since the method by which the age is determined involves comparison of a particular palynological component with that from other European assemblages (Boulter, 1971 a). These other assemblages are from floras which also possess tropical and subtropical forms, which are not necessarily part of that palynological component.

All the genera that have been identified in the Derbyshire flora, with the exception of *Hypnodendron*, have been recorded from other Neogene localities in Europe. Although many of the Derbyshire identifications represent the youngest known occurrences in N.W. Europe (*Smilax*, *Cyrilla*, *Tetracolporopollenites sapotoides* and *Porocolpopollenites rotundus*, for instance, were previously known to extend only up to the European Upper Miocene), and although there is at least one example (and most likely many others) of a species unique to the Derbyshire flora (Boulter, 1969) the entire floral composition can be fully reconciled with the Upper Miocene - Lower Pliocene boundary age if the criterion for the determination is of a comparative kind.

The position of the Miocene/Pliocene boundary in Europe is not yet unequivocally defined (Cicha, 1970), even in terms of marine sediments. Continental deposits are even more difficult to relate one to the other, though in Europe none is regarded unequivocally as being of Miocene/ Pliocene boundary age. On the basis of his palynological studies of the Dutch Neogene, Zagwijn (1960) regarded the Susterian as forming the base of the Pliocene (see Boulter, 1971 a, Fig.1). This means that a few typically Miocene pollen types are found at this base of the Pliocene. Not only is the statigraphy of this part of the geological column most uncertain, but also little is known of European floral history during this time interval. Kirchheimer (1940) was the first to suggest that "the flora of Middle Europe from the Lower to the Middle Pliocene did not at that time undergo any essential changes". This conclusion was made from the analysis of floras from Pont de Gail (which he assumed to be of Lower Pliocene age), Wetterau, Willerhausen, Reuver, and others (of Middle Pliocene age), and Tegelen (of Upper Pliocene age). Although the ages of most of these floras are now considered to be younger than Kirchheimer was led to believe, his suggestion of continuity in the composition of the European flora throughout the Lower Pliocene is not severely challenged by more recent palaeobotanical evidence.

Conclusion

Much previous work on Neogene floras in Europe has referred fossil wood, leaves, seeds and occasionally pollen to the rank of extant species. This has led to suggestions that these European fossil floras were closely similar to those at present occupying various tropical and sub-tropical regions. From the present study of the Upper Miocene - Lower Pliocene flora in Derbyshire, and from an appraisal of other European fossil floras of similar age, modern methods such as palynology and scanning electron microscopy suggest less similarity with modern species than was previously supposed; furthermore, such specific identifications cannot be made with confidence. This is consistent with the current view that European Neogene floras were formed as part of the Arcto-Tertiary province rather than having migrated from S.E. Asia. During the long time interval involved in such migrations, plant evolution was progressing in several ways, some species evolving into new ones whilst others became extinct. It is in the light of these concepts that the Neogene flora of Derbyshire is of importance.

Comparison of fossil organs, however well preserved, with those of modern plant species, is not a simple process. During the investigations on the fine detail of the wood, leaves, seeds and pollen from Derbyshire and modern species of the same genera, it became apparent that intraspecific variations (due to preparation of the specimens, the environment and other variables) were at times very great. When consideration is given to this variability, other problems remain, such as the availability of comparative fossil and herbarium material, the inadequate diagnoses of many fossil taxa, and our ignorance of the modern vegetation especially in tropical regions. Until these difficulties are satisfactorily overcome, no irrefutable evidence will be available to confirm either the hypothesis supported in this paper of incorporation within the Arcto-Tertiary flora or the earlier view that East Asian floras migrated westwards throughout the Tertiary. In the meantime, a body of opinion is mounting to support the view that comparison of fossil types with one another and with extant species can only be satisfactory if the Linnean system of nomenclature is abandoned in favour of a more flexible type of documentation.

The main deductions of this palaeobotanical study are:

1. Identification of the fossil wood, seeds, leaves, pollen and spores show that at least 75 taxa are present in the flora. They are identified either as form genera and species or as modern genera, but never as modern species.

2. Several genera present are now restricted to tropical, subtropical or temperate climates; some are now restricted in distrubution to either North America or East Asia.

3. The flora is made up of mixed woodland and heath elements. It is of an Upper Miocene - Lower Pliocene age.

M.C. Boulter, B.Sc., Ph.D., A.L.S.,
Department of Biological Science,
North East London Polytechnic,
Romford Road,
London E15 4LZ.

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Addendum

Two important developments on the subject of this paper have taken place since it went to press. Firstly, a third plant bearing bed has been discovered at Kirkham's pit, Brassington (SK 217540). It appears to be in the same position relative to the other sediments as at Bee's Nest pit and Kenslow Top pit. Work is now in progress to determine the palynology of the plant bearing clays at this new outcrop. Secondly, the sediments that are referred to in the paper as "pocket deposits" have now been formally recognised as a new Tertiary formation: the Brassington Formation (Boulter, M.C., Ford, T.D., Ijtaba, M., & Walsh, P.T. 1971. Brassington Formation: a Newly Recognized Tertiary Formation in the Southern Pennines. Nature Physical Science, 231; pp. 134-136).