Phil. Trans. R. Soc. Lond. B **311**, 379–447 (1985) [379]
Printed in Great Britain

LATE CAINOZOIC HISTORY OF VEGETATION, FIRE, LAKE LEVELS AND CLIMATE, AT LAKE GEORGE, NEW SOUTH WALES, AUSTRALIA

By G. SINGH† and ELIZABETH A. GEISSLER‡
Department of Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University, P.O. Box 4, Canberra, A.C.T. 2600, Australia

(*Communicated by R. G. West, F.R.S. – Received 29 August 1984*)

[Pullouts 1–5]

CONTENTS

---

† The first author is solely responsible for the pollen counts, the interpretation and the views expressed in this article.
‡ The second author contributed to computer-handling and the plotting of the data.

The results of pollen, spore, algal and charcoal particle analyses from an 18 m core sample, dating from *ca.* 730000–0 a before present (B.P.), from Lake George are described along with an account of a five year study of modern pollen-rain from the same site. Also, pollen analyses of two isolated samples, dating about 4–7 Ma B.P., in a separate core from the same location are reported for comparison. The sedimentary sequence is dated by means of magnetostratigraphy and radiocarbon.

The microfossil record from Lake George provides the longest relatively continuous Quaternary continental sequence yet available from Australia and may document one of the world's longest combined record of vegetation, bush-fires, lake levels and climates together with the record of accompanying plant migrations, redistributions and extinctions. It is so far the only chronologically secure Late Cainozoic palynological database available in Australia that spans the entire Brunhes Chron.

The altitudinal shifts of vegetation belts inferred from the palynological sequence suggest significant past changes in terrestrial temperatures of the order of glacial–interglacial cycles. It is revealed that the upper treeline was depressed by 1200–1500 m and 300–600 m, respectively, during the glacial maxima and the cool–temperate intervals, and reverted during the interglacials. Assuming an average lapse rate of 0.7 °C per 100 m, the drop in mean temperature for the warmest month (January) with respect to the present during the glacial maxima and the cool–temperate periods respectively may have been about 8–10 °C and 2–4 °C. A series of about eight glacial–interglacial cycles (phases I–XIX) are recognized during the Brunhes Chron at Lake George broadly corresponding to stages 1–19 of the deep sea ^{18}O palaeotemperature record.

A correlation between the palaeotemperature sequence and the former lake levels at Lake George is presented for the relatively more continuous section, *ca.* 350000–0 a B.P., with a view to resolve past precipitation changes. It is inferred that periods of considerably lower precipitation than at present prevailed during the glacial maxima. Conversely, periods of higher precipitation than at present occurred for some considerable lengths of time during the interglacials. In general terms, the precipitation levels increased during both interglacials and interstadials with respect to glacial maxima.

The plant microfossil evidence indicates that *Eucalyptus*-dominated, dry sclerophyll (low, open) forests, now growing in the lake catchment, and probably elsewhere in southeastern Australia are the result of a comparatively recent development. It is shown that the relatively 'fire-sensitive' *Casuarina*-dominated forests, combined with several equally or more 'fire-sensitive' rainforest taxa, dominated the vegetation for at least half a million years during all but the last two interglacials. The relatively 'fire-tolerant', *Eucalyptus*-dominated forests started to expand onwards from the last interglacial, some 130000 years ago, in conjunction with large increases in the amount of charcoal in the sediment. Since then, not only did the amount of charcoal remain at a generally high level but the overall dominance of open, eucalypt forest is maintained throughout during the warmer periods except for a cool–temperate interstadial interval (zone D) during the last glacial. The 'fire-sensitive' *Casuarina* (under 23 μm type) as well as all the rainforest taxa declined at the end of the last glacial and finally disappeared from the lake catchment during the Holocene, culminating in the total extinction of *Casuarina* type under 23 μm during the last few hundred years.

Some of the changes in flora during the Brunhes Chron were undoubtedly the result of long-term climatic change but most appear to have been precipitated through increased fire-frequencies only during the last 130000 years (with the maximum impact occurring during the last 10000 years), probably on account of the bush-firing activities of early man in Australia. This presupposes the presence of the Aboriginal people some 90000 years earlier than the oldest available archaeological evidence for human occupation of the Australian continent, a proposition that remains to be tested by future archaeological investigations.

In biogeographical terms, the studies reveal that a number of Gondwanic taxa, commonly seen during the late Tertiary in southeastern Australia, survived well into the Pleistocene and finally disappeared during the late Brunhes from Lake George.

1. Introduction

The present studies seek to use Lake George and its past sedimentary fossil record, including that on lake level fluctuations, as a basis from which to reconstruct the regional palaeobiogeography and terrestrial palaeoenvironmental history. Long-term palaeoclimatic reconstructions of earth's history, from isotopic studies of deep sea cores, are well recognized but corresponding studies from terrestrial sources have lagged a long way behind. This needs to be rectified because the records from deep sea cores alone may not suffice to uncover the range of palaeoclimatic change over the continents and cannot effectively record vegetation history. Continuous, long-term, terrestrial sedimentary deposits, however, are exceedingly hard to come by. The successive movements of glacial snow and ice, during the Pleistocene, have prevented long-term continuity of fossil records in lakes at high latitudes. On the other hand, the lake basins at low and middle latitudes have suffered dry periods with deflation and pedogenesis. Nevertheless, it is mainly in the middle and low latitudes, which have remained free of glacial ice, that there are chances of finding relatively continuous, long-term, sedimentary sequences. The investigations at Lake George (figure 1), represent such an exercise. Here studies on pollen analysis, sedimentology, radiocarbon and palaeomagnetism, have been brought together to verify the relative continuity of the sedimentary record with a view to reconstructing the Late Cainozoic history of the Southern Tablelands of New South Wales (Singh *et al.* 1981*b*).

In 1971, the Commonwealth Bureau of Mineral Resources, Geology and Geophysics (BMR) took a 72 m core from the northern end (BMR Scout Hole no. 4, Canberra; figure 2) of the lake; this core showed thick sequences of fine, deepwater sediments that contained enough fossil

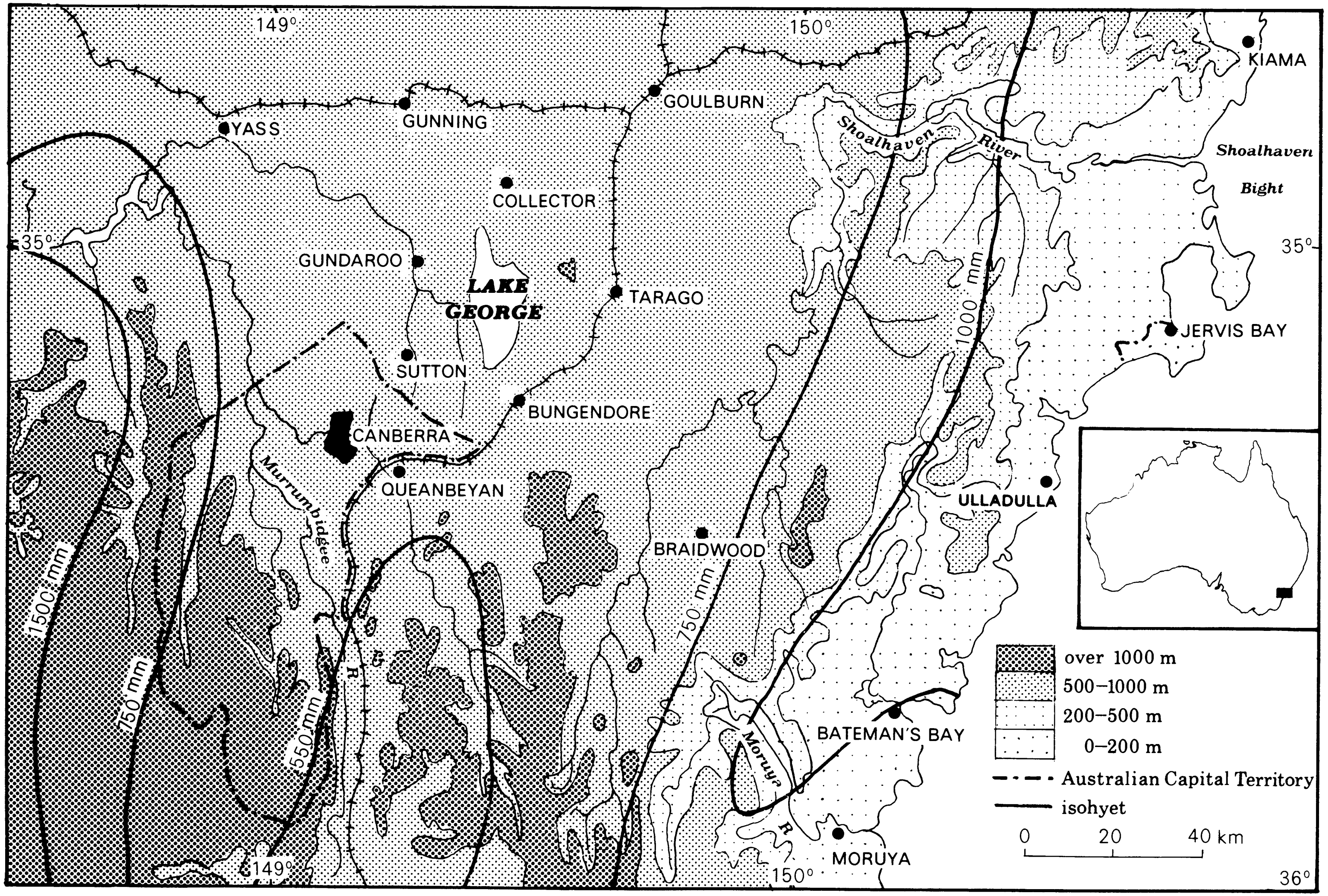


FIGURE 1. Physical features of the Lake George region showing the Southern Tablelands, the Eastern Highlands, the Coastal Fall and the broad pattern of mean annual rainfall in southeastern New South Wales.

pollen to warrant a closer study. But as this core was discontinuous at several points. (Singh *et al.* 1981 *b*), it was not used for pollen analysis, excepting two isolated samples from the 71.65 and 68.6 m levels which were analysed to check on the palynologically defined, Late Miocene–Early Pliocene boundary in the core. In mid-1972, a series of three 12 m cores (Gemco LG 1–3) was recovered from a point close to the site of the BMR core (figure 2). One of these cores, Gemco LG2, was used for pollen analysis while combined bulk material from identical horizons in the three cores was used for obtaining the first series of radiocarbon dates (Bowler *et al.* 1976; Yamasaki *et al.* 1977; Singh *et al.* 1981 *b*). It was soon clear from these that sedimentation in the lake basin had been slow, and that an additional control on the chronology of the sediments was necessary. Consequently, in May 1976, a 36 m oriented, core (Gemco LG4) was obtained for palaeomagnetism from the same site from an improvised sandbag platform, as the lake had risen by then. Later, a palaeomagnetic investigation was carried out on this core by Opdyke (Singh *et al.* 1981 *b*).

Brief accounts of the first half of the pollen-analytical investigations (0–8.5 m section), going back about 350000 a B.P., have appeared in several publications (Bowler *et al.* 1976; Churchill *et al.* 1978; Singh *et al.* 1981 *a*, *b*; Singh 1983) without detailed pollen diagrams. In this paper, the pollen analytical data are being presented in full, from the entire 0–18 m section of the Lake George sediments, extending back to about 730000 a B.P. covering the Brunhes Chron.

2. DESCRIPTION OF THE AREA

(*a*) *Location and lake level fluctuations*

Lake George or 'Wee-ree-Waa', as it was known to the Ngunawal, Aboriginal, people before the arrival of the Europeans in 1820, is one of the large, hydrologically sensitive, terminal, closed intermittent water bodies of internal drainage in Australia. The lake is 25 km long and 11 km wide across its widest part and lies at latitude 35° 05′ S and longitude 149° 25′ E, about 40 km northeast of Canberra (figure 1). It is situated on the Southern Tablelands of New South Wales at 673 m above sea level (a.s.l.) (the lowest point of the lake basin) and about 105 km inland, in the Great Divide of eastern Australia where it runs between the Murrumbidgee and Shoalhaven river systems (figures 1, 2). When the water is 4.6 m deep in the lowest part of the basin the lake covers an area of 155 km^2 and drains a total catchment area of 932 km^2 (figure 2). In general the area immediately surrounding the lake is without strong relief but the Lake George Scarp along the western shore of the lake rises spectacularly to 250 m above the lake bottom. The highest elevation within the catchment reaches to just over 1200 m a.s.l. (figure 2). To the south and southwest of Lake George, rise mountain ranges reaching general heights of 1500–1800 m a.s.l. (figure 1). Mount Kosciusko, the highest peak on the Australian continent, rises to 2229 m a.s.l. in the Snowy Mountains about 140 km southwest of the lake.

Lake George is believed to have no subterranean discharge (Jennings *et al.* 1964). The records of past lake level changes indicate that it has not overflowed for at least 21000 years (Coventry 1973, 1976) and has dried intermittently, during that time. During the last 164 years, its depth has varied frequently ranging between 0–7.3 m (figure 3), without any accumulation of salt crust (figure 4) on the surface of the lake (Burton & Wilson 1973; Singh *et al.* 1981 *b*). The lake floor, when dry, has been frequently used for grazing sheep and cattle. Conversely 'lake-full' conditions have been used for water sport and fishing.

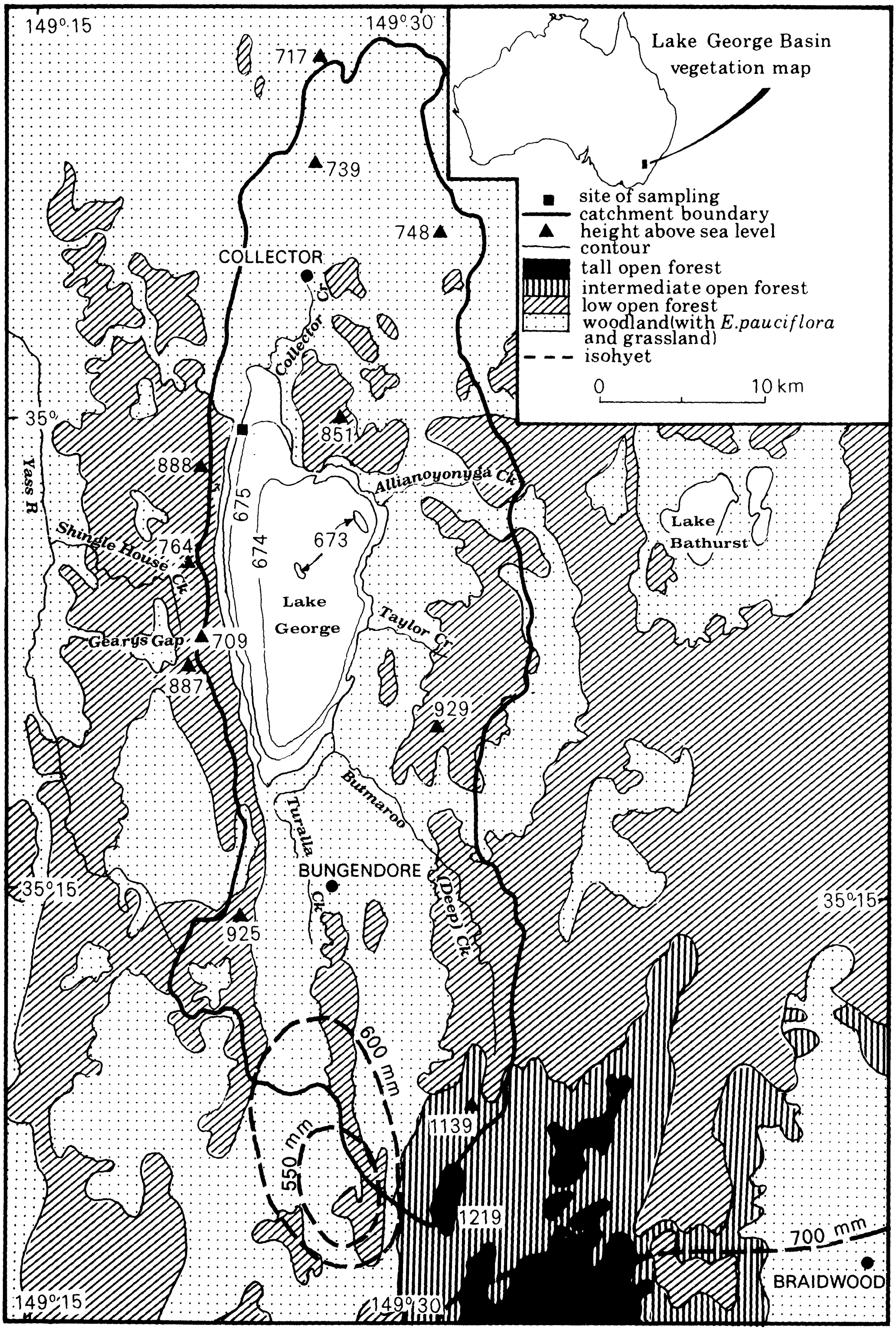


FIGURE 2. Vegetation map of the lake catchment and of the area immediately around the Lake George Basin. The map also shows the site of sampling, the catchment boundary, several points with heights above sea level and the prevailing mean annual rainfall in the region.

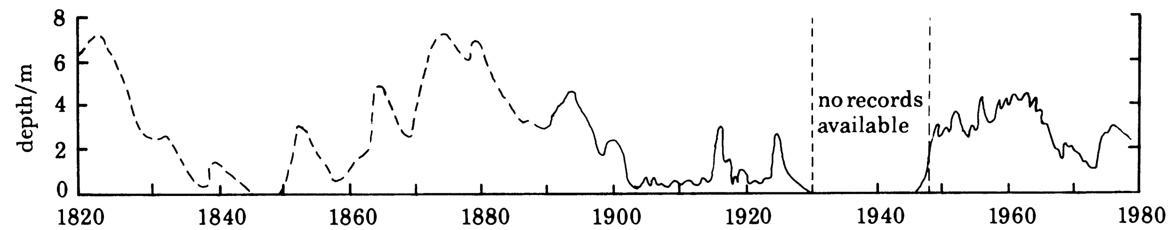


FIGURE 3. Historic records of lake levels, 1819–1979 (updated from Jennings *et al.* (1964), with data courtesy Bureau of Mineral Resources, Canberra).

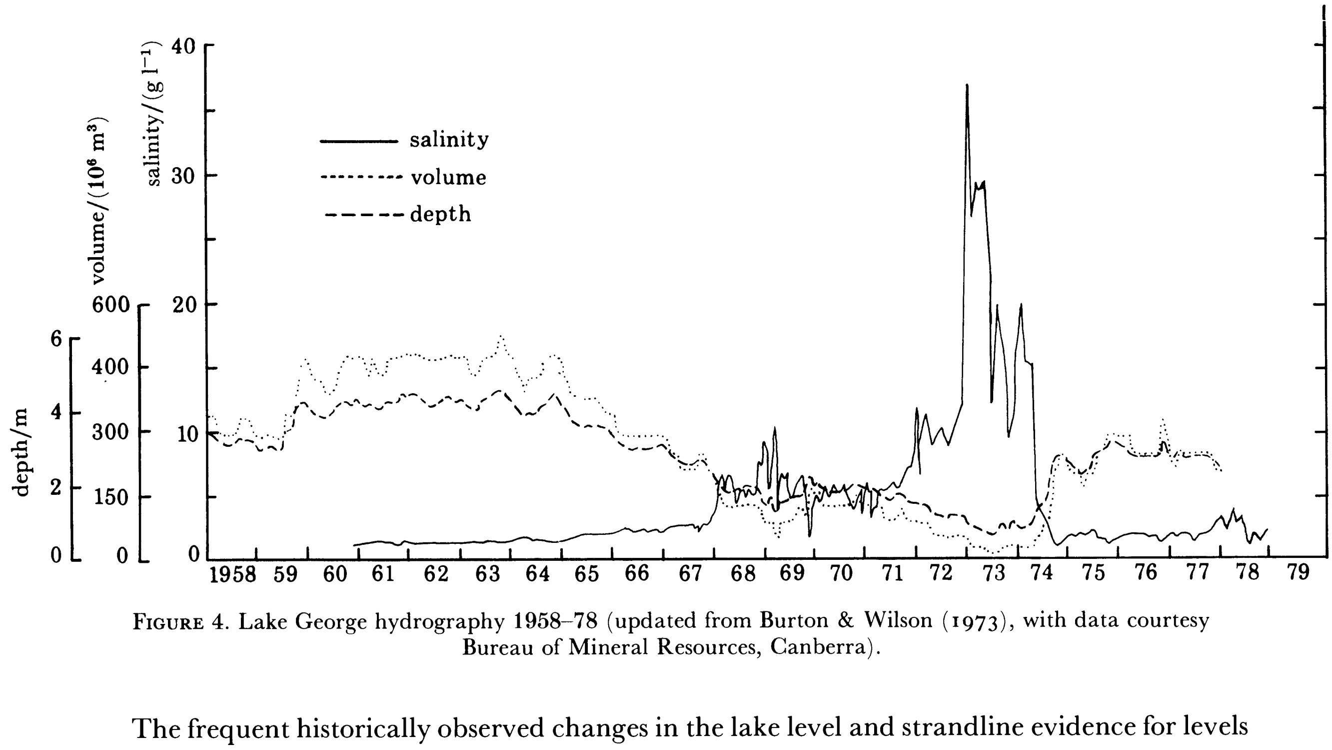


FIGURE 4. Lake George hydrography 1958–78 (updated from Burton & Wilson (1973), with data courtesy Bureau of Mineral Resources, Canberra).

The frequent historically observed changes in the lake level and strandline evidence for levels much higher than 7.3 m above the lake floor in the past (first noticed by Clarke in 1852), have led to a great deal of myth and speculation about the behaviour of the lake (Gale 1927). One of the common beliefs that still persists among some people is the filling of Lake George through underground springs and its emptying through subterranean fissures. As early as 1885–86, Henry Russell had rejected all explanations other than that evaporation was the only outlet and rainfall the only inlet for the waters of Lake George (Russell 1885, 1886). The first support for Russell's idea came from Jennings *et al.* (1964) who, on the basis of their calculations of the water budget inside the lake, suggested that there is a close balance between the average run-off into the lake and average evaporation from it. More recently Jacobson & Schuett (1979) have shown that the fluctuations are a clear response to seasonal and long-term variations in rainfall, evaporation and inflow of streams. Observations by Clarke (1852), Galloway (1967) and Coventry (1973, 1976) have established that the lake once overflowed through an outlet on the western side into a tributary of the Yass River. Further, Coventry's detailed geomorphological studies on abandoned shorelines have demonstrated that the lake level stood 37.6 m deep and last overflowed through Geary's Gap (figure 2), sometime between 27000 and 21000 years ago (Coventry 1973, 1976). These studies also revealed that oscillations to higher lake levels than those recorded during the last 164 years occurred at 15000, 5000, 3000 and possibly 8000 years before present. More recently, sedimentary records of lake level fluctuations at Lake George, going back 4–7 Ma, have been reported by Singh *et al.* (1981*b*).

(*b*) *Geology*

The Lake George trough is surrounded by strongly folded Ordovician greywacké, slate and sandstone in the west, south and southeast, by Upper Silurian–Lower Devonian granite and slightly folded, mainly Silurian acid volcanics, sediments and limestone in the east, and by Devonian sandstone, shale and conglomerate in the north (Strusz 1971). The Lake George fault running meridionally along the scarp to the west of the lake basin is believed to have been active during the Palaeozoic (Jennings *et al.* 1964). The origin of the lake basin has been the subject of several hypotheses (Taylor 1907, 1958; Garretty 1936, 1937; Noakes & Jennings 1954; Jennings *et al.* 1964; Ollier 1977) but, in the absence of detailed tectonic studies of the faulting and dated sedimentary records from the lake basin, there has so far been little consensus among the geologists and geomorphologists. In broad terms it is generally agreed that the lake owes its origin as a closed lake to the disruption of a pre-existing drainage system by post-Palaeozoic warping or faulting (Jennings *et al.* 1964). More recently, it has been suggested from extrapolations from palaeomagnetic studies of lake sediments that the lake was already in existence during the Middle Miocene (Singh *et al.* 1981*b*). Palynological evidence obtained from a spot sample from a thin layer of lignite, overlying shale, in a 39.6 m deep core (LG-9) extracted by Jododex Australia Pty Ltd from a point about 3 km northeast of Kennys Point on the eastern margin of the lake yielded a high percentage of *Nothofagus emarcida* ('brassii' type) pollen, together with gymnospermous pollen forming the next most abundant group. The other common pollen type represented was *Tricolporites endobalteus* ('*Macaranga–Mallotus*' type). According to H. A. Martin (personal communication), this pollen assemblage may indicate Pre-Miocene to Miocene age. Since this sample did not yield pollen belonging to aquatic species, or algae of any kind, it is reasonable to believe that the lignite pre-dated the initiation of the lake and it possibly only indicates a river channel or a local swamp.

(*c*) *Climate*

The climate of the Lake George region has been classed as warm (mesothermal) and subhumid (Köppen type Cfb; Gentilli 1948). It is characterized by uniform mean monthly rainfall during the year. The rainfall gradient falls towards the Lake George region from the south, east and west (figure 1), with mean annual rainfall dropping to 500 mm in the extreme south of the lake basin near Hoskinstown (figure 2, McAlpine & Yapp 1969*b*).

Prevailing winds are mostly from west to northwest for the period from January–March when easterly to southerly winds are more frequent (McAlpine & Yapp 1969*a*). The seasonal weather in the Lake George region is primarily controlled by the alternating northward and southward movement of the subtropical belt of high pressure in the winter and summer respectively. In both seasons the high pressure cells move from west to east across the continent. In winter as this belt moves northwards it is replaced by low-pressure troughs and depressions moving from west to east with their centres usually passing south of the Lake George catchment area. These troughs and depressions give rise to a series of cold fronts which bring both rain and frontal fogs into the region. In summer, rain results from anticyclones, generally centred to the south, and by southerly extensions of tropical low-pressure systems (McAlpine & Yapp 1969*a*). The lake, on the whole, receives a mean annual rainfall of about 650 mm which is uniformly distributed throughout the year even though the erratic nature of the rainfall leads to floods and droughts from time to time. The mean number of rainy days per month rises in winter and spring so that with the generally low rates of evaporation prevailing during that period this leads to a pronounced rise in the lake level; more or less the opposite holds true for summer and autumn. In the mountain ranges to the southwest of Lake George (figure 1), both the mean number of rainy days per month and the mean monthly rainfall rise during the winter months; the westerlies bringing rain into the area during this period become progressively less effective leeward of the mountain ranges. Consequently, the uniformity of mean monthly rainfall in the area east of the mountain ranges, including Lake George, seems largely the result of the rainshadow effect in winter. The easterlies, which are dominantly responsible for the summer rain, on the other hand, do not seem to be affected the same way, as the coastal ranges are much lower than those on the western side. The mean January maximum and July minimum temperatures (dry bulb) for the nearest two stations, Canberra Forestry (581 m a.s.l.) and Yass (Olympic Pool) (505 m a.s.l.) are 20.1 °C and 21.5 °C, and 4 °C and 4.9 °C, respectively. The mean daily temperatures range from 27.5 °C and 27 °C in January to 0.9 °C and 0.1 °C in July at these stations respectively. Frosts are common, except in summer, and in winter the lake basin suffers from cold air drainage (Foley 1945). Snowfalls occur frequently above 1200 m a.s.l. and occasionally in the lower country in winter.

(*d*) *Vegetation and environmental determinants*

(i) *General*

Because of heavy frosts in winter and the high rates of evaporation in summer, the main periods of plant growth are confined to autumn and spring when the soil moisture is freely available, or to exceptional periods of good rainfall during the summer months (Slatyer 1960). On the whole, however, the existing plant communities in the area, as in the rest of southeastern Australia, are believed to be more sensitive to a lowering of temperature than to a lowering of rain; a combination of cold and relatively dry conditions is thought to be the type of climate to which Australian vegetation is least adapted (Costin 1970).

In the Lake George region, Story (1969*a*, *b*), Gunn & Story (1969) and M. P. Austin (personal communication) have shown the vegetation to be broadly zoned in relation to climate and less affected by rock type and soil. Apparently the water relationships have a quite overwhelming influence that smothers most others (Story 1969*a*). They work either directly, through rainfall, or indirectly through factors such as moist or dry winds, relative cold and shelter, etc.

The genus *Eucalyptus* dominates almost all the vegetation zones, through a wide range of climatic régimes from the coast inland, except the areas occupied by coastal heaths, swamps, the treeless frost hollows and the small part above the treeline (above 2000 m a.s.l.), in which alpine herbaceous taxa preponderate (Costin 1954; Austin *et al.* 1983). Of the nearly 550 eucalypt species occurring on the Australian content (Chippendale & Wolfe 1981), more than 100 occur within a radius of 150 km of Lake George. Of these only about 20 are frequent to common and a significant proportion is classed as rare or of restricted occurrence (Chippendale & Wolf 1981). In general, the area extending from the Lake George region to the coast of New South Wales has more eucalypt species than most areas of similar size anywhere in

Australia. Hybridization between compatible species is common; hybrid swarms are believed to have existed only in restricted zones before the arrival of Europeans but have since spread widely following the disturbances of settlement (Pryor 1954).

Eucalypt trees vary in height from 2 to more than 30 m and form low to tall open forests and woodlands (figure 2) (Specht 1970). The northwesterly slopes, which are both sunnier and windier than southeasterly slopes, tend to support more open tree growth and are also subject to harsher stress conditions during periods of drought (Jacob 1955; Pook *et al.* 1966). Cold air drainage into valleys and depressions and regular snowfall in winter at high elevation produce severely cold conditions in these areas. Snow gum (*Eucalyptus pauciflora*, ssp. *niphophila* at high elevations), which can resist a greater degree of cold than any other eucalypt species, forms the upper treeline and also lines the margins of frosty depressions and valleys at lower altitudes. The intervening mountain slopes experience moderate temperate conditions and support low to tall open forests, commonly referred to as dry and wet sclerophyll forests respectively.

The lake, which has remained mostly ephemeral during the last 164 years (figure 3), has *Azolla filiculoides* and *A. pinnata* growing in it from time to time. As a result fossil massulae with embedded microspores and glochidia of *Azolla* are abundantly found in the surface sediments. Under lake-dry conditions, the soil salinity remains moderately low (figure 4) and a thick growth of salt tolerant grass, *Puccinella stricta* (Hook.f.) Blom. and herbs cover the lake surface. *Puccinella stricta* is a polymorphic complex which is poorly circumscribed and understood. It is widely distributed in New Zealand and Australia; in habit the form growing at Lake George is much closer to specimens from New Zealand (M. Lazarides, personal communication) and may thus be introduced. The herbs mostly are *Ranunculus* sp., aff. *papulentus*, and several introduced plant species, such as *Atriplex hastata*, *Spergularia rubra* and *Chenopodium glaucum* spp. *ambiguum*. In wet places occur *Carex appressa*, *Juncus bufonius*, *Triglochin procera*, *Elaeocharis acuta*, and *Phragmites australis*. Along the edges of the lake, on higher ground and on fans, occur several other species of native and introduced grasses mixed with herbs, such as *Lythrum hyssopifolia*, *Dichondra repens*, *Stellaria angustifolia*, *Geranium retrorsum*, *Rumex brownii*, *Wahlenbergia sp.*, *Chenopodium pumilio*, *Cyperus rutilans*, *Epilobium* sp., *Gnaphalium* sp. and several introduced herbs, *Silybum marianum*, *Modiola carolianiana*, *Silene gallica*, *Centaurium erythrea*, *Taraxacum officinalis*, *Trifolium* spp., *Medicago* spp., *Lotus corniculatus* and *Hirschfeldia incana*.

Upslope, in the lake basin and beyond it on the Southern Tablelands and the mountain ranges (figure 2), the vegetation follows the general pattern described for the Queanbeyan–Shoalhaven Area by Story (1969*a*, *b*) and for the high elevations by Costin (1954, 1970) and Austin *et al.* (1983). Above 2000 m a.s.l. are alpine herbfields and grasslands followed downwards by heath, subalpine woodland, wet sclerophyll (tall, open) forest, intermediate sclerophyll forest, dry sclerophyll (low, open) forest, tall woodland, savannah woodland, heath and grassland. Below the subalpine woodland, the order in which the above vegetational groups are listed broadly parallels a change in habitat from favourable conditions (moist, cool–temperate) where wet sclerophyll forest can grow through increasingly unfavourable to extreme conditions (dry, warm–temperature) where only grass can grow.

The vegetation in the lake catchment (figure 2), from the lake shore upwards, grades from grassland through savannah woodland and dry sclerophyll forest (low, open) to intermediate sclerophyll forest. Only a small patch of a few square kilometres of wet sclerophyll forest (tall, open) is found on the highest point (1200 m a.s.l.) inside the lake catchment in the extreme southeast corner of the basin (figure 2). The vegetation, immediately around the lake, has been under constant pressure of human activities for a long time, first through Aboriginal fires (cf. Cambage 1921) and then by European clearing, thinning, burning and grazing so that the area is now reduced to a patchwork of secondary vegetation (cf. Pook *et al.* 1966; Story 1969*a*; Purdie & Slatyer 1976; Purdie 1977*a*, *b*).

The savannah woodland is made up of scattered trees of *Eucalyptus melliodora*–*E. bridgesiana* community with *E. pauciflora* along the margins of frosty grass-covered depressions. Most of the tree vegetation within the catchment is dry sclerophyll (low, open) forest. To the west of the lake the scarp face is covered with forest consisting of *E. rossii*–*E. mannifera* var. *maculosa* community mixed profusely with *E. macrorhyncha*. To the east of the lake, patches of *E. sieberi* community intermixed with *E. rossii*–*E. mannifera* var. *maculosa* community and *E. dives* occur over a wide area. *Casuarina littoralis* is a common associate of *E. sieberi* community. *C. stricta*, a tall shrub or small tree, occurs on a small scale on dry rocky soils and rocky ridges all over in the lake catchment. *C. cunninghamiana* grows in riverside environments and *C. pusilla* occurs on heath mainly east of the lake. At no stage do any of the *Casuarina* species play a dominant role, occurring essentially locally in small pockets. Similarly, stands dominated by *Callitris endlicheri* grow in isolated patches on steep slopes with sandy shallow soils along the Shoalhaven, Molonglo and Murrumbidgee rivers. They also occupy crests and upperslopes of hills near Bredbo (M. P. Austin, personal communication).

On the whole, the dry sclerophyll (low, open) forest has a discontinuous canopy under which grasses are common, ferns rare and the cover of shrubs sparse (Beadle & Costin 1952). As a rule such forests occupy poor soils. Grasses dominate non-sandy areas in particular forming mainly a *Danthonia pallida* and *Poa* community. Areas with aeolian sand are covered with *Imperata* and *Pteridium esculentum*. The shrubby undergrowth is made up of taxa belonging mainly to Proteaceae (for example, *Grevillea*, *Persoonia*, *Banksia*); Myrtaceae (for example, *Micromyrtus*, *Kunzea*, *Leptospermum*); Epacridaceae (for example, *Leucopogon*, *Styphelia*, *Lissanthe*, *Brachyloma*, *Astroloma*, *Melichrus*); Mimosaceae (for example, *Acacia*); Fabaceae (for example, *Daviesia*, *Dillwynia*, *Pultanaea*, *Hovea*, *Hardenbergia*); Compositae (for example, *Cassinia*, *Helichrysum*, *Olearia*) and Santalaceae (for example, *Exocarpos*).

The intermediate sclerophyll forest, in structure and climatic requirements, is between the dry (low, open) and wet sclerophyll (tall, open) forests. It consists of communities dominated by *Eucalyptus sieberi* or *E. radiata* or by *E. dalrympleana*, *E. viminalis* and *E. pauciflora*. Only a small section of this vegetation complex actually occurs within the lake catchment (figure 2). *E. sieberi*-dominated communities extend through dry (low, open), intermediate and wet sclerophyll (tall, open) forests with differences occurring mostly in the undergrowth which in the dry sclerophyll (low, open) forest is extremely sparse and without ferns and fungi but becomes progressively more dense in the intermediate and wet sclerophyll (tall, open) forests.

Wet sclerophyll (tall, open) forest grades imperceptibly from the intermediate sclerophyll forest between 1000 and 1200 m a.s.l. on the Southern Tableland. Further east, towards the coast, under higher rainfall conditions, it occurs down to 550 m a.s.l. (Austin 1978). In the mountain ranges to the south and southwest of Lake George, wet sclerophyll (tall, open) forest is dominated by *Eucalyptus viminalis* along creeks and gullies, and by *E. fastigata* on slopes at its lower limit. At higher elevations *E. delegatensis*, becomes the dominant tree. Towards its upper limit the wet sclerophyll (tall, open) forest shows an admixture of *E. dalrympleana*, *E. delegatensis* and *E. pauciflora*.

The wet sclerophyll (tall, open) forest has a varied tree flora but the understorey is more or less uniform. The latter consists of scattered small trees (*Acacia melanoxylon*) and shrubs, such as *Acacia dealbata*, *Bedfordia salicina*, *Clematis aristata*, *Olearia argophylla*, *Pomaderris aspera*, *Leptospermum lanigerum*, *Hakea microcarpa*, *Drimys lanceolata*, *Coprosma quadrifida*, *C. hirtella*, *Lomatia myricoides*, *Polyscias sambucifolius*, *Persoonia chamaepeuce*, *P. subvelutina*, *Oxylobium ellipticum*, and *O. alpestre*. Ferns are common and are represented by species of *Blechnum*, *Gleichenia*, *Pteridium*, *Histiopteris*, etc. Tree ferns, *Cyathea australis* and *Dicksonia antarctica*, occur frequently in the understorey and in wet gullies.

(ii) *Transition to cool–temperate rainforest*

The wet sclerophyll (tall, open) forest on the Southern Tablelands has many species in the understorey which grow in a typical cool–temperate rainforest in southeastern Australia. The stands characterized by the rainforest transition species, however, occur only towards the coast some 60 km east of Lake George under the influence of increased rainfall (M. P. Austin, personal communication). These groups, according to Austin, generally form a canopy layer of non-eucalypt species, for example, *Elaeocarpus holopetalus* or *Eucryphia moorei*, with dense understorey of *Cyathea australis*, and a few emergent eucalypt trees, usually *E. fastigata* (M. P. Austin, personal communication).

Rainforest communities, with or without eucalypt species, are generally believed to occur on the east coast along drainage lines on very protective sites. Austin (1978), however, points out that they can occur on less protective sites where there is perennial water. A wide range of riverine communities generally dominated by eucalypt species indeed frequently grade into rainforest. A non-eucalypt riverine community, dominated by *Casuarina cunninghamiana*, behaves likewise in several areas. *Casuarina* is a sclerophyllous taxon but in modern times, it does not form *Casuarina*-dominated sclerophyll forests anywhere on the Australian continent.

(iii) *The coastal fall vegetation complex*

The vegetation of the area below the general elevation of the Southern Tablelands extending to the coast (figure 1), is made up dominantly of sclerophyll open (dry and wet) forest (Specht 1970) within which 68 communities have been recognized (Austin 1978). The vegetation is believed to be influenced by three environmental aspects: changes in latitude, altitude and lithology (particularly between granites and sediments).

The sclerophyll forests are treated under three categories: the coastal forests, marked by *Eucalyptus gummifera* on 'poorer sites' and *E. maculata* in more mesic situations, as a northern component and they indeed show a progressive southward restriction to a narrow coastal strip; the upland forests, generally above 250 m a.s.l. (extending to 950 m) and marked by *E. fastigata* and *E. muellerana*, show affinities with communities on the Southern Tablelands; and the riverine forests. The latter are usually composed of eucalypt species but rainforests, which often occur as gallery forests, intergrade between them and the riverine *Casuarina cunninghamiana* communities. Apart from these, other community complexes in the area consist of dune sere, the estuarine communities, particularly with mangroves and *Casuarina glauca*, fresh and brackish water swamps and the heath vegetation.

The rainforests in the east coast region show a marked decrease in species richness going from north to south and from sea level to 800 m.

(iv) *Highland vegetation complex*

Alpine and subalpine communities start to occur upwards from about 1372–1524 m a.s.l. (Costin 1954, 1970). Their lower limit is determined by the winter snow line (continuous snow cover for at least one month). These communities grade from subalpine woodland through heath to herbfield and grassland. The subalpine woodland is made up of snow gum (*E. pauciflora* ssp. *niphophila*, *E. pauciflora*, pendulous form (locally), and *E. stellulata*) with an undercover of heath or grasses. Most of the heath species growing under subalpine woodland also form a zone of their own in between the woodland and the herbfield and grassland communities. The heath vegetation consists of shrubby taxa, such as *Epacris paludosa*, *E. microphylla*, *E. brevifolia* and *Kunzea muelleri* growing in damp situations marginal to bogs, and those that are widespread in rocky places, such as *Oxylobium ellipticum*, *Podocarpus lawrencei*, *Lissanthe montana*, *Phebalium* spp., *Orites lancifolia*, *Prostanthera cuneata*, *Acacia alpina*, *Hovea rosmarinifolia* var. *rosmarinifolia*, *H. purpurea* var *montana*, *Drimys lanceolata*, *Drimys xerophila*, *Leucopogon suaveolens*, *Bossiaea foliosa*, *Leptospermum phylicoides*, *Baekea gunniana* and *Callistemon sieberi*.

The tree vegetation disappears around an elevation of 2000 m a.s.l. (Austin *et al.* 1983). Above this level the herbfield grassland communities prevail and they consist of tussock grasses, *Poa saxicola*, *Danthonia nudiflora* and *Themeda australis*, and herbs, *Calorophus lateriflorus*, *Celmisia asteliifolia*, *Plantago muelleri*, *Montia australasica*, *Caltha introloba*, *Brachycome* sp., etc. In wet places occur *Carex gaudichaudiana*, *Eleocharis acuta*, *Sphagnum cristatum*, *Epacris paludosa*, *Callistemon sieberi*, *Richea continentis*, *Restio australis* and *Astelia alpina*. Fjaeldmark plants consist of *Coprosma pumila*, *Colobanthus affinus*, *Epacris petrophila*, *E. microphylla*, *Ewartia nubigena* and *Helipterum albicans* ssp. *alpinum*. The lack of trees in this zone is considered to result primarily from low summer temperatures (Costin 1967, 1981). As in similar situations around the world (Daubenmire 1954; Tranquillini 1979) tree growth is limited to areas where the mean temperature of the warmest month is 10 °C or greater.

(v) *Fire and vegetation*

The relationship between fire and vegetation history at Lake George has been dealt with briefly in an earlier publication (Singh *et al.* 1981*a*). Further details are present in this paper.

The regional vegetation at Lake George, which is constituted dominantly of sclerophyll taxa, is strongly influenced by fire as is most other sclerophyll vegetation on the Australian continent (Gill *et al.* 1981; Singh *et al.* 1981*a*). Fires are common in a sclerophyll forest because of the high flammability of the vegetation which, in turn, is due to the high content of volatile oils and low levels of inorganic matter in the leaves of many sclerophyll species (King & Vines 1969). Rapid accumulation of fuel through low rates of decomposition of litter, together with features such as loose and hanging bark of several eucalypt species, provide fuel for frequent and easily dispersed fires. Most sclerophyll taxa are endowed with a variety of traits adaptive to fire (Gill 1975) as a result of which their survival capacity against fire is greatly enhanced compared with those lacking such traits, as, for instance, rainforest trees. On the whole, vegetation found in drier places has more traits adaptive to fire than has the vegetation of wetter areas. In general plants with relatively more of such traits are classed as 'fire-tolerant' and those with relatively fewer, or none, are classed as 'fire-sensitive' (Singh *et al.* 1981*a*). In these terms, most of the sclerophyll species are 'fire-tolerant' and are sometimes classed as 'fire-requirers' and 'fire promoters' (Jackson 1968). On the other hand mesophyll taxa growing in rainforests, and often extending into wet sclerophyll (tall, open) forests, are classed as 'fire-sensitive'.

For a long time it has been opined that natural and man-made fires in the past have reduced the distribution of 'fire-sensitive' species in sclerophyll forests (Byles 1932; Christensen *et al.* 1981).

'Fire tolerant' taxa survive fire through a variety of characteristics ranging from thick insulating bark through woody fruits, underground structures with dormant buds (lignotubers) to hard seeds (Gill 1975). Recovery after fire follows three post-fire regenerative strategies in a dry sclerophyll (low, open) forest (Purdie & Slatyer 1976):

(i) regeneration from seeds residual in soil, or unharmed seeds still attached to plants and released after fire;

(ii) regeneration by vegetative regrowth or

(iii) regeneration from both vegetative regrowth and seed.

Vegetative regeneration is by far the most common survival mechanism in a dry sclerophyll (low, open) forest (Christensen & Kimber 1975; Purdie & Slatyer 1976). After a fire there is an immediate rise in floristic diversity followed by its decrease as succession proceeds (Noble & Slatyer 1977). The course of succession depends on the species present before the fire (Pidgeon 1938; Purdie & Slatyer 1976; Noble & Slatyer 1977).

Changes in fire frequency, season of burning and intensity, produce different reactions (Christensen *et al.* 1981). While low intensities of fire (20–350 kW m^{-1}) produce little physical damage and may in fact be insufficient to stimulate prolific germination of seeds belonging to the families Proteaceae, Fabaceae, Myrtaceae and Casuarinaceae, high intensity fires (700 kW m^{-1}) cause immense destruction killing almost all of the above-ground foliage of most species. Fire intensity is closely related to the availability of fuel so that the greater the accumulation of fuel, the greater are the chances of high fire intensity. 'Fire-sensitive' taxa which do not regenerate from vegetative regrowth from subterranean or above-ground parts are greatly affected if an intense fire destroys the current generation and a second one kills their new seedlings before they are able to produce seed. Thus an increase in fire frequency following an intense fire causes the local extinction of 'fire-sensitive' taxa. Thus man-made fires, which may increase fire frequencies, can be extremely harmful to the survival of 'fire-sensitive' plants if they occur soon after an intense fire. Such practices, if continued over a period of time, can deplete a wet sclerophyll forest of all its 'fire-sensitive' taxa and may allow an outward extension of the 'fire-tolerant' dry sclerophyll (low, open) forest. Dry sclerophyll (low, open) forests can withstand fire frequencies of three to four years (Christensen *et al.* 1981) and are most suited to co-exist with high fire frequencies.

Casuarina species are relatively more 'fire-sensitive' than most other sclerophyllous taxa as they have a limited capacity to regenerate vegetatively. Moreover, they are easily killed if all the foliage including the growing points is burnt (Huenke 1976, for *Casuarina stricta*; F. Ingwersen, personal communication). After a fire *Casuarina* species regenerate mostly from seed and if the new generation is destroyed by another fire before a new crop of seeds is produced, the distribution of *Casuarina* is seriously restricted. Thus, high frequency fires can restrict the distribution of *Casuarina* species.

(vi) *Fire and soil*

It is believed that intense fires reduce soil fertility in areas of high rainfall (Jackson 1968) and that the resulting poor soils tend to support sclerophyllous vegetation which is low in mineral matter and hence highly flammable (Vines 1975, 1981). It is suggested by Jackson (1968) that the sclerophylls' capacity to tolerate and use high fire frequencies in competition with other communities have exposed them to selection for persistence on soils of low fertility. Under normal circumstances the fertile soils in wet climates are not likely to dry out and so be susceptible to fire effects but persistent disturbance, with fire, by man could start the spiral and lead to irreversible changes in the character of soils and of vegetation of such areas. According to Springett (1979), a reduction in the diversity of soil organisms brought about through frequent autumn, winter and spring burning increases the rate at which litter accumulates and decreases the rate at which nutrients are returned to the forest cycle.

Infertile soils, when exposed to fires of high intensity, become much more fertile than before, a transformation termed the 'ash-bed effect' (Humphreys & Craig 1981). This enhanced fertility leads to a new flush of regrowth of the 'fire-tolerant' sclerophyllous species already occupying the infertile soils until the next cycle is repeated once again. As the complement of species occupying poor soils is made up of taxa that are 'fire-requirers' as well as 'fire-promoters' (Jackson 1968), the fire frequencies remain at a high level and the 'fire-sensitive' taxa have little chance of encroaching on such sites.

It is generally held that fires can cause changes in the hydrological process by destroying the soil organic cover and by changing the soil through heating, a factor very much dependent on the intensity and duration of fire (Humphreys & Craig 1981). One of the important transformations resulting from fires on soil is the creation or intensification of hydrophobic or water repellent properties (Gilmour 1968; Craig 1968). As a result of the formation of hydrophobic layers in soils by such means surface runoff and erosion may increase greatly following fires (Osborn *et al.* 1964). Substantial increases in streamflow have been reported following intense fires (McArthur 1964; McArthur & Cheney 1965; Brown 1972) in different regions of southeast Australia.

Undoubtedly, many of the environmental determinants described above have been at work in the past at Lake George. Some of these resulted from changes in geology and climate. Others were forced through human impact, first by the Aboriginal inhabitants and later on by the activities of European settlers in Australia. To understand the genesis of the present-day vegetation at Lake George, or in any other part of Australia, it is essential to retrace the steps which led to the development of the modern-day conditions from times before the arrival of man on the Australian continent

3. STRATIGRAPHY AND CHRONOLOGY

(*a*) *General stratigraphy and gross chronology*

The sedimentary stratigraphy has been described earlier by Bowler in Singh *et al.* (1981*b*) from several cores from the drill site including Gemco LG2 which was used for pollen analysis. The stratigraphy and the palaeomagnetic record established in the 0–36 m section of the lake sediments in Gemco LG4 is summarized in figure 5. For details of sedimentary stratigraphy of this and the longer 72 m BMR core, the reader is referred to the earlier publication (Singh *et al.* 1981*b*).

In brief, the sediments consist of clays and sandy clays which are weakly calcareous and low in both organic and inorganic carbon content. In the past, during periods of lake-dry conditions and especially when the escarpment was steep, angular stony gravel found its way to the lake's floor up to more than 1 km from the toe of the escarpment.

The long-term chronology of sediments at Lake George is based on palaeomagnetic studies by Opdyke as described in Singh *et al.* (1981*b*). For the present paper it will suffice to say that the Gauss Chron ended 2.47 Ma ago at a depth of 30.6 m followed by Matuyama Chron (2.47–0.73 Ma, McDougall 1978) which lasted until the 17.4 m depth at which level the Brunhes Chron (0.73–0 Ma) began (figure 5).

Combination of sedimentological criteria and the palaeomagnetic chronology indicate that in broad terms, the Gauss Chron was dominated by deposition under lake-dry or ephemeral lake conditions. Deposition under lake-full conditions after a long break (Singh *et al.* 1981*b*) prevailed from the beginning of Matuyama Chron (2.47–0.73 Ma) and continued intermittently through the Brunhes Chron (0.73–0 Ma). Later on, through the second half of Brunhes Chron (0.4–0 Ma), the lacustrine deposition occurred more frequently and rhythmically than at any other length of time before (Bowler in Singh *et al.* 1981).

(*b*) *Radiocarbon chronology*

The short-term chronology is based on radiocarbon dating of the upper 9 m of the core. Initially three 12 m, 5 cm diameter cores (LG1-3) were extracted from the drill site. Samples for radiocarbon dating (N-1512-19) were obtained by combining material from three cores after matching equivalent stratigraphic horizons in cores LG1 and LG3 with those of the master core LG2. Samples were oven dried and analysed for organic carbon and carbonate content (table 1). Throughout the 0–9 m core, excluding the lowest 50 cm, carbonate content is usually less than 5% while finely dispersed organic carbon rarely exceeds 2%. On the whole the selection of samples was based on material (both organic and inorganic) derived from lacustrine deposition alone. The catchment of the lake does not contain significant geologically old limestones, but there is sufficient evidence of pedogenesis in some parts of the core to lead to the suspicion that both organic and carbonate dates may digress from true ages of deposition. Such obvious pedogenic horizons were not sampled for radiocarbon dating but some samples (N-1516, N-1517) come from horizons which have been slightly affected by ancient pedogenesis (table 1).

Initially, radiocarbon samples were selected with a view towards establishing a chronology on the basis of organic carbon analyses. But on seeing that the inorganic and the organic carbon samples were yielding contradictory results a second series of six samples (N-1814-19) was selected from a separate core by means of a modified large capacity 10 cm diameter sampler (Smith *et al.* 1968) from the same site to check the results from the first series. The depths in this core were again adjusted to master core LG2. In three (N-1814-16) of the six samples selected from this core, radiocarbon dates were obtained from both organic and inorganic carbon fractions (table 2) from the same levels.

The combined results from the first and second series revealed a totally inconsistent pattern in the dates from organic carbon while the carbonate dates formed an orderly sequence increasing with depth in the core (Yamasaki *et al.* 1977). The organic series showed almost a random relationship between depth and age and the scatter of large reversals in the series indicated major contamination. Moreover, despite indications from both the upper organic dates and carbonate dates of the considerable age of the sequence below 400 cm, none of the organic samples, even down to 700 cm, yielded results beyond the ranges of age detection. The consistent production of finite ages regardless of depth pointed to the presence of contamination by a younger component affecting the entire organic carbon series. Further, with the exception

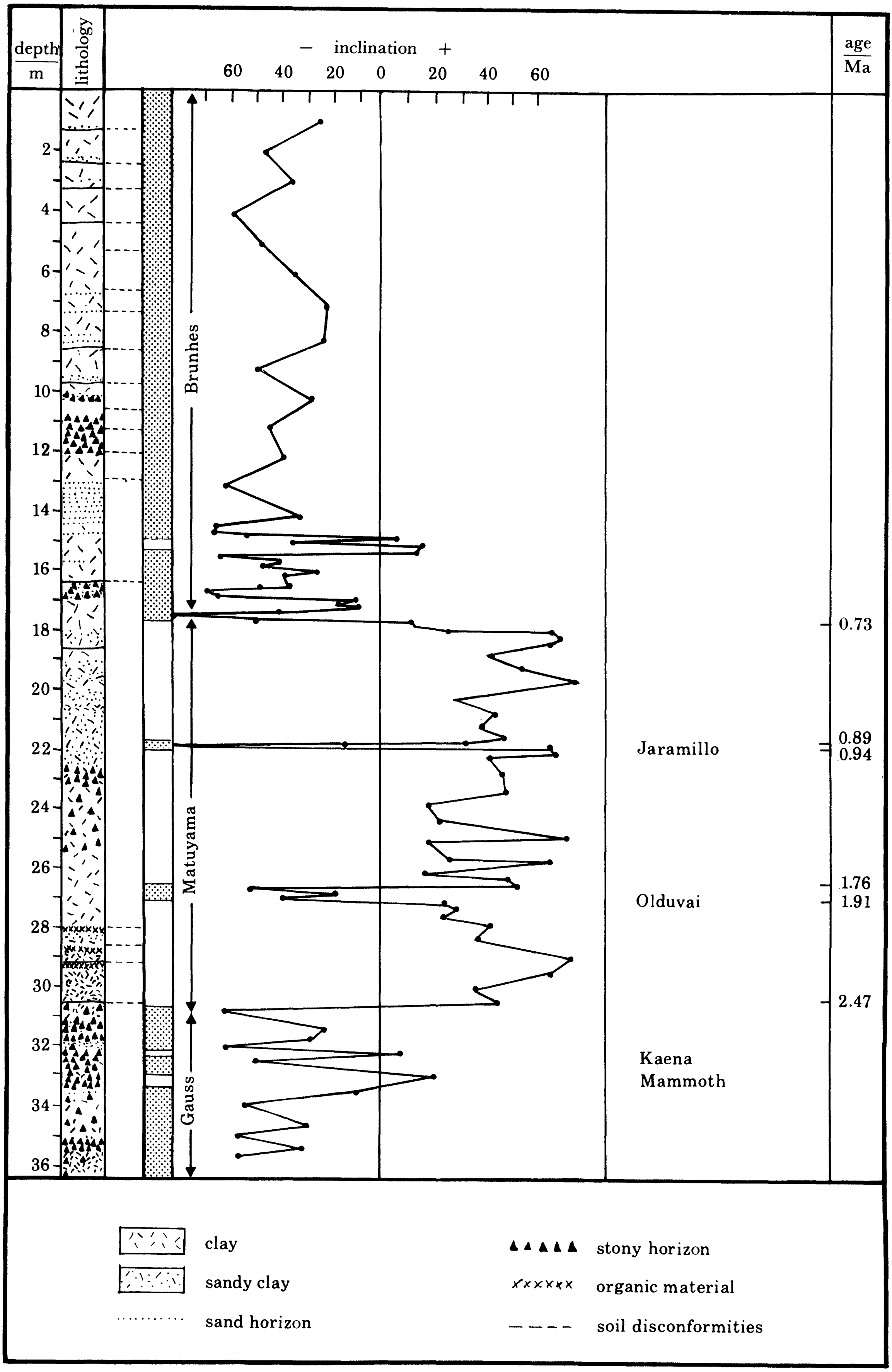


FIGURE 5. Palaeomagnetic stratigraphy at Lake George. (Adapted from Singh *et al.* 1981*b*).

Table 1. Details of some Lake George radiocarbon samples

sample	equivalent depth in master core	organic carbon (%)	inorganic carbon $CaCO_3$ (%)	sample mass g	^{14}C carbon content approx. g	
N-1512	85–89	0.75	16.2	390	7.5‡	carbonate-rich horizon with small fragments and fine, microcrystalline lime mud. Date from inorganic carbon.
N-1513	292–300	1.66	0.90	482	8.0†	sandy clay with organic matter as small black specks. Date from organic carbon.
N-1514	309–314	2.08	0.22	473	9.8†	sands with organic fragments. Date from organic carbon.
N-1515	440–445	0.33	29.1	299	10.5‡	pale creamy layer of marl. Date from inorganic carbon.
N-1516	503–510	1.94	1.68	504	9.8†	dark grey soil zone. Finely divided organic matter. Date from organic carbon.
N-1517	646–653	1.45	0.41	495	7.2†	finely divided organic matter in zone affected by weak pedogenesis. Date from organic carbon.
N-1518	701–706	1.21	0.03	171	5.7†	sandy clay with organic specks common. Date from organic carbon.
N-1519	854–860	0.48	5.70	483	3.3‡	layers of *Coxiella* shells – small sample. Date from inorganic carbon.

† Based on organic carbon. ‡ Based on inorganic carbon.

Table 2. Radiocarbon dates from Lake George

lab no.	depth/cm	radiocarbon age B.P. organic	radiocarbon age B.P. carbonate
N-1845	20–30	975 ± 100	—
ANU-1637‡	20–30	3430 ± 80	—
ANU-1638‡	40–43	5460 ± 170	—
N-1512	85–89	—	7770 ± 110
N-1814	140–150	11300 ± 510	18600 ± 930
N-1815†	180–190	28400^{+1700}_{-1500}	25600 ± 445
N-1816†	225–235	27100 ± 1050	over 37800
N-1817†	280–290	35700^{+4250}_{-2800}	—
N-1513	292–300	12400 ± 460 31300 ± 1170	— —
N-1514	309–314	31300 ± 1170	—
N-1818†	320–330	30300^{+1700}_{-1400}	—
N-1819†	340–350	23000^{+1800}_{-1500}	—
N-1515	440–445	—	over 37800
N-1516	503–510	22500 ± 640	—
N-1517	646–653	3700 ± 1570	—
N-1518	701–706	29600 ± 2500	—
N-1519	854–860	—	over 37800

† Depths adjusted to master core. ‡ NaOH insoluble.

of N1815, organic carbon results were always younger than corresponding inorganic samples from the same or adjacent horizons. On the other hand the inorganic dates when considered alone formed a reasonably consistent time series. When plotted against depth, the uppermost four carbonate dates fall close to a straight line which, projected, reached zero time close to the present sediment surface. Further, all three samples below 200 cm were consistent in being beyond the dating range and were therefore not contaminated significantly by younger carbon. Thus it was quite clear that while the organic analyses gave spurious dates a tentative chronology could be established on the basis of results from the inorganic radiocarbon dates (Bowler *et al.* 1976).

With a view to identifying the source of carbon contamination in the organic material from Lake George as well as to provide further confirmation of the validity of the carbonate series, two samples (ANU-1637-38) weighing 10 kg each, were collected from 20–23 cm and 40–43 cm levels from two large horizontal surfaces (1 m^2) exposed in a pit excavated close to the site of the master core (LG2).

All the 10 kg of sample ANU-1637 and 5 kg of sample ANU-1638 were macerated and suspended in distilled water. Rootlets which were common at the 20–23 cm level were removed by using several grades of sieves. After decantation, the residue was treated with dilute hydrochloric acid to remove carbonates and washed. The material was then suspended in cold 40% (by volume) hydroflouric acid for two weeks after which it was washed before treating it twice with hot dilute hydrochloric acid. After washing the residue free of acid it was treated with 20 g l^{-1} cold sodium hydroxide solution for 4–5 h with occasional stirring. The material was then filtered through a fine sieve and both the sodium hydroxide insoluble (humins) and the sodium hydroxide soluble (humic and fulvic acid) were retained for radiocarbon analyses. The material from the latter fraction, however, did not yield enough carbon for dating. The sodium hydroxide insoluble fraction gave results as follows: ANU-1637; depth 20–23 cm, 3430 ± 80 B.P.; ANU-1638: depth 40–43 cm, 5460 ± 170 B.P. These dates are not only internally consistent with the time-depth curve but also fit into reasonably well the time–depth curve described by the inorganic dates from lower down the sequence.

Unfortunately, large samples from narrowly limited horizons, such as ANU-1637 and ANU-1638, could not be obtained from deeper layers because of the high water-table. As a result it has not been possible to repeat the same experiment on samples from deeper horizons.

4. POLLEN ANALYSIS

(*a*) *Methods*

(i) *Drilling and sampling*

Core samples were collected by percussion drilling by means of a power drill, Gemco 210B, and 45 cm long and 5 cm diameter steel tubes. The cores were subsequently extruded from the steel tubes by hydraulic pump and wrapped in plastic sheets to conserve moisture. Samples for pollen analysis were collected at 5–10 cm intervals and stored in airtight plastic tubes.

(ii) *Modern pollen-rain*

A set of five uncovered Tauber traps (Tauber 1967), I N (N, north), II, III, IV and V, was established on 25 February 1974 on the then dry bed of the lake along a now-defunct fence-line running east–west and passing close to the drill site (figure 6). Each pollen trap was

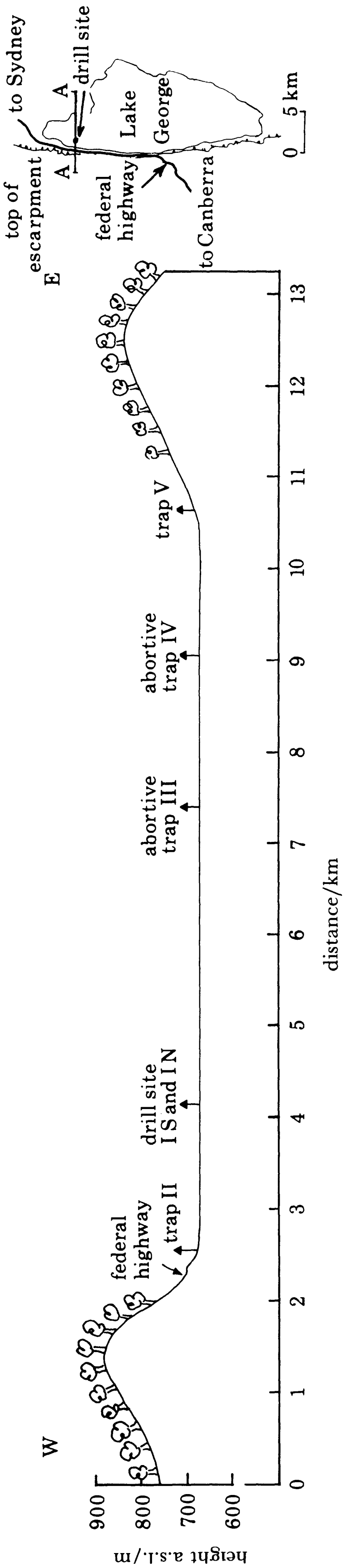


FIGURE 6. Diagram shows location of Tauber pollen traps at Lake George.

wired to a stake within a small fenced-up enclosure, with the collar at the top end of the trap resting on the top of the stake at about 1.2 m above the ground level. Trap I N was positioned close to the drill site. Trap II lay about 1 km west of trap I N on a fluvial fan close to the western shore, about 100 m east of the Federal Highway. Traps III, IV and V were installed eastward of trap I N at distances of 1.6 km, 2.4 km and 3.2 km respectively. Traps II and V sat about 5 m above the lake bottom in a grazed meadow setting. In both cases the dry sclerophyll (low, open) forest occurred some 300 m away on the higher slopes of the lake basin. Traps I N, III and IV occupied the lake bed and were flooded soon after their installation. Only trap I N survived; the other two, III and IV, were destroyed (figure 6).

Trap I S (S, south) was set up close to the site of trap I N on 16 January 1974 for a period of three months. This was done with a view to examining the effects on the pollen catch of the dominantly easterly winds, which blow mainly during January to April each year.

All the traps, excepting I S, were monitored annually. Trap I N was put out of action through further flooding in 1975, after only one collection. Trap II yielded five yearly collections, from 1974 to 1979, and trap V four, from 1975 to 1978, as the collection for the year 1974–75 was destroyed by accident.

The results of the modern pollen-rain investigations are presented at the top of the pollen diagram, under section A of figure 12, as percentages of total land pollen for individual taxa and as influx, grains per square centimetre per year for the total pollen catch.

(iii) *Chemical preparation*

Treatment of sediment samples and of the material accumulated in the pollen traps was carried out using slightly modified standard techniques (Erdtman 1943, 1952; Faegri & Iversen 1964; Tauber 1967; Davis 1969; Singh 1981). A 4 cm^3 sample of sediment was taken in each case and after the usual treatment by HF, 20 $g\ l^{-1}$ (cold) NaOH and $ZnBr_2$ the sample was dehydrated and suspended in a known volume of silicone oil. Acetolysis as well as treatment with strong alkali reagents was avoided as far as possible. Slides for microscopic examination were prepared from 0.02 ml of material suspended in silicone oil and sealed with wax. In the case of material from pollen traps the entire sample was sieved through a 250 μm brass mesh filter to remove any large detritus, such as seeds or insects. It was then filtered through a Sartorius membrane filter (Type SM 113, cellulose nitrate, 47 mm diameter, 5 μm pore size) with the aid of a water-operated vacuum pump. The filter containing the material was then treated by 50 $g\ l^{-1}$ sodium hydroxide, HF (if necessary) and acetolysis mixture and dehydrated before transferring it to a known volume of silicone oil. Slides were prepared as mentioned above.

(iv) *Microfossil determinations*

In general determinations are based on extant taxa found in the Australasian region. The reference material for most of these taxa is available in the form of modern pollen and spore slides in the Department of Biogeography and Geomorphology at the Australian National University, Canberra. The determinations are made mostly at the family or the generic level; only in rare cases have they been extended to the species level. In the latter case the identification is referred to as species type (table 5).

Eucalyptus pollen has been split into four types, I, II, III and IV, based on size and surface characteristics (table 6). Similarly the pollen characterizing the common myrtaceous shrubs in the region has been split into four categories classed as myrtaceous shrub types. In both cases, only the taxa that are extant within 100 km radius of Lake George have been considered in the classification. *Casuarina* pollen is recognized under two categories, type under 23 μm (equivalent diameter) and type over 23 μm (equivalent diameter) (table 5), (cf. Dodson 1975).

(v) *Presentation of microfossil record*

The microfossil data are presented as pollen diagrams in figures 8–14.

Local changes represented by the aquatic and semi-aquatic vegetation in the lake are shown in figures 13–14. The taxa included belong to green algae, *Pediastrum*, *Botryococcus* and *Staurastrum*, a water fern, *Azolla* cf. *filiculoides* or *pinnata*, and higher plant taxa, *Myriophyllum*, *Potamogeton*, *Ruppia*, *Typha* and Restionaceae. As the behaviour of these taxa is to a great extent related to lake level changes, their values, calculated as percentages of total land plant pollen plus individual taxon value, have been used to reconstruct the history of lake levels in the past. The lake level curve is deduced from the behaviour of *Pediastrum* indicating freshwater and therefore deep lake conditions, of *Botryococcus* indicating shallow, permanent-lake conditions and of *Azolla* indicating frequently dry to ephemeral lake conditions (for details see Singh *et al.* 1981*b*). This curve differs slightly from the earlier step-ladder lake level curve presented in Singh *et al.* (1981*b*). The two curves do not contradict each other.

Close to the extreme right of the lake level diagrams (figures 13–14) are shown two columns, (*a*) and (*b*), depicting overall changes in regional vegetation intended to correlate lake level changes with changes in terrestrial vegetation and climate. Columns (*a*) and (*b*) show relative percentages of total trees, shrubs and herbs and of total sclerophyll taxa, cool–temperate, rainforest taxa and herbs, respectively. The diagrams are supplemented by columns showing gross stratigraphy of sediments and chronology. The pollen zonation shown at the extreme left of the diagrams is based on criteria established from changes in regional vegetation.

Changes in regional vegetation during the Brunhes Chron are detailed in three pollen diagrams (figures 10–12) in which pollen and spore frequency values of individual taxa are shown as percentages of total land plant pollen. A whole slide was counted for pollen in each sample with a view to determining pollen concentration per cubic centimetre values in the sediment. These are shown in a separate column in the three pollen diagrams. The same count was used as a pollen sum for calculating percentages of individual taxa. It may be noted that the pollen sum in the Brunhes Chron samples varies from sample to sample, depending on pollen concentration in the sediment, and may have introduced slight distortions in the percentage values. Samples with small pollen counts have been treated with caution for purposes of interpretation of the fossil record. They are only cumulatively valuable. The short late Tertiary histograms from the 71.65 m and 68.6 m levels in the BMR core (figures 8–9) are also based on percentages in terms of total land plant pollen. The pollen sum used in these samples, however, did not exceed 100 pollen grains.

Charcoal particles were counted in all the samples (figures 10–12). Charcoal particle frequency values are presented in a separate column as surface area percentage values per unit volume of sediment in each sample. The values are estimated by determining percentage cover of cross sectional area of all visible charcoal particles in volumetrically standardized pollen slides. This was achieved by the use of eight random points on an eye piece grid of equidimensional squares (Singh *et al.* 1981*a*), each of which, if touched by a charcoal particle, was counted, while running the grid along a traverse on the slide. The 0–10 cm core section was analysed for charcoal particles at 1 cm intervals and the results are shown as a separate curve alongside the longer charcoal particle curve in figure 12, inset.

The percentage curves of most pollen and spore taxa and of charcoal particles are provided with exaggeration (×5 and ×10) curves.

The three Brunhes Chron pollen diagrams (figures 10–12) depicting changes in regional vegetation are arranged sequentially in time. The data on modern pollen rain are placed first in section A (figure 12) followed by section B which deals with the fossil pollen sequence from the lake sediments. Pollen diagram 1*a* (figure 12) includes the uppermost section of the fossil pollen sequence from 5 to 340 cm depth, pollen diagram 1*b* (figure 11) the middle section from 300 to 855 cm depth and pollen diagram 1*c* (figure 10) the lowermost section from 800 to 1800 cm depth.

Taxa whose pollen or spores occur only very occasionally are not given separate curves in the pollen diagrams. Their percentage values are shown separately in an abbreviated form at the right hand extreme end of the pollen diagrams.

(*b*) *Sources of plant microfossils and charcoal particles*

(i) *Pollen and spores*

Some idea of the sources of pollen and spores in the Lake George sediments can be had from the pollen-rain data monitored by traps I N (N, north), I S (S, south), II and V (figures 6, 12, section A) and their comparison with the fossil pollen and spore spectrum from the top five centimetres of the lake sediment (figure 12, section B). It is significant that the character of pollen assemblages in the pollen-rain samples (figure 12, section A) and the pollen spectrum from the top of the fossil pollen sequence (figure 12, section B) show a remarkable similarity. In both cases the pollen spectra reflect the *Eucalyptus*-dominated, open savannah woodland to dry sclerophyll (low, open) forest vegetation now living within the lake catchment. As the pollen and spores of cool–temperate rainforest taxa, *Podocarpus*, *Drimys*, *Cyathea*, *Dicksonia*, *Gleichenia*, *Lycopodium*, etc. most of which grow within less than 50 km radius of Lake George, do not occur in any of these pollen spectra, it is reasonable to suppose that the vast majority of pollen and spores entering the lake basin come from the vegetation actually growing within the lake catchment. From this, one may conclude that the regional winds probably do not play a significant role in long distance transport of pollen and spores in the area and that the pollen is transported mainly by local wind dispersal and local run-off. As it rains on only about 25% of the days in a year, the rainout component of pollen in the sediment may be proportionately small. Likewise, as there are no significant perennial rivers or streams and the run-off mostly ceases soon after the rains, the water input of pollen is probably also small. *Acacia* polyads which, on account of their large size, are not transported far from their source by wind and which are more liable to reach the sediment as a result of water transport, in fact, show higher values in the pollen-trap samples than in the sediment. Nevertheless, this balance may not have been true for all times and proportionately more pollen and spores may have entered the lake sediment through water transport in the past than do so now.

The pollen influx values, grains per square centimetre per year, measuring the combined gravitational and rainout component in the pollen traps, vary widely from one year to the next as shown in figure 12, section A. Between the years 1974 and 1979, the total influx ranged between 500 and 4000 grains per square centimetre per year in trap II on the western shore.

Similarly the influx in trap V on the eastern shore, for the years 1975–1979, ranged between 800 and 4000 grains per square centimetre per year. On the whole, except for the year 1975–76 during which traps II and V showed discordant values of 500 and 2100 grains per square centimetre per year respectively, reasonably comparable results were obtained in the two traps for the same years.

Comparisons between the annual influx values and the annual rainfall from two stations, Canberra and Collector, in the region (figure 7) showed no significant correlations. This is contrary to the results obtained from the arid country near Lake Frome in northeastern South Australia where a reasonable correlation was noticed between pollen influx and annual rainfall (Singh 1981).

In trap I N, situated at the drill site (figure 6), the influx value of 1400 grains per square centimetre per year for the year 1974–75 is less than half the influx value of 3200 obtained for the same year in trap II. This shows that the pollen in the atmosphere was reduced by half or more beyond about 1 km from its source. This, once again, demonstrates that the pollen and spores produced by the vegetation in the region are not prone to long distance transport by wind.

Trap I S was installed at the drill site (figure 6) for a short period of only three months of dominantly easterly winds from January to April, in 1974, with a view to catching pollen and spores from the relatively distant moister vegetation zones to the south east and east of Lake George (figure 2). In fact it showed little evidence of the presence of pollen and spores from this source (figure 12, section A). Thus, seasonally as well as annually, there is little reason to believe that any significant quantities of pollen found in the lake sediments will have originated as a result of long distance wind or water transport.

The pollen and spores of aquatic plant taxa in the sediment almost certainly originated from the lake itself. Fluctuations of their values in the past are interpreted as reflections of changes in the lake level (figures 13–14).

(ii) *Algal colonies*

Of the three fossil taxa of green algae (*Pediastrum*, *Botryococcus* and *Staurastrum*) found in the lake sediments (figures 13–14), none exist in the lake today even though the lake has attained fresh to brackish water conditions, and depth up to 7.3 m, for short periods of time during the last 164 years (figure 3). *Pediastrum* and *Staurastrum* are freshwater algae with salinity tolerance of about 1.7 g l^{-1} (Churchill *et al.* 1978). As the lake has only occasionally attained such low salinity (figure 4) for any sustained length of time during the last 164 years of recorded history (figure 3), these taxa may not have been able to grow in the dominantly brackish water environments. *Botryococcus* colonies, however, can grow under conditions ranging from freshwater to brackish water but, as the lake has been fluctuating widely at short intervals, the alga may not have been able to multiply in sufficient numbers for lack of stable environments. The source for the fossil algal colonies found in the lake sediments is undoubtedly the lake basin itself.

(iii) *Spores and glochidia of Azolla*

Spores and glochidia of *Azolla* cf. *filiculoides*, or *pinnata*, occur either singly or embedded in massulae, in the surface sediments. They almost certainly originate under today's ephemeral lake environments (Singh *et al.* 1981*b*).

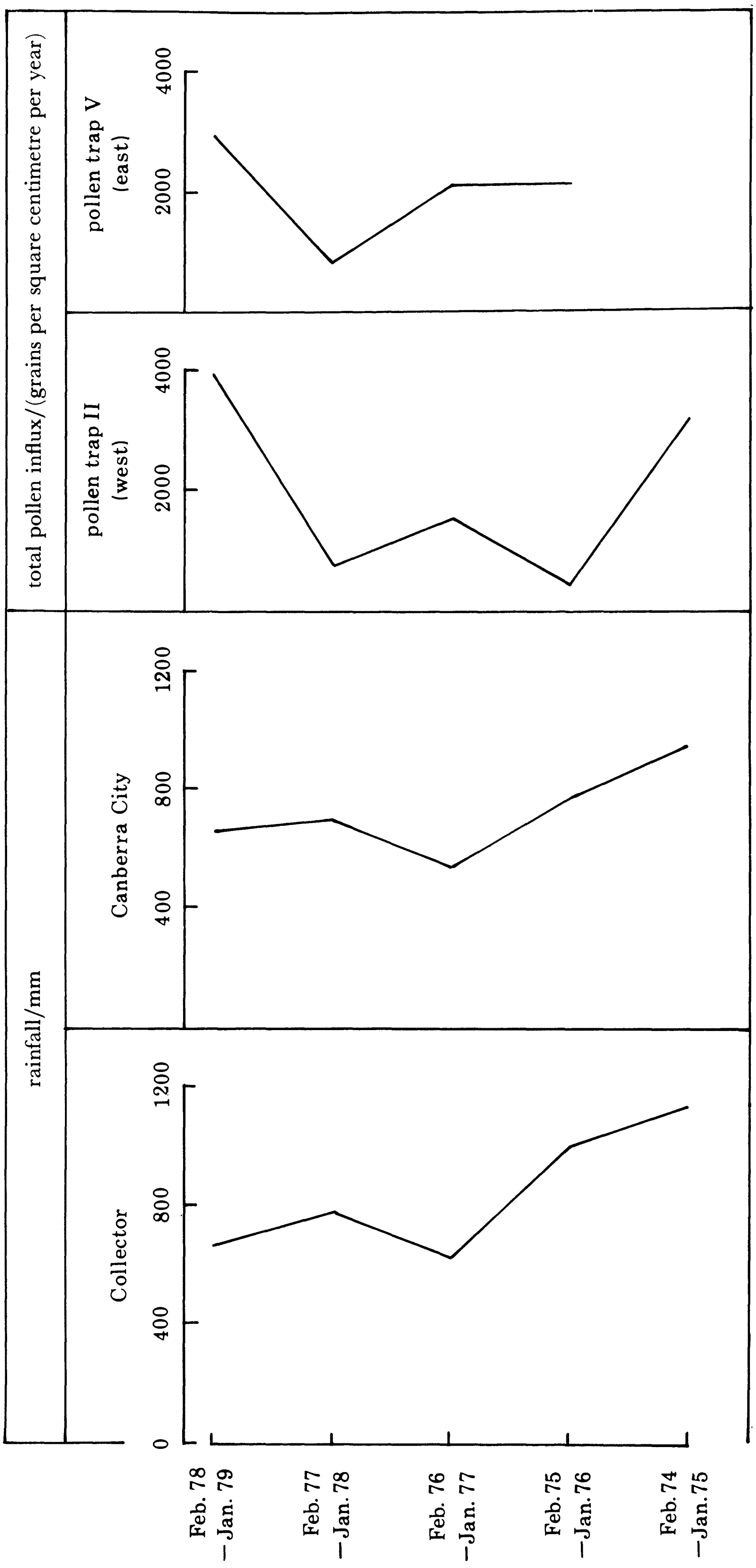


Figure 7. Diagram shows absence of direct correlation between mean annual rainfall at Collector and Canberra City on one hand and the total pollen influx grains per square centimetre per year on the other obtained from Pollen Traps II and V at Lake George from February 1974 to January 1979.

(iv) *Microscopic charcoal particles*

Charcoal particles of microscopic dimensions occur in a dispersed state in the lake sediments. Charcoal-rain studies by Clark (1983) show that charcoal particles are not carried to any great distance by wind transport from their source. As charcoal particles are also not found in significant numbers in pollen traps II and V, situated about 300 m away from the nearest forested area, despite fires having gone through the forest during the trapping period, it is likely that they have been mostly transported into the lake, from within the lake catchment, by water. Following Clark (1983) it is assumed that their numbers in the sediment increase immediately following a fire and diminish gradually over several years until the charcoal source is stabilised or covered by undergrowth. A certain proportion of charcoal particles probably continues to flow into the lake in run-off between successive fires. Since each sample in the pollen profile is representative of hundred of years of sedimentation the charcoal particles contained in the individual samples represent the cumulative result of all the fires that may have occurred during that period of time. Under these circumstances the charcoal particle values alone cannot be used to infer fire frequencies over any given period of time.

(*c*) *Zonation and description of the plant fossil record*

(i) *Pre-Brunhes*

The sediments below the Brunhes Chron at Lake George, (contained in Gemco LG4 and BMR Scout Hole no. 4 cores) (Singh *et al.* 1981*b*) do not show good pollen preservation to a depth of 68 m. Even below that level, only two samples, at the 68.6 m and 71.65 m levels in the BMR core, yielded countable pollen and the results obtained from them, based on 100 counts each, are presented in figures 8–9. This part of the BMR core, through extrapolation from palaeomagnetic dates in the top 36 m section (Singh *et al.* 1981*b*), dates to between 4 and 7 Ma B.P.

In the older of the two samples (71.65 m level, figure 8), Proteaceae is dominant with 43% of the total land plant pollen, followed by Gleicheniaceae (23), *Micrantheum* type (19), Epacridaceae (5), *Nothofagus* '*brassii*' type (3), *Podocarpus* (1), *Microcachrys* (1) and *Eucalyptus* type, (1) (pollen counts by E. Kemp). On the other hand, the younger sample from the 68.6 m level (figure 9) showed *Casuarina* dominant with 36% of the total land plant pollen, followed by *Nothofagus brachyspinulosa*, '*fusca*' type (14), *Dacrycarpus* type *Podocarpus* (12), *Podocarpus elliptica* (7), Myrtaceae (7), *Dacrydium florinii* (3.6), *Eucalyptus* type (3.6), Cupressaceae (3.6), *Acacia* (3.6), *Haloragis* (3.6), *Micrantheum* (3.6) and fern spores (3.6) (pollen counts by H. A. Martin).

The two pollen spectra (figures 8–9) present different pictures of vegetation but in each case rainforest taxa form part of the assemblage. There is no evidence for the presence of *Eucalyptus* to any significant extent at either of the two levels. Mostly shrubby vegetation, consisting of Proteaceae and *Micrantheum* and ferns, belonging to Gleicheniaceae appear to have dominated the rather dense plant cover at the 71.65 m level, in association with rainforest tree and shrub taxa *Nothofagus* '*brassii*' type, *Podocarpus* and *Microcachrys*. At the 68.6 m level, *Casuarina* appears to have dominated the vegetation and it, together with taxa belonging to Myrtaceae (including *Eucalyptus*), *Acacia* and *Haloragis*, is suggested to have formed an open forest in which many rainforest taxa (*Nothofagus brachyspinulosa*, '*fusca*' type; *Dacrycarpus* type *Podocarpus*, *P. elliptica* and *Dacrydium florinii*) lived side by side with dominantly sclerophyll taxa. The overall character

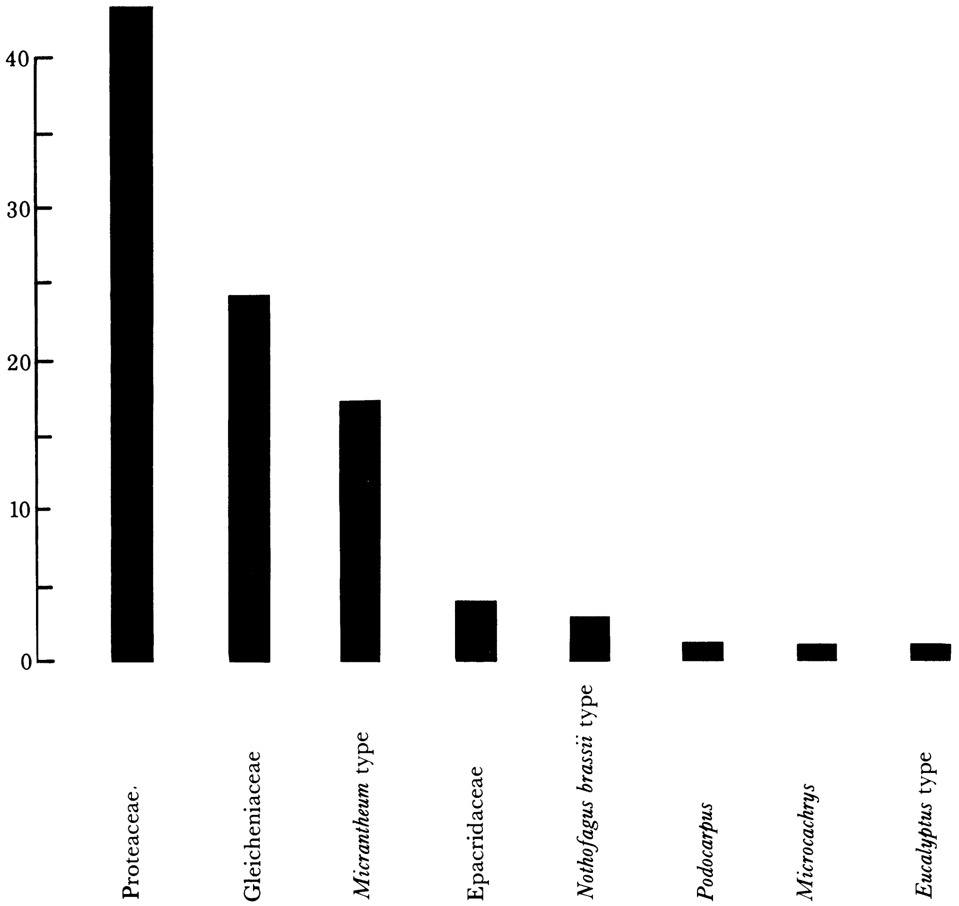


FIGURE 8. Histogram of a Late Tertiary pollen spectrum from Lake George dating about 4–7 Ma. Pollen and spore values are expressed as percentages of total pollen and spores of dry land plants. The sample was collected in a depth of 71.65 m in the BMR core.

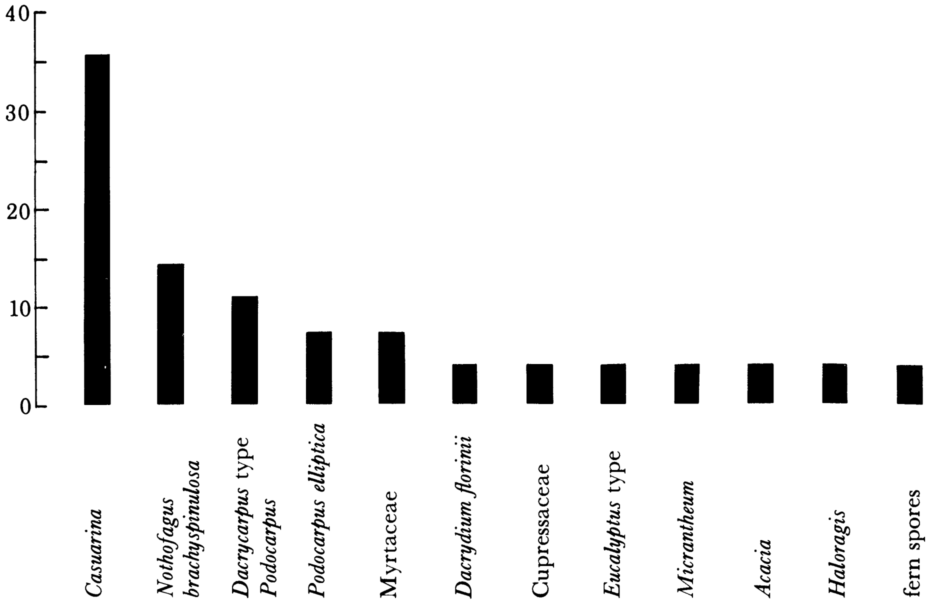


FIGURE 9. Histogram of a Late Tertiary pollen spectrum from Lake George dating about 4–7 Ma. Pollen and spore values are expressed as percentages of total pollen and spores of dry land plants. The sample was collected from a depth of 68.6 m in the BMR core.

of this open forest is reminiscent of the lower to middle Brunhes age interglacial, *Casuarina*-dominated, vegetation, described later from the Lake George pollen profile. However, the lower to middle Brunhes age interglacial plant assemblages were more open and contained a substantial component of grasses and Tubuliflorae. They also had a lower degree of representation of rainforest taxa.

The sample at the 71.65 m level lacked large quantities of charcoal particles and it would appear that fire activity was very low at that time. On the other hand, significant quantities of charcoal particles, broadly comparable with the amounts for the early Brunhes Chron interglacials, occur at the 68.6 m level which shows that forest fires were prevalent at that time. However, the fact that a number of 'fire-sensitive' rainforest taxa continued to survive suggests that the fire frequencies were probably not high enough to eliminate them and that infrequent, intense fires, with sufficiently long fire-free intervals allowing regeneration, occurred at that time.

Both the lack of *Botryococcus*, *Pediastrum* and the pollen and spores of aquatic taxa and the nature of corresponding sediments at the 71.65 m level (Singh *et al.* 1981 *b*), show that the lake had very little water in it. On the other hand, the presence of *Botryococcus* and *Pediastrum* at the 68.6 m level clearly demonstrates that deep, freshwater lake conditions occurred at that time (cf. Singh *et al.* 1981 *b*).

(ii) *Brunhes*

The fossil pollen sequence from the top 17.6 m of the combined Gemco LG2 and LG4 cores (figures 10–14, pullouts 1–5) is representative of the Brunhes Chron. The sequence is divided into 17 local pollen zones representing periods of relative stability or consistent change in vegetation. Wherever there are short-term changes within a pollen zone, it is further subdivided into subzones. As there is no modern, long-distance transport of pollen into the Lake George basin, the past changes in vegetation depicted by the pollen sequence are considered to represent changes in the plant communities actually growing within the lake catchment.

In the condensed pollen diagram from Lake George, covering the last 350000 years, published earlier (Singh *et al.* 1981 *a*), the pollen zonation extended, sequentially in time, from zones K to A. In the present fully completed pollen diagrams, the total timespan has been more than doubled. The present sequence is thus provided with six additional pollen zones, that is zones Q, P, O, N, M and L (figures 10–14). Of these, zones M and L are solely based on changes in charcoal particle frequency values normally associated with non-forested and forested periods, respectively, in the Lake George sequence, as fossil pollen and spores are not preserved in this section of the core. In view of the frequent absence of preserved pollen in the lower half of the pollen sequence the locations of zone boundaries for the section between zones Q and K are tentative (figures 10 and 13).

Zone Q (1760–1605 cm; figures 10 and 13; table 5). The zone straddles the Brunhes–Matuyama boundary at the 1740 cm level (figures 5 and 10). An approximate date of about 740000 a B.P. can therefore be estimated for the oldest pollen bearing sample at the 1760 cm level in this zone. Fossil pollen shows extremely low concentrations (under 100 grains per cubic centimetre) and is often badly preserved in this section of the core. The picture of vegetation therefore remains uncertain. The two pollen-bearing samples at the 1760 cm and 1670 cm levels appear to represent parts of two separate sclerophyll forest intervals. The vegetation pictures presented by each of these samples show the presence of *Casuarina* forests associated with rainforest taxa. The older sample at the 1760 cm level is dominated by *Casuarina* type over 23 μm which appears to have lived in association with rainforest taxa such as *Nothofagus* '*brassii*' type, *N. menziesii* type, *Microcachrys*, *Podocarpus* and *Cyathea*. Grasses (Poaceae) and Tubuliflorae formed the herbaceous component. The younger sample at the 1670 cm level is less reliable as it is based on an extremely small pollen count. The sample shows one grain each of *Casuarina* types over 23 μm and under 23 μm, *Podocarpus*, *Lycopodium* type I, *Pteris*, Liliaceae and ferns. The herbaceous component was low and may have been shaded out by the forest community.

Fire activity, as judged from the amount of charcoal particles in the sediment (figure 10), appears to have been at a low level at the time of both these samples, and considering the largely 'fire-sensitive' nature of the overall vegetation found in these samples it seems likely that the fires were infrequent.

The presence of *Pediastrum* and *Botryococcus*, together with *Myriophyllum* pollen, at the 1760 cm level shows that deep, permanent freshwater conditions prevailed (figure 13). On the other hand, the occurrence of *Botryococcus* and *Typha* pollen at the 1670 cm level indicates that shallow permanent water existed in the lake at that time. Both these conditions in zone Q are consistent with results from sedimentary facies analysis which shows the deposition of deep water clays at the 1760 cm level and of slope mantle stony debris at the 1670 cm level (Singh *et al.* 1981 *b*). Shallow permanent water also appears to have existed in the lake towards the top of the zone. However, a soil disconformity at the 1650 cm level shows that the lake had dried at least once for some considerable time during the period of zone Q.

Zone P (1605–1510 cm; figures 10 and 13; table 5). The zone is, once again, beset with scarcity of fossil pollen (under 100 pollen grains per cubic centimetre) in the sediment. Its beginning and end may be defined by the consistent rise and fall in the values of charcoal particles at the 1605 cm and 1510 cm levels respectively. That the period of high charcoal values was indeed forested is supported by the two pollen spectra from this zone at the 1590 cm and 1580 cm levels. Both these spectra show the existence of a *Casuarina*–rainforest mixture. At the 1590 cm level, *Casuarina* type under 23 μm, grew together with *Nothofagus* '*brassii*' type, *Podocarpus*, *Cyathea*, *Lycopodium* type I, and *Gleichenia*. The ground-cover was constituted mainly of Tubuliflorae and grasses and some Liliaceae and ferns. Fire activity, as seen from the moderately low values of charcoal particles, appears to have remained at a relatively low level. This is consistent with the presence of 'fire-sensitive' *Nothofagus* '*brassii*' type, and other rainforest taxa at this level. At the younger 1580 cm level, there is an increase in the proportion of *Casuarina* in the forest. This is seen from the overall increase in the *Casuarina* pollen values as well as by the addition of *Casuarina* type over 23 μm in the forest assemblage. Here the *Casuarina*-dominated forest is associated with taxa such as *Podocarpus*, *Microcachrys*, *Cyathea*, *Dicksonia*, *Lycopodium* type I, *Plantago*, grasses, Cyperaceae, *Dianella*/*Stypandra* type, cf. *Astelia*, *Anthoceros* and some ferns. The rise in charcoal particle values shows that fire activity was common.

The fossil algal record shows that the lake had deep, permanent freshwater in the first half of the zone but, later on, this changed to shallow water in the upper half.

Zone O (1510–1465 cm; figures 10 and 13; table 5). The pollen zone is based on three consecutive pollen- and charcoal-bearing samples. The pollen concentration lies between 700 and 1000 grains per cubic centimetre in two of the samples. The zone is marked by poor development of tree vegetation and also by the very low charcoal particle values in the sediment. The landscape appears to have been covered largely by open herb-field, dominated by

Tubuliflorae, grasses and Ranunculaceae. The few tree species present belong to *Casuarina* type under 23 μm, *Casuarina* type over 23 μm, *Eucalyptus*, and *Podocarpus*. Other plant species occur in small numbers and consist of *Cyathea*, *Lycopodium* type I, *Hovea*, Liguliflorae (cf. *Microseris*), *Plantago*, *Haloragis*, Chenopodiaceae, Cyperaceae and *Anthoceros*. The low values of charcoal in the zone suggest that fire activity was low.

The lake appears to have had brief, deep, permanent freshwater conditions at the beginning of the zone (indicated by the presence of *Botryococcus* and *Pediastrum*) but, later on, turned ephemeral (as shown by the occurrence of *Azolla* and the sharp decline in the values of *Botryococcus*).

Zone N (1465–1300 cm; figures 10 and 13; table 5). The pollen concentrations in the sediment rise considerably and range from under 100 to 2800 grains per cubic centimetre in this zone. It is possible that the greater diversity of taxa seen in this zone is partly the result of a higher pollen count facilitated, in turn, by the rise in the pollen concentration in the sediment. The zone starts with a rise in the values of sclerophyll taxa, mainly *Casuarina* types under 23 μm and over 23 μm, accompanied by a sharp rise in the charcoal particle curve. The zone ends where the *Casuarina* values fall together with a marked decline to sustained low charcoal particle values. While the two *Casuarina* types start to rise almost together at the base of zone N, *Casuarina* type over 23 μm, attains its peak development before that of *Casuarina* type under 23 μm. The *Casuarina* forest remains largely open in the first half of the zone, as is evident from the abundant grasses and Tubuliflorae associated with the forest during that period. *Eucalyptus* types III and IV appear momentarily together with myrtaceous shrub types I and III and Cheopodiaceae. The occasional presence of *Orites* and cf. *Astelia* pollen suggests that they occurred sporadically in wet places. A single occurrence of *Nothofagus* '*fusca*' type, is noted in this section even though rainforest taxa, on the whole, are scarce. The charcoal particle values are high and suggest that fire activity was common. Later on, in the second half of the zone, *Casuarina* type under 23 μm replaces the over 23 μm type; the grasses, Chenopodiaceae and Tubuliflorae decline, and *Callitris*, *Podocarpus*, *Elaeocarpus* and *Grevillea* begin to make their appearance. The charcoal particle curve also declines suggesting the fire activity had become considerably reduced. The undergrowth is dominated by Tubuliflorae, *Plantago*, grasses and Cyperaceae, and these taxa grow together with a sparse population of *Drimys*, *Cyathea*, *Exocarpos*, *Acacia*, *Banksia*, *Hovea*, *Asperula*, Liguliflorae, *Bursaria*, *Hibbertia*, *Dodonaea*, *Haloragis*, *Pseudanthus*, *Beyeria*, *Pittosporum*, *Pomaderris*, *Pimelia*, Ranunculaceae, Liliaceae, *Geranium*, *Rumex*, *Galium* and *Sida*. Sufficiently wet places appear to have existed for *Riccia* and *Anthoceros* to grow in the community from time to time. Towards the end of the zone both grasses and Tubuliflorae decline and *Eucalyptus* types III, IV and V, occur occasionally. In the uppermost sample, *Casuarina* type under 23 μm is shown to grow in association with *Eucalyptus* types VI and VII, *Phyllocladus*, *Nothofagus* '*brassii*' type, *Podocarpus*, *Orites*, *Cyathea*, *Lycopodium* type I, *Haloragis*, Chenopodiaceae, Poaceae, Cyperaceae, Liliaceae and ferns. The low charcoal values suggest that fire activity, on the whole, was at a low ebb in the upper half of the zone, a feature that is consistent with the progressive reduction in the herbaceous community and the addition of 'fire-sensitive' rainforest taxa in the vegetation in zone N.

Casuarina-dominated forests, associated with cool–temperate taxa, such as in zone N and other subsequent zones, do not occur anymore on the Australian continent.

The high values of *Botryococcus* and *Pediastrum* colonies, and *Myriophyllum* pollen, show that the lake continued to have deep freshwater for the most part of the zone.

Zone M (1300–1160 cm; figures 10 and 13; table 5). As both pollen and other plant microfossils are lacking between the 1300–1160 cm levels, the zonation of this part of the diagram is based solely on the values of charcoal particles in the sediment. By analogy with other younger pollen bearing zones (for example, zones F–K), zone M, in view of the extremely low representation of charcoal particles in the sediment, may be taken to suggest the existence of a treeless, open vegetation. As algal and other local aquatic plant remains are also not preserved in the sediment, the behaviour of the lake remains uncertain (figure 13). However, the occurrence of laminated clay during the lower half of the zone (Bowler in Singh *et al.* 1981 *b*) demonstrates that mostly permanent to deep lake conditions prevailed during that time. After that a soil disconformity ensues together with evidence for sustained slope mantle deposition in the form of stony clays, both indicating that the conditions were dominantly dry in the later half. The sequence of lake conditions in zone M is reminiscent of the broadly similar sequences found in zones G and I (figure 14), representing herb-dominated, mostly treeless periods.

Zone L (1160–920 cm; figures 10 and 13; table 5). But for the *Botryococcus* colonies found between the 1160–1120 cm and 1010–920 cm levels (figure 13), plant microfossils are not preserved in the sediment in this zone. Therefore, this section of the pollen diagram, once again, is zoned solely on the behaviour of charcoal particle values (figure 10). The charcoal curve starts to rise from the 1155 cm level and attains high values between 1025–925 cm. It then declines suddenly at the 920 cm level. By analogy with the pollen-bearing younger zones F–K (figure 11), the consistently high representation of charcoal particles in the sediment between the 1160 and 920 cm levels may be taken to indicate the presence of forest vegetation.

The continuous presence of *Botryococcus* colonies at the beginning and the end of the zone show that shallow, permanent lake conditions prevailed during those intervals (figure 13). The occurrence of slope mantle debris, together with three soil disconformities during the time between, indicate that lake-dry conditions existed from time to time (cf. Bowler in Singh *et al.* 1981 *b*). On the whole, the lake appears to have alternated between periods of shallow, permanent water to lake-dry conditions. There is no evidence that deep lake conditions had ever been reached during this zone.

Zone K (920–815 cm; figures 10–11 and 13–14; table 5). Plant microfossils are preserved much more continuously in the sediment upwards of zone K. The pollen concentration, however, remains below 100 grains per cubic centimetre in this zone. The zone starts with a consistent drop in the values of charcoal particles and is marked by the occurrence of periods dominated by cool–temperate rainforest taxa or by herbs. At no stage do sclerophyll taxa rise to attain a dominant position. Both *Casuarina* type under 23 µm and *Eucalyptus* make sporadic appearances with *Casuarina* occurring more frequently than *Eucalyptus*. Herbaceous communities, marked mainly by grasses, dominate the first half of the zone. Other species associated are *Lycopodium* type I, and members of Cyperaceae and Liliaceae. Both *Dianella–Stypandra* type and cf. *Astelia* rise towards the middle of the zone. It seems that first grasses and lycopods, and then *Dianella–Stypandra*, joined to form the bulk of the openland vegetation. *Casuarina and Eucalyptus* trees probably occurred only sparsely around the lake. Cf. *Astelia* and Cyperaceae occupied wet ground. Other taxa which occurred only sporadically were, *Cyathea*, myrtaceous shrubs, *Grevillea*, Tubuliflorae, *Plantago*, Chenopodiaceae, *Haloragis* and ferns.

In the second half of the zone, the sclerophyll vegetation becomes even sparser; the grasses and Liliaceae decline and the plant communities become dominated by cool–temperate, rainforest taxa, such as *Cyathea* and *Lycopodium* type I, which grow in conjunction with ferns and *Anthoceros*. *Podocarpus*, *Orites*, *Pteris*, *Plantago* and *Halorogis* occur sporadically. Both Cyperaceae and cf. *Astelia* probably occupied wet ground. The consistently low values of charcoal particles in the zone suggest that fire activity was uncommon.

The lake attained deep, freshwater conditions at the beginning of the zone, as shown by the occurrence of *Pediastrum*, but became dry or ephemeral (indicated by *Azolla*) soon afterwards. This is followed by the lake fluctuating between permanent, shallow and dry, or ephemeral regimes (figures 13–14). Shallow water conditions, however, remain for a greater length of time than any other mode during the entire zone. *Typha* and members of Restionaceae probably grew along the shallow lake margins.

Zone J (815–670 cm; figures 10–11 and 13–14; table 5). The pollen concentration rises and attains high values of over 10000 grains per cubic centimetre in the second half of the zone. The zone is marked by a consistent rise in the values of sclerophyll tree vegetation, mainly *Casuarina* type under 23 μm and by the decline of herbaceous taxa. Cool–temperate rainforest taxa continue to occur alongside the *Casuarina*-dominated forest. The zone ends where the sclerophyll tree vegetation finally declines giving way to the expansion of openland vegetation.

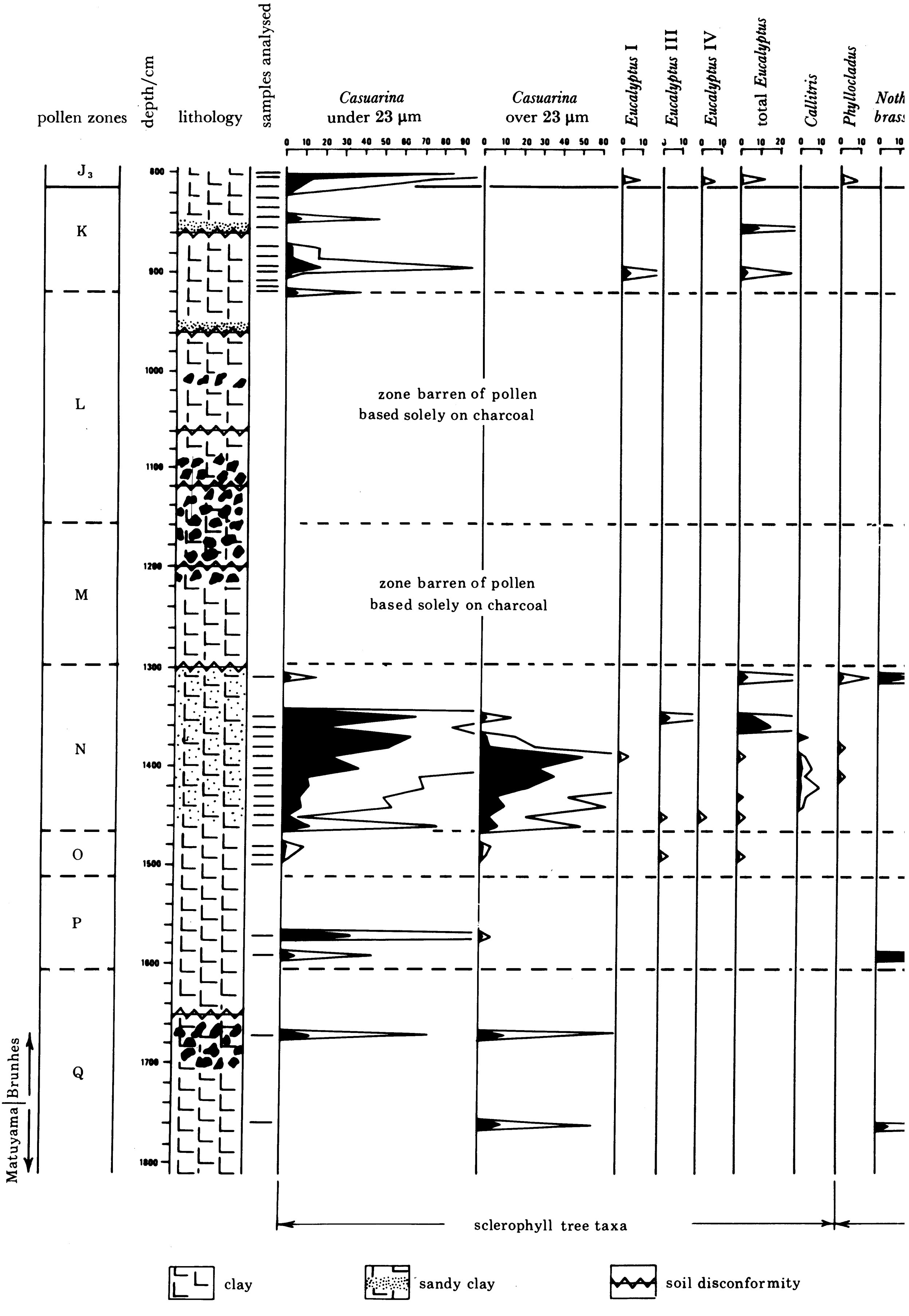
The charcoal particle curve rises gradually and attains moderately high levels in the middle of the zone. It then declines towards the end.

Zone J is divided into three subzones, J_3, J_2 and J_1.

Subzone J_3 (815–780 cm; figures 10–11 and 13–14). *Casuarina* type under 23 μm values rise steeply and *Casuarina*-dominated forests establish themselves in this subzone. Sclerophyll taxa other than *Casuarina* type under 23 μm, however, remain extremely low. They consist of *Casuarina* type over 23 μm, *Eucalyptus* type I, *Eucalyptus* type IV, myrtaceous shrub type IV, *Exocarpos* and *Grevillea*. Cool–temperate rainforest taxa associated with the community occur frequently and consist of *Cyathea*, *Lycopodium* type I, *Lycopodium* type II, *Podocarpus*, *Phyllocladus* and *Drimys*. Others that occur only sporadically are *Dicksonia*, *Histiopteris* and *Gleichenia*. The herbaceous cover is sparse and consists of *Haloragis*, grasses, *Plantago*, Cyperaceae, Liliaceae, ferns and *Anthoceros*. Cf. *Astelia* appears to have occupied wet ground along with *Typha* and members of Restionaceae. *Myriophyllum* grew sporadically in the lake. Other taxa whose pollen occurs occasionally are Tubuliflorae, Goodeniaceae, Ranunculaceae, Chenopodiaceae and *Dianella–Stypandra* type. There is little change in the charcoal particle curve, suggesting that fire activity remained uncommon. The subzone ends with a decline in the values of *Casuarina* at the 780 cm level.

The presence of *Pediastrum* and *Staurastrum* colonies in the sediment shows that the lake continued to have deep, fresh water for most of the subzone. The single presence of *Azolla* spores at the beginning of the subzone, in the presence of *Pediastrum* in the same sample, probably indicates a period of short spells from ephemeral lake to deep, freshwater lake conditions.

Subzone J_2 (780–695 cm; figures 11 and 14). *Casuarina* type under 23 μm rises once again and its high representation is sustained throughout this subzone. Other sclerophyll taxa remain more or less at the same level as in subzone J_3. In addition, *Eucalyptus* type III, myrtaceous shrub type II and *Acacia* make brief appearances but their representation is at a very low level. The cool–temperate rainforest taxa show an overall decline and taxa such as *Podocarpus*, *Drimys*, *Lycopodium* types I and II, and *Phyllocladus* are less frequently represented than in the earlier subzone. *Cyathea*, however, maintains its high values and *Dicksonia* and *Gleichenia* occur sporadically as before. *Nothofagus* '*brassii*' type and *Histiopteris* each make a single appearance and the pollen of *Pseudanthus* occurs twice during the subzone. The herbaceous vegetation, on


pollen zones
depth/cm
lithology
samples analysed
Casuarina under 23 μm
Casuarina over 23 μm
Eucalyptus I
Eucalyptus III
Eucalyptus IV
total Eucalyptus
Callitris
Phyllocladus
Noth
brass
0 10 20 30 40 50 60 70 80 90
0 10 20 30 40 50 60
0 10
0 10 20
J3
K
L
M
N
O
P
Q
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
zone barren of pollen based solely on charcoal
zone barren of pollen based solely on charcoal
Matuyama
Brunhes
sclerophyll tree taxa
clay
sandy clay
soil disconformity

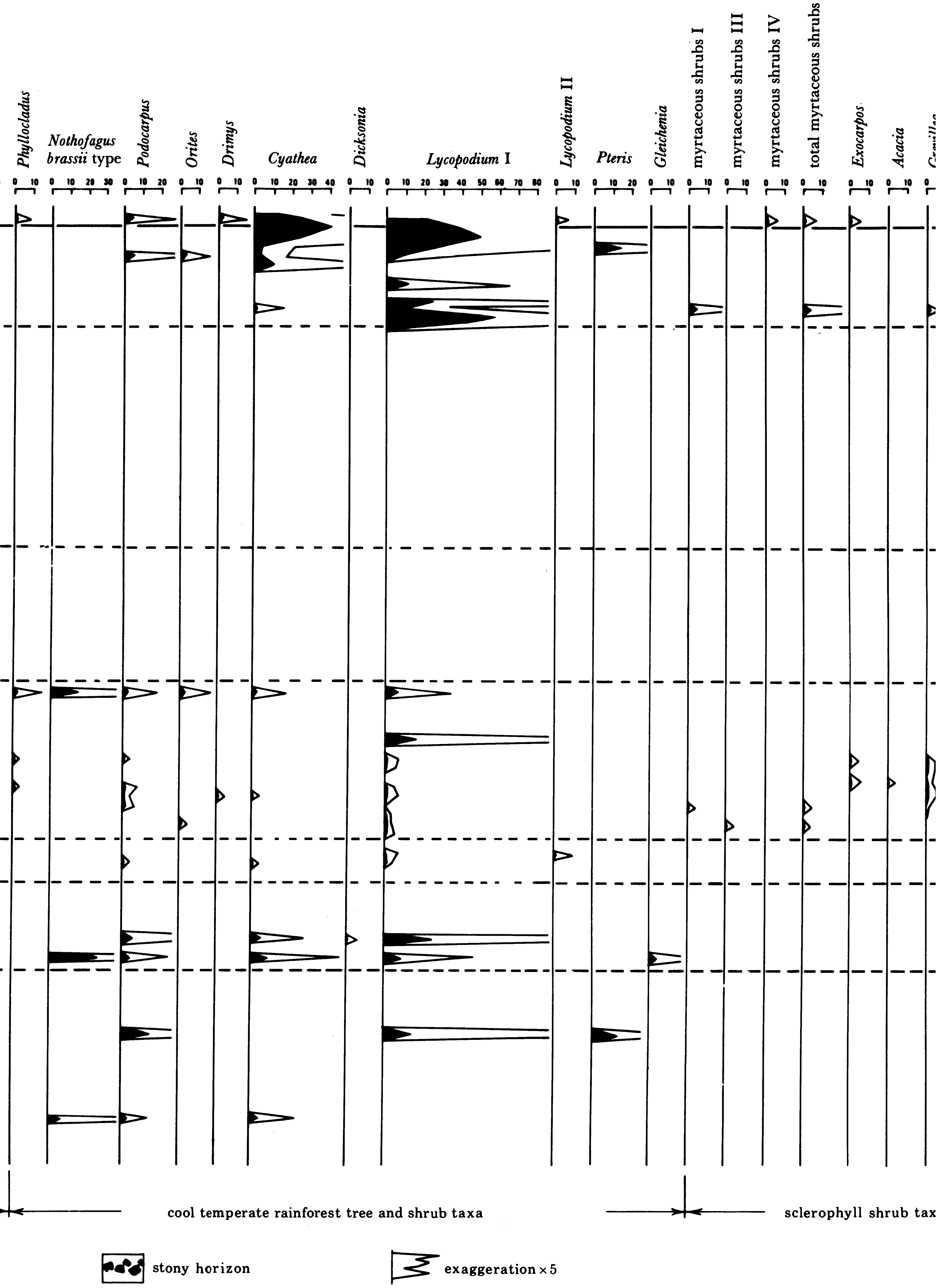
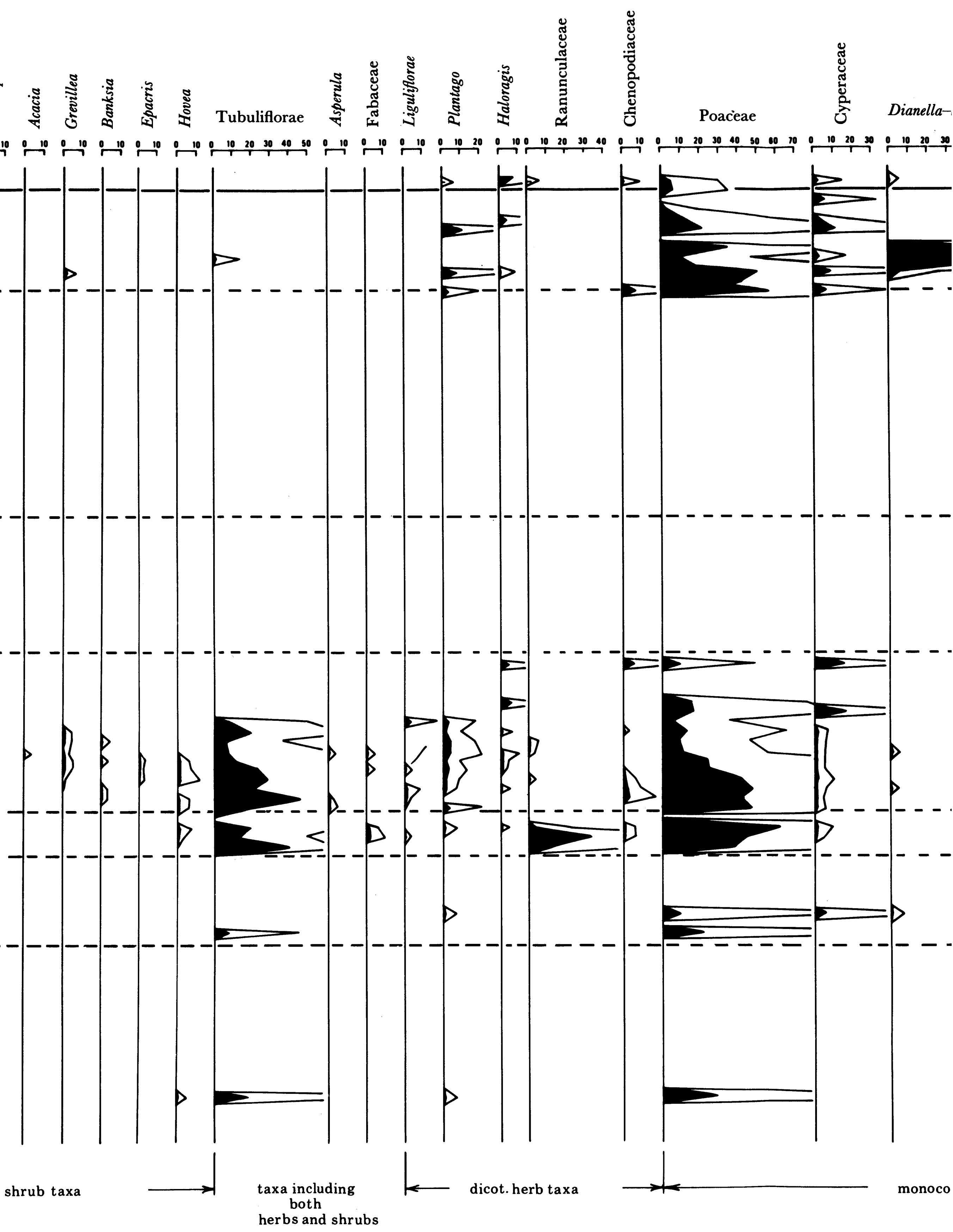
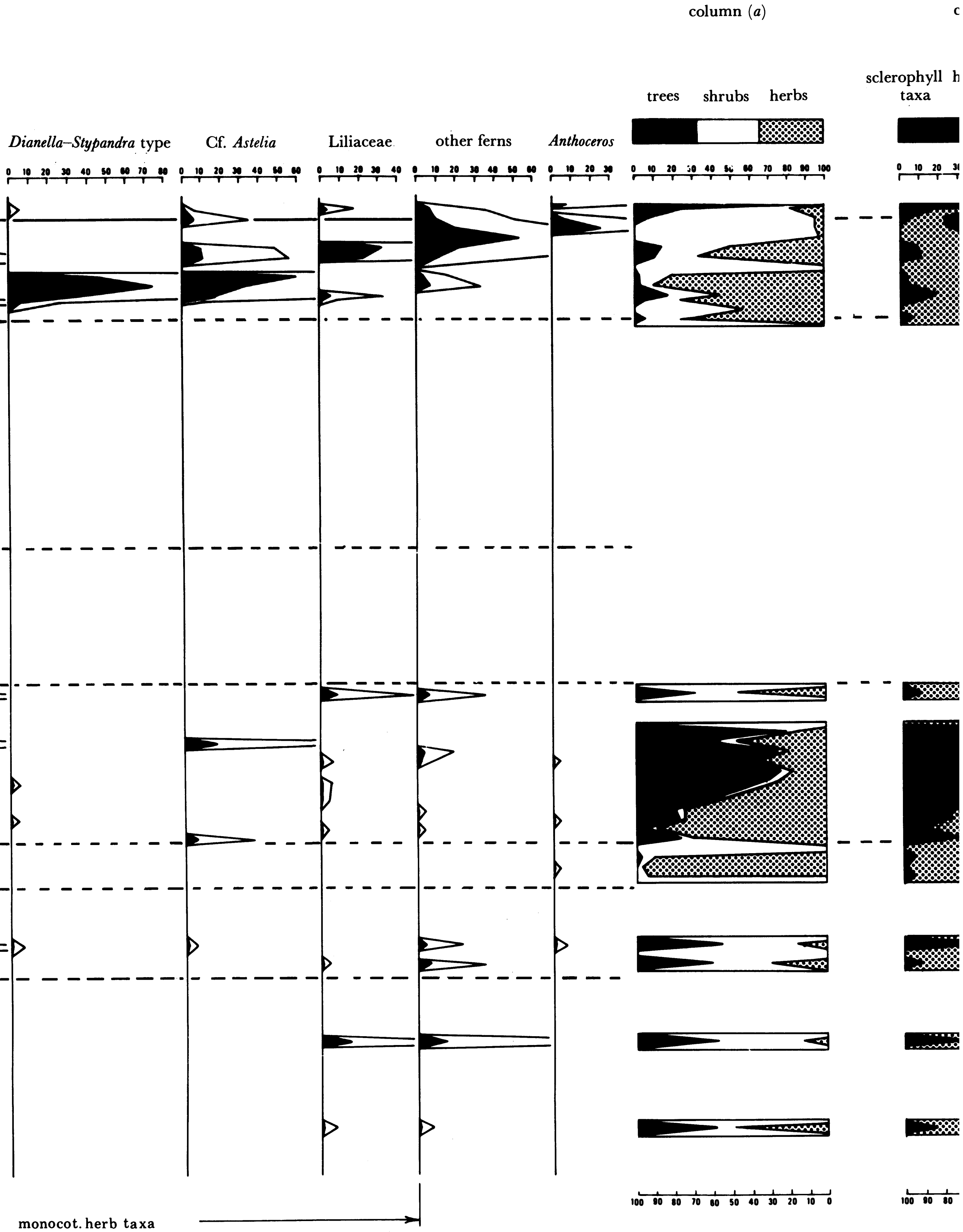


FIGURE 10. Pollen dia
Lake George. Pol

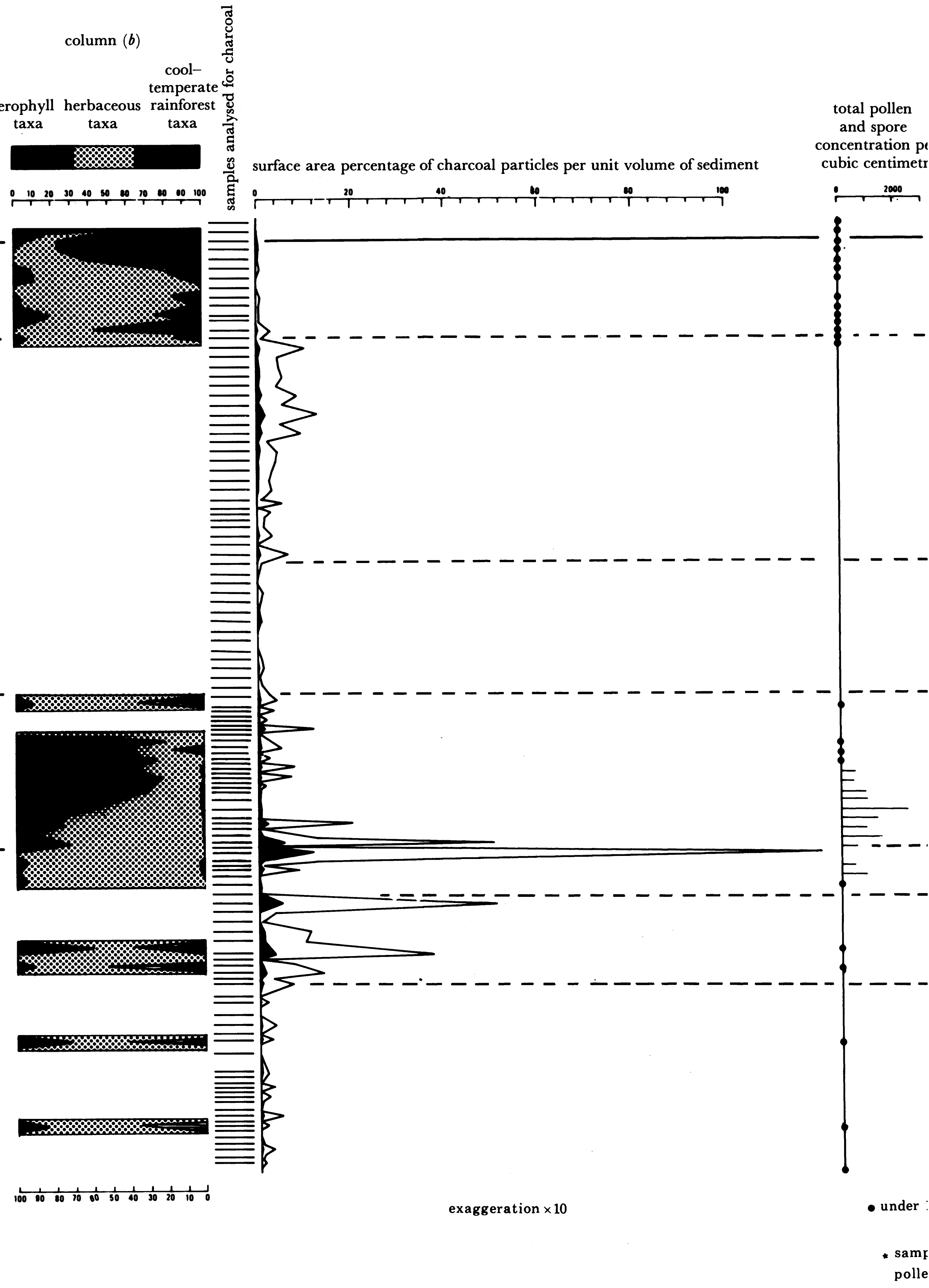


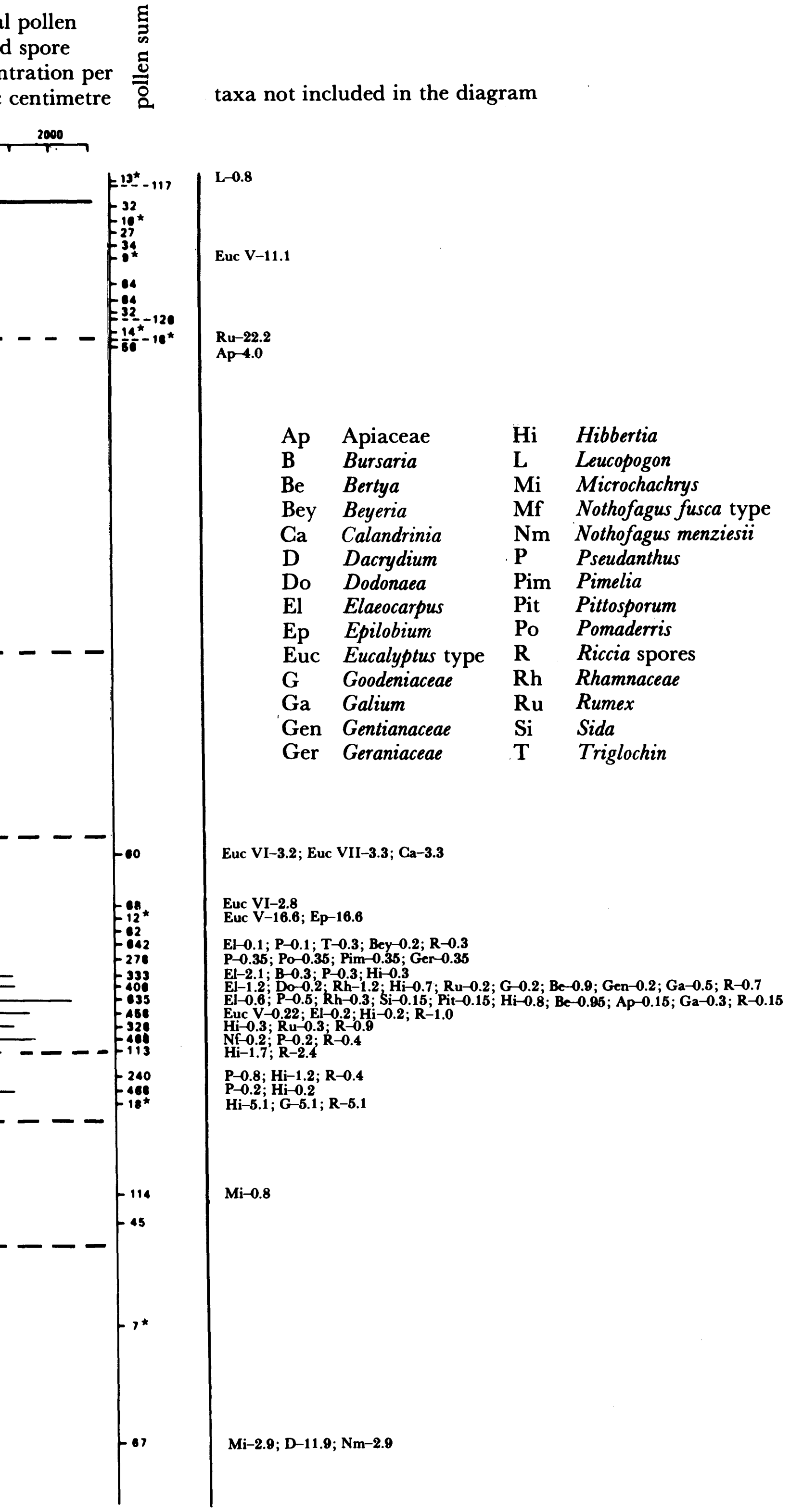
Pollen diagram 1*c* shows the lowest part (800–1800 cm depth) of the fossil pollen sequence from eorge. Pollen and spore values are expressed as percentages of total pollen and spores of dry land

plants. Charcoal particle
Total pollen and spore c



al particle values are expressed as surface area percentage values per unit volume of sediment.
nd spore concentration per cubic centimetre is shown in a separate column.

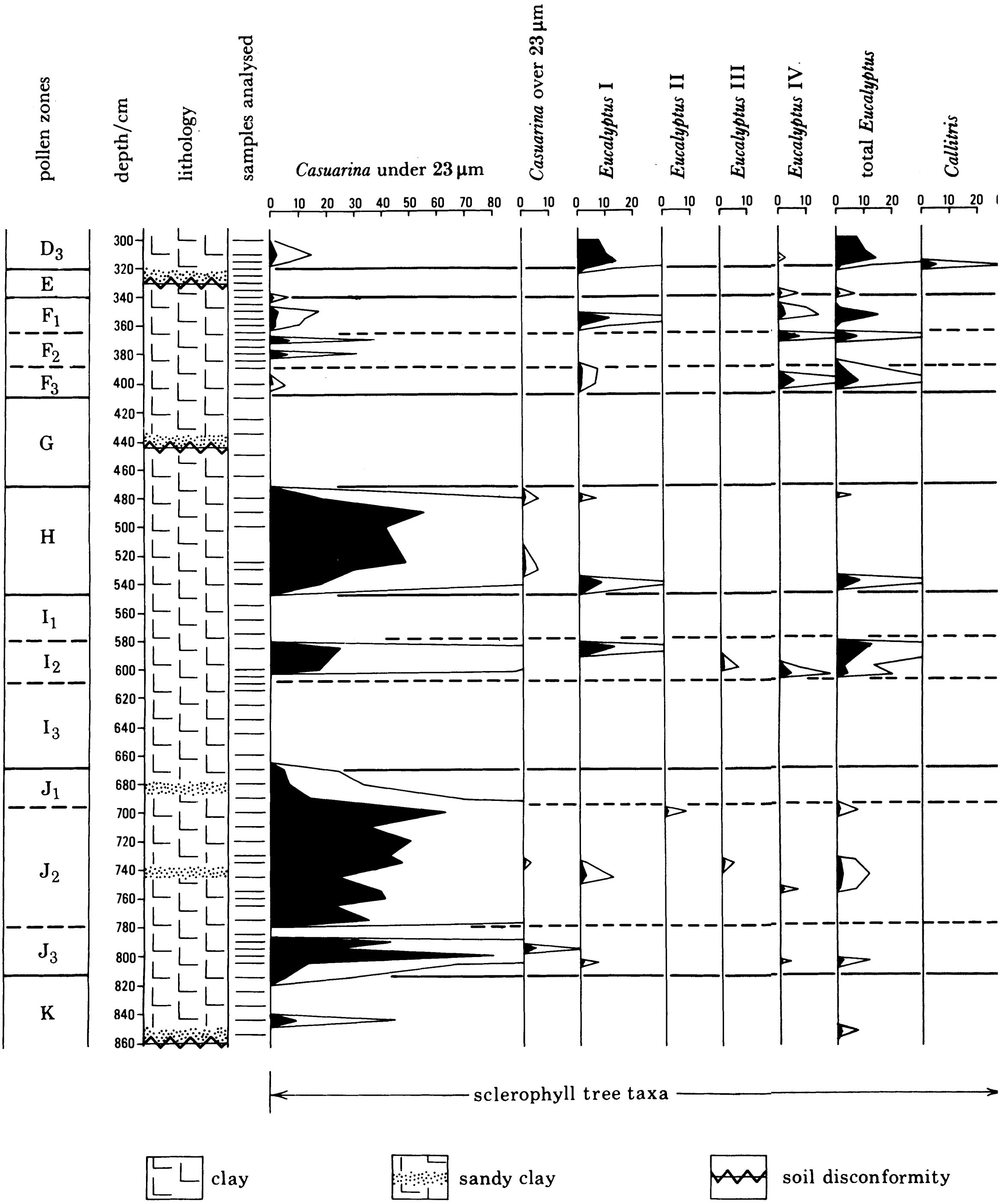

column (*b*)
erophyll taxa
herbaceous taxa
cool–temperate rainforest taxa
0 10 20 30 40 50 60 70 80 90 100
samples analysed for charcoal
surface area percentage of charcoal particles per unit volume of sediment
0 20 40 60 80 100
total pollen and spore concentration pe
cubic centimetr
0 2000
100 90 80 70 60 50 40 30 20 10 0
exaggeration × 10
● under
* samp
polle

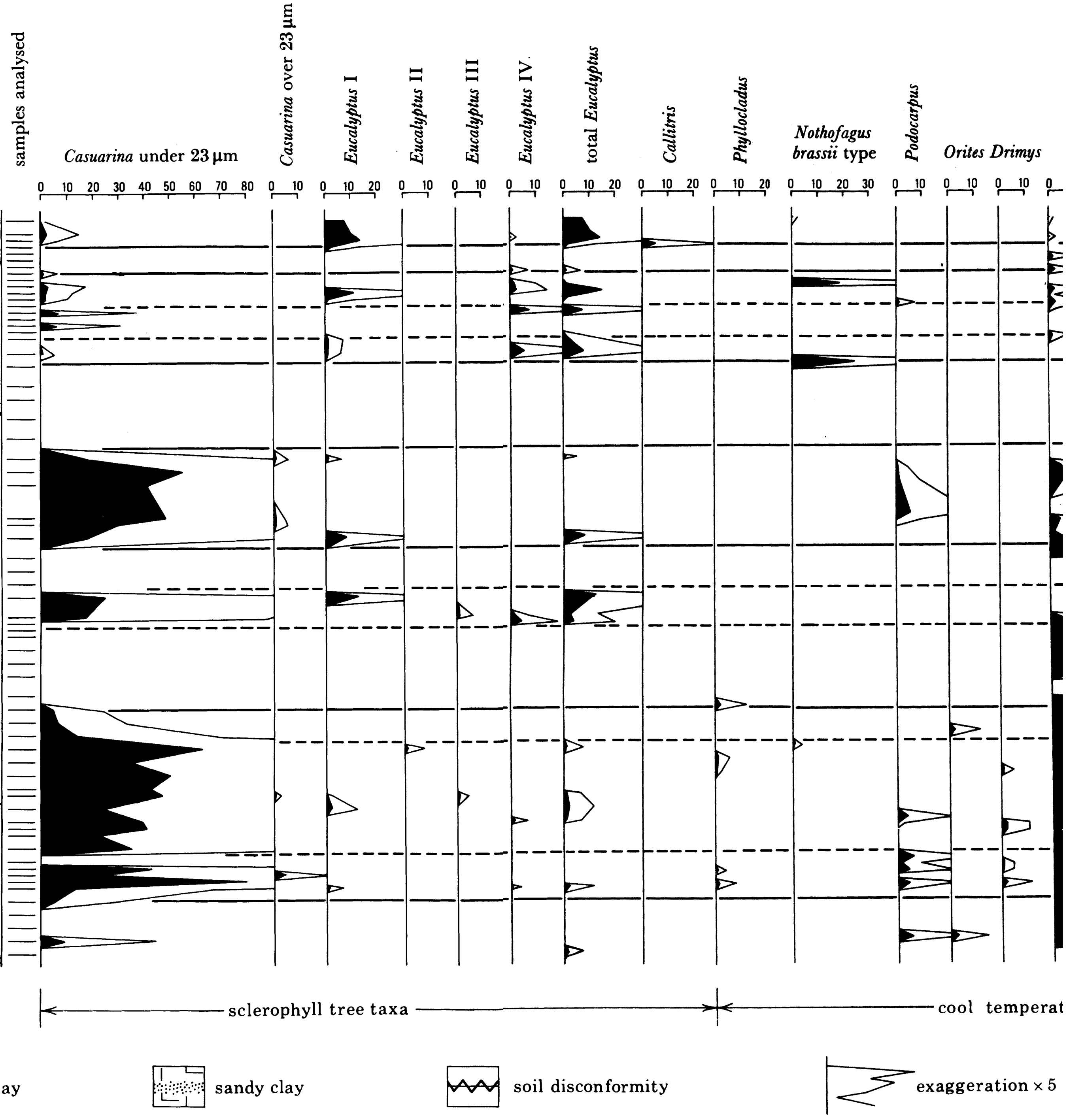


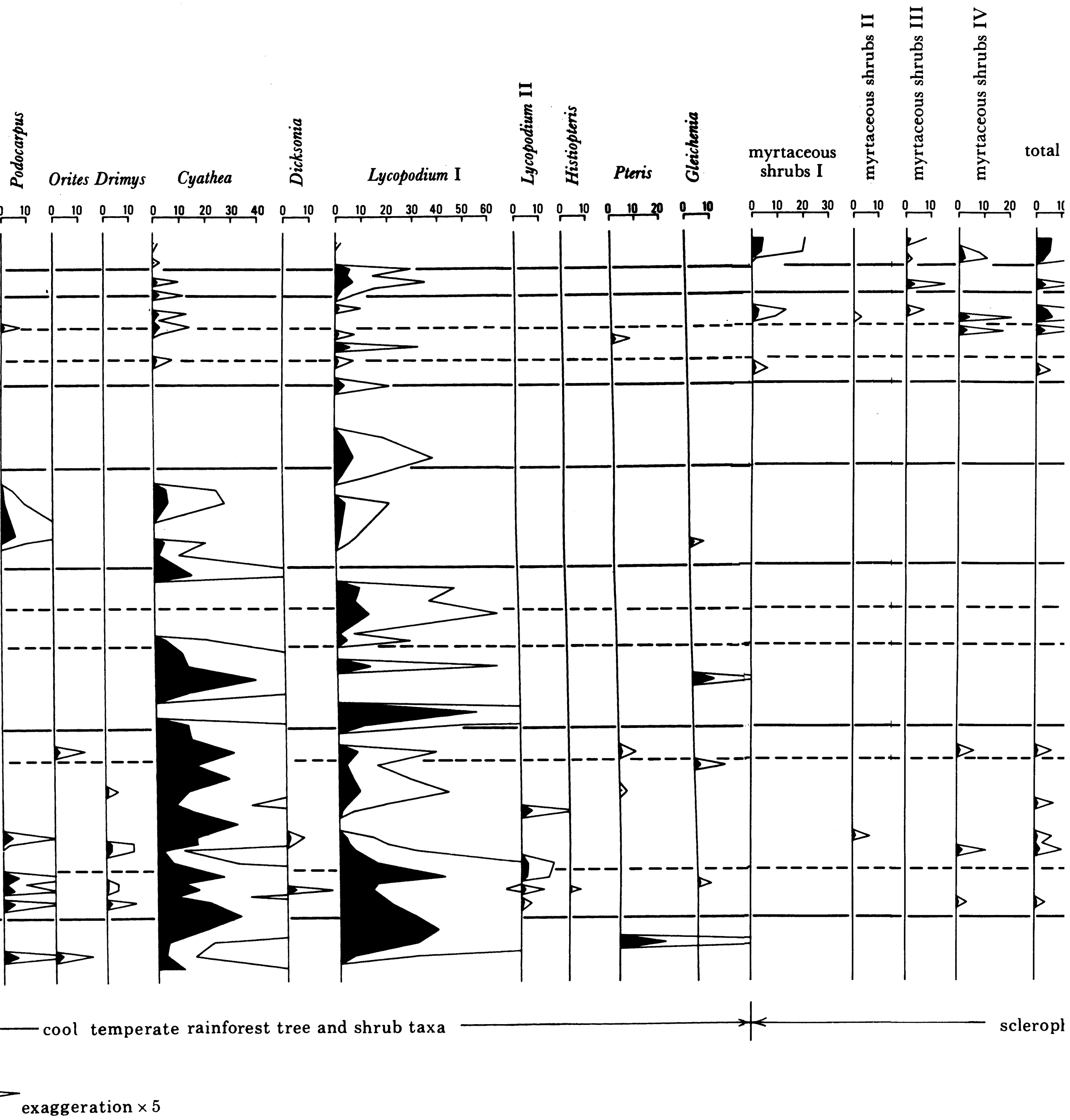
Ap	Apiaceae	Hi	*Hibbertia*
B	*Bursaria*	L	*Leucopogon*
Be	*Bertya*	Mi	*Microchachrys*
Bey	*Beyeria*	Mf	*Nothofagus fusca* type
Ca	*Calandrinia*	Nm	*Nothofagus menziesii*
D	*Dacrydium*	P	*Pseudanthus*
Do	*Dodonaea*	Pim	*Pimelia*
El	*Elaeocarpus*	Pit	*Pittosporum*
Ep	*Epilobium*	Po	*Pomaderris*
Euc	*Eucalyptus* type	R	*Riccia* spores
G	*Goodeniaceae*	Rh	*Rhamnaceae*
Ga	*Galium*	Ru	*Rumex*
Gen	*Gentianaceae*	Si	*Sida*
Ger	*Geraniaceae*	T	*Triglochin*

● under 100

* samples with extremely small pollen counts


pollen zones
depth/cm
lithology
samples analysed
Casuarina under 23 µm
Casuarina over 23 µm
Eucalyptus I
Eucalyptus II
Eucalyptus III
Eucalyptus IV
total Eucalyptus
Callitris
0 10 20 30 40 50 60 70 80
0 10
0 10 20
D3
E
F1
F2
F3
G
H
I1
I2
I3
J1
J2
J3
K
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
720
740
760
780
800
820
840
860
sclerophyll tree taxa
clay
sandy clay
soil disconformity


samples analysed
Casuarina under 23 µm
0 10 20 30 40 50 60 70 80
Casuarina over 23 µm
0 10
Eucalyptus I
0 10 20
Eucalyptus II
0 10
Eucalyptus III
0 10
Eucalyptus IV
0 10
total *Eucalyptus*
0 10 20
Callitris
0 10 20
Phyllocladus
0 10 20
Nothofagus brassii type
0 10 20 30
Podocarpus
0 10
Orites
0 10
Drimys
0 10
0
sclerophyll tree taxa
cool temperat
ay
sandy clay
soil disconformity
exaggeration × 5


Podocarpus
Orites
Drimys
Cyathea
Dicksonia
Lycopodium I
Lycopodium II
Histiopteris
Pteris
Gleichenia
myrtaceous shrubs I
myrtaceous shrubs II
myrtaceous shrubs III
myrtaceous shrubs IV
total
0 10
0 10
0 10
0 10 20 30 40
0 10
0 10 20 30 40 50 60
0 10
0 10
0 10 20
0 10
0 10 20 30
0 10
0 10
0 10 20
cool temperate rainforest tree and shrub taxa
scleroph
exaggeration × 5

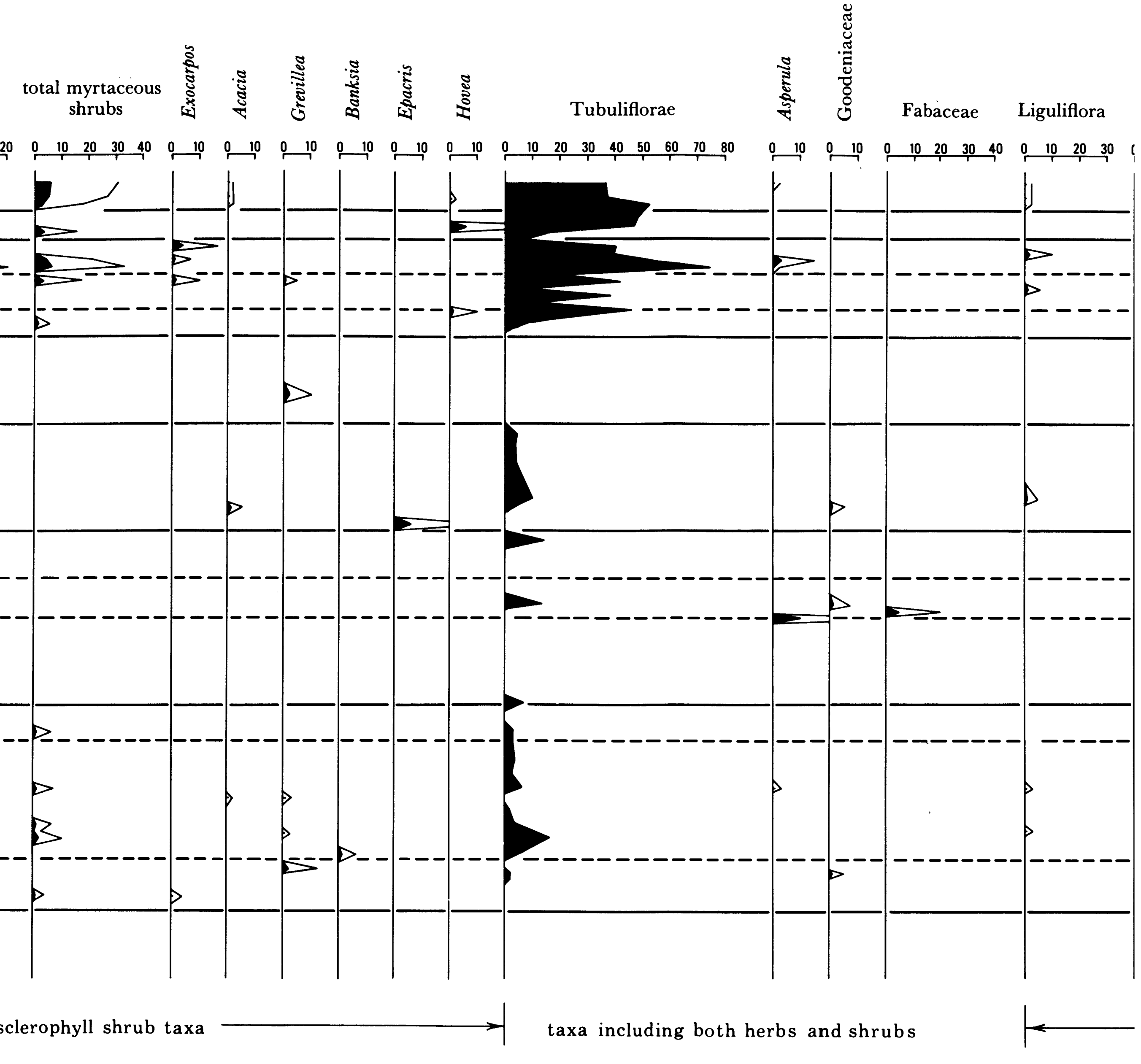
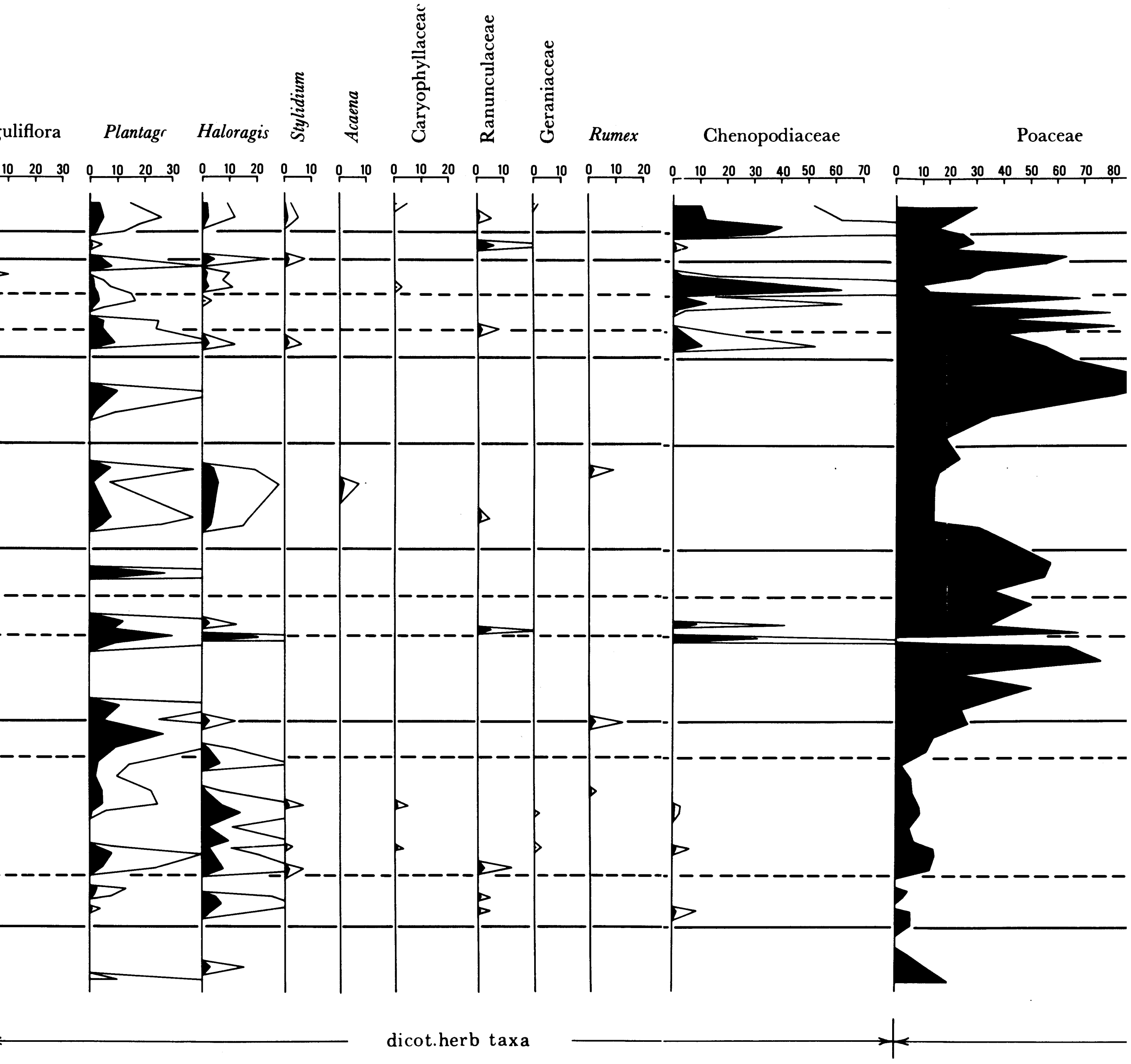
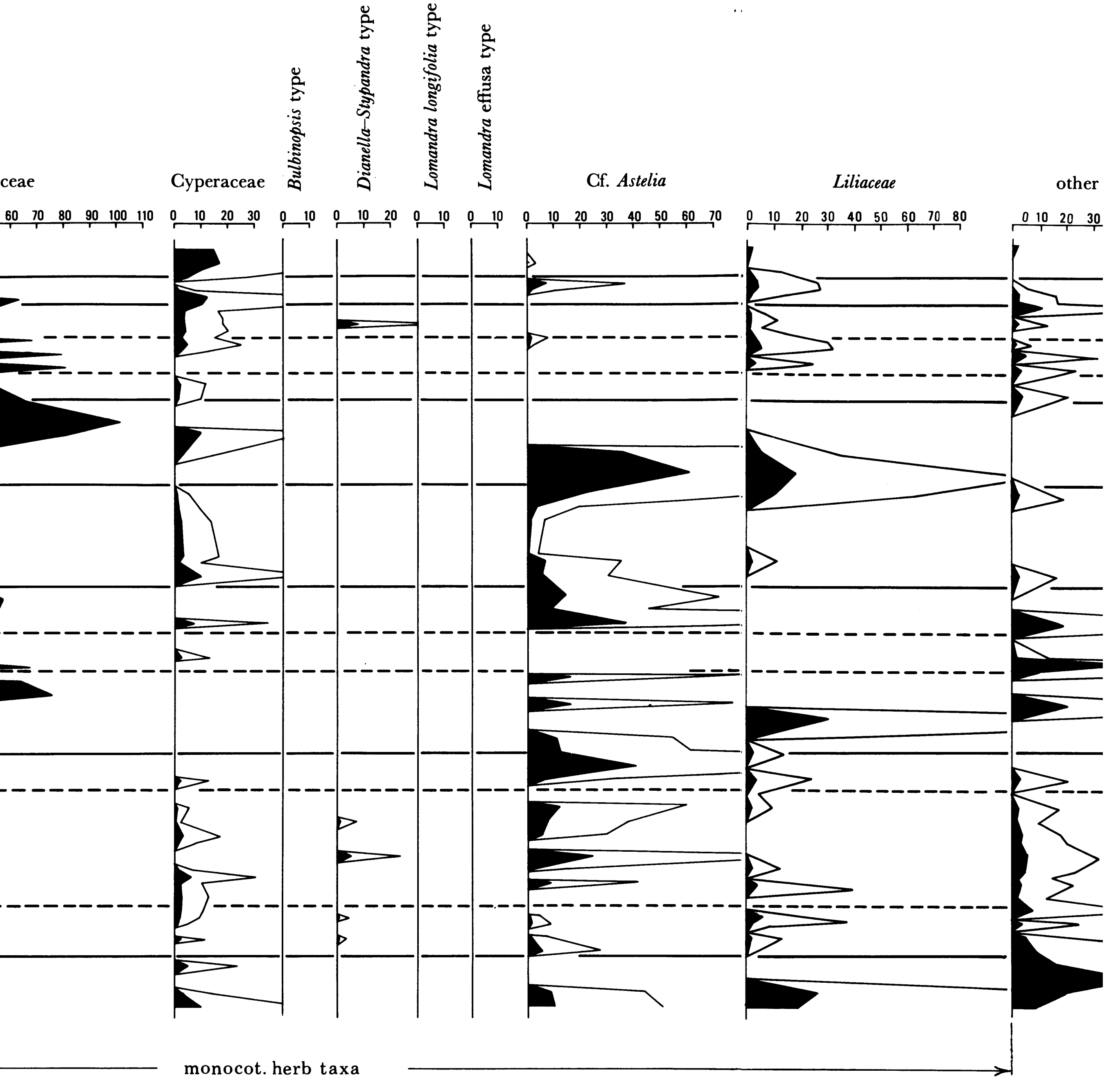


FIGURE 11. Pollen
George. Polle

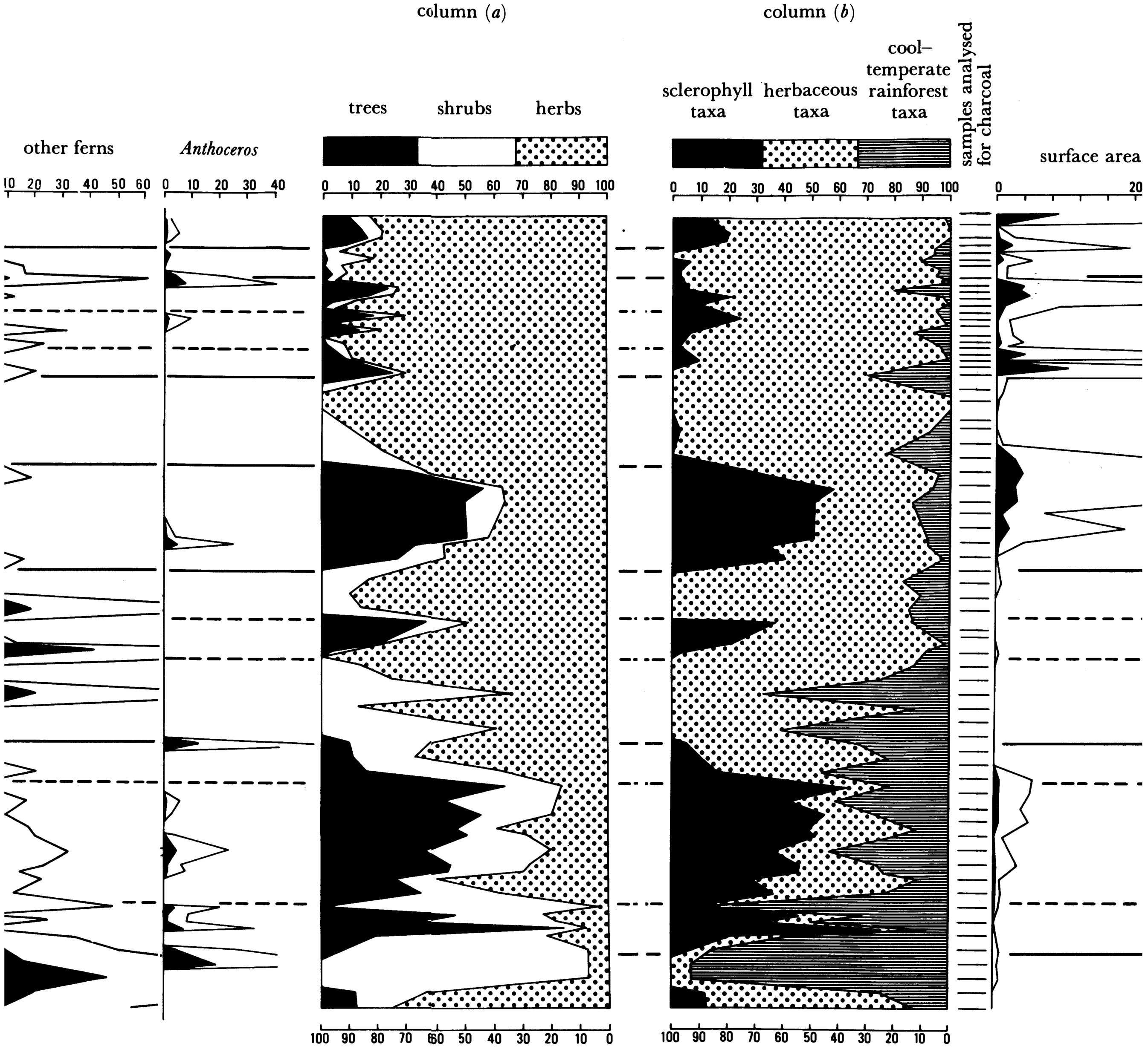


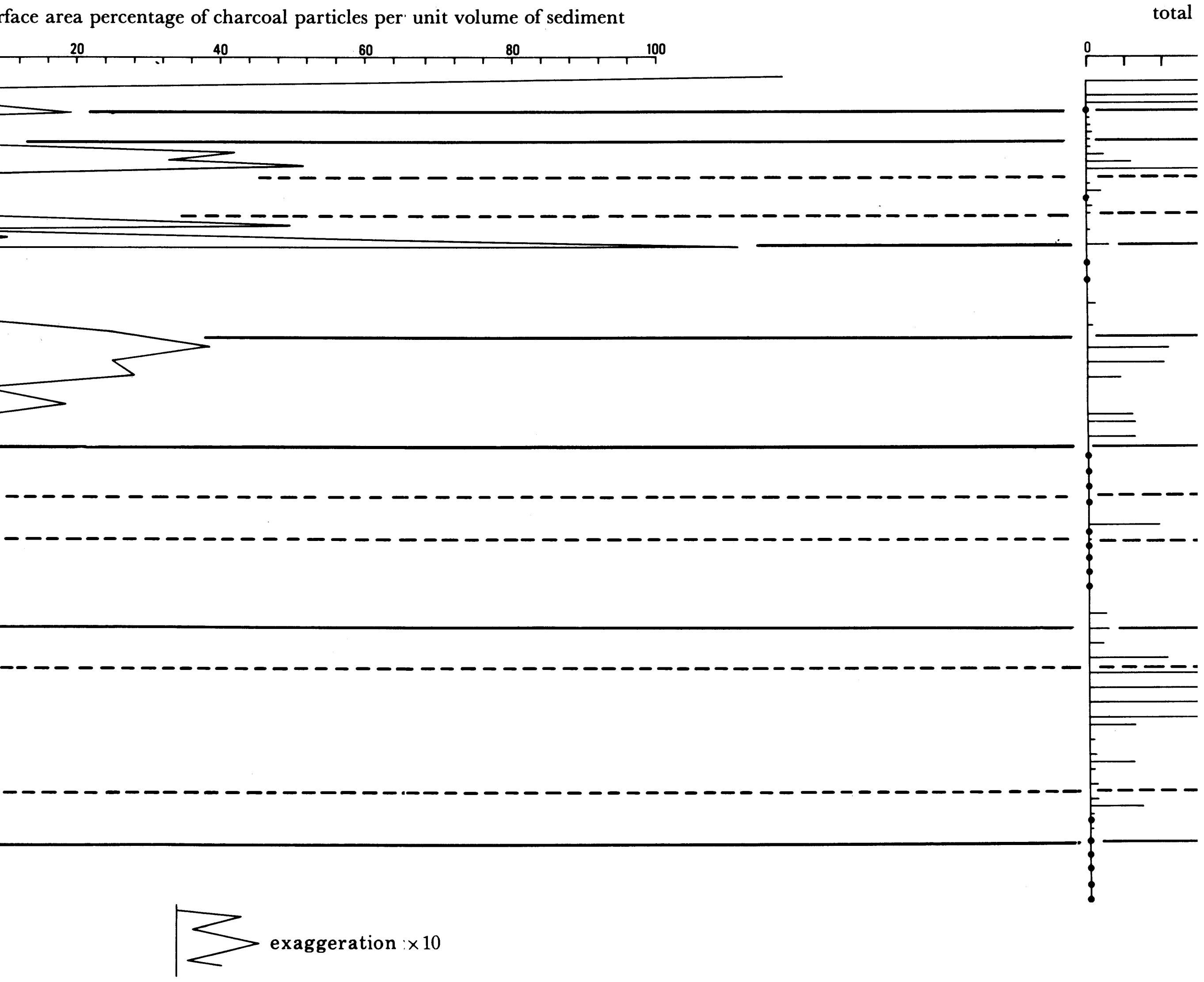
11. Pollen diagram 1*b* shows the middle part (300–855 cm depth) of the fossil pollen sequence from Lake
orge. Pollen and spore values are expressed as percentages of total pollen and spores of dry land plants.

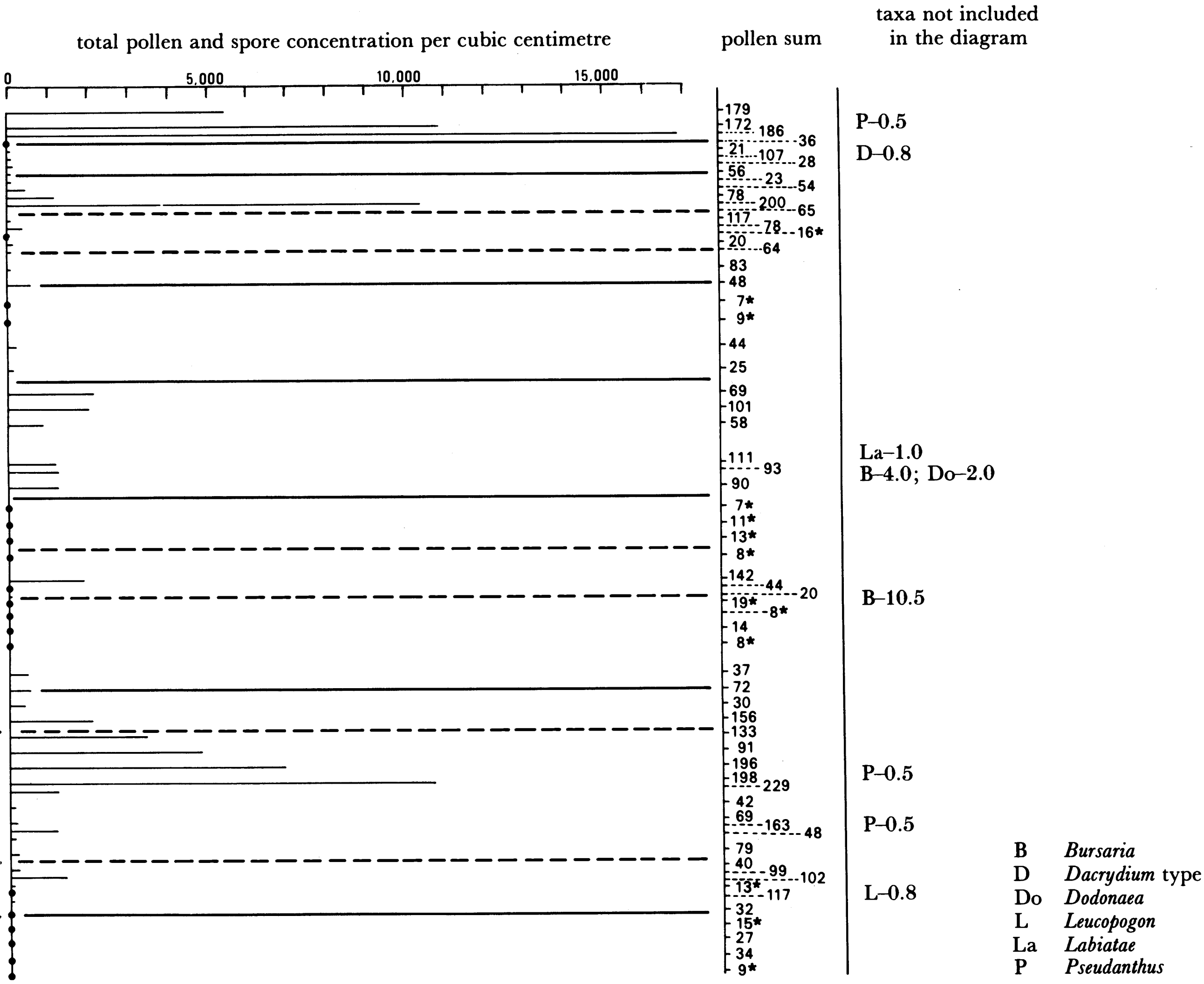
Charcoal particle values
pollen and spore concent



le values are expressed as surface area percentage values per unit volume of sediment. Total e concentration per cubic centimetre is shown in a separate column.

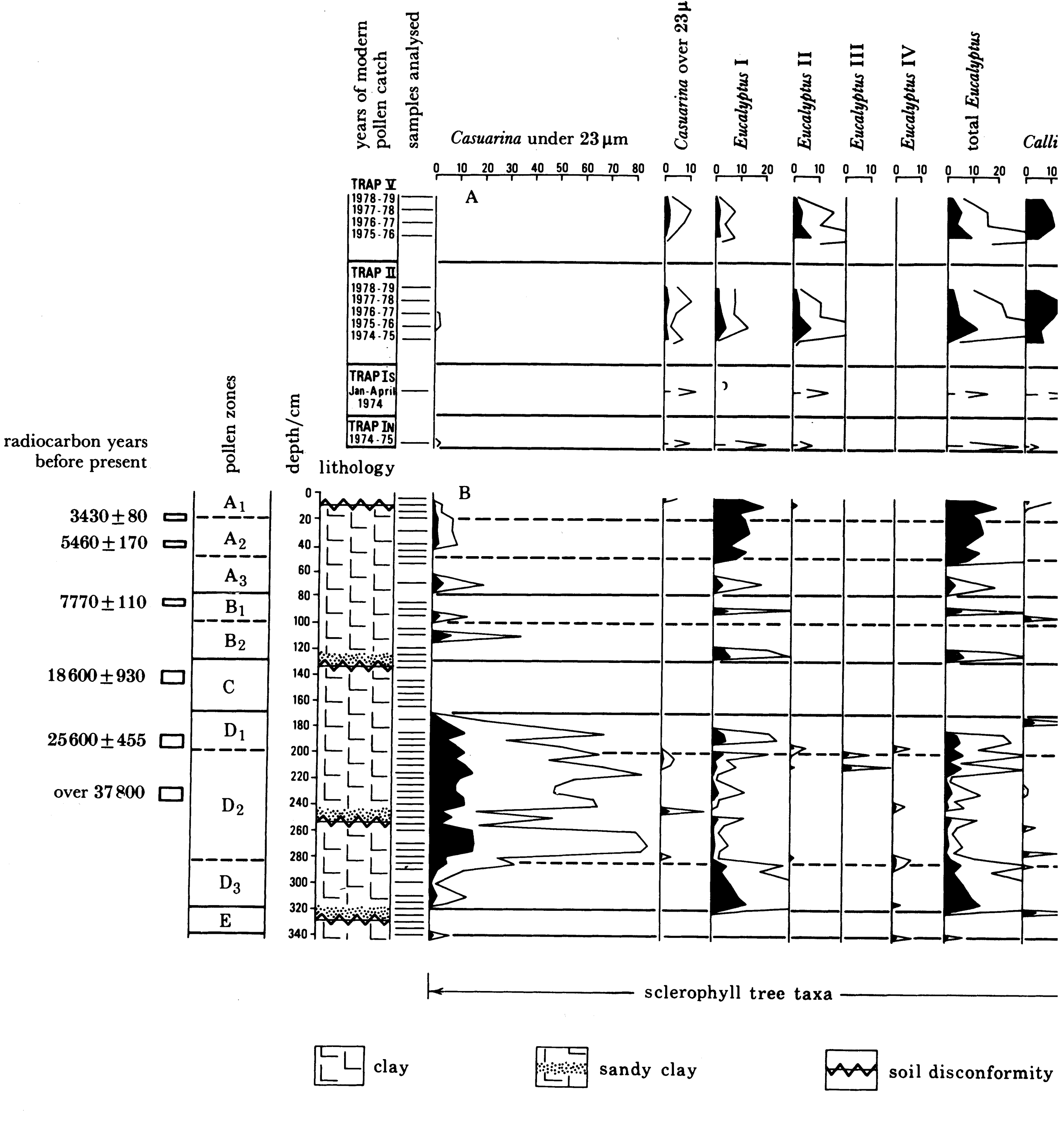

column (*a*)
column (*b*)
other ferns
10 20 30 40 50 60
Anthoceros
0 10 20 30 40
trees
shrubs
herbs
0 10 20 30 40 50 60 70 80 90 100
100 90 80 70 60 50 40 30 20 10 0
sclerophyll taxa
herbaceous taxa
cool-temperate rainforest taxa
0 10 20 30 40 50 60 70 80 90 100
100 90 80 70 60 50 40 30 20 10 0
samples analysed for charcoal
surface area
0
20

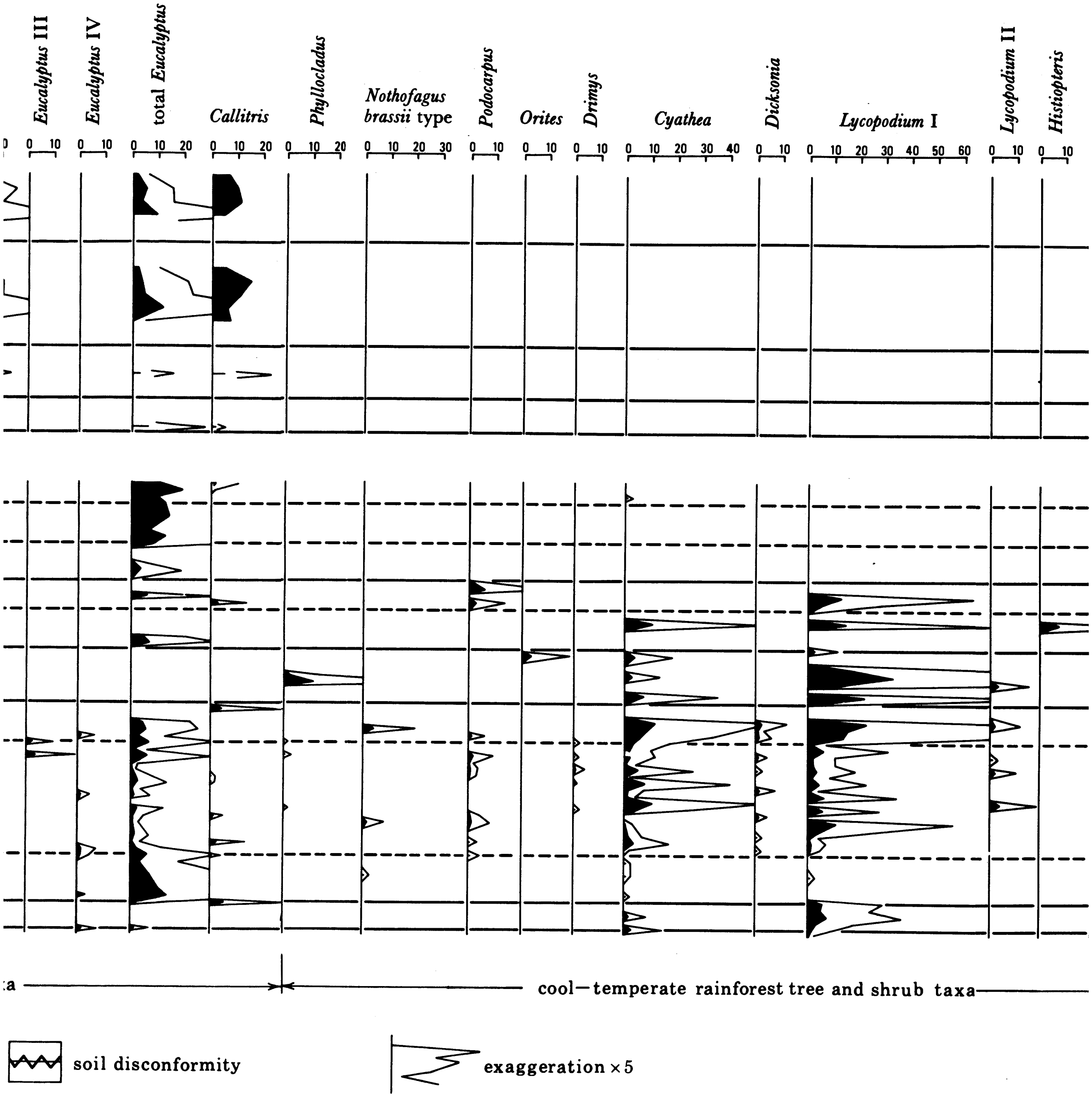

rface area percentage of charcoal particles per unit volume of sediment
total
20
40
60
80
100
0
exaggeration :×10



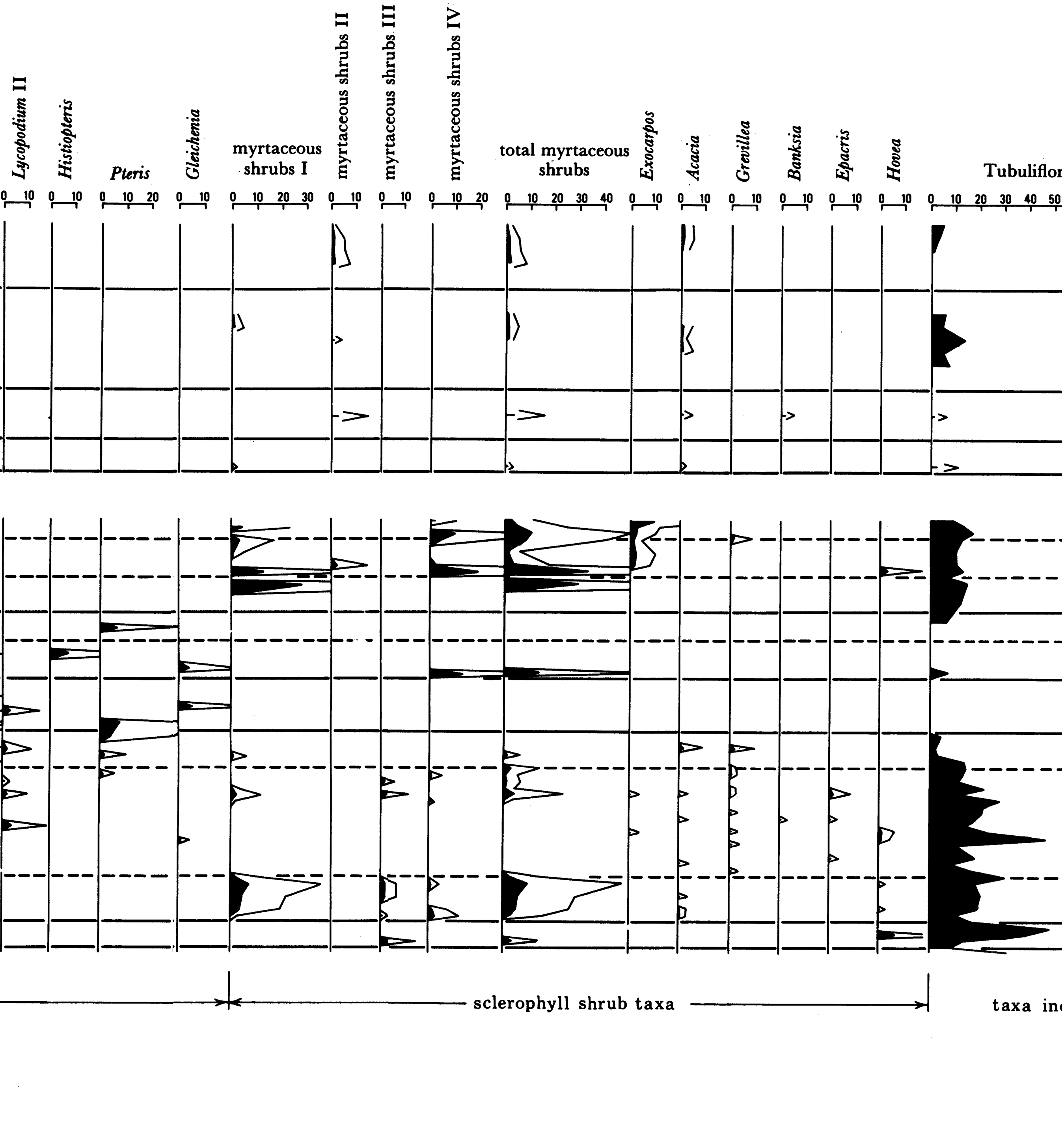
• under 100

* samples with extremely small pollen counts


years of modern pollen catch
samples analysed
Casuarina under 23 µm
Casuarina over 23 µm
Eucalyptus I
Eucalyptus II
Eucalyptus III
Eucalyptus IV
total *Eucalyptus*
Calli
0 10 20 30 40 50 60 70 80
0 10
0 10 20
A
B
TRAP V
1978-79
1977-78
1976-77
1975-76
TRAP II
1978-79
1977-78
1976-77
1975-76
1974-75
TRAP IS
Jan-April
1974
TRAP IN
1974-75
radiocarbon years before present
pollen zones
depth/cm
lithology
3430±80
5460±170
7770±110
18600±930
25600±455
over 37800
A1
A2
A3
B1
B2
C
D1
D2
D3
E
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
sclerophyll tree taxa
clay
sandy clay
soil disconformity



Eucalyptus III
Eucalyptus IV
total Eucalyptus
Callitris
Phyllocladus
Nothofagus brassii type
Podocarpus
Orites
Drimys
Cyathea
Dicksonia
Lycopodium I
Lycopodium II
Histiopteris
0 10
0 10
0 10 20
0 10 20
0 10 20
0 10 20 30
0 10
0 10
0 10
0 10 20 30 40
0 10
0 10 20 30 40 50 60
0 10
0 10
:a
cool—temperate rainforest tree and shrub taxa
soil disconformity
exaggeration × 5


Lycopodium II
0 10
Histiopteris
0 10
Pteris
0 10 20
Gleichenia
0 10
myrtaceous shrubs I
0 10 20 30
myrtaceous shrubs II
0 10
myrtaceous shrubs III
0 10
myrtaceous shrubs IV
0 10 20
total myrtaceous shrubs
0 10 20 30 40
Exocarpos
0 10
Acacia
0 10
Grevillea
0 10
Banksia
0 10
Epacris
0 10
Hovea
0 10
Tubuliflo
0 10 20 30 40 50
sclerophyll shrub taxa
taxa in

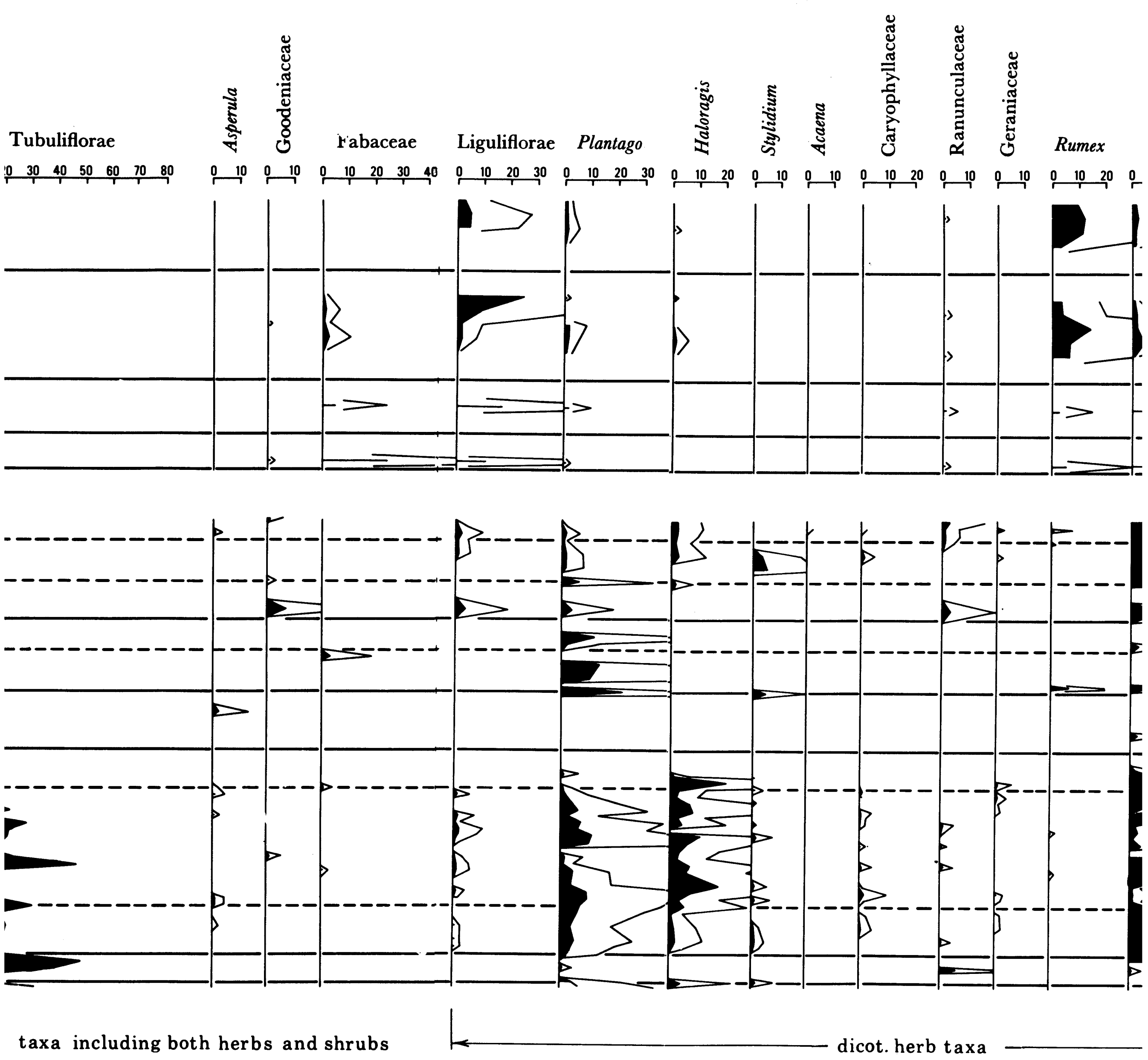
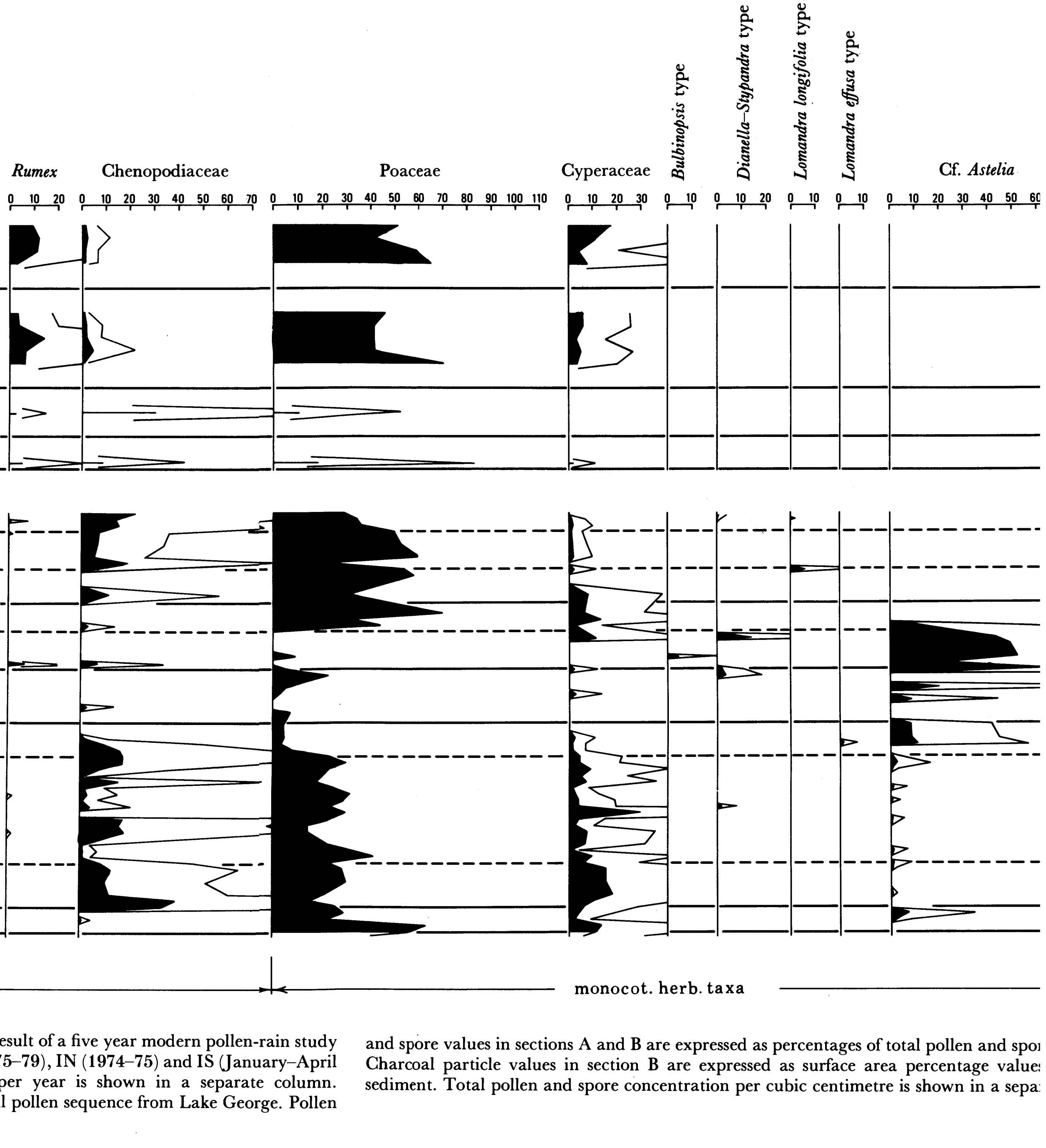
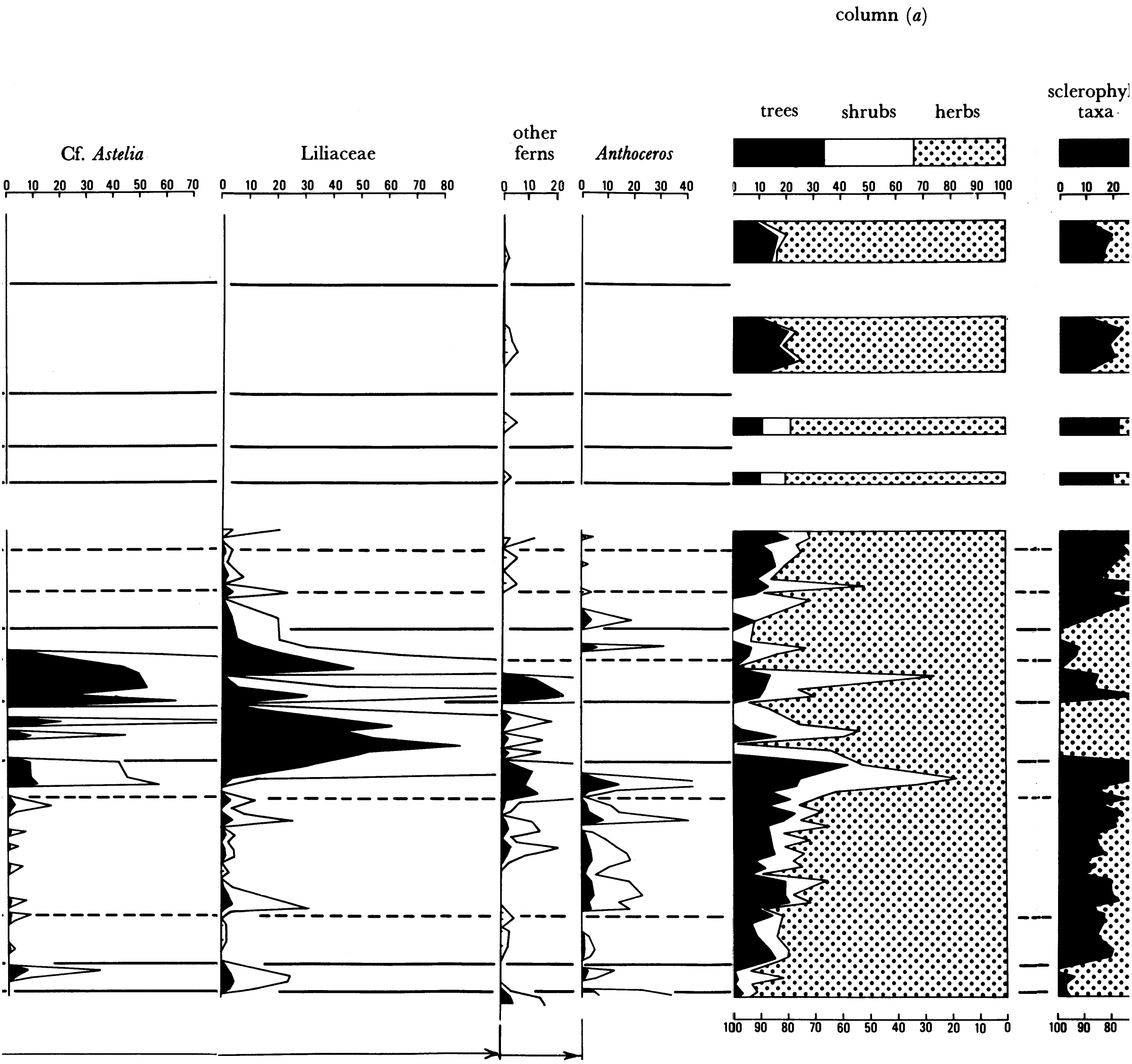


FIGURE 12. Pollen diagram 1*a*, sections A and B. Section A shows the result of a fiv
at Lake George as observed from Pollen Traps II (1974–79), V (1975–79), IN (
1974). Total pollen and spore influx per square centimetre per year is
Section B shows the uppermost part (5–340 cm depth) of the fossil pollen seq

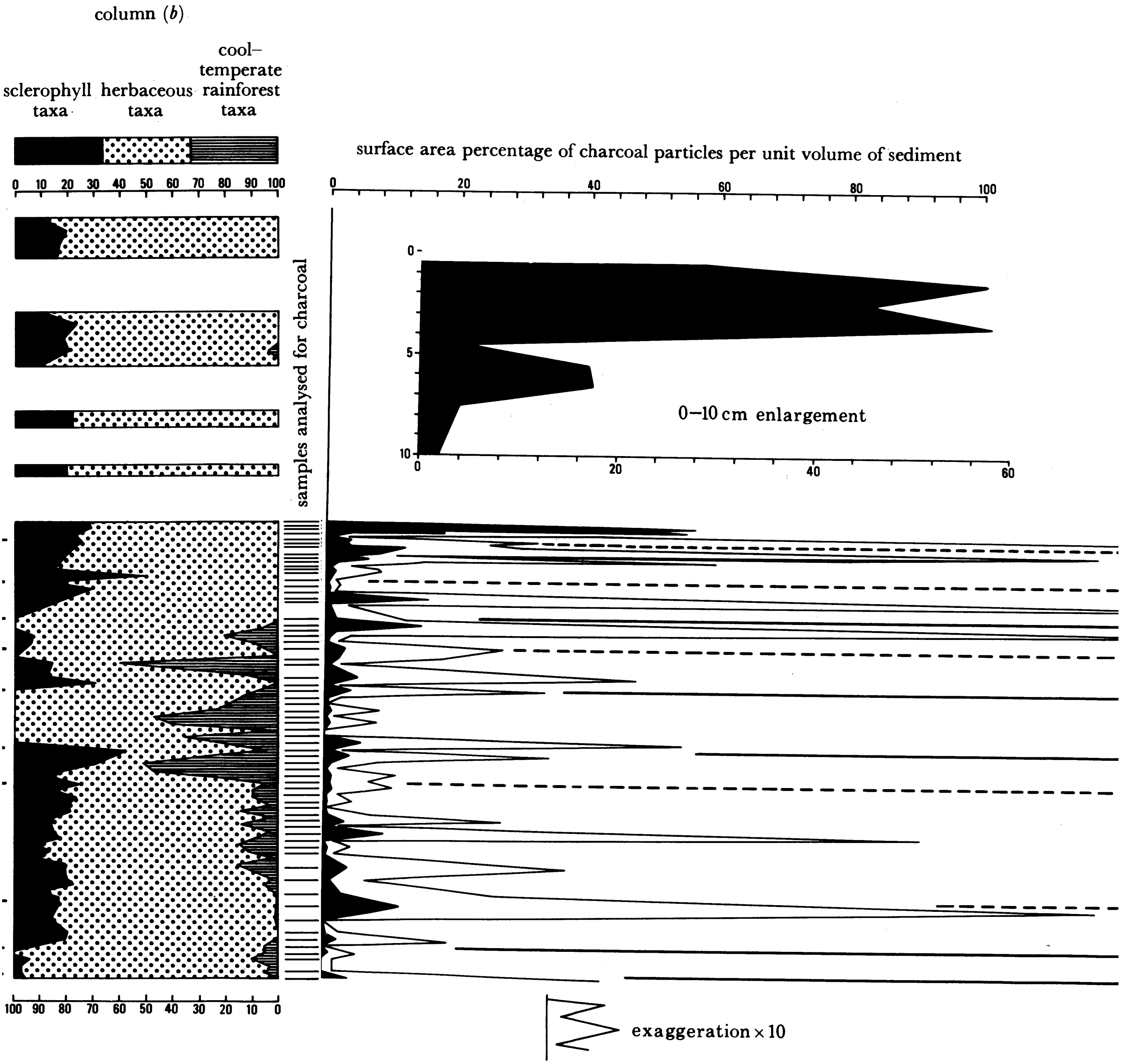


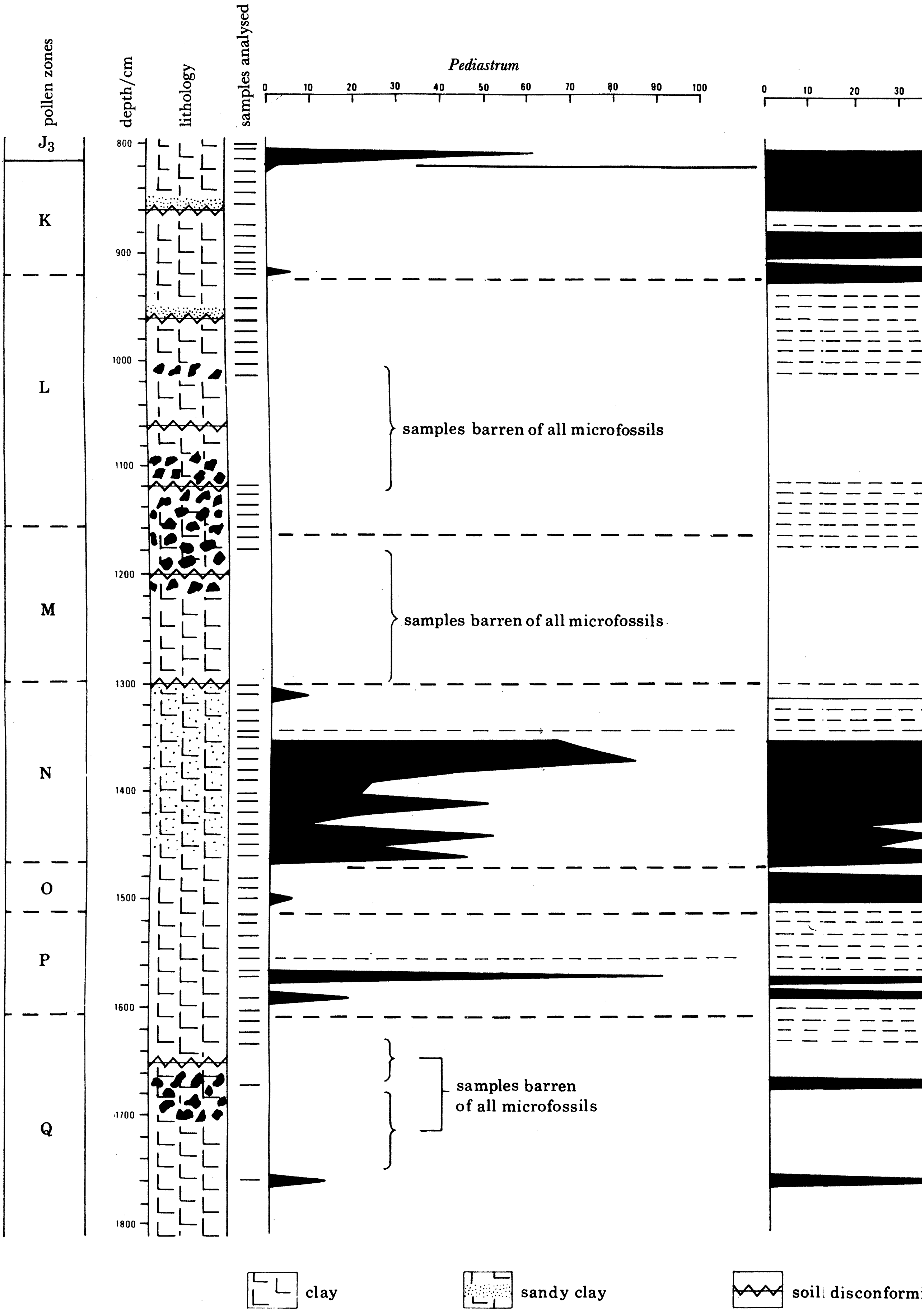
esult of a five year modern pollen-rain study
5–79), IN (1974–75) and IS (January–April
per year is shown in a separate column.
l pollen sequence from Lake George. Pollen

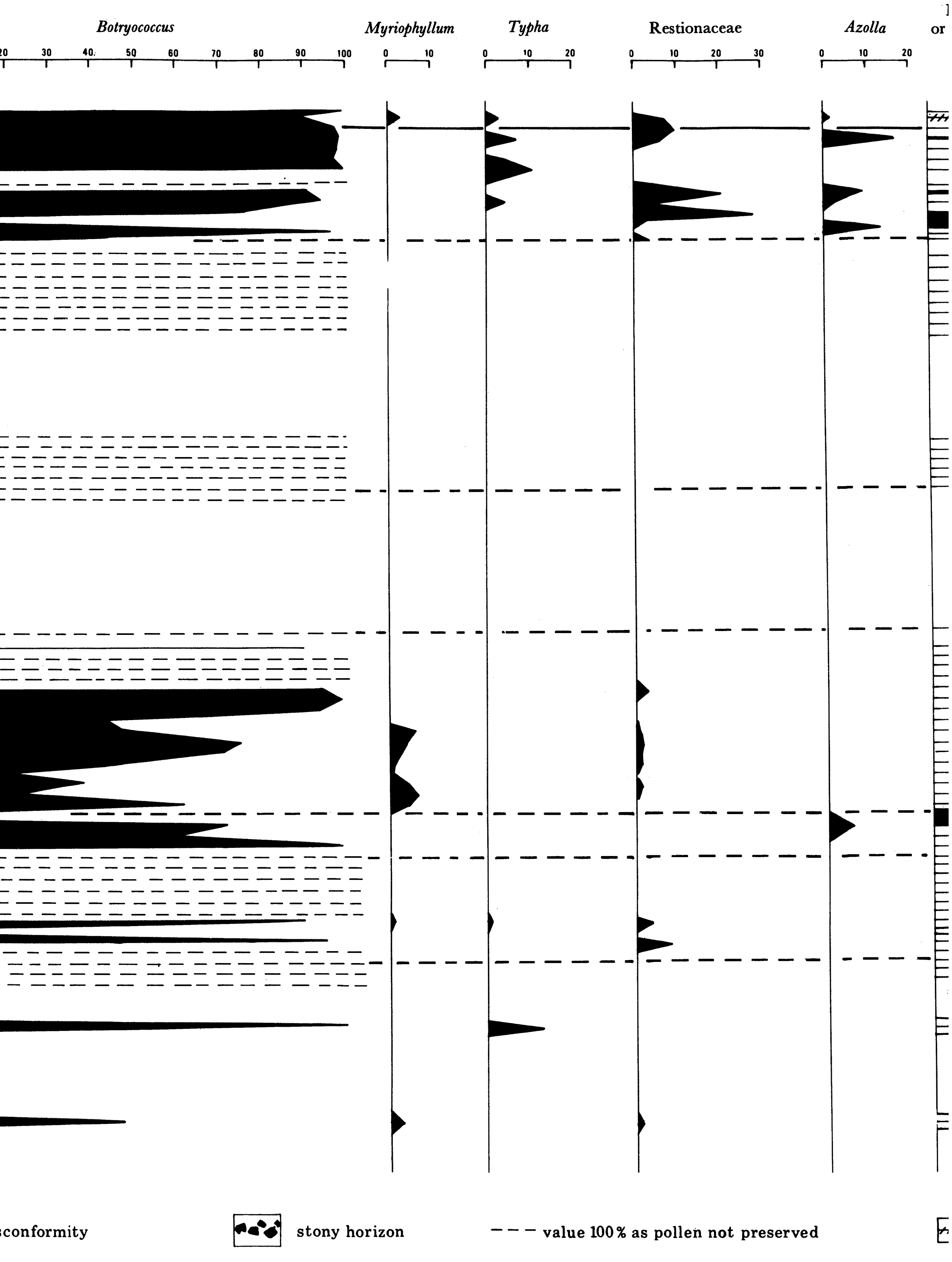
and spore values in sections A and B are expressed as percentages of total pollen and spo
Charcoal particle values in section B are expressed as surface area percentage value
sediment. Total pollen and spore concentration per cubic centimetre is shown in a sepa

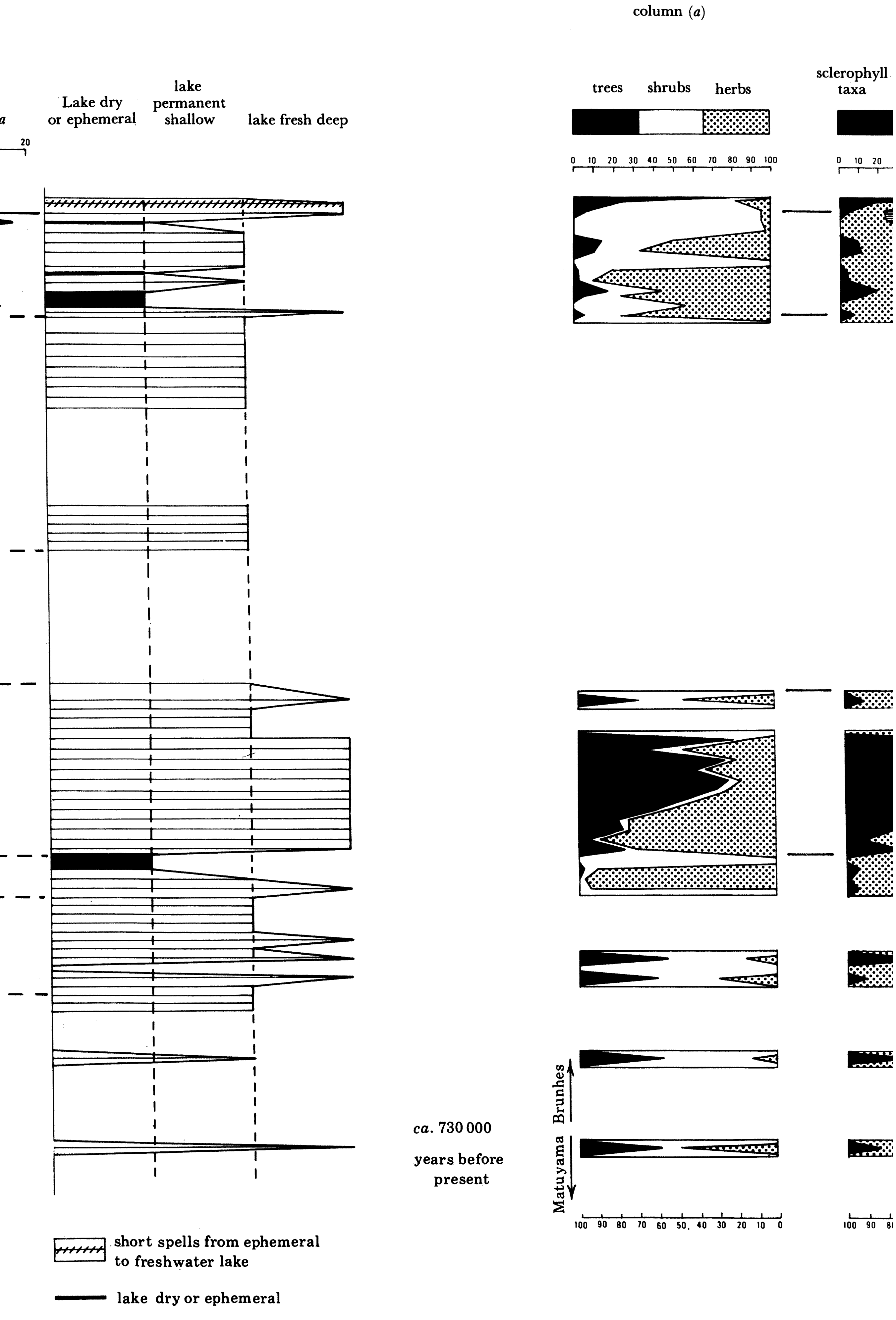


total pollen and spores of dry land plants.
a percentage values per unit volume of
e is shown in a separate column.


column (*b*)
sclerophyll taxa
herbaceous taxa
cool–temperate rainforest taxa
0 10 20 30 40 50 60 70 80 90 100
samples analysed for charcoal
100 90 80 70 60 50 40 30 20 10 0
surface area percentage of charcoal particles per unit volume of sediment
0 20 40 60 80 100
0 5 10
0 20 40 60
0–10 cm enlargement
exaggeration × 10


pollen zones
depth/cm
lithology
samples analysed
Pediastrum
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
J3
K
L
M
N
O
P
Q
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
samples barren of all microfossils
samples barren of all microfossils
samples barren
of all microfossils
clay
sandy clay
soil disconform


Botryococcus
20 30 40 50 60 70 80 90 100
Myriophyllum
0 10
Typha
0 10 20
Restionaceae
0 10 20 30
Azolla
0 10 20
or
sconformity
stony horizon
value 100% as pollen not preserved


column (*a*)
a
20
Lake dry or ephemeral
lake permanent shallow
lake fresh deep
trees
shrubs
herbs
sclerophyll taxa
0 10 20 30 40 50 60 70 80 90 100
0 10 20
ca. 730 000
years before present
Brunhes
Matuyama
100 90 80 70 60 50 40 30 20 10 0
100 90 8
short spells from ephemeral to freshwater lake
lake dry or ephemeral

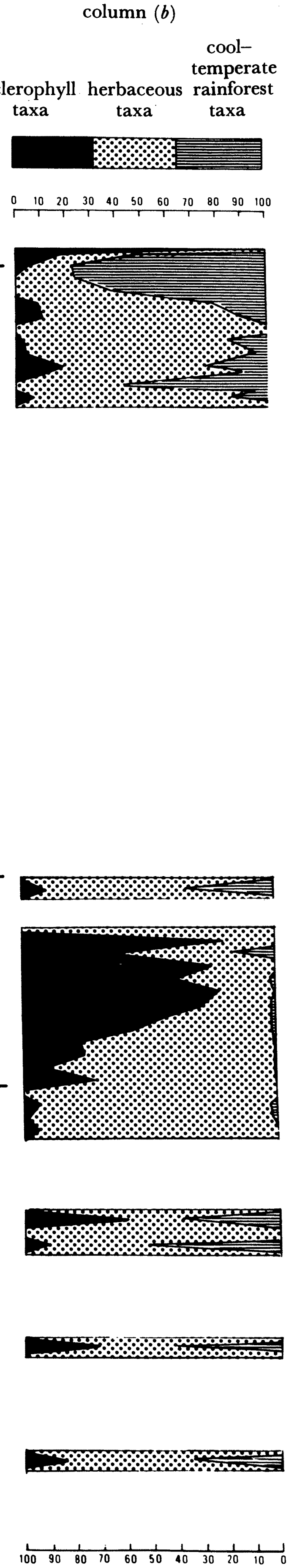


FIGURE 13. Diagram shows overall changes in vegetation, climate and lake levels as deduced from regional pollen, *Pediastrum* and *Botryococcus* algal colonies, spores of *Azolla* and the pollen of aquatic and subaquatic plants, *Myriophyllum*, *Typha* and Restionaceae in the lowest section (800–1800 cm) of the local pollen sequence at Lake George. Local pollen, spore and algal colony values are expressed as percentages of total pollen and spores of dry land plants plus individual taxon values. Changes in regional vegetation and climate are shown in two diagrams of relative percentages of total trees, shrubs and herbs (column *a*) and of total sclerophyll taxa, herbaceous taxa and cool–temperate rainforest taxa (column *b*). The presence of fossil *Pediastrum* colonies has been taken to indicate the occurrence of fresh water to at least 7 m depth. The occurrence of fossil *Botryococcus* colonies is indicative of shallow, open water conditions and of fossil *Azolla* spores of seasonally dry to ephemeral environments. Occurrences of *Azolla* spores and *Pediastrum* colonies together have been taken to indicate short-term fluctuations ranging from ephemeral to deep, freshwater lake conditions.

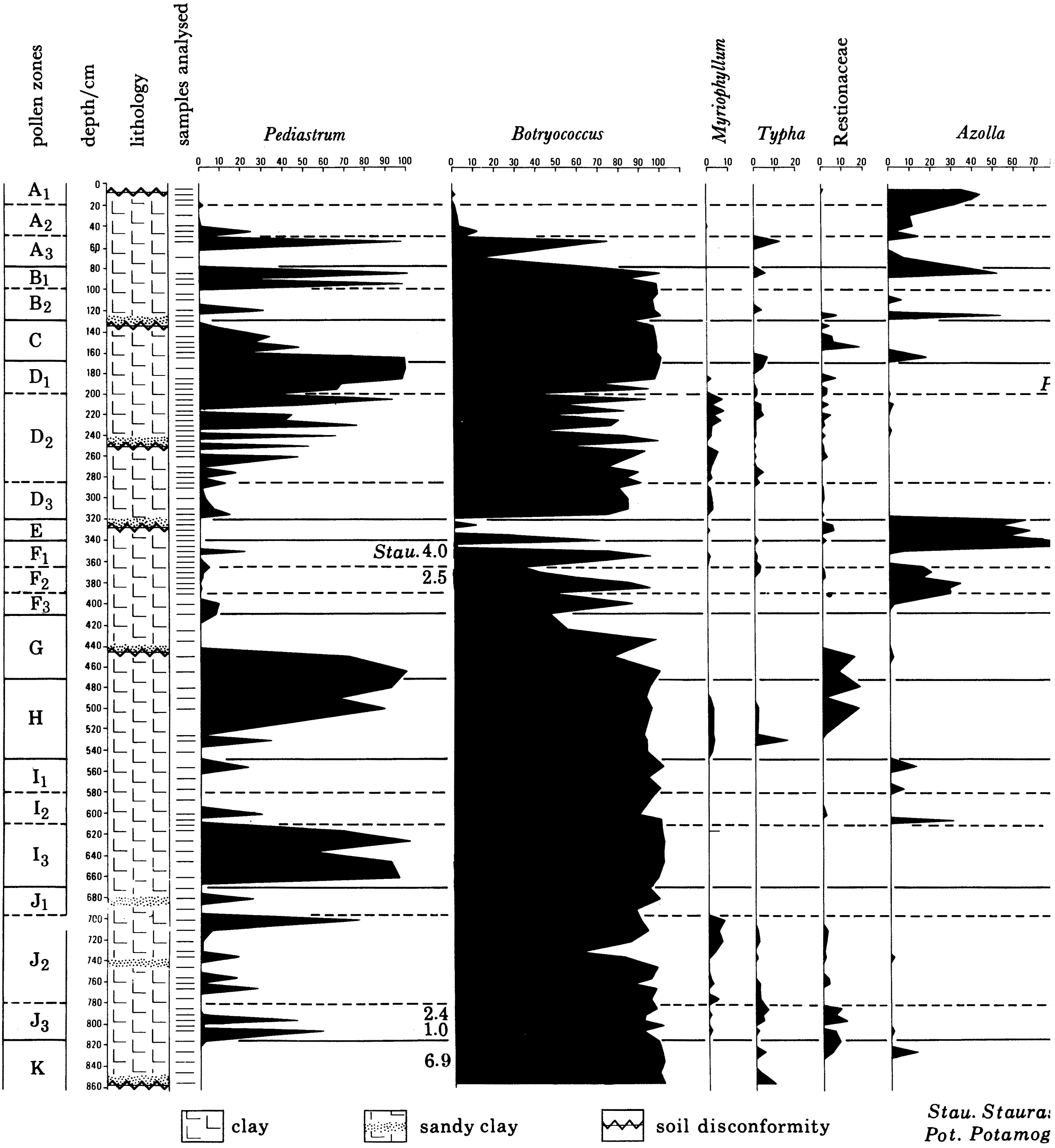
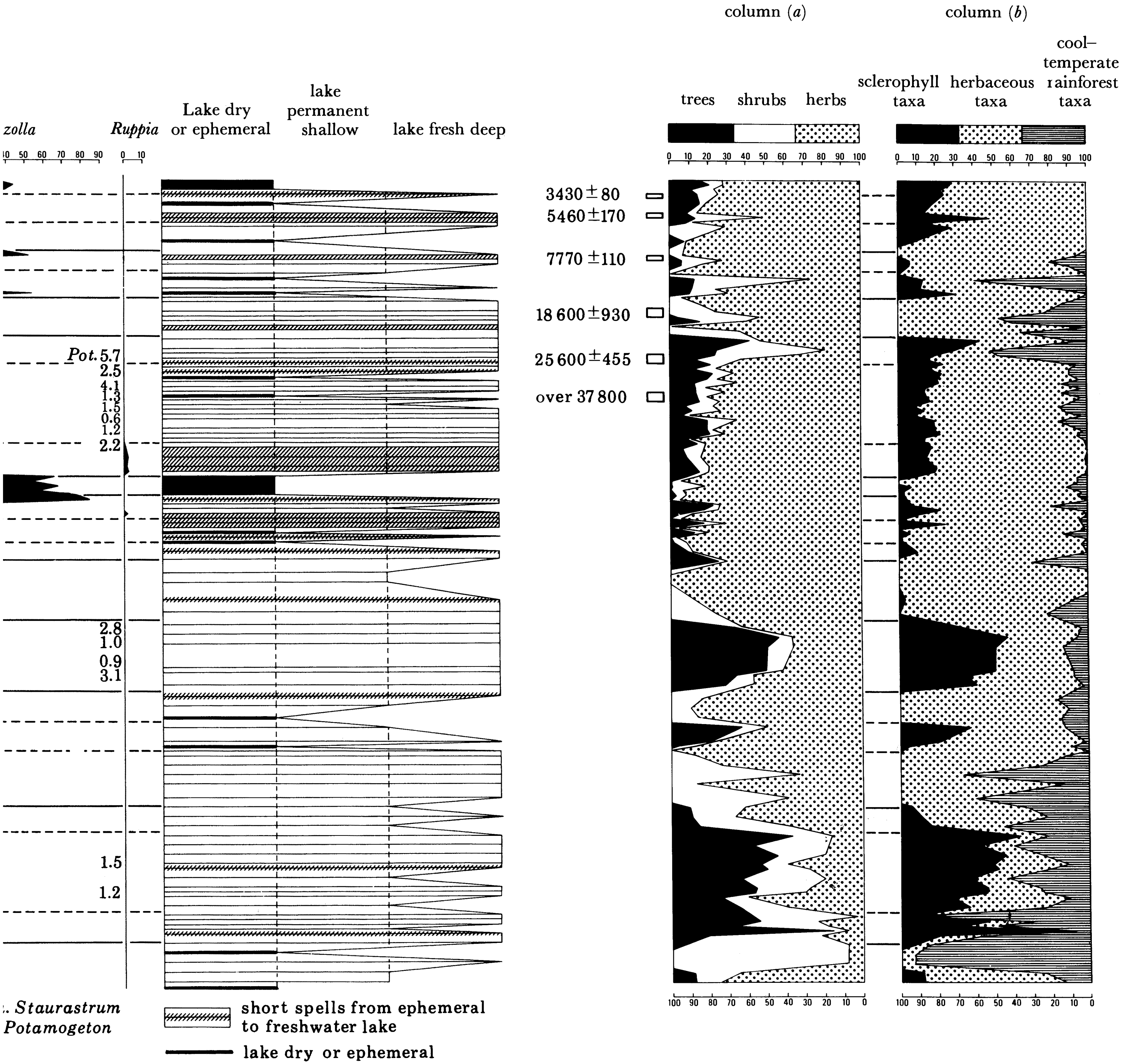


Figure 14. Diagram shows overall changes in vegetation, climate and lake levels as deduced from regional p *Pediastrum*, *Staurastrum* and *Botryococcus* algal colonies, spores of *Azolla* and the pollen of aquatic and subaq plants, *Myriophyllum*, *Potamogeton*, *Ruppia*, *Typha* and Restionaceae in the upper part (5–855 cm depth) o local pollen sequence at Lake George. Local pollen, spore and algal colony values are expressed as percen of total pollen and spores of dry land plants plus individual taxon values. Changes in regional vegetation climate are shown in two diagrams of relative percentage of total trees, shrubs and herbs (column *a*) a



egional pollen,
nd subaquatic
depth) of the
as percentages
egetation and
umn *a*) and of

total sclerophyll taxa, herbaceous taxa and cool–temperate rainforest taxa (column *b*). The presence of fossil *Pediastrum* and *Staurastrum* colonies has been taken to indicate the occurrence of fresh water to at least 7 m depth. The occurrence of fossil *Botryococcus* colonies and *Ruppia* pollen is indicative of shallow, openwater conditions and of fossil *Azolla* spores of seasonally dry to ephemeral environments. Occurrence of *Azolla* spores and *Pediastrum* and *Staurastrum* colonies together have been taken to indicate short-term fluctuations ranging from ephemeral to deep, freshwater lake conditions.

the whole, remains lowly represented but *Haloragis*, *Plantago* and ferns probably formed a significant ground-cover. Members of Tubuliflorae either formed a part of the shrub understorey or grew as herbs. Other taxa which appear to have been a part of the ground-cover are grasses, Cyperaceae, Liliaceae and *Anthoceros*. Cf. *Astelia*, Cyperaceae and *Anthoceros* probably occupied wet places. Other taxa occur only sporadically. These are *Asperula*, Liguliflorae, Stylidium, Caryophyllaceae, Ranunculaceae, Geraniaceae, *Dianella–Stypandra* types and Chenopodiaceae.

The charcoal particle values rise but reach only moderately high levels in this subzone. As the vegetation occurring in the subzone is largely 'fire-sensitive', it is likely that forest fires were infrequent.

Pediastrum continues to be present for the most part together with *Botryococcus*, *Myriophyllum*, *Typha* and Restionaceae. The pollen of *Potamogeton* appears twice and *Azolla* spores once, altogether showing that shallow to deep, freshwater lake conditions prevailed for the great majority of the time during the subzone.

Subzone J_1 (695–670 cm; figures 11 and 14.) *Casuarina* type under 23 μm suffers a decline in this subzone accompanied by a corresponding rise in the values of herbaceous taxa. Other sclerophyll taxa, except myrtaceous shrubs type IV, disappear. The grasses and *Plantago* values rise showing that they probably began to dominate the landscape. Among the cool–temperate rainforest taxa, only *Cyathea* values continued to remain high but showed an overall declining trend. *Lycopodium* type I, *Pteris*, Tubuliflorae, *Haloragis*, Cyperaceae, Liliaceae, ferns and *Anthoceros*, occur sporadically. Cf. *Astelia* values, however, rise and it appears to have flourished together with some *Orites* in wet places at the beginning of the subzone.

The charcoal particle curve disappears showing that fire activity was at its lowest level during this period.

Pollen of aquatic plants also disappears but the continued presence of *Botryococcus* and some *Pediastrum* shows that the lake fluctuated between shallow and deep freshwater.

Zone I (670–545 cm; figures 11 and 14; table 5). The pollen concentration remains below 100 grains per cubic centimetre in all samples in the zone except two at the 660 cm and 600 cm levels where it rises to about 500 and 2000 grains per cubic centimetre respectively.

But for a short forested period in subzone I_2, the zone is characterized by the preponderance of herbaceous vegetation and the lack of tree vegetation. The charcoal particle values remain at their lowest showing that fires were probably extremely uncommon.

The zone is divisible into three subzones, I_3, I_2, and I_1.

Subzone I_3 (670–605 cm; figures 11 and 14). The trees completely disappear and the vegetation is constituted of mainly grasses, ferns and herbs in this subzone. The grass values continue to rise and grasslands may have increasingly formed the bulk of the open vegetation. *Cyathea* probably occupied protective gullies in good numbers and cf. *Astelia* grew on swampy ground around the lake. Other taxa occur less frequently. These are *Lycopodium* type I, *Plantago*, Liliaceae, ferns and *Gleichenia*. On the whole, grasses, together with a variety of cool–temperate pteridophytic taxa, appear to have clothed the landscape during this subzone.

The continued presence of high frequencies of *Pediastrum* and *Botryococcus* colonies shows that deep, freshwater lake conditions prevailed. Fires appear to have been practically non-existent during this subzone as no sign of charcoal was detected at any level.

Subzone I_2 (605–580 cm; figures 11 and 14). The subzone is characterized by the rise of *Casuarina* type under 23 μm and its occurrence in successive association with three different categories of *Eucalyptus* types, IV, III and I. It ends with the disappearance of these taxa. The subzone marks a brief period of establishment of a mixed *Casuarina–Eucalyptus* forest. The continued presence of high values of grass pollen in the subzone shows that the forest was rather open. Of the cool–temperate rainforest taxa, *Cyathea* occurred only at the beginning of the subzone whereas *Lycopodium* type I continued to be present throughout. Of the other associated taxa, *Plantago*, *Haloragis*, ferns and Chenopodiaceae occur in the first half of the subzone. Tubuliflorae, *Asperula*, Goodeniaceae, Fabaceae, Ranunculaceae, Cyperaceae and *Bursaria* pollen is seen only sporadically.

From the small amount of charcoal particles present in the sediment it seems that fire activity remained low during the subzone.

Pediastrum colonies and *Azolla* spores occur in only one sample each. Similarly, as *Botryococcus* colonies continue to be represented throughout, it would appear that the lake mostly remained shallow but that short spells of both freshwater and ephemeral conditions occurred sporadically.

Subzone I_1 (580–545 cm; figures 11 and 14). The vegetation marks a return to the pattern found in subzone I_3. The sclerophyll forest disappears once again, and grasses rise to regain their earlier dominance. Other plant species which do well in this subzone are *Lycopodium* type I and cf. *Astelia*. *Cyathea*, ferns, Tubuliflorae, *Plantago* and Cyperaceae appear only for very short durations. The vegetation, on the whole, appears to have presented an open meadow-like landscape in which grasses dominated the scene together with *Lycopodium* type I. Fires, as attested by the virtual lack of charcoal in the sediment, appear to have been very rare.

Pediastrum colonies appear only once and *Azolla* spores twice during the subzone. *Botryococcus* colonies, however, remain at a high level. All these features can be taken to indicate that the lake fluctuated from ephemeral to dry conditions at the beginning of the subzone to shallow intermittently freshwater conditions at the top of the subzone. The lake-dry condition appears to have been brief as there is no evidence of a soil disconformity in the sediment in the subzone.

Zone H (545–470 cm; figures 11 and 14; table 5). The pollen concentration rises and remains from 1000 to 2000 grains per cubic centimetre in this zone. The zone is also marked by the return of *Casuarina*-dominated forests, the decline of open grasslands and by the overall rise in fire activity. While *Casuarina* type under 23 μm, continues to be the most dominant element of the forest, *Casuarina* type over 23 μm and *Eucalyptus* type I occur sporadically from time to time. Cool–temperate rainforest taxa such as *Podocarpus*, *Cyathea* and *Lycopodium* type I continue to occur for most of the time. The shrub taxa were poorly represented and it seems that the forest ground-cover was mostly constituted of members of Tubuliflorae *Plantago*, *Haloragis*, grasses and Cyperaceae. Cf. *Astelia* declines and remains mostly at a low level. *Gleichenia*, *Acacia*, *Dodonaea*, *Hovea*, Goodeniaceae, Liguliflorae, *Acaena*, Ranunculaceae, Labiatae, *Rumex*, Liliaceae, ferns, and *Anthoceros* occur only sporadically.

From the nature of the charcoal particle curve it appears that fire activity rose side by side with the development of the sclerophyll forest and died down along with its demise at the end of the zone. As the vegetation remained largely 'fire-sensitive', it appears that the fires were infrequent.

The presence of *Pediastrum* and *Botryococcus* colonies and the pollen of several swamp plants in the sediment showed that deep, freshwater, lake conditions continued to prevail throughout the course of the zone and that aquatic and subaquatic plant species, such as *Myriophyllum*, *Potamogeton*, *Typha* and Restionaceae, grew in the lake basin.

Zone G (470–410 cm; figures 11 and 14; table 5). The pollen concentration falls and stays from 100 to 300 grains per cubic centimetre throughout this zone. The sclerophyll forest disappears and is replaced by an overall preponderance of herbaceous vegetation. The charcoal particle values declined likewise and maintained a very low profile. Together these show that the fire activity remained at a very low level throughout this zone. The herbaceous vegetation probably formed an open meadow that was made up of taxa such as *Lycopodium* type I, *Plantago*, grasses, Cyperaceae and Liliaceae. The only woody element noted was a single instance of the pollen of *Grevillea* found about the middle of the zone. Of all the taxa, grasses appear to have dominated the scene for the most part. Cf. *Astelia* pollen rose steeply at the beginning and it may have flourished together with Restionaceae in swampy areas. They, however, both die out in the later half in conjunction with a drop in the lake level.

The high values of both *Pediastrum* and *Botryococcus* colonies at the beginning of the zone showed that deep, freshwater lake conditions continued from zone H until about the middle of zone G when the development of a soil disconformity and the presence of *Azolla* spores in the sediment showed that the lake had dropped considerably. Shallow, permanent lake conditions prevail in the second half of the zone.

Zone F (410–340 cm; figures 11 and 14; table 5). The pollen concentration rises and varies from 100 to 10500 grains per cubic centimetre. The zone is marked by the beginning of a sclerophyll forest in which *Eucalyptus* and myrtaceous shrubs, for the first time, consistently dominate the forest vegetation. *Casuarina*, for the first time, takes a second place. The zone is equally marked by the extraordinary rise in the amount of charcoal particles in the sediment, a feature that tends to become the norm from zone F upwards in the pollen sequence (figures 11–12). The frequency of cool–temperate rainforest taxa diminishes markedly in comparison with the earlier sclerophyll forest periods. On the other hand, the herbaceous component increases showing that the sclerophyll forests in zone F were more open than at any time during the earlier forested zones in the Brunhes Chron.

The generally high values of *Azolla* spores, in conjunction with fluctuating values of *Pediastrum* and *Botryococcus* colonies, show that the lake ranged from mostly dry, or ephemeral, to occasionally deep, freshwater condition during zone F.

The zone is divisible into three subzones, F_3, F_2 and F_1.

Subzone F_3 (410–390 cm; figures 11 and 14). The subzone begins with a sample having high values of *Nothofagus* '*brassii*' type, and grass pollen. Other associated taxa consist of *Lycopodium* type I, Cyperaceae, and ferns. Charcoal particle values are at a very low level. All this shows that either an isolated stand of *Nothofagus* '*brassii*' type grew close to Lake George, in an otherwise open grassland with low fire activity, or that the *Nothofagus* '*brassii*' type pollen was redeposited in the sediment from an older horizon while grasslands occupied the countryside around Lake George. As all the fossil *Nothofagus* grains found in the sediment were well preserved and also they occur afterwards in the succeeding zones, it may be suggested that the 'brassii' type probably grew in the area.

With the decline of both *Nothofagus* '*brassii*' type and *Lycopodium* type I, *Eucalyptus* types I and IV, and *Casuarina* type under 23 µm make their appearance and occur together with the pollen of myrtaceous shrub type I, Tubuliflorae, *Plantago*, *Haloragis*, *Stylidium*, Chenopodiaceae and grasses. While Tubuliflorae rises, grasses show a consistent fall in their values in this subzone. Both Tubuliflorae and Chenopodiaceae reach high values. All these changes in vegetation were accompanied by a spectacular increase in the charcoal particle values which showed that fire activity had increased markedly at the same time. At the end of the subzone the dominant sclerophyllous vegetation is joined by some *Cyathea*, *Lycopodium* type I, and Ranunculaceae, and the charcoal particle values decline indicating reduction in fire activity.

The lake shows deep, freshwater conditions at the beginning of the subzone, in conjunction with the occurrence of cool–temperate rainforest taxa, *Nothofagus* '*brassii*' type and *Lycopodium* type I. Later on, the lake shows a rapid decline to dry, or ephemeral, conditions. The latter transformation in the lake accompanies the increase in charcoal particles in the sediment and also the change to the relatively 'fire-tolerant', *Eucalyptus*-dominated, open sclerophyll vegetation.

Subzone F_2 (390–365 cm; figures 11 and 14). *Eucalyptus* declines and, but for one sample at the end of the subzone, it does not occur during this interval. *Casuarina* type under 23 μm, rises twice but fails to establish a continuous presence. Grasses, Tubuliflorae, Liliaceae, *Plantago* and ferns do well whereas *Cyathea*, *Lycopodium* type I, *Pteris*, myrtaceous shrubs, *Exocarpos*, *Grevillea*, Liguliflorae, *Haloragis*, Chenopodiaceae, Cyperaceae, cf. *Astelia* and *Anthoceros* either occur sporadically, or rise, towards the end of the subzone. Fire activity, as judged by the low charcoal particle values in the sediment, appears to have declined markedly. On the whole, the vegetation remained open and the trees probably never formed a sclerophyll forest for more than a short period of time.

There is little change in the behaviour of the lake since subzone F_3. But, as both *Pediastrum* and *Staurastrum* colonies occur together with *Azolla* spores at the end of the subzone, it is suggested that the lake experienced short spells from ephemeral to deep, freshwater conditions at that time.

Subzone F_1 (365–340 cm; figures 11 and 14). The pollen concentration reaches the high value of 10500 grains per cubic centimetre in this subzone. Tree vegetation occurs much more consistently than in the earlier two subzones. *Eucalyptus* types I and IV, form much of the sclerophyll vegetation. The charcoal particle values rose, once again, as in subzone F_3, showing that fire activity was at a high level during the subzone. *Casuarina* type under 23 μm formed a continuous curve but the taxon probably took a second place in the sclerophyll forest community in comparison with *Eucalyptus*. Cool–temperate rainforest taxa, *Nothofagus* '*brassii*' type, *Podocarpus*, *Cyathea* and *Lycopodium* type I, occur only sporadically. On the other hand, taxa associated with open forest, such as myrtaceous shrub types I, II, III and IV, *Exocarpos*, Tubuliflorae, *Plantago*, *Haloragis*, Chenopodiaceae and grasses do well in this subzone and appear to have formed much of the shrub understorey and the forest ground-cover. Other taxa that occur to varying degrees in the community are Cyperaceae, Liliaceae, *Asperula*, Liguliflorae, *Stylidium*, Caryophyllaceae, *Dianella–Stypandra* type, ferns and *Anthoceros*.

Both *Pediastrum* and *Staurastrum* colonies occur in the subzone and these, together with the nearly continuous presence of *Botryococcus* and, later on, of *Azolla* spores in the subzone, show that the lake had reached deep, freshwater, conditions in the first half of the subzone but had then fallen to short spells of ephemeral and freshwater conditions. *Myriophyllum*, *Ruppia*, *Typha* and Restionaceae appear to have grown sporadically in the lake.

Zone E (340–320 cm; figures 11 and 14; table 5). The pollen concentration declines and varies from under 100 to 200 grains per cubic centimetre. The sclerophyll vegetation, especially the trees, disappears once again. Open land herbaceous communities, consisting of *Lycopodium* type I, grasses, Liliaceae, ferns and Tubuliflorae flourish instead. Other taxa grow only occasionally to a small extent. These are *Cyathea*, myrtaceous shrub type III, *Hovea*, *Plantago*, Ranunculaceae and Chenopodiaceae. Cf. *Astelia*, together with Restionaceae and Cyperaceae, probably grew in wet places. A single grain of *Dacrydium* was noticed in the zone at the 330 cm level but it is uncertain whether the plant actually grew anywhere close to Lake George.

The charcoal particle values decline and stay at the low level throughout showing that fire activity had probably slackened during the course of this zone.

Pediastrum and other freshwater indicator species are absent and *Botryococcus* colonies decline markedly. On the other hand, all the samples show high values of *Azolla* spores which, in the absence of freshwater species, suggest that the lake had remained dry or ephemeral throughout. This is further corroborated by the development of soil disconformity and the intensity of soil overprint in terms of pedogenesis seen in the sediments belonging to this zone (figure 14) (Bowler in Singh *et al.* 1981*b*).

Zone D (320–170 cm; figures 11–12 and 14; table 5). The pollen concentration rises steeply and ranges from 200 to 16500 grains per cubic centimetre in this zone.

The upper part of the zone reaches the range of radiocarbon dating and the chronological control improves in consequence.

The top of the zone D is dated to *ca.* 23000 a B.P. through interpolation between radiocarbon dates above and below that level. The sclerophyll vegetation returns. At first *Eucalyptus–Casuarina* and then *Casuarina–Eucalyptus*, forests, expand and dominate the tree vegetation. Cool–temperate rainforest taxa, especially *Cyathea* and *Lycopodium* type I, increase progressively from the base to the top of the zone. On the other hand herbaceous vegetation tends to decline upwards.

The charcoal particle values rise and fluctuate widely at generally high levels showing that fire activity, on the whole, remained significantly prominent during the zone (figure 12). As the relatively 'fire-tolerant' eucalypt component of vegetation remained mostly well represented throughout the zone, the rises in the charcoal curve can be considered to have been the result of continued frequent fires.

The presence of high values of *Pediastrum* colonies, together with the pollen of several other freshwater aquatics, such as *Myriophyllum*, *Potamogeton* and *Typha*, in most of the samples in the zone, show that the lake remained largely deep and fresh except two brief intervals where the presence of *Azolla* spores and the absence of *Pediastrum* indicate that the lake had turned dry, or ephemeral.

The zone is divisible into three subzones, D_3, D_2 and D_1.

Subzone D_3 (320–285 cm; figures 11–12 and 14). *Eucalyptus* type I values rise steeply along with those of myrtaceous shrub type I, *Plantago*, *Haloragis*, Chenopodiaceae and Poaceae (grasses) at the beginning of the subzone. Some other taxa such as *Casuarina* type under 23 μm, *Eucalyptus* type IV, myrtaceous shrub types III and IV, and *Acacia* also rise moderately at about the same time together with a significant rise in the charcoal particle values. Cool–temperate rainforest taxa are represented by two single occurrences of *Nothofagus 'brassii'* type and *Lycopodium* type I and three of *Cyathea*. As the rainforest taxa remain lowly represented, it appears that a form of wet sclerophyll (tall, open) eucalypt forest had been established with an understory of myrtaceous shrubs and *Acacia*. The ground-cover was made up of grasses with members of Tubuliflorae, *Plantago*, *Haloragis*, and Chenopodiaceae. Cyperaceae probably occupied wet areas around the lake. A forest of this kind today can tolerate fire return frequencies as high as five to ten years. This vegetation complex lasts for the most part of the subzone except that *Casuarina* type under 23 μm, begins to overtake *Eucalyptus* as the dominant sclerophyll tree element towards the end and the myrtaceous shrub understorey plant species give way to a more herbaceous grassy ground-cover. The pollen and spores of other taxa such as *Hovea*, *Asperula*, Liguliflorae, *Stylidium*, Caryophyllaceae, Ranunculaceae, Geraniaceae, cf. *Astelia*, Liliaceae, ferns and *Anthoceros* occur in small numbers.

The presence of *Pediastrum* colonies, together with salt-tolerant *Ruppia* pollen in the subzone, shows that the lake fluctuated between dry, or ephemeral, and deep, freshwater conditions at short intervals. *Botryococcus* colonies, *Myriophyllum* and Restionaceae pollen occur frequently.

Subzone D_2 (285–200 cm; figures 12 and 14). The roles of *Casuarina* type under 23 μm and *Eucalyptus* type I are reversed and *Casuarina* type under 23 μm forms the dominant species in the sclerophyll forest in this subzone. *Eucalyptus* type I declines and plays a subdominant role. Other sclerophyll tree taxa occur only sporadically and consist of *Casuarina* type over 23 μm, *Eucalyptus* types II, III and IV and *Callitris*. The average charcoal particle values stayed at about the same level as in subzone D_3. A number of cool–temperate taxa, *Cyathea*, *Lycopodium* type I, *Dicksonia*, *Podocarpus*, *Drimys* and *Lycopodium* type II, either rise to high values or are more frequently encountered in the subzone. Others, *Phyllocladus*, *Nothofagus* '*brassii*' type, *Histiopteris*, *Pteris* and *Gleichenia* occur singly, or sporadically. All this shows that a *Casuarina*-dominated sclerophyll forest, associated with *Eucalyptus* and several cool–temperate taxa, occurred throughout this subzone. This vegetation differs from the earlier Brunhes *Casuarina*-dominated assemblages in having a much greater proportion of *Eucalyptus* in the forest. This plant grouping, as much as the earlier *Casuarina*-dominated assemblages, is now totally missing from the modern day forests in Australia. The shrubby understory, except for the top of the subzone, shows few myrtaceous shrubs and it appears to have been made up of an assortment of variously represented taxa, such as *Grevillea*, *Acacia*, *Epacris*, *Exocarpos*, *Banksia*, *Hovea*, *Asperula*, and probably several Tubuliflorae shrub taxa, and ferns. Myrtaceous shrub types I, III and IV occur occasionally towards the top of the subzone. The ground-cover in this largely open sclerophyll forest consists dominantly of grasses (Poaceae) followed by other taxa, such as in order of diminishing importance: *Plantago*, *Haloragis*, Tubuliflorae (herb taxa), Chenopodiaceae, Cyperaceae, Liguliflorae, Liliaceae, ferns, Caryophyllaceae, *Stylidium*, Ranunculaceae, Geraniaceae and *Rumex*. Members of Cyperaceae, Ranunculaceae, *Anthoceros* and cf. *Astelia* probably grew in swampy places.

The almost continuous presence of *Pediastrum* colonies in the subzone showed that the lake remained deep and fresh for most of the time. In the second half, however, both the occurrence of *Azolla* spores in several samples and the presence of a soil disconformity around the 240 cm level show that the lake had briefly dried, or was ephemeral, around 35000 and 32000 a B.P.

Subzone D_1 (200–170 cm; figures 12 and 14). The subzone reaches the range of radiocarbon dating. The beginning of the subzone can thus be dated to about 28000 a B.P. and the end to *ca.* 23000 a B.P. *Casuarina* type under 23 μm, declines but still continues to be the dominant species in the sclerophyll forest throughout the subzone. *Eucalyptus* type I also declines temporarily at the beginning of the subzone but then recovers to attain relatively high values; then it disappears in the second half of the subzone. *Eucalyptus*, types II and IV, and *Callitris* occur singly. The average charcoal particle values remain more or less at the same level as in subzones D_3 and D_2. Cool–temperate rainforest taxa, *Cyathea*, *Dicksonia* and *Lycopodium* type I, reach their highest extent and importance in the first half of the subzone and then decline. *Pteris*, however, rises towards the end. *Nothofagus* '*brassii*' type, *Podocarpus* and *Lycopodium* type II occur only singly in the first half.

Sclerophyll shrub taxa, myrtaceous shrub type I, *Acacia* and *Grevillea* again occur singly.

Tubuliflorae as well as herbaceous taxa, *Plantago*, *Haloragis*, Chenopodiaceae, Poaceae and Cyperaceae decline. On the other hand, both Liliaceae and ferns rise. As *Cyathea*, *Lycopodium* type I, *Dicksonia* and *Pteris* are also well represented in the subzone, it seems that the ground-cover was made up mainly of ferns, fern allies and Liliaceae. Cf. *Astelia* and *Anthoceros* appear to have been well represented.

Pediastrum values continue to rise in the subzone together with those of *Botryococcus*. As there are no *Azolla* spores, or soil disconformities occurring during the same period, it appears that the lake stayed deep and fresh throughout subzone D_1. This is corroborated by the dating of the highest abandoned shoreline found in the Lake George basin between about 27000 and 21000 a B.P. (Coventry 1976). According to Coventry's evidence the lake stood 37.6 m deep and overflowed for the last time in its history during that period.

Zone C (130–70 cm; figures 12 and 14; table 5). The zone extends from *ca.* 23000 to *ca.* 16000 a B.P. (formerly estimated from *ca.* 22000 to *ca.* 18000 a B.P. in Singh *et al.* (1981*a*)). The pollen concentration declines and stays mostly below 200 grains per cubic centimetre. A single sample at the end of the zone, however, showed a concentration of about 500 grains per cubic centimetre.

The zone is marked by the total disappearance of sclerophyll forests, once again, and their replacement by an open land herbfield vegetation. Of the tree vegetation, only the pollen of *Phyllocladus* is seen and that in two samples at the middle of the zone. The tall groundcover is poorly developed and consists of isolated occurrences of *Cyathea*, *Pteris*, *Gleichenia*, *Asperula*, *Bursaria* and ferns. The herbaceous cover, on the other hand, is preponderant and is made up of *Lycopodium* type I, Liliaceae and Poaceae. Some other taxa, such as *Stylidium*, Chenopodiaceae, Cyperaceae, Cruciferae and *Dianella–Stypandra* type, occur only very sporadically. While cf. *Astelia* declined sharply at the beginning it appears to have returned during the middle of the zone.

Charcoal particle values remained low throughout, except in one sample at the beginning of the zone, showing that fire activity had remained at a moderately low level. However, unlike all the earlier treeless zones, charcoal particles are found in greater quantities in zone C. This shows that some fire activity had persisted throughout this treeless episode.

Pediastrum colonies fall steeply from their earlier high values. As *Azolla* spores make a simultaneous appearance, it seems that the lake had dropped considerably and perhaps oscillated between short spells of dry, or ephemeral, and freshwater lake conditions between about 22000 and 21000 a B.P. Subsequently, the lake rises briefly to deep, fresh conditions but falls to permanent saline lake conditions at the end of the zone between *ca.* 17000 and *ca.* 16000 a B.P. In fact, the soil disconformity indicative of a fall to lake-dry, or ephemeral, conditions lies at the 135 cm level dating to *ca.* 17000 a B.P. (Singh *et al.* 1981*b*).

Ostracod analysis from the same levels in an adjacent core (Gemco LG4) showed that the lake fluctuated between fresh and slightly saline conditions between *ca.* 15600 and *ca.* 17400 a B.P. (De Deckker 1982).

Zone B (130–80 cm; figures 12 and 14; table 5). The zone extends from *ca.* 16000 to *ca.* 7500 a B.P. The pollen concentration continues to remain low and mostly ranges from 100 to 200 grains per cubic centimetre. It reaches a level of 300 grains per cubic centimetre in only one sample in the middle of subzone B_1. The zone, as a whole, is marked by the return of sclerophyll tree vegetation. The charcoal particle values also rise consistently, once again, to high levels. The zone is divisible into subzones B_2 and B_1.

Subzone B_2 (130–100 cm; figures 12 and 14). The subzone extends from *ca.* 16000 to *ca.* 10200 a B.P. *Eucalyptus* type I rises at the beginning of the subzone but disappears early. Later, *Casuarina* type under 23 μm occurs in two adjacent samples and myrtaceous shrub type IV appears in one sample at the beginning of the subzone and not again. All this shows that sclerophyll vegetation returned occasionally after a prolonged absence during zone C. The charcoal particle values show an overall rise in the subzone showing that fire activity had increased.

Cool–temperate rainforest taxa such as *Cyathea*, *Lycopodium*, *Histiopteris* and *Gleichenia* continued to occur sporadically but *Lycopodium* type I was seen less frequently than in zone C. *Cyathea* spores occur for the last time in any significant numbers. However, ferns ('other ferns') rise, together with herbaceous taxa such as Liliaceae and *Plantago*, whereas grasses (Poaceae) decline. On the other hand, cf. *Astelia* appears to have grown abundantly along with some *Typha* and Restionaceae. Tubuliflorae, Fabaceae, *Rumex*, Chenopodiaceae, Cyperaceae, *Bulbinopsis* type and *Dianella–Stypandra* type occur sporadically.

The algal and the aquatic vegetation in the subzone shows that the lake turned dry, or ephemeral, twice; once at the beginning of the subzone at the 125 cm level, dated around 15000 a B.P., and a second time towards the top of the subzone around 12000 a B.P. Both these episodes are evidenced by the occurrence of *Azolla* spores. On the other hand, the lake rose to freshwater depth for a short period around 14000 a B.P. The lake remained shallow and probably saline between *ca.* 12000 to *ca.* 10000 a B.P. Both *Typha* and Restionaceae occur only once each during subzone B_2.

Subzone B_1 (100–80 cm; figures 12 and 14). The subzone extends from *ca.* 10200 to *ca.* 7400 a B.P. Cool–temperate taxa, *Podocarpus*, *Lycopodium* type I, *Pteris* and cf. *Astelia* occur for the last time and disappear before the end of the subzone. *Podocarpus* happens to be the last cool–temperate rainforest taxon to disappear. Poaceae (grasses) values start to rise steeply together with those of Cyperaceae and *Plantago*. Liliaceae values decline. Sclerophyll tree vegetation is represented by single occurrences of *Casuarina* type under 23 μm, *Eucalyptus* type I, and *Callitris*. Similarly, Chenopodiaceae and possibly herbaceous Tubuliflorae and Fabaceae and *Anthoceros* occur singly in the subzone. On the whole, grasslands appear to have been the dominant element in the largely meadow-like landscape in which *Lycopodium* type I, *Plantago*, and Liliaceae featured prominently in the first half. Cyperaceae values remain moderately high throughout. The ferns decline and the tree vegetation continues to be sparse. The charcoal particle values show only one high peak at the 80 cm level.

Both *Pediastrum* and *Botryococcus* values reach a high level at the beginning of the subzone showing that the lake turned deep and fresh just after *ca.* 10000 a B.P. This condition appears to have lasted until *ca.* 7700 a B.P. about which time the combined presence of *Pediastrum* and *Azolla* in the same sample at the 85 cm level shows that the lake had started to oscillate between short spells of dry, or ephemeral, and deep freshwater lake conditions. This situation appears to last to the end of the subzone.

Zone A (80–0 cm; figures 12 and 14; table 5). The pollen concentration rises progressively upwards in this zone and ranges from under 100 to 19000 grains per cubic centimetre. The zone extends from *ca.* 7400 to 0 a B.P. It is marked by the first development of an apparently typical dry sclerophyll (low, open) eucalypt forest, like the one now in the lake catchment and represented by the pollen trap catches. The vegetation assemblage is characterized by the total absence of cool–temperate rainforest taxa and by the overall scarcity of ferns in the groundcover.

These features appear for the first time in this zone during the entire Brunhes Chron at Lake George. The changes in vegetation are accompanied by the highest ever increases in the charcoal particle values.

The zone is divisible into subzones A_3, A_2, and A_1.

Subzone A_3 (80–50 cm; figures 12 and 14). The subzone extends from *ca.* 7400 to *ca.* 6000 a B.P. The pollen concentration remains low, from 100 to 200 grains per cubic centimetre. Both *Casuarina* type under 23 μm and, *Eucalyptus* type I pollen occur only once during the subzone showing that the tree vegetation had continued to be sparse. Cool–temperate rainforest taxa do not occur anymore. Tubuliflorae (probably both shrubs and herbs) values rise and start a well developed frequency curve for the first time since the end of zone D. Grasses (Poaceae) remain at a high level and appear to have dominated much of the landscape together with Tubuliflorae. Both the Liliaceae and Cyperaceae values decline whereas those of myrtaceous shrub type I rise towards the top. Other taxa occur only very sporadically and consist of Goodeniaceae, Liguliflorae, *Plantago*, Ranunculaceae, Chenopodiaceae, *Culcita* and *Anthoceros*.

In appears that a savannah woodland type of vegetation, the kind that now dominates the lower parts of the lake catchment, began to establish itself in this subzone. The vegetation was free of all cool–temperate rainforest taxa and appears to have been dominated mainly by herbs. The charcoal particle values rise at the 50 cm level showing that fire activity rose towards the end of the subzone.

Except for one sample at the 55 cm level, *Pediastrum* is completely absent in the subzone. The presence of low values of *Botryococcus*, combined with those of *Azolla*, at the 70 cm level, shows that the lake had turned dry, or ephemeral, about 7000 years ago. Later on, the presence of *Pediastrum*, together with a rise in the *Botryococcus* values towards the top of the subzone, is indicative of a rise in the lake level to deep, freshwater conditions just before 6000 a B.P.

Subzone A_2 (50–20 cm; figures 12 and 14). The subzone extends from *ca.* 6000 to *ca.* 3200 a B.P. The pollen concentration levels rise steeply reaching a peak of 18000 grains per cubic centimetre towards the top of the subzone.

Eucalyptus type I rises and starts to occur regularly at levels between 8 and 15%. Similarly, *Casuarina* type under 23 μm forms a short curve for the first time since the end of zone D, but its values never rise above 2%. Myrtaceous shrubs, mainly types I and IV, start to occur more frequently together with *Exocarpos*. Likewise, grasses (Poaceae) and Chenopodiaceae values rise and together represent the dominant herbaceous vegetation in the subzone. Other taxa which also do well as Tubuliflorae (probably mixed herbs and shrubs), *Plantago*, *Haloragis*, *Stylidium*, Cyperaceae and to a smaller extent Liliaceae. Both ferns and *Anthoceros* show very low values. Similarly, myrtaceous shrub type II, *Hovea*, Caryophyllaceae, Ranunculaceae and Geraniaceae pollen occur mostly as single grains. The charcoal particle values remain consistently high for the most part of the subzone and it is suggested that fire activity remained at a high level.

It is clear that an apparently typical, eucalypt-dominated, dry sclerophyll (low, open) forest had been established, in almost its present day form, in the lake catchment some 6000 years ago. The only major difference from the present day forests is that *Casuarina* type under 23 μm, then, formed a small part of the forest community whilst it is totally absent at the present day.

Botryococcus values decline markedly while those of *Azolla* rise steeply. Considering that *Pediastrum* occurred at the beginning as well as at the end of the subzone suggests that the lake oscillated at short intervals from ephemeral to deep, freshwater conditions at the beginning of the subzone between *ca.* 6000 and 5000 a B.P. and also at the end about 3200 a B.P. In the middle of the subzone, about 4000 a B.P., the lake had dried, or was ephemeral.

Subzone A_1 (20–0 cm; figures 12 and 14). The subzone extends from *ca.* 3200 to 0 a B.P. The pollen concentration ranges from 13000 to 19000 grains per cubic centimetre and reaches its highest value at the 5 cm level, estimated to date under 500 a B.P. *Eucalyptus* type I reaches its highest values whereas *Casuarina* type under 23 μm declines until it completely disappears towards the top of the subzone. On the other hand, *Casuarina* type over 23 μm makes a renewed appearance for the first time since subzone D_2 (figure 12). Grasses (Poaceae) and Tubuliflorae decline but Chenopodiaceae rises further still. *Eucalyptus* type II and *Callitris* reappear after a long absence towards the top of the subzone. The increasingly high values of pollen and charcoal (figure 12, inset) seen in the subzone may partly be due to their relatively recent deposition and to lack of disintegration to normal equilibrium levels in the sediment. Nevertheless, the rise in the charcoal values in the top 3 cm (figure 12, inset) is enormous and must reflect a higher frequency of burns than in earlier time perhaps attributable to the early European settlements (cf. Curr 1883).

The end of the subzone is depicted by the pollen trap records, for the years 1974–79, figured in section A at the top of the pollen diagram (figure 12), and described earlier in the text. However, as the pollen trap data do not take into account the algal and the aquatic and slopewash component of pollen, which is normally contained in sediment, the information is supplemented by microfossil record from a surface sample from the drill site (table 3).

TABLE 3

	taxon	percentages of total land plant pollen
trees	*Eucalyptus* type I	9.4
	Pinus	6.9
shrubs	Myrtaceous shrub type IV	1.7
	Exocarpos	1.7
shrubs or herbs	Tubuliflorae	5.2
herbs	Poaceae	14.8
	Chenopodiaceae	50.0
	Liguliflorae	5.2
	Ranunculaceae	6.9
	Cyperaceae	1.7
	Malvaceae	1.7
	ferns	1.7
	Azolla spores	235.0
	Anthoceros spores	3.5
	Botryococcus colonies	3.5
	total trees	**14.8**
	total shrubs	**3.5**
	total herbs	**80.0**
	total sclerophyll taxa	**13.0**
	total cool–temperate rainforest taxa	**0.0**
	total land plant pollen sum	**74**
	total pollen and spores	**309**
	total pollen and spore concentration grains per cubic centimetre	**4635**

It is of interest that the pollen concentration is only 4635 grains per cubic centimetre in the surface sample (table 3) compared with nearly 19000 in the samples at the 5 cm and 10 cm levels in the core (figure 12, section B). As this number is almost equivalent to one year's pollen and spore influx in the 1978–79 pollen traps II and V records (figure 12, section A), it cannot be explained in terms of sheer destruction of vegetation during the immediate past. The explanation possibly lies in the uncompacted and unconsolidated nature of the surface sediments. Qualitatively, the pollen spectra from pollen trap samples for the period 1974–79 (figure 12, section A), individually as well as collectively, show a high degree of similarity with the spectrum from the surface sample. In fact, all the pollen spectra, both from the pollen traps and the surface sample, faithfully reflect the presence of grasslands, open savannah woodland and the dominant dry sclerophyll (low, open) eucalypt forests in the lake catchment. The spectra also truly reflect the modern day introductions of plant species such as *Pinus*. The pollen trap records also depict the modern day invasion by weeds such as *Echium* spp. and *Rumex* spp. All these introduced taxa except *Rumex* are unrepresented in the fossil record. The isolated occurrences of *Rumex* pollen in the fossil sequence is ascribed to the few native species found in Australia. On the other hand, the high values of *Rumex* pollen in the pollen traps are undoubtedly due to the luxuriant growth of introduced *Rumex* species in the pastures developed in the lake catchment in the last 164 years.

Comparable results with increased diversity of taxa are obtained from a moss cushion sample taken from an opening inside the dry sclerophyll forest on the escarpment slope facing the lake along the western shore (table 4).

TABLE 4

	taxon	percentages of total land plant pollen
trees	*Casuarina* type over 23 µm	0.9
	Eucalyptus type I	49.0
	Callitris	0.6
	Pinus	1.5
	Ulmus	0.2
shrubs	Myrtaceous shrub type IV	0.4
	Acacia	7.5
	Persoonia	0.6
	Exocarpos	0.6
	Loranthaceae	0.4
shrubs or herbs	Tubuliflorae	2.0
herbs	Poaceae	10.8
	Cerealia	0.6
	Chenopodiaceae	2.9
	Liguliflorae	2.7
	Plantago	0.9
	Acaena	0.9
	Caryophyllaceae	4.0
	Geraniaceae	0.2
	Rumex	12.4
	Cyperaceae	1.5
	Liliaceae	0.2
	ferns	0.2
	total trees	**52.5**
	total shrubs	**9.7**
	total herbs	**38.0**
	total sclerophyll taxa	**60.3**
	total cool-temperate rainforest taxa	**0**

The results from the moss cushion from inside the forest remain much the same in qualitative terms as those from the pollen traps and the surface sample from the lake sediment. Besides the presence of *Pinus* and *Rumex* pollen, two other introduced plants, *Ulmus* and Cerealia, also show up in the moss cushion. The local presence of taxa such as *Eucalyptus*, *Acacia*, Liguliflorae, *Acaena*, Caryophyllaceae and *Rumex*, and the overall local abundance of tree and shrub vegetation, in the moss cushion sample, contrast with the more general picture shown by the pollen trap and the surface sample records from outside the forested area. On the other hand, the lack of cool–temperate rainforest taxa and the faithful depiction of the overall character of forests in the lake catchment provide a common link.

On the whole, the changes in vegetation in subzone A_1, reflect the final stages in the development of dry sclerophyll, eucalypt-dominated forests in the lake catchment. *Casuarina* type under 23 μm, a species that still remains undetermined, finally disappeared sometime during the last 1000 years. During this time interval, *Casuarina* type over 23 μm, *Callitris* and several other plant species reappear after a long absence and continue to the present day.

5. REVIEW AND SYNTHESIS

The microfossil record from Lake George, notwithstanding gaps in the lower part of the sequence, is unique in several ways. Most of all, it is, so far, the only chronologically secure, relatively continuous Late Cainozoic palynological database available in Australia, which spans the entire Brunhes Palaeomagnetic Chron from *ca.* 730000 years ago to the present. The microfossil data provide a factual basis for the reconstruction of Late Cainozoic vegetation and its dynamic interaction with bush fires, combined with oscillating palaeoclimates in southeastern Australia. The altitudinal shifts of vegetation belts, inferred from the palynological sequence, suggests significant past changes in terrestrial temperatures of the order of glacial–interglacial cycles. A correlation between the palaeotemperature record and the former lake levels provides reasonable grounds for the resolution of past precipitation changes. Correlations such as this are critically important to recognize periods of absolute rise and fall in precipitation. The precipitation cycles cannot be resolved from the history of lake levels alone (as the lakes can rise and fall due to changes in evaporation irrespective of changes in rainfall) but require additional information about prevailing temperatures from the same stratigraphic levels as those indicating high, or low, lake levels. The combined evidence of palaeotemperatures and lake levels from Lake George therefore presents the opportunity to identify periods of absolute high and low precipitation within the more complex history of *effective* wetness and dryness in southeastern Australia.

(*a*) *The palaeotemperature curve and its correlation with deep sea* ^{18}O *cycles*

Fossil pollen and spores of trees, shrubs, herbs and ferns provide the basis for the reconstruction of the palaeotemperature curve at Lake George (figure 15). As the vast majority of modern pollen and spores entering the lake basin come from plants growing within the lake catchment (figure 12, section A), any significant changes in the terrestrial pollen and spore record from the past may be translated in terms of vegetational changes inside the lake basin. This has already been outlined in the description of the data above. It is assumed that the present day zonation of altitudinal belts in the region is the result of a combination of prevailing temperature and moisture regimes, on one hand, and the long-term selective influence of high

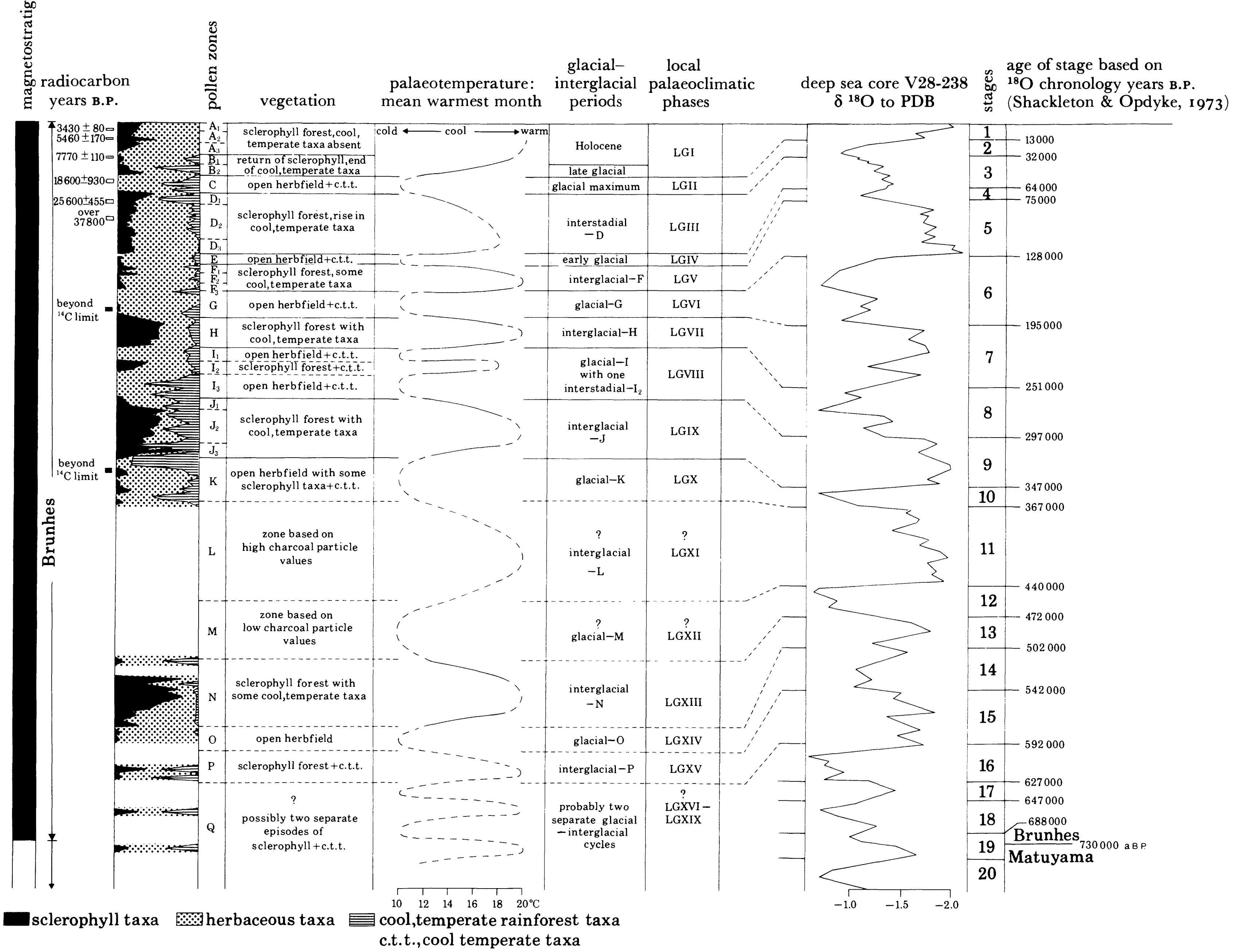


FIGURE 15. Diagram shows broad correlations between two independent Brunhes Chron palaeotemperature curves; one derived from the palynological sequence from Lake George and the other from the deep sea core V28–238 record (Shackleton & Opdyke 1973). The diagram also summarizes the vegetational and palaeoclimatic zonation recognized in the Lake George sequence.

and low fire frequencies on the other. Except in exceptional cases, the environmental history of the basin is derived by analogy with apparent present day correlations.

At present, the vegetation inside the lake catchment ranges from warm temperate, dry sclerophyll (low, open) eucalypt forests to eucalypt woodlands to grassland, all of which are adapted to survive through relatively high fire frequencies. The catchment is almost completely devoid of the relatively 'fire-sensitive', cool–temperate rainforest taxa. On the other hand, the surrounding uplands and mountains, at the highest elevations, are covered with treeless alpine and subalpine communities. At medium elevations, the vegetation consists of wet sclerophyll (tall, open) eucalypt forests associated with many cool-temperate rainforest taxa which are adapted to relatively low fire frequencies and greater soil moisture than is available at Lake George.

In the past, any change in the temperature affecting alpine, subalpine, wet or dry sclerophyll vegetation would have promoted downward or upward movement of the vegetation belts leading to their successive entries into, and exits from, the lake basin. As these movements would have undoubtedly brought about successive changes in the character of the pollen-rain inside the lake basin, the past changes in vegetation in the fossil record, among other things, indicate changes in the temperature regime at Lake George. The palaeotemperature curve (figure 15) takes the present day vegetation–altitude gradient as a modern analogue and traces the movements of the upper treeline and other vegetation zones, through time, assuming an average lapse rate of 0.7 °C per 100 m. The modern treeline, at *ca.* 2000 m a.s.l., is equated with 10 °C mean warmest month temperature as under other similar situations around the world.

The palaeotemperature curve (figure 15) is derived from the two composite pollen diagrams of relative percentages of total trees, shrubs and herbs (figures 10–12, column *a*) and of total sclerophyll taxa, cool–temperate rainforest taxa and herbs (figures 10–12, column *b*). The dominance of herbs, especially in the presence of cool–temperate taxa, has been taken to represent cold conditions, and the dominance of mainly cool–temperate rainforest taxa to indicate intermediate, cool–temperate conditions. The dominance of sclerophyll tree and shrub taxa, on the other hand, is indicative of warm–temperate conditions.

By using these criteria, it is estimated that the upper treeline was depressed by 1200–1500 m and 300–600 m, respectively, during the cold maxima and the cool–temperate intervals. Assuming an average lapse rate of 0.7 °C per 100 m the drop in mean temperature for the warmest month with respect to the present during these intervals may have been about 8–10 and 2–4 °C, respectively (figure 15) (Singh 1983). The fact that *Nothofagus* cf. *cunninghamii* grew between 1680 m and 1780 m altitude 35000 years ago, as evidence by the dated stump discovered in a blockstream of the Toolong Range in the Snowy Mountains of New South Wales (Caine & Jennings 1968), suggests that the mean January temperatures may have at times, dropped only 1.5 °C from that of the present day during Interstadial-D (figure 15). As the estimated intermediate temperatures in the palaeotemperature curve are based on the movements of cool–temperate rainforest taxa, which are also influenced by high and low fire frequencies, it is likely that they are open to a greater margin of error.

The major fluctuations in the palaeotemperature curve undoubtedly represent important palaeoclimatic episodes. The *magnitude* of the cold–warm phase oscillation and the timing of the last one which is adequately dated is the same as that associated with glaciation elsewhere on land. Consequently these phases are equated with glacial–interglacial sequence. Local palaeoclimatic phases (hereafter mentioned as phases) LG I–XIX, cover the entire Brunhes

Chron (figure 15). Phases I–XIV, representing pollen zones A to O, are easier to define as the zones have sharp boundaries based on pollen or charcoal values or both, (figures 10–12, 15). These phases, it is suggested, represent a series of six glacial–interglacial oscillations including a long interstadial (phase LG III, zone D) embedded within the last glacial period (zones E–B_2). It is of interest that these palaeoclimatic oscillations broadly compare with the similar number of stages (1–14) of the deep sea ^{18}O palaeotemperature record dated from 0 to 502000 a B.P. (Shackleton & Opdyke 1973, figure 15). To correlate the two sequences is an important step because the magnitude of deep sea core palaeotemperature reconstructions is so small that subtle argument is needed to equate them with glacial–interglacial oscillations on land. Their comparison with the Lake George sequence provides a crucial *link* between the data from deep sea cores on one hand and land data on the other. This also allows dependence on the deep sea cores for the detailed chronology within the palaeomagnetic units at Lake George (figure 15).

Before phase XIV, the fossil evidence for climatic change becomes sketchy. While it is likely that the two pollen-bearing levels in zone P, each representing a forested interval, come from a single interglacial, the same cannot be said about the two widely separated pollen-bearing samples, again representing forested periods, in zone Q (figures 10 and 15). It is arguable that the two forested levels in zone Q come from distinct interglacials separated by, as yet, undocumented treeless intervals. Assuming this to be the case, the terrestrial palaeotemperature sequence from Lake George (phases LG I–XIX) would be seen to match, phase by phase, with stages 1–19 of the deep sea ^{18}O palaeotemperature record during the Brunhes Chron dated from 0 to 730000 a B.P. (figure 15).

Geomorphological records of Quaternary glaciations on mainland Australia are restricted to a small area of less than 50 km^2 in the Snowy Mountains of New South Wales, some 140 km southwest of Lake George. So far, records of only one glaciation, pertaining to the last glacial episode Würm, are securely documented, though some of the largest cirques may have been initiated during an earlier glaciation (Galloway 1963). In Western Tasmania, Lewis, (1934, 1939, 1945) indicated at least three glaciations but later work of Jennings & Banks (1958), Derbyshire *et al.* (1965) and Davies (1967) suggested that there was not definite evidence for more than one glaciation. More recent stratigraphic work by Colhoun (1978), however, has brought out some evidence that showed that Tasmania experienced multiple glaciations. In any case, except for the last glacial episode, there is so far no established chronological framework for Quaternary glaciations in Australia. The last glaciation (Margaret Glaciation) (equated with phases LG II, III and IV at Lake George, figure 15), according to Colhoun (1982), culminated in Western Tasmania about 19000 years ago and ended by about 10000 a B.P. During this episode in the West Coast Range a small ice cap, averaging about 250 m in thickness, along with valley and cirque glaciers, covered about 110 km^2 of terrain. The equilibrium line altitude of the ice masses varied from 690 to 1000 m with an average of 830 m for the ice cap implying an average temperature decrease of 6.8 °C for the maximum glaciation (Colhoun 1982). On the Central Plateau the ice cap is suggested to have covered under 1500 km^2 (E. A. Colhoun, personal communication). The penultimate glaciation (Henty Glaciation), equated with Glacial-G, phase LG VI, at Lake George (figure 15), is thought to have been a much more extensive event during which in the West Coast Range an ice sheet and associated outlet glaciers covered over 1000 km^2 of terrain, and locally attained thicknesses of 300–400 m (Colhoun 1982). The average reduction in temperature at the height of this glaciation is thought to have reached to about 7.4 °C. By comparison, Glacial-G (phase LG VI) at Lake George (figure 15), documents one of the most persistent of the treeless glacial episodes in the entire sequence. Also, it is greater in severity by far than either phase LG IV (early last glacial) or phase LG II (the last glacial maximum) during the last glacial period. Comparisons of the earlier glaciations recorded at Lake George with equivalent terrestrial episodes on the Australian continent are, as yet, impossible but undoubtedly a great deal of glacial activity did take place from time to time as illustrated by the evidence from Lake George. According to Colhoun (1982), the very strong chemical weathering of igneous clasts in some of the glacigenic deposits of Western Tasmania suggests that glaciations before the penultimate glaciation may have occurred, but these have not yet been satisfactorily demonstrated stratigraphically. Colhoun (1978) attributes the lemon-thyme tillite, previously regarded as Pleistocene, to the late Tertiary.

(*b*) *Palaeoprecipitation*

The combined evidence of lake level and palaeotemperature changes from Lake George may be used to provide a broad framework of absolute rise and fall in precipitation. Figure 16 presents overlapping curves of lake level and palaeotemperature changes at Lake George. The two curves are derived from data recovered from the same samples in the core and cover a continuous record of the last 350000 years. The combined record is set against columns showing pollen zonation and estimated and radiocarbon ages, on one hand, and the break-up of the palaeotemperature curve into glacial–interglacial periods, on the other.

The comparison of the two records shows that there is no simple relationship between the periodicity of lake level changes and glacial–interglacial cycles. The lake levels clearly exhibit intermittent rises during interglacials, when the evaporation was presumably high and, conversely, intermittent falls during glacials, when evaporation must have been at its lowest. It is clear that interglacial and glacial periods cannot be equated with interpluvial and pluvial periods respectively, as was often claimed in the past. On the contrary, it may be inferred from the present record that periods of lower precipitation than at present must have prevailed for some considerable intervals of time during the glacial periods. The dry to ephemeral lake conditions during the glacial maxima (figure 16), when the mean January temperatures stood 8–10 °C below those of the present, show that the drop in precipitation may have been about 50 % (cf. Galloway 1965). A similar state of the lake during the cool–temperate intervals would have required a lesser drop in precipitation. These estimates are subject to the assumption that there was no significant increase in windiness or that the average winter temperatures were not significantly higher than those of today. It is further assumed that the lake level fluctuations were not unduly influenced by changes in vegetation inside the lake catchment, although some influence on this count cannot be ruled out (see later on in the discussion).

Based on the above premises, a number of periods of lesser precipitation than that of the present may be recognized during the four glacial intervals of the last 350000 years (figure 16). These are two short periods in Glacial-K, three in Glacial-I, one in Glacial-G and seven long and short ones in the last glacial (pollen zones E, D, C and subzone B_2) (figure 16). For the period for which radiometric dating is available during the last glacial, six of them occurred around *ca.* 35000 a B.P., *ca.* 32000 a B.P., *ca.* 22000 to *ca.* 21000 a B.P., *ca.* 17000 to *ca.* 16000 a B.P., *ca.* 15000 a B.P. and around *ca.* 12000 a B.P.

The *rises* in lake level during each of the four interglacials show increases in precipitation above that of the present, assuming that the temperature and evaporation were more or less

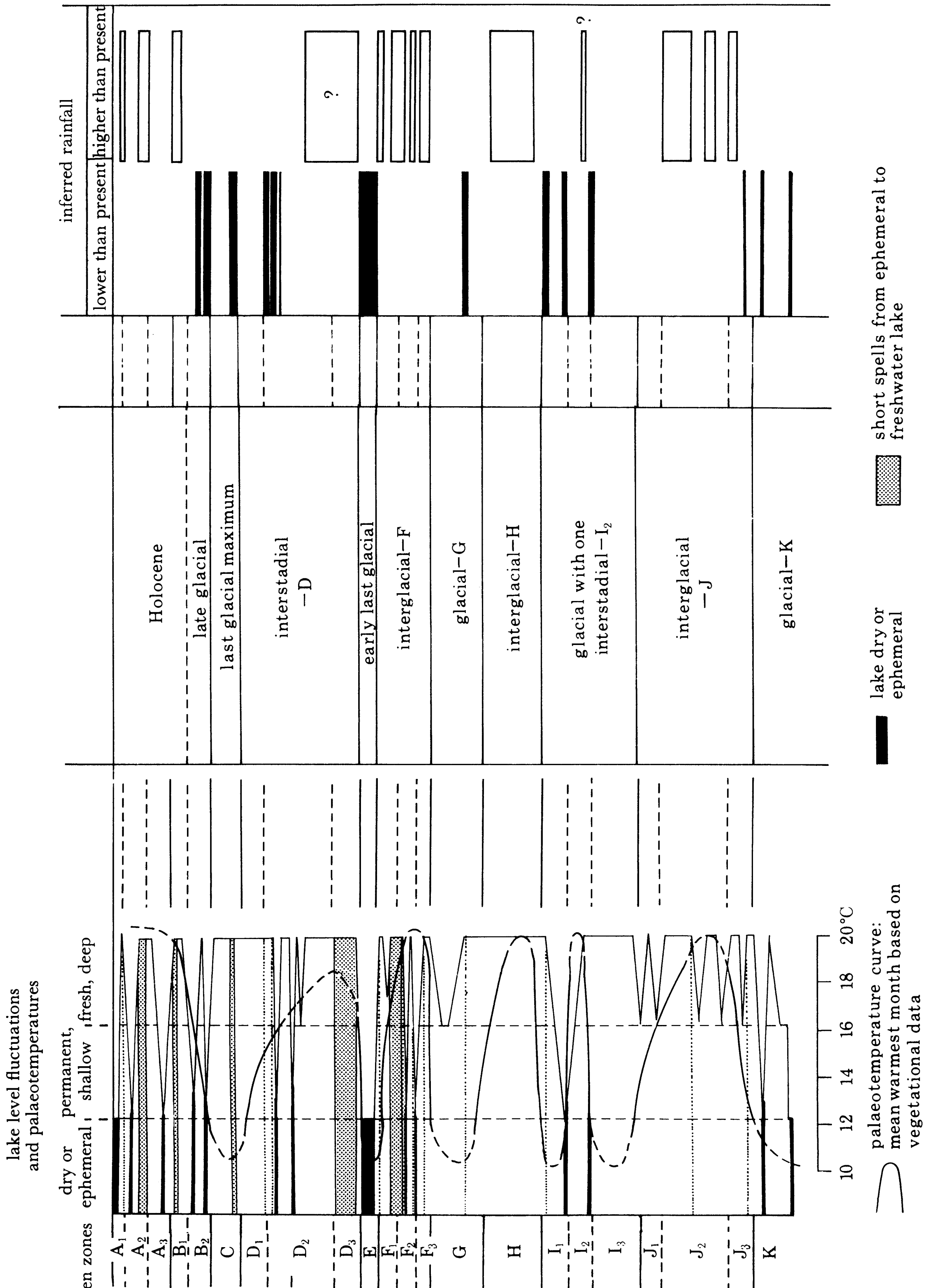


FIGURE 16. Diagram shows inferred periods of high and low rainfall as derived from the overlapping of the palaeotemperature and the lake level curves through the last 350000 years at Lake George.

the same during each of the interglacials. On this basis the following rises in precipitation may be recognized during the last four interglacials: two short and one long periods in Interglacial-J, one long period in Interglacial-H, four short periods in Interglacial-F and three short periods during the Holocene (figure 16). The precipitation during the Holocene rose sometime between *ca.* 10000 and *ca.* 7700 a B.P., *ca.* 6000 and *ca.* 5000 a B.P., and around 3200 a B.P.

The rises in the lake level during Interstadials-I_2 and D (figure 16) may have been influenced by marginally lower evaporation at those times in response to the lower temperatures than those of the present. But as the temperatures during interstadials were undoubtedly higher than those during glacial maxima, the high lake levels must represent a rise in precipitation relative to that during low lake level periods of the glacial maxima.

If the results from Lake George studies are extrapolated regionally over the whole of southeastern Australia, one is led to conclude that the high lake levels obtained in the Willandra Lakes of New South Wales from about 56000 to 25000 a B.P. were probably the result of reduced evaporation during Interstadial-D, rather than due to any absolute increase in rainfall (cf. Bowler 1975; Bowler *et al.* 1976; J. M. Bowler pers. comm.). On the other hand, the rise in lake levels during the early and middle Holocene, experienced at Lake Keilambete, western Victoria (Bowler & Hamada 1971; Dodson 1974*a*), Lake Leake and Wyrie Swamp, southeast South Australia (Dodson 1974*b*, 1977), must be considered to have been the result of an absolute increase in rainfall compared with that of the present. By the same token the fall in lake levels all over southeastern Australia at the peak of the last glacial maximum, accompanied by evidence of aridity on the Australian continent within the same time bracket (Bowler 1975), can be explained only in terms of an absolute decline in rainfall.

It is of interest that the timing of increased rainfall in southeastern Australia, including Lake George, during the early and middle Holocene broadly matches with periods of climatic amelioration at Lake Frome in the arid northeast of South Australia (Singh 1981). There it was shown that the periods of amelioration related to periods of higher summer rainfall than the present, a feature dependent on the southward shift of low pressure monsoonal depressions, now centring over northern Australia. The summer monsoon activity in northern Australia and its extension southwards is closely tied with the large scale Southern Oscillations–Walker Oscillation (S.O.–W.O.) teleconnection patterns (Allan 1983). If the Holocene rises in rainfall were the result of southward shifts of monsoon depressions, then the falls in rainfall during the cold glacial periods must be the result of corresponding northward shifts of the same systems (cf. CLIMAP Project members 1976; Singh *et al.* 1974; Wasson *et al.* 1983; Swain *et al.* 1983).

(*c*) *Palaeoecology and vegetation dynamics*

The Australian flora is commonly treated in terms of three main elements; the 'Australian' the 'Antarctic' and the 'Malaysian' sometimes called the 'Indo-Malayan' (Burbidge 1959). Apart from these, the other important floristic element is the arid Australian flora centred in the Eremean Zone (Tate 1890; Diels 1906; Gardner 1944).

It is generally held that vast areas of the Australian continent were covered by rainforest, represented mainly by the 'Antarctic' element, until some 20 million years ago. This rainforest was made up of cool–temperate Gondwanic taxa including araucarians, *Podocarpus*, *Phyllocladus*, *Dacrydium* and *Nothofagus* (Kemp 1978; Martin 1978; Walker & Singh 1981; Singh 1982). The first signs of the opening of a part of this rainforest complex are the patches of grassland between gallery forests in Central Australia during the Middle Miocene (Callen & Tedford 1976; Kemp

1978). This is often interpreted as the beginning of protracted periods of aridity on the Australian continent. But the eucalypt-dominated sclerophyll forest (represented mainly by the 'Australian', element, *Eucalyptus*), which covers most of Australia today, seems not then to have made its appearance. Nevertheless, *Eucalyptus* had already evolved, as attested by the occurrence of its fossil fruits and leaves in the diatomite of the Middle Miocene Chalk Mountain Formation in the Warrumbungle Mountains of New South Wales (Holmes *et al.* 1982) and it was presumably only a matter of time and the right conditions before it could start to spread over the continent. It is generally believed, largely from undated fossil records, that the modern eucalypt-dominated sclerophyll forest, with its fire-prone characteristics, arose in the interval between the latest Miocene and the early Pleistocene (Kemp 1981; Martin 1978). The dated Late Tertiary and Pleistocene pollen records from Lake George, however, show that the eucalypt-dominated forests arose actually in the late Brunhes Chron at this site (see later in the discussion).

(i) *The role of Casuarina*

There is an enormous gap of 3–4 Ma between the Late Tertiary and the early Brunhes pollen records at Lake George (figures 9–10). Nevertheless, a certain degree of continuity is maintained by the vegetation. Above all, *Casuarina* dominates the sclerophyll forest at both ends of the gap (figures 9–10) and occurs together with several rainforest taxa with which it is not associated at the present day. Moreover, *Eucalyptus* was a minor element. However, the rainforest taxa associated with the Late Tertiary *Casuarina* forest were of a moister facies (for example, *Nothofagus brachyspinulosa 'fusca'* type, *Dacrycarpus* type *Podocarpus* and *Dacrydium florinii*) than those associated with the Brunhes *Casuarina* forest (for example, *Podocarpus*, *Drimys*, *Cyathea*, *Lycopodium*, *Dicksonia*, *Gleichenia*, etc.). In the former case, open forest taxa, Poaceae (grasses), Tubuliflorae and Chenopodiaceae were not common whereas all of them grew freely by the time of the early Brunhes. Besides these changes, the rainforest taxa, as a whole, show an overall decline in their numbers, including the local extinction of *Dacrycarpus* which is now found in New Guinea. All these changes in vegetation point towards drier conditions during the Brunhes Chron than in the Late Tertiary.

During the Brunhes Chron, *Casuarina*, type under 23 μm (equivalent diameter, size range 16–23 μm), was the dominant sclerophyll forest species throughout all the interglacials before the last one. Thereafter, it rises temporarily, only once, during Interstadial-D. Later, it lingers on, in much smaller numbers, into the late Holocene (figure 12). It has, however, no known living representatives in the Australian *Casuarina* flora as described from their pollen by Kershaw (1970). But as this pollen type continues to occur in minute quantities in modern pollen-rain samples at Lake George (figure 12), one suspects that the species producing this pollen is still extant and may yet be found growing in small, highly protective areas. A similar sized *Casuarina* fossil pollen is reported to occur in substantial quantities in the pre-Holocene sediments in southeastern South Australia (Dodson 1975). This suggests that one, or more, undescribed species of *Casuarina*, producing relatively small sized pollen, existed in large numbers over a wide area. These fossil pollen types are smaller than the Tertiary fossil pollen, *Casuarinidites cainozoicus*, referred to *Casuarina*, which has been found in all States in Australia (Cookson & Pike 1954). They are also smaller than the *Casuarina* pollen type found at the 68.8 m level in the BMR core at Lake George, described earlier (figure 9). The latter *Casuarina* pollen type (over 23 μm) occurs sporadically throughout, except in zone N (figure 10), during which it occurs as codominant with *Casuarina* type under 23 μm. The larger sized form (over 23 μm) is the only type that is now commonly found in the modern pollen-rain samples at Lake George (figure 12). This form is referable to a number of extant species, such as *Casuarina cunninghamiana*, *C. stricta*, *C. littoralis* and *C. luehmanni*, all of which occur in small stands on the Southern Tablelands of New South Wales, and in the region immediately around Lake George (table 5). Of these species, *C. cunninghamiana* and *C. stricta* are the two more common species in the area. *C. cunninghamiana*, which grows along stream courses, is more mesic than *C. stricta*, which occupies drier sites throughout southeastern Australia and Tasmania, from the coast to areas up to 1000 m above sea level. In terms of size, the fossil pollen, type under 23 μm, comes closest to the pollen of *C. cunninghamiana* (equivalent diameter 26–28 μm). It is, therefore, possible that the unknown *Casuarina* species were, or are, related to *C. cunninghamiana*. Riverine communities, dominated by *C. cunninghamiana*, frequently grade into rainforest on the South Coast along drainage lines on very protective sites (Austin 1978). A similar situation may have occurred on a wider scale during the *Casuarina*-dominated Brunhes Chron interglacials, in conjunction with a number of cool–temperate rainforest taxa at Lake George.

Casuarina first appears in the Australian plant fossil record during the Paleocene (Martin 1978) but it is not recorded as a dominant species until much later. From the present evidence from Lake George, *Casuarina* may be regarded as the first genus to constitute dominantly sclerophyllous forests. Unless it is shown from future work that *Casuarina* was displaced by *Eucalyptus*, or some other sclerophyll forest species, during the long gap between the Late Tertiary and the early Brunhes Chron, the time from which continuous records are available, it can be considered to have dominated the sclerophyll forests at Lake George from 4 to 7 Ma to the end of the penultimate interglacial, some 195000 years ago (Interglacial-H, figures 11 and 15). In fact, the last burst of *Casuarina* dominance ended with Interstadial-D, only some 25000 years ago. During the Brunhes Chron alone, *Casuarina* is seen to have dominated the sclerophyll forest vegetation during every known interglacial before Interglacial-F for almost half a million years, that is, from the base of the Brunhes Chron to the end of Interglacial-H (figures 10–11). This strong hold on the landscape, which probably stretched over several million years and survived many climatic oscillations, implies an exceptionally high degree of resilience in *Casuarina's* part (cf. Walker 1982). This feature is to some extent reflected in the wide range of habitats presently occupied by the genus. Some species grow close to, or in association with, rainforest communities in Queensland and southeastern Australia. Others grow along the sea coasts, river banks and swamps. Yet others grow in extremely hot, arid environments. However, because the genus is now unrepresented at high altitudes, it is generally inferred that none of the species can withstand low temperatures at alpine and subalpine elevations.

In its early history, *Casuarina* is believed to have been a rainforest associate (Kemp 1981). At present, there are at least 30 species (?), all endemic to Australia except the very widely distributed *C. equisetifolia*, (Burbidge 1963). A number of *Casuarina* species fix nitrogen through root nodules in which the bacterium *Rhizobium* is linked to host cells (Coyne 1973), a quality that helps them to be effective pioneer plants. However, there is little evidence to suggest that *Casuarina* is replaced in any successional way by *Eucalyptus*. *Casuarina* stands originate from recently transported seed rather than from lignotubers or buried seed. Some evidence, admittedly for *C. stricta*, suggests that regeneration from seed in the same place can be repeated indefinitely (Hueneke 1976). Viability of seed by which they mainly reproduce is rather short.

Young growth of *Casuarina stricta* occurs from rootstocks at the ground level after a fire but this regenerative capacity is limited and cannot cope with frequent fires. Therefore any repeated burning of *Casuarina* seedlings before they are able to produce a fresh crop of seeds is fatal to its persistence. In this regard it is not resilient. *Casuarina pusilla*, a dry heathland species, is known to recover in three years after fire from rootstocks (Specht *et al.* 1958) but tree species of *Casuarina* need a longer fire-free interval to recover. In *C. stricta*, seed cones are first produced at age 5–8 years and some years may elapse before the seed is shed (Hueneke 1976). Thus unless there is a fire-free interval of at least 5–6 years individuals cannot grow into mature trees.

On the other hand, *Eucalyptus* tree species in a dry sclerophyll (low, open) forest (presently dominant in the Lake George catchment) can withstand fires at 3–4 year intervals. *Casuarina*, like many other 'fire-sensitive' taxa (for example, most rainforest species), can regenerate with ease after infrequent, intense fires provided there is a sufficiently long fire-free interval following each fire. As the frequency of lightning-induced fires is largely controlled by sufficiency of fuel build-up and climate, such fires cannot be generated at frequent intervals. It is, therefore, reasonable to suggest that infrequent, lightning-induced, intense, fires may have prevailed throughout the *Casuarina*-dominated forest intervals from the Late Tertiary well into the Brunhes Chron at Lake George and explain the charcoal record from the sediments. This pattern of forest fires would have not only allowed the continued dominance of *Casuarina* during the warm periods but it would have also allowed the continued survival of many of the rainforest taxa in the largely sclerophyllous forest. The fact that taxa belonging to a drier facies of rainforest had displaced the moister Late Tertiary rainforest taxa during the Brunhes Chron suggests that the overall climatic conditions had gradually become drier by the time of the Brunhes interglacials. As a result, the lightning-induced, intense, fires may have become more effective and perhaps penetrated more deeply than was the case during the Late Tertiary. This development would have opened *Casuarina* forest to invasions by grasses, Tubuliflorae and Chenopodiaceae, a feature encountered during all the Brunhes Chron interglacials. It is conceivable that similar drier climatic conditions also existed from time to time before the Brunhes Chron. One such long dry period is documented in the sedimentological record of the 72 m BMR core from Lake George by Bowler (Bowler in Singh *et al.* 1981 *b*). In this core, Bowler demonstrates a long phase of lake-dry or ephemeral conditions from 3.3–5.8 Ma to 2.5 Ma. If Bowler's interpretation of the sedimentological record is accepted, this phase must be the longest dry period in the Late Cainozoic history of Lake George. Undoubtedly, this dry phase would have had a profound effect on the vegetation of that period in that part of Australia and may have brought about the change in the rainforest taxa from a moister to a drier facies assemblage during the Late Tertiary. But whether such a long drawn out change in climate did allow a displacement of the *Casuarina*-dominated forest by a *Eucalyptus*-dominated forest at Lake George, remains uncertain. It is, however, likely that while the drier climates led to more effective fires, they probably also had an inverse effect on the fuel build-up which, in turn, reduced the chances of a subsequent fire soon after the one before. This reduction in fire frequencies would have allowed longer fire-free intervals for the regeneration of the *Casuarina* forest. It is significant that a number of *Casuarina* tree species still continue to dominate the woodlands in the Australian arid zone, where the lack of fuel build-up disallows frequent natural or man-made, intense, fires. During the relatively dry Late Tertiary phases, as well as during each of the Brunhes Chron, *Casuarina*-dominated, interglacials, *Eucalyptus* communities may have existed as small 'islands' in the largely *Casuarina*-dominated forests. Their role may

Table 5. Ecology of fossil taxa and their occurrence in the sedimentary profile

taxon	family	plant remain	local pollen zones																	habit	vegetation type	ecology and distribution mainly in southeastern New South Wales
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q			
Algae																						
Botryococcus	Heterokontae	c	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	aq.	brackish and freshwater alga	Cf. *B. braunii*, common in brackish and freshwater lakes and ponds.
Pediastrum	Hydrodictyaceae	c.	A_{2-3}	x	x	x	.	x	x	x	x	x	x	.		x	x	x	x	aq	freshwater alga	Cf. *P. boryanum*, common in freshwater lakes with salinity under 1.7 g l^{-1}.
Staurastrum	Desmidiaceae	c						F_{1-2}				x	x			x	x	x	x	aq.	freshwater alga	Freshwater lakes with salinity under 1.7 g l^{-1}
Bryophyta																						
Anthoceros	Anthocerotaceae	sp.	x	B_1		x	x	F_2	.	x		x	x			x	x	x		lithophyte	liverwort	Damp sites.
Riccia	Ricciaceae	sp		.					.							x	x			lithophyte	liverwort	Damp sites.
Pteridophyta																						
Azolla	Salviniaceae	sp.g.	x	x	x	D_2	x	x	x		I_{1-2}	J_{2-3}	x				x			aq	free-floating water-fern	Cf. *A filiculoides* and for *A. pinnata*, common in ephemeral lakes and ponds.
Cheilanthes	Adiantaceae	sp			.	D_2							.							f.	fern, d s.f.	Hardy, drought-resistant ferns in dry sclerophyll forests
Culcita	Dennstaedtiaceae	sp.	A_3	.						.						.	.			f.	fern, w.s.f.	Cf. *C. dubia*, hardy fern in sclerophyll forests and open ground. Can withstand repeated fires.
Cyathea	Cyatheaceae	sp.	A_1	B_2	x	x	x	x		x	x	x	x			x	x	x	x	f.	tree-fern, w.s.f., r f.	Cf. *C. australis*, common in cool–temperate forests especially closer to the coast. Grows mainly in wet fern gullies, but can also occur in open forests on mountain sides. *C. cunninghamii* grows in the deepest, shadiest fern gullies in Victoria and is highly sensitive to fire.
Dicksonia antarctica	Dicksoniaceae	sp				D_{1-2}						J_{2-3}						x		f.	tree-fern, w s.f., r f.	Common in cool–temperate forests in wet gullies or on damp sheltered mountain slopes
Gleichenia	Gleicheniaceae	sp		B_2	x	D_2	.			x	I_3	J_{2-3}						x		f.	fern, w.s.f., r.f.	Two species, *G. circinata* and *C. microphylla*, frequent to common in cool–temperate forests.
Histiopteris	Dennstaedtiaceae	sp.		B_2								J_3								f.	fern, w.s.f., r.f.	One species, *H histiopteris*, widespread in fern gullies in cool–temperate forests
Lycopodium I	Lycopodiaceae	sp		x	x	x	x	x	x	x	x	x	x			x	x	x	x	f.	fern, w s.f., r.f.	Cf. *L. varium*, extremely localized in cool–temperate forests.
Lycopodium II	Lycopodiaceae	sp		.	x	D_{1-2}		.			.	J_{2-3}					x		.	f.	fern, s.a.w.	Cf. *L. fastigatum*, common in subalpine woodlands.
Pteris	Adiantaceae	sp		B_1	x	D_{1-2}		F_2				J_{1-2}	x						x	f.	fern, w.s.f., r.f.	Cf. *P. tremula*, scattered through cool–temperate forests.
Gymnospermae																						
Callitris	Cupressaceae	p	p t, A_1	B_1		D_{1-2}	x	.								x				t	s w, d.s.f.	Cf. *C. endlicheri*, localized on shallow soil of stony slopes or rock ridges.
Dacrydium	Podocarpaceae	p					x		.				.							t	r f.	Cf. *D. franklinii*, endemic to cool–temperate Tasmania. Extinct on mainland Australia.
Microcachrys	Podocarpaceae	p																x	x	s	s a w	Cf. *M. tetragona*, endemic to cool–temperate Tasmania. Extinct on mainland Australia.
Phyllocladus	Podocarpaceae	p			x	D_{1-2}					.	x				x				t	r.f.	Cf. *P. aspleniifolius*, endemic to cool–temperate Tasmania. Extinct on mainland Australia
Pinus	Pinaceae	p	p t	.				.				.								t.	plantation	Several species of *Pinus* introduced at various times during the last 100 years, or more.
Podocarpus	Podocarpaceae	p		B_1		D_{1-2}		F_{1-2}		x		J_{2-3}	x			x	x	x	x	t or s	w s f., r f., s a w	*P lawrencei*, restricted to cool–temperate high elevations. *P. elatus*, grows in rainforest on the South Coast of New South Wales
Angiospermae																						
Monocotyledoneae																						
Astelia	Liliaceae	p		x	x	x	x	F_2	x	x	I_{2-3}	x	x			x	x	x		h	a h, r.f.	*A. alpina* restricted to alpine bogs. *A. nervosa* found under *Nothofagus cunninghamii* grows in cool-temperate rainforests in Victoria Now much reduced due to the effects of successive forest fires (Willis 1972)
Bulbinopsis type	Liliaceae	p		B_2																h	s.w, d s f., w.s f., a.h.	Cf. *B. bulbosa*, widespread in grassy woodlands and throughout the mountains up to the highest elevations
Cyperaceae	Cyperaceae	p	p t, x	x	x	x	x	x	x	x	I_{1-2}	x	x			x	x	x		h.	s.w., d s f., w.s.f., s a w, a h	Several species grow at various altitudes, generally under swampy conditions.
Dianella/ Stypandra type	Liliaceae	p	A_1	B_2	x	D_2		F_1				J_{2-3}								h	d s f., w s f., s a w	*D tasmanica*, common in forest gullies and subalpine woodlands *D. revoluta* and *S. glauca*, common in dry sclerophyll forests
Lomandra longifolia type	Liliaceae	p	x			.	.													h	widespread	Abundant from sea-level to alpine elevations.
L effusus type	Liliaceae	p				D_1														h.	widespread	Western New South Wales, mainly in the dry sandy country
Poaceae	Poaceae	p	p t, x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	h	s w, d s f., w s f., s a w, a h	Common from sea-level to alpine elevations, but infrequent in closed forests and rainforests.
Restionaceae	Restionaceae	p	A_1	B_2	x	x	x	F_2	x	x	I_2	J_{2-3}	x			x		x	x	h	semi-aquatic	Cf. *Restio australis* and *Calorophus minor*, common in mountain swamps and bogs at high elevations
Ruppia	Ruppiaceae	p		B_1		D_3		F_1												h	aq	Cf. *R maritima*, common in brackish water lakes.
Sparganium	Sparganiaceae	p	p t																.	h	aq	Cf. *S. antipodum* grows in freshwater swamps and edges of water courses
Triglochin	Juncaginaceae	p														x				h	semi-aquatic	Grows throughout temperate Australia.
Typha	Typhaceae	p	A_3	x	x	D_{1-2}	.	F_{1-2}		x	I_3	J_{2-3}	x					x	x	h	semi-aquatic	Cf. *T domingensis* and *T orientalis*, both grow in swampy areas.
Dicotyledoneae																						
Acacia	Mimosaceae	polyad	p t			x				x		J_2				x				s	s w, d s f., w s f., s a w	Several species occur in woodlands and forests from sea-level to subalpine elevations
Acaena	Rosaceae	p	x							x										h	s w, d.s.f., w s f., s a w.	*A ovina*, common herb in grazed areas or in dry sclerophyll forests. *A anserinifolia*, common in mountain gullies at high elevations
Apiaceae	Apiaceae	p											x			x				h	s.w to s.a w	Several species in woodlands and forests from sea-level to subalpine areas
Araliaceae	Araliaceae	p	p t					.												s.	w s.f.	Cf. *Polyscias sambucifolius*, common in wet sclerophyll forest
Asperula	Rubiaceae	p	A_1			D_{2-3}		F_1			I_{2-3}	J_2								h	s w to a.h	Several species grow from low to high elevations
Banksia	Proteaceae	p.	p t			D_2						J_2				x				s	s w to s a w	Cf. *B. marginata* occurs from sea-level to subalpine elevations excepting wetter mountain forests
Bertya	Euphorbiaceae	p	p t													x				s	scrub	Several species in wet and dry sclerophyll forest. Cf. *B. rosmarinifolia* grows in scrub on river banks
Beyeria	Euphorbiaceae	p				.										x				s	w.s.f.	*B lasiocarpa* and *B viscosa* grow commonly in the coastal wet sclerophyll forests
Billardiera	Pittosporaceae	p				D_2														s	s f.	*B. longiflora* occurs in sclerophyll forest, *B. scandens* in dry sclerophyll forest
Bursaria	Pittosporaceae	p			x											x				s	s.w., d s f.	Cf. *B spinosa*, common in savannah woodland and dry sclerophyll forest
Calandrinia	Portulacaceae	p	p t					.												h	widespread	Several species in wet and dry sclerophyll forest.
Caryophyllaceae	Caryophyllaceae	p	A_{1-2}			D_{2-3}		F_1				J_2								h	widespread	Several taxa occur from sea-level to alpine elevations.
Casuarina under 23 µm	Casuarinaceae	p	p t, x	x		x		x		x		x				x	x	x	x	t	s f.	Pollen under 23 µm at the equator Size of pollen does not compare with any known *Casuarina* species.
Casuarina over 23 µm	Casuarinaceae	p	p t, A_1			D_2				x		J_{2-3}				x	x	x	x	t	s.w, d s.f.	Pollen over 23 µm at the equator. *C cunninghamiana*, common along river banks *C. stricta*, grows on dry stony ridges and low hills below 750 m. *C littoralis*, and *C. luehmannii* also occur in the area.
Chenopodiaceae	Chenopodiaceae	p	p t, x	x	x	x	x	x		.	I_2	J_{2-3}				x	x			h.	s w, d.s.f.	*Rhagodia nutans* grows in woodland and dry sclerophyll forest *Chenopodium pumilio* occurs in disturbed areas after summer rain Also several introduced taxa occur in the region.
Comesperma	Polygalaceae	p				D_2										.				s	s.f., swamp	Of the three species of *Comesperma* occurring in the area, *C. retusum* grows in swamps at high elevations, *C ericinum* in dry sclerophyll forest and *C volubile*, a twiner on shrubs in sclerophyll forests at medium and low elevations.

Convolvulaceae	Convolvulaceae	p.	p t	.		.	.						.				.		.	h.	widespread	Cf. *Convolvulus erubescens*, common in natural pastures.
Cruciferae	Cruciferae	p.	.	.	x	D_2					.	.		.		.	.			h	widespread	A number of taxa, *Cardamine*, *Lepidium* and *Drabastrum* form a part of the herbaceous cover in the area.
Drimys	Winteraceae	p	.	.		D_{1-2}			.	.	.	J_{2-3}		.		x			.	s.	w.s.f.	Cf. *D. lanceolata*, common in cool-temperate forests.
Dodonaea	Sapindaceae	p	.			D_2	x	.	.	x	.		.			x				s.	d.s.f.	Cf. *D. viscosa*, common in dry sclerophyll forest.
**Echium*	Boraginaceae	p	p.t.			.	.	.		.						.		.	.	h	widespread	Cf. *E. lycopsis*, introduced, grows wild on disturbed ground and along the roadside
Epacris	Epacridaceae	p		.	.	D_2	.	.		x	.	.	.			x				s	mainly swamps	Several species occur mainly in swamps at high elevation.
Eucalyptus type I	Myrtaceae	p.	p.t., x	x		x		F_1, F_3		x	I_2	J_{2-3}				x				t.	s f.	See table 6.
Eucalyptus type II	Myrtaceae	p.	p.A_1	.	.	D_{1-2}	.	.	.	.	.	J_2		.	.				.	t.	s.f.	See table 6.
Eucalyptus type III	Myrtaceae	p				D_{1-2}		.		.	I_2	J_2			.	x	x		.	t	s.f.	See table 6
Eucalyptus type IV	Myrtaceae	p	.		.	x		x		.		.	.	.	.	x				t	s.f.	See table 6
Eucalyptus type V	Myrtaceae	p.		.	.	.				.			x	.	.	x				t	s.f.	See table 6
Eucalyptus type VI	Myrtaceae	p.										.				x			.	t	s.f.	See table 6
Eucalyptus type VII	Myrtaceae	p.		.			.		.							x				t.	s.f.	See table 6.
Euphorbiaceae	Euphorbiaceae	p.	p t	.	.		.	.		.						.				h	widespread	Cf. *Euphorbia* spp of which several are introduced and grow on disturbed ground.
Euphrasia?	Scrophulariaceae	p	p.t		.				.				.		.		.			h	mainly s w	*Euphrasia* spp. grow mainly at high elevations. Only one species is reported to occur down to about 900 m.
Exocarpos	Santalaceae	p.	A_{1-2}	.				F_{1-2}	.			J_3		.		x				s.	d.s.f.	Cf. *E. cupressiformis*, common in dry sclerophyll forest
Fabaceae type	Fabaceae	p.	p t	B_2		D_{1-2}		.	.	.	I_2		.	.		x	x		.	h or s.	widespread	A wide variety of taxa belonging to Fabaceae are represented in the region
Galium	Rubiaceae	p.	.		.		.	.				.	.			x				h.	widespread	Several species of *Galium* occur in sclerophyll forests and in damp shady places in the region
Gentianaceae	Gentianaceae	p.		.									.			x				h	widespread	Several taxa represented in the region
Geraniaceae	Geraniaceae	p.	A_{1-2}			x	.	.	.	.		J_2			.	x				h.	widespread	The family Geraniaceae is represented by various species of *Geranium*, *Pelargonium* and *Erodium* in the area
Goodeniaceae	Goodeniaceae	p.	p t., x		.	D_2		.		x	I_2	J_3				x			.	h or s	widespread	The family Goodeniaceae is represented by a number of genera occurring in a wide variety of habitats.
Grevillea	Proteaceae	p.	A_{1-2}			D_{1-2}	.	F_2	x			J_{2-3}				x				s.	s.w., d s f., w.s.f., s.w	Several species of *Grevillea* grow at various elevations in savannah woodland to subalpine woodland.
Haloragis	Haloragaceae	p	p t, x			x		x	.	x	I_2	x	x			x	x			h	s.w, d.s.f., w s f., s w	The genus *Haloragis* is represented by several species growing as undergrowth in sclerophyll forests or in swamps from low to high elevations
Hibbertia	Dilleniaceae	p.	p t.					.								x	x			s.	s.w, s f.	Several species of *Hibbertia* grow in sclerophyll forests
Hovea	Fabaceae	p.	A_2		.	D_{2-3}	x	F_{2-3}		.		.				x	x			s	d.s f., w.s f., s w	A number of species of *Hovea* occur over a wide range of altitude in sclerophyll forests or subalpine woodland.
Hypericum	Guttiferae	p	p t.				.		.											h	s.w, d.s.f., w s f., s w	Three species of *Hypericum*, including one introduced species, *H. perforatum* var *angustifolium*, a noxious weed, grow in the area
Labiatae	Labiatae	p.	A_1																	h or s	widespread	Several taxa belonging to the family Labiatae occur under a wide range of habitats
Leucopogon	Epacridaceae	p											x					.		s.	s.w, d s f., w s f., s w	Most species of *Leucopogon* in the area occur in savannah woodland and dry sclerophyll forests. *L gelidus* occurs in wet sclerophyll forest and *L. suaveolens* in subalpine woodland
Liguliflorae	Compositae	p	p.t, x			D_{2-3}		F_{1-2}		x		J_2				x	x			h	widespread	Pollen of Liguliflorae in the modern pollen rain belong mostly to introduced species but fossil pollen compare closely to *Microseris scapigera*, the sole representative of Genus *Microseris* in Australia
Lythrum	Lythraceae	p	p t																	h	widespread	Two species, *L hyssopifolia* and *L salicaria*, occur commonly in damp places in the area
Montia	Portulacaceae	p				D_2						.			.					h	widespread	Cf. *M fontana* grows in seepage areas at lower elevations
Myoporaceae	Myoporaceae	p.	p t																	s.	widespread	The occurrence of Myoporaceae pollen in the modern pollen rain appears to be due to long distance transport.
Myriophyllum	Haloragaceae	p	A_2	.	.	x	x	F_1		x	I_3	J_{2-3}								aq	freshwater aquatic	Several *Myriophyllum* species grow in freshwater swamps and pools in the area
Myrtaceous shrubs I	Myrtaceae	p	p t, x			x		F_1, F_3				.				x				s	s f.	See table 6
Myrtaceous shrubs II	Myrtaceae	p	p t., A_2					F_1				J_2								s	s f.	See table 6.
Myrtaceous shrubs III	Myrtaceae	p		.		D_{2-3}	x	F_1								x		.		s	s.f.	See table 6.
Myrtaceous shrubs IV	Myrtaceae	p	A_{1-2}	B_2		D_{2-3}		F_{1-2}				J_{1-3}								s	s f.	See table 6.
Nothofagus	Fagaceae	p		.		D_{1-3}		F_1, F_3				J_2	.			x		x	x	t	r f.	*N.* '*brassii*' type presently grows in New Guinea Extinct in Australia
'*brassii*' type																					open deciduous	Cf. *N. gunnii* is now confined to cool-temperate areas in Tasmania Extinct in Australia
N '*fusca*' type	Fagaceae	p	.				.		.							x					r f.	Cf. *N. cunninghamii* grows at restricted sites in southeastern Victoria and cf *N moorei* in small patches in New South Wales and Queensland
N. '*menziesii*' type	Fagaceae	p.	.		.					.						.			x			
Orites	Proteaceae	p			x							J_1	x							s	s w. and alpine heath	Cf. *O lancifolia*, common as undershrub in subalpine woodlands. Also forms alpine heath at high elevations.
Papavaraceae	Papavaraceae	p	p t.																	h.	introduced	A number of taxa belonging to Papavaraceae occur as introduced weeds in the area
Pimelia	Thymelaeaceae	p.										.				x				h.	open forest	Several species in the area
Pittosporaceae	Pittosporaceae	p	p t									.				x	x	.		s	s f.	Cf. *Pittosporum*, uncommon in the area
Plantago	Plantaginaceae	p	p t, x	x		x	x	x	x	x	x	x	x							h	s f., a h	*P. varia* grows commonly in dry and wet sclerophyll forests. *P glacialis*, *P muelleri*, *P alpestris* and *P. euryphylla* grow in alpine herbfields at high elevations
Pomaderris	Rhamnaceae	p			.					.	.				.	x				s	w s.f	Several species of *Pomaderris* represented in the region
Portulacaceae	Portulacaceae	p	p.t	.																h	d.s f.	Cf. *Calandrinia eremaea*, common at low elevations in dry sclerophyll forest
Potamogeton	Potamogetonaceae	p				D_{2-3}					x	J_2								aq	mostly freshwater	A number of *Potamogeton* species occur in swamps, rivers and ponds throughout Australia.
Pseudanthus	Euphorbiaceae	p				D_3						J_2				x	x			s	widespread	Several species of *Psendanthus* occur under relatively wetter conditions than at present around Lake George in southeastern Australia.
Ranunculus	Ranunculaceae	p	p t, x			D_{2-3}	x	F_{2-3}	x		I_2	J_{2-3}								h	damp places	Several *Ranunculus* species occur in the area *R ?papulentus* grows along the wet edges of Lake George
Rhamnaceae	Rhamnaceae	p	p t	.	.	.							.							s	d s.f.	Cf. *Cryptandra* spp; *C amara* var *longiflora*, common in dry sclerophyll forest
Rumex	Polygonaceae	p	p t, A_1	B_2		D_2			x		I_{1-2}		x			x				h	damp and low-lying places	*R dumosus*, *R brownii* and *R. tenax* occur in the area in open and damp habitats
Sida	Malvaceae	p														x				h	widespread	Several species represented in this region.
Solanum	Solanaceae	p	p t																	h -s.	widespread	A number of natural and introduced *Solanum* species occur in the area
Stackhousia	Stackhousiaceae	p	p t	.																h	widespread	*Stackhousia monogyna* commonly occurs in woodland and forest habitats
Stylidium	Stylidiaceae	p	A_2	B_2		D_{2-3}		F_1, F_3	.			J_2				x	x	x	x	h	s f., all elevations	Cf. *S. graminifolium*, common in sclerophyll forests at all elevations
Tubuliflorae	Asteraceae	p	p t, x	x		x	x	x	x		x	x							.	h -s	widespread	Most of the taxa belonging to Tubuliflorae in the area belong to herbs; only some belong to shrubs The herbaceous taxa mostly grow in open habitats; shrub taxa grow in sclerophyll forests as an understorey.
Urticaceae	Urticaceae	p.	p t								.									h	w s f. or introduced	*Urtica incisa* grows in shaded damp sites in forest gullies *U urens* is introduced and is common in gardens, near settlements and in grazed pastures

p, pollen; sp, spore; g, glauchidia; c, colony; t, tree; s, shrub; h, herb; aq, aquatic; f, fern; p.t., pollen trap; x, present; s.w savannah woodland; s f., sclerophyll forest; d s.f., dry sclerophyll forest; w s f., wet sclerophyll forest; r f., rainforest; s a w, sub-alpine woodland; a h alpine herbfield; *, introduced have been essentially opportunistic, their presence being maintained through their ability to exploit recurring local disturbances (cf. Jarman & Brown 1983; Smith & Guyer 1983).

The absence of *Casuarina* from the Lake George record during the glacial periods is attributed to the *Casuarina* forest belts dropping considerably below Lake George altitude during the glacial interval by reason of *Casuarina's* inability to withstand low, alpine and subalpine temperatures. They, possibly, survived along the coast, or in small protected refugia on the Tablelands, where largely open, treeless, herbfield and grasslands prevailed during those times. There is no equivalent of present-day subalpine eucalypt vegetation shown in the pollen diagrams until the last interglacial so it is uncertain what kind of tree vegetation constituted the upper treeline during earlier times. One possibility is that one or more of the, now, extinct species of *Casuarina* constituted the upper treeline in the past. Alternatively, as cool–temperate taxa were the last to disappear during every glacial, and the fact that at no stage did tree species (for example, *Nothofagus*, *Phyllocladus*, *Podocarpus*) dominate this vegetation assemblage, it is possible that a set of cool–temperate taxa grew as a scrub close to the present-day upper treeline, now, occupied by 'snow gum' (*Eucalyptus pauciflora* ssp. *niphophila*). The occurrence of *Nothofagus* cf. *cunninghamii* wood, dated at *ca.* 35000 a B.P., in quartz gravels beneath the head of one of the blockstreams of the Toolong Range, between 1680 and 1780 m altitude above sea level, in the Snowy Mountains of New South Wales, showed that this tree taxon grew to at least that height in subzone D_2 of Interstadial-D (figures 12 and 15) (Caine & Jennings 1968).

There is little charcoal in the sediments belonging to glacial intervals, in marked contrast with interglacials. From this it is reasonable to infer that glacial vegetation did not generate sufficient fuel to allow significant fires to take place during these times (cf. Shackleton *et al.* 1983). On the other hand, the rise in the charcoal values with every interglacial suggests that warm conditions were conducive to growth of more productive plants and hence more fuel build-up which allowed lightning fires to take place from time to time.

Casuarina species, on account of their light seeds and their nitrogen-fixing qualities, probably migrated and established as pioneers, with ease, after the end of each glacial period. Unlike *Eucalyptus*-dominated sites, there is a considerable build-up of soil and litter organic matter, nitrogen and calcium under a *Casuarina* forest (Hueneke 1976). The continued occurrence of these forests would have promoted richer soils which, in turn, would have allowed mesophytic (rainforest) taxa to grow as an understorey. It is also likely that the rapid spread of *Casuarina* roots led to a more stable soil surface and the rapidly formed litter layer under dense stands reduced runoff and leaching of soil nutrients (cf. Hueneke 1976).

Casuarina (*C. stricta*) exhibits characteristics of both successional and steady-state species (light-seededness, fast growth rate in early years and a long life span of over 200 years in the absence of fire) (Hueneke 1976). In the absence of fire *Casuarina* experience natural thinning and proceed to form an open *Casuarina* woodland after 40 or 50 years. Under conditions of frequent fires the steady-state is not reached and the stands are ultimately replaced by fire-adapted *Eucalyptus*. However, since the *Eucalyptus* seeds are compact and without wings the invasion is slow and it can take several hundred years before a *Eucalyptus* woodland or forest is established. All this shows how persistently frequent the fires have to be before a *Casuarina*-dominated forest is replaced by a *Eucalyptus*-dominated forest. Under the infrequent, natural fire régimes, as may have prevailed during the Tertiary and for most of the Pleistocene interglacial periods at Lake George, the transformation to a *Eucalyptus* forest may have been very difficult indeed. Yet, this transformation was accomplished with the beginning of the last interglacial, some 128000 years ago, and lasted to the present day (figures 11–12).

(ii) *The Eucalyptus forest*

It is evident from the pollen record that an equivalent of the modern *Eucalyptus*-dominated wet sclerophyll (tall, open) forest had been established at the beginning of the last interglacial. This forest was much more open and had a far greater groundcover of grasses and other herbaceous taxa than in any of the earlier Brunhes Chron interglacials. Alongside these developments, the charcoal particle curve also rises to considerably higher values than in any of the earlier three interglacials (zones L, J and H, figure 11) and marginally higher than during the interglacial pollen zones P and N (figure 10). It is practically impossible to draw inferences regarding fire frequencies or fire intensities from relative quantities of charcoal particles in the sediment with the degree of resolution of sampling attained at Lake George. Nevertheless, the increase in charcoal in successive samples, each of which represents several hundred years of sedimentation, in conjunction with a change to a more 'fire-tolerant' plant assemblage (amenable to withstand high fire frequencies), during the last interglacial, especially when the relatively 'fire-sensitive' taxa also fail to rise at the same time, could be taken to indicate a rise in fire frequencies, rather than fire intensities.

Eucalyptus, now comprising some 550 species in Australia, is generally regarded as one of the most 'fire-tolerant' tree groups in the world (McArthur 1968). The taxonomic status of individual species is not always well defined probably partly because the species within the genus are still in a state of flux. A very large number of them may have originated in the not too distant past. All eucalypts generate a lot of fuel, which makes them attract fires to a greater extent than any other vegetation in Australia. The leaves contain both oil and resin which make them highly flammable. A number of studies have shown that eucalypt species, with rainforest understoreys or in wet or dry (tall or low, open) sclerophyll forests, do not generate without fire (Gilbert 1959; Ashton 1956; Cunningham 1960). On the other hand, they all regenerate abundantly after fire in both dry and wet (low and tall, open) sclerophyll forests (Mount 1964). All but 12–15 eucalypt species have lignotubers. Being partly underground, the lignotuber is seldom damaged by fire so that the trees survive by sprouting from the numerous dormant buds embedded in the bulbous mass. If all the leaves and small branches are scorched, the thousands of epicormic buds studding the trunk and branches help them to revive within a few months of the fire. The dormant bud strands are deeply embedded and can withstand killing of the bark and phloem and may occasionally survive the death of the cambium (McArthur 1968). These qualities, in conjunction with the varying degrees of insulation provided by the bark characteristics of different species, endow eucalypts with one of the highest survival capacities against high fire frequencies (Gill 1975). As a result, in both wet and dry (tall and low, open) eucalypt-dominated, sclerophyll forests and woodlands, most species present before burning become re-established quickly within a few months after the fire through surviving vegetative organs, remaining seeds in soil, or through the opening of woody fruits after fire (Petrie 1925; Beadle 1940; Baird 1958; Gilbert 1959; Cremer & Mount 1965; Christensen & Kimber 1975; Gill 1975). Among the eucalypt-dominated communities, the dry sclerophyll (low, open) forest, which now occupies the Lake George catchment, has the capacity to withstand fires at three to four year intervals.

All this suggests that the transformation to a 'fire-tolerant', eucalypt-dominated vegetation at the beginning of the last interglacial at Lake George must have involved a marked increase in fire frequencies. It is significant that the changes accompanying this transformation, first noticed during zone F (figure 11), are maintained through the succeeding forested periods to the present day. Not only does the amount of charcoal in the sediment remain at a generally high level but the overall dominance of open, eucalypt forest is maintained throughout, except for the short periods of the glacial maximum (zone C, figure 12) and subzones D_2 and D_1 of Interstadial-D (zone D, figure 12) during which both *Casuarina* and the cool–temperate rainforest taxa show a subdued, temporary revival, due mainly to the relatively moister (and therefore relatively less fire-prone) environments (as shown by high lake levels) prevailing during that time. Charcoal particles are present throughout in the form of fluctuating high peaks and troughs, often in much greater quantities than during the earlier, warmer intervals, and reaching unprecedented levels in the uppermost layers. Alongside these developments, the 'fire-sensitive' taxa (for example, *Casuarina* and the cool–temperate rainforest taxa) decline progressively (excepting subzones D_2 and D_1, figure 12) until they all (excepting some very low values of *Casuarina*) disappear during the Holocene (figure 12). It is abundantly clear that the conditions that led to the retardation of the 'fire-sensitive' *Casuarina*-dominated forest, and its associated cool–temperate taxa, during the last interglacial, continue to the present day. The climax of this development was reached during the Holocene when, for the first time, there was complete destruction of the entire 'fire-sensitive', cool–temperate rainforest assemblage of the Lake George basin (figure 12).

(iii) *Mechanisms of change*

What caused this tremendous change in vegetation? The progressive depletion of 'fire sensitive' taxa and the selection of the relatively 'fire-tolerant' taxa in the vegetation, in conjunction with the simultaneous large increase in the amounts of charcoal in the sediment, suggest a big increase in the fire frequencies at the beginning of the last interglacial. The question is what caused the increase in fire frequencies? Was it a change to a drier climate?

It has been pointed out earlier that drier climates, on their own, cannot lead to increased fire frequencies as they inhibit plant growth and, therefore, disallow a rapid fuel build-up following each fire. However, if the climate were to become consistently erratic, periods of good rainfall frequently interrupted by periods of drought, the former allowing a quick growth and hence the supply of fuel, and the latter a fire climate, frequencies of lightning-induced fires might rise sufficiently to favour the expansion of a 'fire-tolerant' *Eucalyptus*-dominated vegetation against a 'fire-sensitive' vegetation. The lake level curve from Lake George (figure 13–14) does indicate a relative increase in fluctuations between high and low lake levels during the last interglacial, as well as during subzone D_3 and the Holocene, in comparison with all the earlier interglacials. But whether these lake level fluctuations are representative of consistently erratic, short-term, 3–10 year cycles cannot be ascertained from the present evidence. On the other hand, the lightning-induced fires in the present day, fire-prone, eucalypt forests have been shown to be an infrequent cause of wild fires (Gilbert 1959; Jackson 1968; Kirkpatrick 1977). Moreover, the evidence from other parts of the world does not indicate generally drier climates since the beginning of the last interglacial period. Furthermore, the Holocene has never been considered to be the driest interglacial on record, as a purely climatically derived interpretation of the pollen record from Lake George would have us believe. Therefore, the possibility must be considered whether the change to relatively frequent lake level fluctuations in Lake George, since the last interglacial, is, in fact, partly the result of a palaeohydrological change brought about by the change over to the eucalypt-dominated vegetation in the lake catchment. It could also be that the change to the eucalypt-dominated vegetation actually resulted from either the progressive depletion of nutrients in soil through time (Beadle 1954, 1962, 1966), or the bush-burning activities of the technologically fire-oriented, early Aboriginal people (Singh *et al.* 1981). This presupposes the presence of the Aboriginal people some 90000 years earlier than the oldest available evidence for human occupation of the Australian continent (Flood 1983).

As pointed out earlier, modern *Casuarina stricta* stands, unlike the eucalypt-dominated forests and woodlands, allow considerable build-up of soil and litter organic matter, nitrogen and calcium, leading to a more stable soil surface, reduced run-off and reduced leaching of soil nutrients (Hueneke 1976). It is therefore likely that, in the *Casuarina*-dominated interglacials, the run-off from stable soils was gradual, and spread out through more of the year (hence saving the water from being evaporated back into the atmosphere soon after the rains) than is presently the case under the high run-off regime of the dry sclerophyll eucalypt (low, open) forests in the lake catchment. The former conditions would have induced a relatively continuous discharge of water into the lake from the forested catchment which, in turn, would have acted as a buffer against frequent changes in lake level. On the other hand, the situation would have been significantly changed with the arrival of the eucalypt-dominated forest in the lake catchment. In the presence of high fire frequencies in this plant community there is little organic litter left after each fire and, as the hydrophobic or water-repellent properties of soils are also intensified after frequent fires (Gilmore 1968; Craig 1968), the run-off and suspended load concentration would have risen to a much greater level. As there is also little water left in the ground, because of the lack of organic litter, any perturbation in the rainfall régime is immediately reflected in terms of frequent lake level fluctuations. Some idea of the increase in the run-off and sediment concentration over the last 128000 years, at Lake George, can be gained from the rates of sedimentation. These increase progressively from 1.5 cm^3 per 1000 years in zone F to 1.8 cm^3 per 1000 years in zone E, 3.57 cm^3 per 1000 years in zone D, 5 cm^3 per 1000 years in zone C, and 7.2 cm^3 per 1000 years in zones A–B (Singh *et al.* 1981*b*). The aggregate rate of sedimentation from zone G to the Brunhes–Matuyama boundary comes to 2.2 cm^3 per 1000 years (3.52 g cm^{-2} per 1000 years) which is considerably less than the rate of 3.28 cm^3 per 1000 years (4.59 g cm^{-2} per 1000 years) from zones A–F (Singh *et al.* 1981*b*). At whatever level the lake stands, each successive return to that level over time will face a reduction in volume available to receive sediment and so some increase in vertical accretion rate must ensure even without change in run-off and sediment concentration; it is thought, however, that so far this factor has been small in effect. Therefore, it is reasonable to suggest that the increase in fire frequencies was probably responsible for the destabilization of soils, on the one hand, and the increased run-off and the relatively frequent lake level fluctuations, on the other, starting with the last interglacial period. From this, one may also conclude that the same high fire frequencies probably led to depletion of nutrients and the destruction of nutrient recycling organisms (Springett 1979) contained in soils in the lake catchment which, in turn, promoted the further expansion of the low nutrient-demanding eucalypt-dominated forests (Jackson 1968). According to Jackson (1965, 1968), soil fertility and fire frequency generally interact in an inverse fashion. Thus, in the presence of high fire frequencies, there is no reason to invoke the idea of progressive, long-term, depletion of nutrients in soils through time (Beadle 1954, 1962, 1966) to explain the changes in vegetation, at the beginning of the last interglacial period, at Lake George.

One may therefore look to the third choice, that is, the possibility of the entry of man into Australia at the beginning of or before the last interglacial period as the agent of increased fire frequencies through his habitual bush-burning activities (Jones 1969).

The history of man's control on fire goes back more than half a million years in the eastern hemisphere (Leakey 1981). It is therefore reasonable to assume that the first Aboriginal people entering Australia were well versed in the use of fire technology for clearing, game hunting and 'fire-stick' farming (Jones 1969). From early historical accounts it is known that the Aboriginal people led a nomadic life and systematically burnt and managed areas around them to promote productivity as well as to clear bush for hunting and other activities (Mitchell 1848; Curr 1883). Later on, the first European settlers carried this activity a step forward, thus: 'Another job which cost us some trouble every year was burning off portions of the run on which we had no sheep for some time, or had only partially fed off; it being well known that the feed which springs up after a fire, is particularly wholesome and fattening' (Curr 1883, p. 355). This burning was carried out as follows: 'our practice was to set to work on the windward position... on some hot windy day at about eleven o'clock... we set fire to dry branches, which we dragged along the ground across the wind... In this way, a fire was set a-going in a line from one to five miles, and then left to chance. Sometimes burning off was a very troublesome job, on other occasions the flames went merrily ahead in every direction, now rushing up the tall stems of a thousand Eucalypts, the leaves of which it shrivelled like old parchment' (Curr 1883, pp. 355–356). Despite all this annual burning by the European settlers, the essential nature of the dry sclerophyll (low, open) forests does not appear to have changed substantially in the lake catchment as attested by the fossil evidence (figure 12). This is because the vegetation was already well adapted to meet high fire frequencies (cf. Christensen *et al.* 1981; Purdie & Slatyer 1976) at the hands of the earlier Aboriginal populations, who probably burnt the vegetation every few years, if not as frequently as the Europeans. As Curr (1883) points out, the Aboriginal man was 'constantly setting fire to the grass and trees, both accidentally and systematically for hunting purposes. Living principally on wild roots and animals, he tilled his land and cultivated his pasture with fire; and we shall not, perhaps, be far from the truth if we conclude that almost every part of New Holland was swept over by a fierce fire, on an average, one in every five years'. Fire was used by the Aboriginals for fun, signalling, clearing, hunting, promoting productivity, cooking, illumination, tree-felling, clearing camping places, direction-keeping and for ceremonial occasions (Jones 1969; Gould 1971; Hallam 1975). While mature rainforest supports sparse higher animal life, the open sclerophyll communities carry a wide variety of crustaceans, insects, birds, reptiles, monotremes and marsupials (Jackson 1968). This must have provided a great incentive to the early Aboriginal people to convert mixed forests into the relatively more open wet and dry sclerophyll forest types through frequent burning. Indirect evidence that the Aboriginal people had increased fire frequencies comes from the fact that after settlement by the Europeans, and the decline or extinction of Aboriginal populations in Tasmania, fires in high-rainfall areas became less frequent but more intense (King 1963; Bowman & Jackson 1981). This reduction in fire frequencies promoted the return of rainforest species to sclerophyll forests (Cremer 1960; Jackson 1968). On the whole, considering the close relationship between fire and the Aboriginal way of life, it is reasonable to argue that their bush-burning activities could have been an important factor in the progressive demise of the 'fire-sensitive' *Casuarina*-dominated forest and its associated rainforest taxa, as well as in the proliferation of the 'fire-tolerant', eucalypt-dominated forest and other associated 'fire-tolerant' taxa at Lake George (cf. Jackson 1968; Bowman & Jackson 1981) had they occupied Australia some 130000 years ago. It is also arguable that this change in vegetation may not have been a local feature of the Lake George basin and that the long-term effects of man's burning activities may have provided suitable niches for the 'fire-tolerant' taxa to radiate, expand and develop ecosystems, such as the wet sclerophyll (tall, open) and dry sclerophyll (low, open) forests in the humid zones of Australia. Bowman & Jackson (1981) see the effect of short fire-free intervals in mixed forests (rainforest with an overstorey of emergent sclerophyll species) thus: 'If the fire occurs in a mixed forest... before the rainforest trees have reached sexual maturity but after the maturity of sclerophyllous species, a wet sclerophyll (tall, open) forest results'.

The oldest archaeological material discovered, in Australia, however, is by no means as old as 130000 a B.P., at which the change to 'fire-tolerant' vegetation takes place at Lake George. The radiocarbon dated evidence for man in Australia, so far, goes back to 40000 a B.P. at a number of sites (Flood 1983). As this date is so close to the upper limit of resolution of the technique of radiocarbon dating, the estimation of real dates for the oldest sites is beset by difficulties (Flood 1983) but few have estimated more than 50000 to 60000 a B.P. for the oldest sites (Flood 1983). The proposition that there was a connection between early Aboriginal burning and the spread of 'fire-tolerant' eucalypt-dominated vegetation from the beginning of the last interglacial therefore remains to be tested by future archaeological investigations.

6. Broad implications

The pollen and charcoal particle evidence from Lake George demonstrates that the dry sclerophyll (low, open) forest in the catchment, and possibly elsewhere on the Southern Tablelands, is a comparatively recent development. This vegetation complex grades into an equally 'fire-tolerant' eucalypt woodland and grassland in the stressful frosty hollows and merges, upwards and coastwards, with a marginally less 'fire-tolerant' intermediate sclerophyll (intermediate tall, open) and wet sclerophyll (tall, open) eucalypt forests, along the rising rainfall gradient of the region. It seems likely that a gradation of decreasing fire frequencies, imposed through constraints of increasing moisture, may have determined the composition and distribution of these vegetation types in time (cf. Ashton 1981). The wet sclerophyll (tall, open) eucalypt forest lasted at Lake George for some 100000 years after its inception at the beginning of the last interglacial. It virtually came to an end at the close of zone D, about 23000 years ago, with episodic occurrences lasting through the Late Pleistocene and the early Holocene from *ca.* 16000 to 8000 a B.P. The local history of dry sclerophyll (low, open) eucalypt forest started only during the early Holocene. These short time spans contrast strongly with the much longer record of at least half a million years for the earlier *Casuarina*-dominated forests at Lake George.

The fact that the first eucalypt forest at Lake George was wet sclerophyll (tall, open) poses the question of whether the modern dry sclerophyll (low, open) forest species actually lived in the early wet sclerophyll (tall, open) forest during the last interglacial, or evolved during the Holocene, or migrated from drier regions. Further, as the eucalypt forest has been shown to have arrived so late at Lake George, and possibly elsewhere on the Southern Tablelands, one wonders whether some of the eucalypt species now growing in the region have, evolved since the beginning of the last interglacial, some 128000 years ago. Presently, there are at least 25 common eucalypt species within a radius of 100 km from Lake George (table 6). All the seven broad categories of *Eucalyptus* pollen types, recognized in the sediments from the lake, are represented by one, or more, of these species (table 6). However, these species may not be the only representatives in the context of a wider area, or in terms of all the extant eucalypt species in Australia.

TABLE 6. DISTRIBUTION OF *EUCALYPTUS* AND OTHER MYRTACEOUS TAXA IN THE LAKE GEORGE REGION

fossil pollen type	description of pollen	closest comparable taxa within 100 km radius of Lake George	vegetation type
Eucalyptus type I	3-parasynocolporate, oblate, equatorial diameter 15–20 µm, sides slightly concave, straight or slightly convex, sexine faintly ornamented, pattern obscure	*Eucalyptus bridgesiana*	Common, savannah woodland or dry sclerophyll forest species below 760 m.
		E. dalrympleana	Common, intermediate and wet sclerophyll forest species above 1070 m.
		E. delegatensis	One of the dominant wet sclerophyll forest species above 1070 m.
		E. dives	Common species of dry sclerophyll forest margins and dry mountain slopes to 1220 m
		E. fastigata	Common, wet sclerophyll forest species above 1070 m.
		E. goniocalyx	Uncommon, dry sclerophyll forest or savannah woodland species.
		E. melliodora	Common, savannah woodland species.
		E. nortonii	Uncommon, savannah woodland or dry sclerophyll forest species below 760 m.
		E. pauciflora	A variable species extending from margins of frost hollows at low elevations to elevations above 1220 m.
		E. rubida	Marginal to dry sclerophyll forest or on drier mountain slopes.
Eucalyptus type II	3-parasyncolporate, oblate equatorial diameter 20–25 µm, sides slightly concave, straight or slightly convex, sexine faintly ornamented, pattern obscure	*E. macrorhyncha*	Common species of dry sclerophyll forest below 915 m.
		E. pauciflora	A variable species extending from margins of frost hollows at low elevations to elevations above 1220 m.
		E. perriniana	Uncommon species restricted to montane areas.
		E. radiata	Common, intermediate sclerophyll forest species.
		E. stellulata	Common in cold mountain valleys or in subalpine communities at high elevations.
		E. viminalis	Common in mountain gullies especially close to perennial creeks in intermediate and wet sclerophyll forest.
Eucalyptus type III	3-parasyncolporate, oblate, equatorial diameter 10–15 µm, sides straight or concave, sexine psilate	*E. microcorys*	Wet sclerophyll forest species in the coastal region.
Eucalyptus type IV	3-parasyncolporate, oblate, equatorial diameter 15–20 µm, sides slightly concave, straight or slightly convex, sexine psilate	*E. polyanthemos*	Savannah woodland species, occasionally found in dry sclerophyll forest.
		E. rossii	Common, dry sclerophyll forest species. Grows on stony slopes with shallow soils.
		E. bauriana	Wet sclerophyll forest species in the coastal region.
		Backhausia myrtifolia	Wet sclerophyll species in the coastal region.
Eucalyptus type V	3-parasyncolporate, oblate, equatorial diameter 20–30 µm, sides straight or concave, sexine distinctly ornamented	*E. pilularis*	Common, wet to dry sclerophyll species, common in southern coastal New South Wales from sea level to 300 m elevation. Grows to 600 m in the north of the state and in Queensland.
		E. stricta	One of the hardiest wet sclerophyll species on the Blue Mountains in southeastern New South Wales.

Eucalyptus type VI	3-parasyncolporate, oblate, equatorial diameter 15–20 μm, sides convex, sexine psilate	*E. aggregata*	Uncommon dry sclerophyll species on Southern Tablelands of New South Wales.
Eucalyptus type VII	3-parasyncolporate, oblate, equatorial diameter 20–25 μm, sides straight or concave, sexine psilate	*E. cinerea*	Uncommon, dry sclerophyll species around Lake George; common through north to Central Tablelands of New South Wales.
myrtaceous shrub type I	3-syncolporate, oblate, equatorial diameter 10–15 μm, sides concave or nearly straight, sexine faintly ornamented, pattern obscure	*Baeckea gunniana* *B. utilis* *Micromyrtus ciliata* *Leptospermum myrtifolium* *L. parvifolium*	Common shrub of swamps at high elevations. Common shrub in forest gullies and swamps at high elevations. Grows in dry sclerophyll forest. Common shrub in forest gullies and high mountain valleys and swamps. Intermediate sclerophyll forest.
myrtaceous shrub type II	3-syncolporate, oblate, equatorial diameter 15–20 μm, sides concave or nearly straight, sexine faintly ornamented, pattern obscure	*Leptospermum juniperinum* *Kunzea muelleri*	Common on slopes of gullies at lower elevations. Common shrub of subalpine elevations.
myrtaceous shrub type III	3-syncolporate, oblate, equatorial diameter 10–15 μm, sides concave or nearly straight, sexine psilate	*Leptospermum phylicoides*	Grows at high elevations in cold mountain valleys.
myrtaceous shrub type IV	3-syncolporate, oblate, equatorial diameter 10–15 μm, sides convex or nearly straight, sexine faintly ornamented, pattern obscure	*Micromyrtus ciliata*	Grows in dry sclerophyll forest.

A number of Gondwanic taxa, commonly seen during the Late Tertiary in southeastern Australia survived well into the Pleistocene and finally disappeared during the late Brunhes Chron from Lake George. *Microcachrys*, *Nothofagus* '*menziesii*' type, and *N.* '*fusca*' type stayed until the early Brunhes, whereas *Phyllocladus* and *Nothofagus* '*brassii*' type disappeared only during the Late Pleistocene. *Dacrydium* lingered on until the last interglacial but *Podocarpus* ended only some 8000 years ago. Of all these taxa, *Microcachrys*, *Dacrydium*, *Nothofagus* '*brassi*' type, *N.* '*fusca*' type and *Phyllocladus* are no longer extant on mainland Australia. *Nothofagus* '*brassii*' type now grows in New Guinea whilst the other four taxa grow in Tasmania. Only two species belonging to *Nothofagus* '*menziesii*' type, *N. moorei* and *N. cunninghamii*, still grow on mainland Australia. Very probably the increase in fire frequencies on mainland Australia led to the demise of these Gondwanic taxa. In cases where relics of this once widely distributed flora exist to the present day, their spread is restricted to small, isolated pockets well short of their climatically determined limits.

Some of the changes in the flora were the result of long-term climatic change, but most appear to have been precipitated through increase in fire frequencies, during the last 128000 years. If the cause of the latter changes was man, then surely the artefactual nature of the eucalypt-dominated vegetation at Lake George, and possibly elsewhere, cannot be minimized. The question is whether modern man has the will, the capacity and above all the motivation, to restore the original vegetation. Man is a dynamic part of the developing ecosystems and it is important that he recognizes the history of his own impact on vegetation since he first started to use fire as a tool to change his environments around the world. It is only then that he can successfully set upon a course of restoration and management. The modern practice of forest management through controlled burning is at best helping to maintain *status quo* in the man-altered ecosystems inherited from the Aboriginal people and the early European settlers in Australia. To restore the primaeval forests, even on a small scale, will require a much greater effort and planning on the part of the community at large. If the fruits of restoration are weighed, purely on economic grounds, in terms of advantages gained in having less fire-prone forests, improved soils, greater subsurface storage of moisture, the existence of more perennial lakes and rivers and an overall more hospitable environment to man and animals, then surely modern man has good enough reasons to reverse the damage.

We are indebted to Professor D. Walker and Dr J. N. Jennings for their constructive criticism and suggestions while going through the manuscript, to the late G. M. Burton and Mr P. Wilson of the Bureau of Mineral Resources, Geology and Geophysics, Canberra, for allowing the use of the BMR core from Lake George, to Jododex Australia Pty Ltd and Mr Guido Cifali for the use of a lignite sample from their core (LG9) from close to Kennys Point, to Dr E. Kemp and Dr H. A. Martin for providing pollen counts from two Late Tertiary samples and to Mr H. Polach and Mr John Head for radiocarbon dating. We are also beholden to Dr J. M. Bowler and Dr N. D. Opdyke for their earlier collaboration in laying the groundwork for this paper (see Singh *et al.* 1981*b*). A work such as this could not have been completed without a lot of assistance. We thank, Mrs D. Moss for the charcoal particle counts, Mr Karl Shaw and Dr Bob Henry for their assistance in drilling, Mr D. Moser for pollen extractions, Mr A. W. Schuett, Mr A. McDonell, Mr M. Campion, Mr J. Magee, Mr J. Neale and Mr J. R. Caldwell for their assistance in the field, laboratory and workshop, Mrs J. Tode and Ms C. Twang for the typing of the manuscript and Mr K. Mitchell and Ms S. Jeffcoat for drawing the figures.

REFERENCES

Allan, R. J. 1983 Monsoon and teleconnection variability over Australasia during the southern hemisphere summers of 1973–77. *Mon. Weath. Rev.* **111**, 113–142.

Ashton, D. H. 1981 Fire in tall open-forests (wet sclerophyll forests). In *Fire and the Australian biota* (ed. A. M. Gill, R. H. Groves & I. R. Noble), pp. 339–366. Canberra: Australian Academy of Science.

Ashton, D. H. 1956 Studies on the autecology of E. regnans. Unpublished Ph.D. thesis, University of Melbourne.

Austin, M. P. 1978 Vegetation. In *Land use on the South Coast of New South Wales* (ed. M. P. Austin & K. D. Cocks), vol. 2, *Bio-physical background studies* (ed. R. H. Gunn), pp. 44–67. Melbourne: Commonwealth Scientific and Industrial Research Organization, Australia.

Austin, M. P., Cunningham, R. B. & Good, R. B. 1983 Altitudinal distribution of several eucalypt species in relation to other environmental factors in southern New South Wales. *Aust. J. Ecol.* **8**, 169–180.

Baird, A. M. 1958 Notes on the regeneration of Garden Island after the 1956 fire. *J. Proc. R. Soc. West. Aust.* **41**, 102–107.

Beadle, N. C. W. 1940 Soil temperature during forest fires and their effect on the survival of vegetation. *J. Ecol.* **28**, 180–192.

Beadle, N. C. W. 1954 Soil phosphate and the delimitation of plant communities in eastern Australia. *Ecology* **35**, 370–375.

Beadle, N. C. W. 1962 An alternative hypothesis to account for the generally low phosphate content of Australian soils. *Aust. J. agric. Res.* **13**, 434–442.

Beadle, N. C. W. 1966 Soil phosphate and its role in moulding segments of the Australian flora and vegetation, with special reference to xeromorphy and sclerophylly. *Ecology* **47**, 992–1007.

Beadle, N. C. W. & Costin, A. B. 1952 Ecological classification and nomenclature. *Proc. Linn. Soc. N.S.W.* **77**, 61–82.

Bowler, J. M. 1975 Deglacial events in southern Australia: their age, nature, and palaeoclimatic significance. In *Quaternary studies* (ed. R. P. Suggate & M. M. Cresswell), pp. 75–82. Wellington: The Royal Society of New Zealand.

Bowler, J. M. & Hamada, T. T. 1971 Late Quaternary stratigraphy and radiocarbon chronology of water level fluctuations in Lake Keilambete, Victoria. *Nature, Lond.* **232**, 330–332.

Bowler, J. M., Hope, G. S., Jennings, J. N., Singh, G. & Walker, D. 1976 Late Quaternary climates of Australia and New Guinea. *Quat. Res.* **6**, 359–394.

Bowman, D. M. J. S. & Jackson, W. D. 1981 Vegetation succession in southwest Tasmania. *Search* **12**, 358–362.

Brown, J. A. H. 1972 Hydrologic effects of a bushfire in a catchment in south-eastern New South Wales. *J. Hydrol.* **15**, 77–96.

Burbidge, N. T. 1959 The phytogeography of the Australian region. *Aust. J. Bot.* **8**, 75–211.

Burbidge, N. T. 1963 *Dictionary of Australian plant genera.* Sydney: Angus & Robertson Ltd.

Burton, G. M. & Wilson, E. G. 1973 Lake George, N.S.W.: its relevance to salinity problems in agriculture. *Rec. Bur. Miner. Resour. Geol. Geophys. Aust.* **1973/166**, 1–8.

Byles, B. U. 1932 A reconnaissance of the mountainous part of the River Murray catchment in New South Wales. *Comm. Forestry Bureau, Canberra, Bull.* no. 13.

Caine, N. & Jennings, J. N. 1968 Some blockstreams of the Toolong Range, Kosciusko State Park, New South Wales. *J. Proc. R. Soc. N.S.W.* **101**, 93–103.

Callen, R. A. & Tedford, R. H. 1976 New late Cenozoic rock units and depositional environments, Lake Frome area, South Australia. *Trans. R. Soc. S. Aust.* **100**, 125–167.

Cambage, R. H. 1921 Exploration between the Wingecarribee, Shoalhaven, Macquarie and Murrumbidgee Rivers. *J. Proc. R. Aust. hist. Soc.* **7**, 217–288.

Chippendale, G. M. & Wolfe, L. 1981 *The natural distribution of Eucalyptus in Australia.* Canberra: Australian National Parks and Wildlife Service.

Christensen, P. E. & Kimber, P. C. 1975 Effect of prescribed burning on the flora and fauna of south-west Australian Forests. *Proc. Ecol. Soc. Aust.* **9**, 85–106.

Christensen, P., Recher, H. & Hoare, J. 1981 Responses of open forests (dry sclerophyll forests) to fire regimes. In *Fire and the Australian biota* (ed. A. M. Gill, R. H. Groves & I. R. Noble), pp. 367–393. Canberra: Australian Academy of Science.

Churchill, D. M., Galloway, R. W. & Singh, G. 1978 Closed lakes and the palaeoclimatic record. In *Climatic change and variability – a southern perspective* (ed. A. B. Pittock, L. A. Frakes, D. Jenssen, J. A. Peterson & J. W. Zillman), pp. 97–108. Cambridge: Cambridge University Press.

Clark, R. L. 1983 Fire history from fossil charcoal in lake and swamp sediments. Unpublished Ph.D. thesis, Australian National University.

Clarke, W. B. 1852 Letter from the Rev. W. B. Clarke to the Colonial Secretary, on the metalliferous prospects of the county of Murray and on the vicinity of Lake George (Seventeenth Report). *Great Britain Parliamentary Papers*, vol. 1, *Discovery of gold in Australia*, pp. 83–86.

CLIMAP Project members, 1976 The surface of ice-age earth. *Science, Wash.* **191**, 1131–1137.

Colhoun, E. A. 1978 Recent Quaternary and geomorphological studies in Tasmania. *Aust. Quat. Newsl.* **12**, 2–15.

Colhoun, E. A. 1982 The glaciations of the West Coast Range, Tasmania, *XI INQUA Cong. Abst.* vol. II, 42.

Costin, A. B. 1954 *A study of the ecosystems of the Monaro region of New South Wales.* Sydney: Government Printer.

Costin, A. B. 1967 Alpine ecosystems of the Australasian region. In *Arctic and alpine environments* (ed. H. E. Wright & W. H. Osburn), pp. 55–87. Bloomington: Indiana University Press.

Costin, A. B. 1970 Vegetation, soils, and climate in late Quaternary southeastern Australia. In *Aboriginal man and environment in Australia* (ed. D. J. Mulvaney & J. Golson), pp. 26–37. Canberra: Aust. Nat. Univ. Press.

Costin, A. B. 1981 Alpine and subalpine vegetation. In *Australian vegetation* (ed. R. H. Groves), pp. 361–376. Cambridge: Cambridge University Press.

Cookson, I. C. & Pike, K. M. 1954 Some dicotyledonous pollen from Cainozoic deposits in the Australian region. *Aust. J. Bot.* **2**, 197–219.

Coventry, R. J. 1973 Abandoned shorelines and the late Quaternary history of Lake George, New South Wales. Unpublished Ph.D. thesis, Australian National University.

Coventry, R. J. 1976 Abandoned shorelines and the late Quaternary history of Lake George, New South Wales. *J. geol. Soc. Aust.* **23**, 249–273.

Coyne, P. D. 1973 *Some aspects of the autecology of Casuarinas, with particular reference to nitrogen fixation.* Unpublished Ph.D. thesis, Australian National University.

Craig, F. G. 1968 Effect of fire and heat on the physical properties of soils. Unpublished Ph.D. thesis, University of Melbourne.

Cremer, K. W. 1960 Eucalypts in rainforest. *Aust. For.* **24**, 120–126.

Cremer, K. W. & Mount, A. B. 1965 Early stages of plant succession following the complete felling and burning of *Eucalyptus regnans* forest in the Florentine Valley, Tasmania. *Aust. J. Bot.* **13**, 303–322.

Cunningham, T. M. 1960 The natural regeneration of *E. Regnans.* Bull. 1, School of Forestry, University of Melbourne.

Curr, E. M. 1883 *Recollections of squatting in Victoria.* Melbourne: George Robertson.

Daubenmire, R. 1954 Alpine timberlines in the Americas and their interpretation. *Bot. Stud. Butler Univ.* **11**, 119–136.

Davies, J. L. 1967 Tasmanian landforms and Quaternary climates. In *Landform Studies from Australia and New Guinea* (ed. J. N. Jennings & J. A. Mabbutt), pp. 1–25. Canberra: Australian National University Press.

Davis, M. B. 1969 Palynology and environmental history during the Quaternary period. *Am. Scient.* **57**, 317–332.

De Deckker, P. 1982 Late Quaternary ostracods from Lake George, New South Wales. *Alcheringa* **6**, 305–318.

Derbyshire, E., Banks, M. R., Davies, J. L. & Jennings, J. N. 1965 A glacial map of Tasmania. *R. Soc. Tasmania, Spec. Pub.* no. 2.

Diels, L. 1906 *Die Pflanzenwelt von West Australien.* Leipzig: W. Engelmann [reprinted 1976].

Dodson, J. R. 1974*a* Vegetation and climatic history near Lake Keilambete, western Victoria. *Aust. J. Bot.* **22**, 709–717.

Dodson, J. R. 1974*b* Vegetation history and water fluctuations at Lake Leake, southeastern South Australia. 1. 10,000 B.P. to Present. *Aust. J. Bot.* **22**, 719–714.

Dodson, J. R. 1975 Vegetation history and water fluctuations at Lake Leake south-eastern South Australia. II. 50,000 B.P. to 10,000 B.P. *Aust. J. Bot.* **23**, 815–831.

Dodson, J. R. 1977 Late Quaternary palaeoecology of Wyrie Swamp, southeastern South Australia *Quat. Res.* **8**, 97–114.

Erdtman, G. 1943 *An introduction to pollen analysis.* Massachusetts: Chronica Botanica, Waltham.

Erdtman, G. 1952 *Pollen morphology and Taxonomy.* Stockholm: Almqvist & Wiksell.

Faegri, K. & Iversen, J. 1964 *Textbook of pollen analysis*, 2nd rev. edn. Copenhagen. Munksgaard.

Flood, J. 1983 *Archaeology of the dreamtime.* Sydney: Collins.

Foley, J. C. 1945 Frost in the Australian region. *Australia. Bur. Meteorol. Bull.* no. 32.

Gale, J. 1927 *Canberra: history and legend.* Queanbeyan: A. M. Fallik.

Galloway, R. W. 1963 Glaciation in the Snowy Mountains: a re-appraisal. *Proc. Linn. Soc. N.S.W.* **88**, 180–198.

Galloway, R. W. 1965 Late Quaternary climates in Australia. *J. Geol.* **73**, 603–618.

Galloway, R. W. 1967 Dating of shore features at Lake George, New South Wales. *Aust. J. Sci.* **29**, 477.

Gardner, C. A. 1944 The vegetation of Western Australia. *J. Proc. R. Soc. West. Aust.* **28**, 11–87.

Garretty, M. D. 1936 Some notes on the physiography of the Lake George region, with special reference to the origin of Lake George. *J. Proc. R. Soc. N.S.W.* **70**, 285–293.

Gentilli, J. 1948 Two climatic systems applied to Australia. *Aust. J.Sci.* **11**, 13–16.

Gilbert, J. M. 1959 Forest succession in the Florentine Valley, Tasmania. *Pap. Proc. R. Soc. Tasm.* **93**, 129–151.

Gilmour, D. A. 1968 Hydrological investigations of the soil and vegetation types in the lower Cotter catchment. *Aust. For.* **32**, 243–256.

Gill, A. M. 1975 Fire and the Australian flora: a review. *Aust. For.* **38**, 4–25.

Gill, A. M., Groves, R. H. & Noble, I. R. 1981 *Fire and the Australian biota.* Canberra: Australian Academy of Science.

Gould, R. A. 1971 Uses and effects of fire among the Western Desert Aborigines of Australia. *Mankind* **8**, 14–24.

Gunn, R. H. & Story, R. 1969 General description of the Queanbeyan–Shoalhaven area. In *Lands of the Queanbeyan–Shoalhaven area A.C.T. and N.S.W.* C.S.I.R.O. Aust. Land Research Series no. 24, 16–21.

Hallam, S. 1975 *Fire and hearth.* Canberra: Australian Institute of Aboriginal Studies.

Holmes, W. B. K., Holmes, F. M. & Martin, H. A. 1982 Fossil *Eucalyptus* remains from the Middle Miocene Chalk Mountain Formation, Warrumbungle Mountains, New South Wales. *Proc. Linn. Soc. N.S.W.* **106**, 298–310.

Hueneke, K. 1976 Aspects of autecology and secondary succession of Casuarina stricta on Canberra's hills. Unpublished M.Sc. thesis (Forestry), Australian National University.

Humphreys, F. R. & Craig, F. G. 1981 Effects of fire on soil chemical, structural and hydrological properties. In *Fire and the Australian biota* (ed. A. M. Gill, R. H. Groves & I. R. Noble), pp. 177–200. Canberra: Australian Academy of Science.

Jackson, W. D. 1968 Fire, air, water and earth – an elemental ecology of Tasmania. *Proc. Ecol. Soc. Aust.* **3**, 9–16.

Jacobs, M. R. 1955 *Growth habits of the eucalypts.* Canberra. Government Printer.

Jacobson, G. & Schuett, A. W. 1979 Water level, balance, and chemistry of Lake George, New South Wales. *J. Bur. Min. Resour. Geol. Geophys., Aust.* **4**, 25–32.

Jarman, S. J. & Brown, M. J. 1983 A definition of cool temperate rainforest in Tasmania. *Search* **14**, 81–87.

Jennings, J. N. & Banks, M. R. 1958 The Pleistocene glacial history of Tasmania. *J. Glaciol.* **3**, 298–303.

Jennings, J. N., Noakes, L. C. & Burton, G. M. 1964 Notes on the Lake George and Lake Bathurst excursion. In *Geological excursions, Canberra district*, pp. 22–34. Canberra: Commonwealth of Australia, Department of National Development.

Jones, R. 1969 Fire-stick farming. *Aust. Nat. Hist.* **16**, 224–228.

Kemp, E. M. 1978 Tertiary climatic evolution and vegetation history in the southeast Indian Ocean region. *Palaeogeog. Palaeoclimatol. Palaeoecol.* **24**, 169–208.

Kemp, E. M. 1981 Pre-Quaternary fire in Australia. In *Fire and the Australian biota* (ed. A. M. Gill, R. H. Groves & I. R. Noble), pp. 3–21. Canberra: Australian Academy of Science.

Kershaw, A. P. 1970 Pollen morphological variation within the Casuarinaceae. *Pollen Spores* **12**, 145–161.

King, A. R. 1963 The influence of colonisation on the forests and the prevalence of bushfires in Australia. C.S.I.R.O. Division of Physical Chemistry, mimeo report.

King, N. K. & Vines, R. G. 1969 Variation in the flammability of the leaves of some Australian forest species. C.S.I.R.O. (Aust.) Division of Applied Chemistry, mimeo report.

Kirkpatrick, J. B. 1977 The impact of man on the vegetation of the west coast region. In *Landscape and Man* (ed. M. R. Banks & J. B. Kirkpatrick), pp. 151–156. Hobart: Royal Society of Tasmania.

Leakey, R. E. 1981 *The making of mankind.* London: Michael Joseph Ltd.

Lewis, A. N. 1934 A correlation of the Tasmanian Pleistocene glacial epochs and deposits. *Pap. Proc. R. Soc. Tasm.*, 1933, pp. 75–86.

Lewis, A. N. 1939 Notes on Pleistocene glaciation, Mt. Field to Strahan. *Pap. Proc. R. Soc. Tasm.*, 1938, pp. 161–173.

Lewis, A. N. 1945 Pleistocene glaciation in Tasmania. *Pap. Proc. R. Soc. Tasm.*, 1944, 41–56.

McAlpine, J. R. & Yapp, G. A. 1969*a* Climate of the Queanbeyan Shoalhaven area. In *Lands of the Queanbeyan–Shoalhaven area. A.C.T. and N.S.W.* C.S.I.R.O. Aust. Land Research Series no. 24, pp. 57–75.

McAlpine, J. R. & Yapp, G. A. 1969*b* Climate map, 1:350000. In *Lands of the Queanbeyan–Shoalhaven area, A.C.T. and N.S.W.* C.S.I.R.O. Aust. Land Research Series no. 24.

McArthur, A. G. 1964 Streamflow characteristics of forested catchments. *Aust. For.* **28**, 106–118.

McArthur, A. G. 1968 The fire resistance of eucalypts. *Proc. Ecol. Soc. Aust.* **3**, 83–90.

McArthur, A. G. & Cheney, N. P. 1965 The effect of management practice on streamflow and sedimentation from forested catchments. *J. Inst. Engs Aust.* **37**, 417–425.

McDougall, I. 1978 The present status of the geomagnetic polarity time scale. In *The earth: its origin, structure and evolution* (ed. M. W. McElhinny), pp. 543–566. London: Academic Press.

Martin, H. A. 1978 Evolution of the Australian flora and vegetation through the Tertiary: evidence from pollen. *Alcheringa* **11**, 181–202.

Mitchell, T. L. 1848 *Journal of an expedition into the interior of tropical Australia, in search of a route from Sydney to the Gulf of Carpentaria.* London: Longman.

Mount, A. B. 1964 The interdependence of the eucalypts and forest fires in southern Australia. *Aust. For.* **28**, 166–172.

Noakes, L. C. & Jennings, J. N. 1954 Lake George excursion notes. *A.N.Z.A.A.S. Canberra* (unpublished).

Noble, I. R. & Slatyer, R. O. 1977 Post fire succession of plants in Mediterranean ecosystems. In *Proceedings of the Symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems* (ed. H. A. Mooney & C. E. Conrad), pp. 27–36, U.S.D.A. For. Serv. Gen. Tech. Rep. WO-3.

Noble, I. R. & Slatyer, R. O. 1981 Concepts and models of succession in vascular plant communities subject to recurrent fire. In *Fire and the Australian biota* (ed. A. M. Gill, R. H. Groves & I. R. Noble), pp. 313–335. Canberra: Australian Academy of Science.

Ollier, C. D. 1977 Early landform evolution. In *Australia: a geography* (ed. D. N. Jeans), pp. 85–98. Sydney: Sydney University Press.

Osborn, J. F., Pelishek, R. E., Krammes, J. S. & Letey, J. 1964 Soil wettability as a factor in erodibility. *Proc. Soil. Sci. Soc. Am.* **28**, 294–295.

Petrie, A. H. K. 1925 An ecological study of the flora of Mt. Wilson. II. The *Eucalyptus* forests. *Proc. Linn. Soc. N.S.W.* **50**, 145–166.

Pidgeon, I. M. 1948 The ecology of the central coast of New South Wales. II. Plant succession on the Hawkesbury sandstone. *Proc. Linn. Soc. N.S.W.* **63**, 1–26.

Pook, E. W. & Moore, C. W. E. 1966 The influence of aspect on the composition and structure of dry sclerophyll forest on Black Mountain, Canberra, A.C.T. *Aust. J. Bot.* **14**, 223–242.

Pryor, L. D. 1954 Plant communities. In *Canberra, a nation's capital* (ed. H. L. White), pp. 162–177. A.N.Z.A.A.S. Handbook for Canberra.

Purdie, R. W. 1977*a* Early stages of regeneration after burning in dry sclerophyll vegetation. I. Regeneration of the understorey by vegetative means. *Aust. J. Bot.* **25**, 21–34.

Purdie, R. W. 1977*b* Early stages of regeneration after burning in dry sclerophyll vegetation. II. Regeneration by seed germination. *Aust. J. Bot.* **25**, 35–46.

Purdie, R. W. & Slatyer, R. O. 1976 Vegetation succession after fire in sclerophyll woodland communities in south-eastern Australia. *Aust. J. Ecol.* **1**, 223–236.

Russell, H. C. 1885 Anniversary address. *J. Proc. R. Soc. N.S.W.* **19**, 1–28.

Russell, H. C. 1886 Notes upon floods in Lake George. *J. Proc. R. Soc. N.S.W.* **20**, 241–260.

Shackleton, N. J. & Opdyke, N. D. 1973 Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific Core V28–238: Oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year scale. *Quat. Res.* **3**, 39–55.

Shackleton N. J., Hall, M. A., Line, J. & Shuxi, C. 1983 Carbon isotope data in Core V19–30 confirm reduced carbon dioxide concentration in the ice age atmosphere. *Nature, Lond.* **306**, 319–322.

Singh, G. 1981 Late Quaternary pollen records and seasonal palaeoclimates of Lake Frome, South Australia. In *Salt lakes* (ed. W. D. Williams), pp. 417–430. Reprinted from *Hydrobiologia* 80/82. The Hague: Dr W. Junk Publishers.

Singh, G. 1982 Environmental upheaval: the vegetation of Australasia during the Quaternary. In *A history of Australasian vegetation* (ed. J. M. B. Smith), pp. 90–108. Sydney: McGraw-Hill Book Company.

Singh, G. 1983 Late Quaternary vegetation and lake level record from Lake George, New South Wales: 32+/−5KA; 25−20KA; 18+/−2KA; 15−10KA; 7+/−2KA. In *Proceedings of the First CLIMANZ Conference, Howman's Gap, Victoria, Australia*, February 8–13, 1981 (ed. J. Chappell & J. Grindrod), pp. 23, 41, 66, 85, 99. Canberra: Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University.

Singh, G., Joshi, R. D., Chopra, S. K. & Singh, A. B. 1974 Late Quaternary history of vegetation and climate of the Rajasthan desert. *Phil. Trans. R. Soc. Lond.* B **267**, 467–501.

Singh, G., Kershaw, A. P. & Clark, R. 1981*a* Quaternary vegetation and fire history in Australia. In *Fire and the Australian biota* (ed. A. M. Gill, R. H. Groves & I. R. Noble), pp. 23–54, Canberra: Australian Academy of Science.

Singh, G., Opdyke, N. D. & Bowler, J. M. 1981*b* Late Cainozoic stratigraphy, palaeomagnetic chronology and vegetational history from Lake George, N.S.W. *J. geol. Soc. Aust.* **28**, 435–452.

Slatyer, R. O. 1960 Agricultural climatology of the Yass Valley. Division of Land Research and Regional Survey Technical Paper no. 6, 1–30. Melbourne: Commonwealth Scientific and Industrial Research Organization, Australia.

Smith, A. G., Pilcher, J. R. & Singh, G. 1968 A large capacity had-operated peat sampler. *New Phytol.* **67**, 119–127.

Smith, J. M. B. & Guyer, I. J. 1983 Rainforest–eucalypt forest interactions and the relevance of the biological nomad concept. *Aust. J. Ecol.* **8**, 55–60.

Specht, R. L. 1970 Vegetation. In *The Australian environment* (ed. G. W. Leeper), pp. 44–67. Melbourne: C.S.I.R.O. and Melbourne Univ. Press.

Specht, R. L., Rayson, P. & Jackman, M. 1958 Dark Island Heath (Ninety-mile Plain, S.A.). VI. Pyric succession: changes in composition, coverage, dry weight, and mineral nutrient status. *Aust. J. Bot.* **6**, 59–88.

Springett, J. A. 1979 The underground movement: soil. In *A natural legacy. Ecology in Australia* (ed. H. F. Recher, D. Lunney & I. Dunn), pp. 44–57. Sydney: Pergamon.

Swain, A. M., Kutzbach, J. E. & Hastenrath, S. 1983 Estimates of Holocene precipitation for Rajasthan, India, based on pollen and lake-level data. *Quat. Res.* **19**, 1–17.

Story, R. 1969*a* Vegetation of the Queanbeyan–Shoalhaven area, A.C.T. and N.S.W. In *Lands of the Queanbeyan–Shoalhaven area, A.C.T. and N.S.W.* C.S.I.R.O. Aust. Land Research Series no. 24, 111–133.

Story, R. 1969*b* Vegetation map, 1:350000. In *Lands of the Queanbeyan–Shoalhaven area, A.C.T. and N.S.W.* Land Research Series no. 24.

Strusz, D. L. 1971 Canberra, A.C.T. and N.S.W., 1:250000 Geological Series – Explanatory Notes. Canberra: Aust. Govt. Publ. Service.

Tate, R. 1890 *A handbook of the flora of extratropical South Australia.* Adelaide: Education Department.

Tauber, H. 1967 Investigations of the mode of pollen transfer in forested areas. *Rev. Palaeobot. Palynol.* **3**, 277–286.

Taylor, T. G. 1907 The Lake George Senkungsfeld, a study of the evolution of Lakes George and Bathurst, N.S.W. *Proc. Linn. Soc. N.S.W.* **32**, 325–345.

Taylor, T. G. 1958 *Sydneyside Scenery and how it came about (also Canberra and Kosciusko).* Sydney: Angus & Robertson.

Tranquillini, W. 1979 *Physiological ecology of the alpine timberline.* Berlin: Springer-Verlag.

Vines, R. G. 1975 Bushfire research in CSIRO. *Search* **6**, 73–78.

Vines, R. G. 1981 Physics and chemistry of rural fires. In *Fire and the Australian biota* (ed. A. M. Gill, R. H. Groves & I. R. Noble), pp. 129–149. Canberra: Australian Academy of Science.

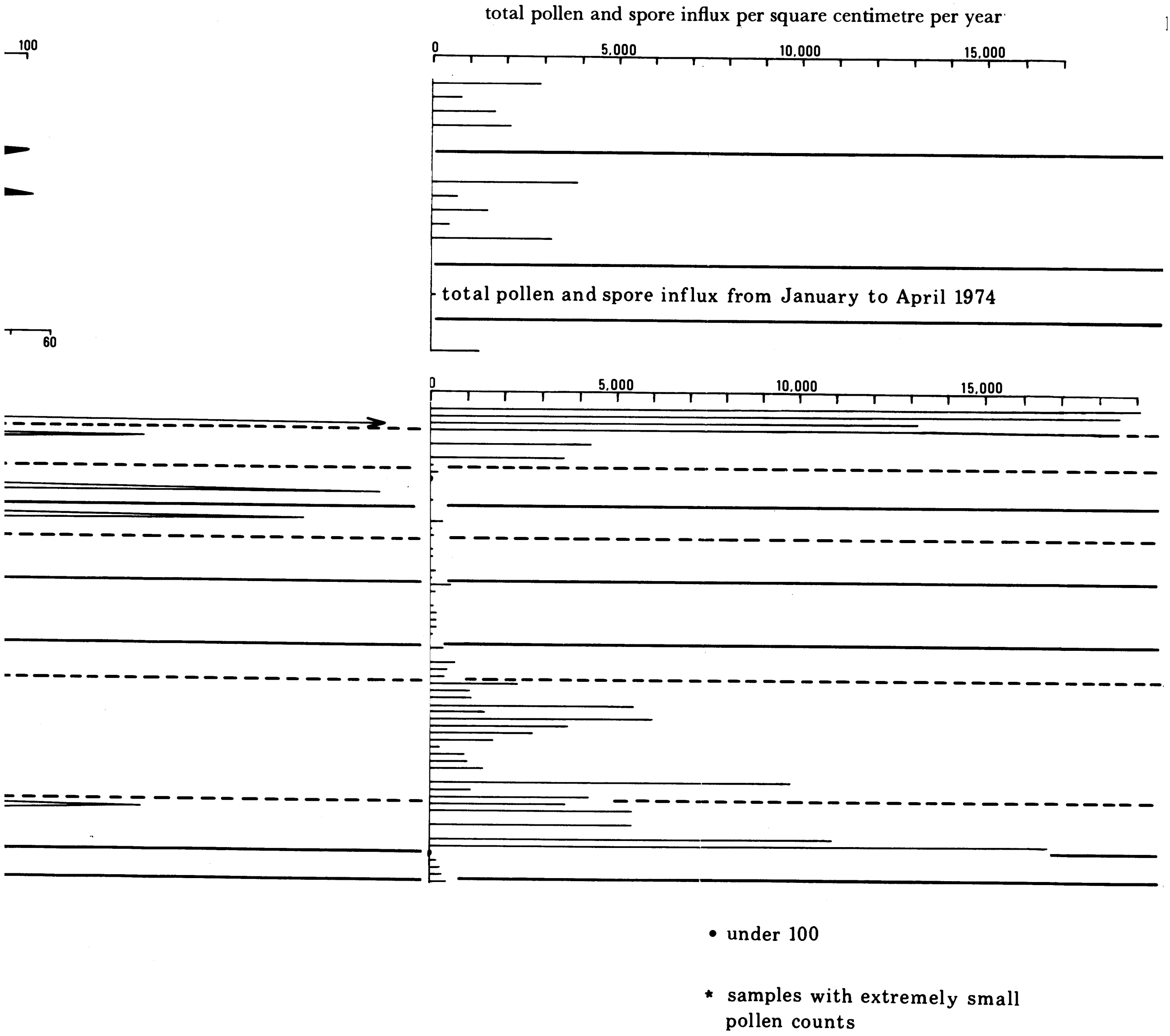
Walker, D. 1981 The development of resilience in burned vegetation. In *The plant community as a working mechanism* (ed. E. I. Newman), pp. 27–43. Oxford: Blackwell Scientific Publications.

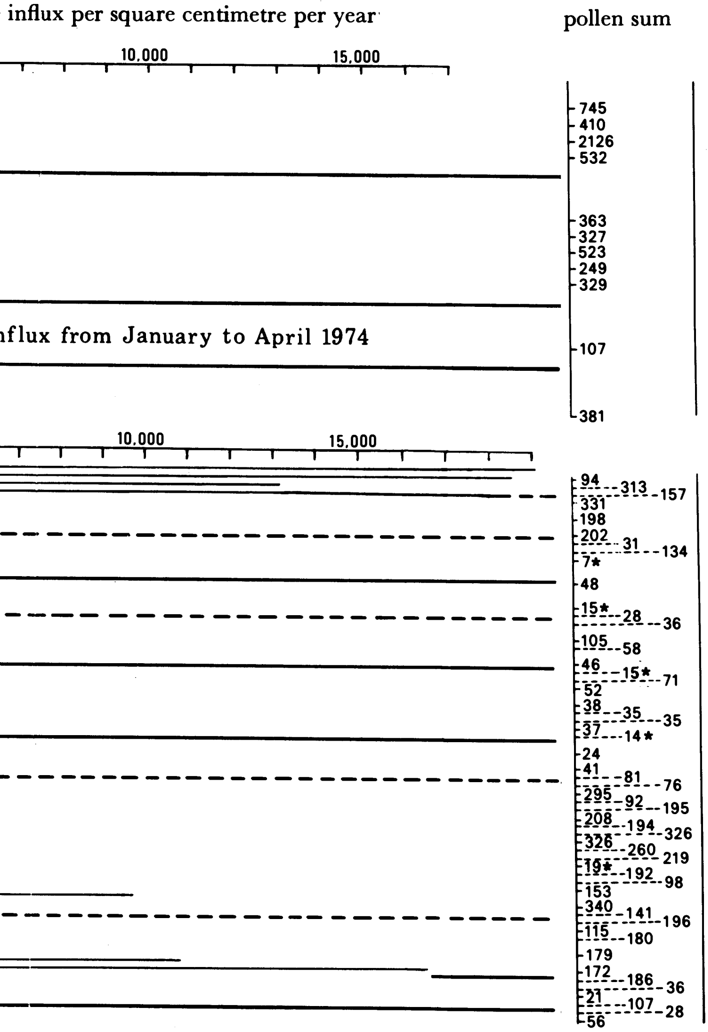
Walker, D. & Singh, G. 1981 Vegetation history. In *Australian vegetation* (ed. R. H. Groves), pp. 26–43. Cambridge: Cambridge University Press.

Wasson, R. J., Rajaguru, S. N., Misra, V. N., Agrawal, D. P., Dhir, R. P., Singhvi, A. K. & Rao, K. K. 1983 Geomorphology, late Quaternary stratigraphy and palaeoclimatology of the Thar dunefield. *Z. Geomorph. N. F.* **45**, 117–151.

Willis, J. H. 1972 *A handbook to plants in Victoria*. Melbourne: Melbourne University Press.

Yamasaki, F., Hamada, C. & Hamada, T. 1977 Riken natural radiocarbon measurements. IX. *Radiocarbon* **19**, 62–95.


total pollen and spore influx per square centimetre per year
100
0
5,000
10,000
15,000
total pollen and spore influx from January to April 1974
60
0
5,000
10,000
15,000
• under 100
* samples with extremely small pollen counts



taxa not included in the diagram

E–0.3; S–0.1; Ec–0.53; Po–0.1; Pi–1.2
Ec–0.5; Po–0.2; Ly–0.2; Pi–0.2
E–0.2; A–0.04; Hy–0.18; Pi–1.26
Ec–0.37

Pa–0.3; Ec–0.82; Co–0.3; Sp–0.27; Pi–1.6
E–0.3; Pit–0.3; St–0.3; Ec–1.2; Pi–1.8
Pit–0.2; Hi–0.4; Rh–0.4; Ec–0.4; Pi–2.8
Be–0.4; Pi–1.6
E–0.3

S–0.9; Ur–1.8

Ec–0.5; Po–0.8; My–0.26; Pi–1.6; Eu–2.9

La–0.3

Cu–0.7

B–2.7
Cr–3.7

Cr–0.3
Cr–0.4
Cr–0.4
Do–0.4
Bi–0.4; Ch–0.4
M–0.3
C–0.7
P–0.5
Do–0.8

- • under 100
- * samples with extremely small pollen counts

A	Araliaceae	E	Euphorbiaceae	P	*Pseudanthus*
B	*Bursaria*	*Ec	*Echium*	Pa	Papaveraceae
Be	*Bertya*	Eu	*Euphrasia?*	*Pi	*Pinus*
Bi	*Billardiera*	H	*Hakaea*	Pit	Pittosporaceae
C	*Comesperma*	Hi	*Hibbertia*	Po	Portulacaceae
Ch	*Cheilanthes*	Hy	*Hypericum*	Rh	Rhamnaceae
Co	Convolvulaceae	La	Labiatae	S	*Solanum*
Cr	*Cruciferae*	Ly	*Lythrum*	Sp	*Sparganium*
Cu	*Culcita*	M	*Montia*	St	*Stackhausia*
Do	*Dodonaea*	My	Myoporaceae	Ur	Urticaceae

* introduced taxa

FIGURE 10. Pollen diagram 1*c* shows the lowest part (800–1800 cm depth) of the fossil pollen sequence from Lake George. Pollen and spore values are expressed as percentages of total pollen and spores of dry land plants. Charcoal particle values are expressed as surface area percentage values per unit volume of sediment. Total pollen and spore concentration per cubic centimetre is shown in a separate column.

FIGURE 11. Pollen diagram 1*b* shows the middle part (300–855 cm depth) of the fossil pollen sequence from Lake George. Pollen and spore values are expressed as percentages of total pollen and spores of dry land plants. Charcoal particle values are expressed as surface area percentage values per unit volume of sediment. Total pollen and spore concentration per cubic centimetre is shown in a separate column.

Figure 12. Pollen diagram 1*a*, sections A and B. Section A shows the result of a five year modern pollen-rain study at Lake George as observed from Pollen Traps II (1974–79), V (1975–79), IN (1974–75) and IS (January–April 1974). Total pollen and spore influx per square centimetre per year is shown in a separate column. Section B shows the uppermost part (5–340 cm depth) of the fossil pollen sequence from Lake George. Pollen and spore values in sections A and B are expressed as percentages of total pollen and spores of dry land plants. Charcoal particle values in section B are expressed as surface area percentage values per unit volume of sediment. Total pollen and spore concentration per cubic centimetre is shown in a separate column.

A	Araliaceae	E	Euphorbiaceae	P	*Pseudanthus*
B	*Bursaria*	*Ec	*Echium*	Pa	Papaveraceae
Be	*Bertya*	Eu	*Euphrasia?*	*Pi	*Pinus*
Bi	*Billardiera*	H	*Hakaea*	Pit	Pittosporaceae
C	*Comesperma*	Hi	*Hibbertia*	Po	Portulacaceae
Ch	*Cheilanthes*	Hy	*Hypericum*	Rh	Rhamnaceae
Co	Convolvulaceae	La	Labiatae	S	*Solanum*
Cr	*Cruciferae*	Ly	*Lythrum*	Sp	*Sparganium*
Cu	*Culcita*	M	*Montia*	St	*Stackhousia*
Do	*Dodonaea*	My	Myoporaceae	Ur	Urticaceae

* introduced taxa

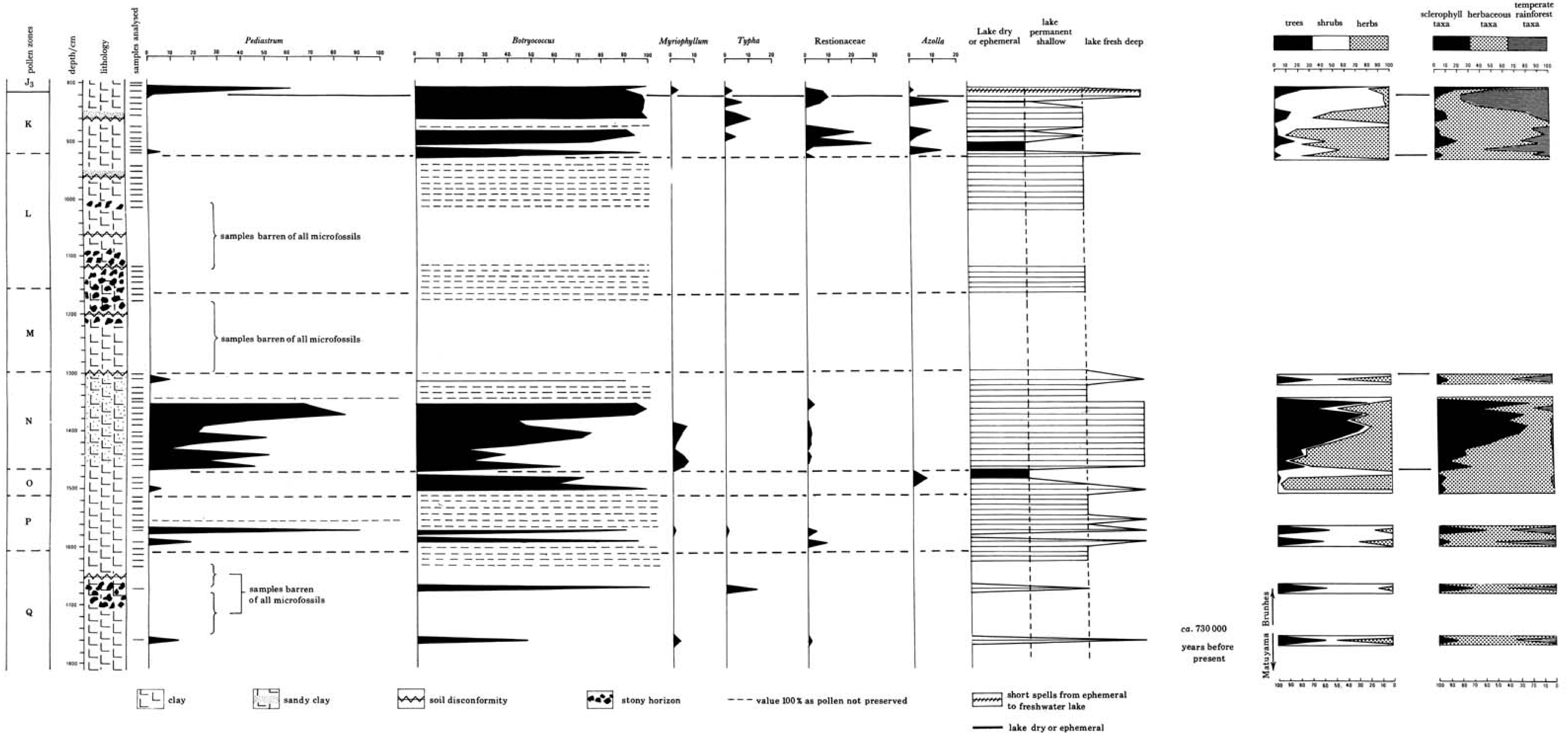


Figure 13. Diagram shows overall changes in vegetation, climate and lake levels as deduced from regional pollen, *Pediastrum* and *Botryococcus* algal colonies, spores of *Azolla* and the pollen of aquatic and subaquatic plants, *Myriophyllum*, *Typha* and Restionaceae in the lowest section (800–1800 cm) of the local pollen sequence at Lake George. Local pollen, spore and algal colony values are expressed as percentages of total pollen and spores of dry land plants plus individual taxon values. Changes in regional vegetation and climate are shown in two diagrams of relative percentages of total trees, shrubs and herbs (column *a*) and of total sclerophyll taxa, herbaceous taxa and cool–temperate rainforest taxa (column *b*). The presence of fossil *Pediastrum* colonies has been taken to indicate the occurrence of fresh water to at least 7 m depth. The occurrence of fossil *Botryococcus* colonies is indicative of shallow, open water conditions and of fossil *Azolla* spores of seasonally dry to ephemeral environments. Occurrences of *Azolla* spores and *Pediastrum* colonies together have been taken to indicate short-term fluctuations ranging from ephemeral to deep, freshwater lake conditions.

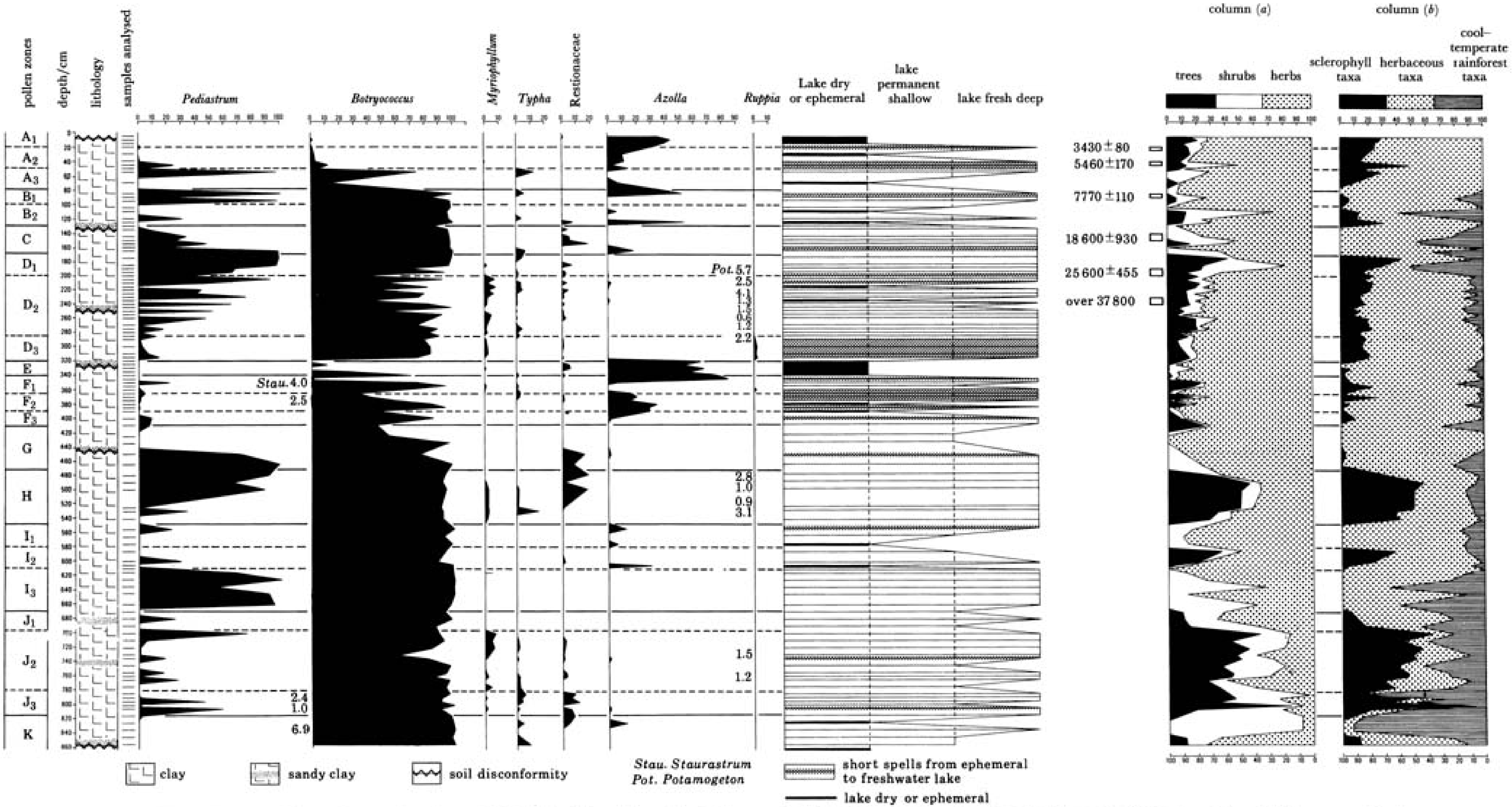


FIGURE 14. Diagram shows overall changes in vegetation, climate and lake levels as deduced from regional pollen, *Pediastrum*, *Staurastrum* and *Botryococcus* algal colonies, spores of *Azolla* and the pollen of aquatic and subaquatic plants, *Myriophyllum*, *Potamogeton*, *Ruppia*, *Typha* and Restionaceae in the upper part (5–855 cm depth) of the local pollen sequence at Lake George. Local pollen, spore and algal colony values are expressed as percentages of total pollen and spores of dry land plants plus individual taxon values. Changes in regional vegetation and climate are shown in two diagrams of relative percentage of total trees, shrubs and herbs (column *a*) and of total sclerophyll taxa, herbaceous taxa and cool–temperate rainforest taxa (column *b*). The presence of fossil *Pediastrum* and *Staurastrum* colonies has been taken to indicate the occurrence of fresh water to at least 7 m depth. The occurrence of fossil *Botryococcus* colonies and *Ruppia* pollen is indicative of shallow, openwater conditions and of fossil *Azolla* spores of seasonally dry to ephemeral environments. Occurrence of *Azolla* spores and *Pediastrum* and *Staurastrum* colonies together have been taken to indicate short-term fluctuations ranging from ephemeral to deep, freshwater lake conditions.