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Summary of the age and paleoecology of the Miocene Manuherikia Group, Central Otago, New Zealand

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Pollen analyses of ten sections through the Miocene Manuherikia Group of Central Otago have confirmed the presence of a number of paleoenvironments previously determined by sedimentological studies. The depositional environments include peat swamps, levees, flood plains, braided channels, permanent and ephemeral lakes, inter- distributary bays, beaches and back swamps. Most localities contain a complex mixture of sedimentary types and a great diversity in the spore-pollen assemblages reflecting a dynamic, constantly changing, local environment caused by a combination of tectonic activity, changing climatic patterns, fire, soil parent material and sedimentary sources.

The climate was warm temperate, probably never subtropical, moist and humid, although subject to periodic droughts. Fire played a significant role in some areas as indicated by the abundance of charcoal in some samples.

The oldest sediments occur in the east of the study area around Gimmerburn. These sediments fall into the upper part of the *Proteacidites isopogiformis* Zone of early Miocene (Otaian-Altonian) age. All other sequences through the Manuherikia Group fall into the *Tricolpites latispinosus* Zone of early Miocene (Altonian and possibly slightly younger) age. Sediments of late Miocene (Taranaki Series) age at some localities are assigned to the Maori Bottom Group.

Keywords: palynology, paleoecology, paleoclimate, depositional environments, stratigraphy, Miocene, Manuherikia Group, Maori Bottom Group, Central Otago lignites, Central Otago, New Zealand

INTRODUCTION

The mineral resources of Central Otago have been investigated over a number of years, prompted more recently by rising oil prices and the development of hydroelectric schemes which had the potential to inundate possible economic coal deposits. Detailed sedimentological studies were carried out by Douglas (1985a,b) and Douglas *et al.*, (1977). Palynological analyses were undertaken to confirm or deny the presence of Oligocene terrestrial sedimentation, and to determine depositional environment, paleoclimate and vegetational history. Some aspects of this work have been presented by Douglas (1985a,b) and Mildenhall (1977). It was realised early on in the study that zoning the lignites would be difficult in sediments that appeared to have been deposited in a relatively short space of time and in many different local environments. A local zonation has evolved and will be discussed more fully in a proposed taxonomic bulletin on the Central Otago lignites (Mildenhall and Pocknall in press).

The Central Otago lignites form part of the lower Miocene Manuherikia Group, covering ?Permian to Jurassic basement schists and greywackes. Subsequent movement and deformation of the group during the Kaikoura Orogeny has resulted in erosion of all but the small proportion of the original sedimentary sheet now preserved in intermontane basins and fault-angle depressions (Fig. 1). Overlying the Manuherikia Group are gravels, loesses and soils of the upper Miocene Maori Bottom Group, and Quaternary outwash gravels.

Previous age assessments of the Manuherikia Group and the Central Otago lignites have ranged from Oligocene-Miocene (Harrington, *in* Fleming, 1959) to Miocene-Pliocene

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(Couper and Harrington, *in* Fleming, 1959). Hector (1884) regarded the Manuherikia Formation (=Group) as upper Miocene; subsequent workers considered them to be of Miocene or Oligocene age (Suggate and Couper, 1952; Couper, 1953; 1960; Carter and Landis, 1972; Suggate *et al.*, 1978).

METHODS

Ten sequences in Central Otago have been analysed for pollen. Two of the sequences (Kawarau River; Vinegar Hill) are surface sections; eight are drillholes (see Fig. 1 for localities). Coring in these drillholes was not continuous, and mostly only the lignites were cored. This meant that only a small range of possible lithologies was studied, and the sequences examined were incomplete. Others (*e.g.* Lowburn) were predominantly unfossiliferous. Numerous spot samples from isolated surface sections, including Cambrians and Harliwichs Coal Mine (Fig. 1), were also examined to augment the sequences studied. Over 200 samples have been examined, of which about 5%-10% contain few or no palynomorphs.

GEOLOGY

The geological setting of the Manuherikia Group is comparatively uncomplicated. The group consists of an extensive and thick (*c.* 850 m) unit of fluviatile and lacustrine sediments. The oldest sediments appear to have been deposited in the east around Gimmerburn, near Ranfurly, from a lower to middle Tertiary marine transgression which climaxed in the late Oligocene. Earliest deposition began with quartz gravel deposited in narrow braided channels cut into the exposed schist basement. Eventually a fluvial plain developed with a complex of low gradient meandering channels and local back swamps which accumulated considerable thicknesses of peat. Subsequently a large, long-lived, freshwater lake was formed, Lake Manuherikia of Douglas (1985a, b), which covered over 5600 km^2. In this sedimentary setting there were several sub-environments, ranging from stagnant freshwater bays (Nevis Oil Shale) to peat swamps (Roxburgh coal seam in Harliwich's Mine). Ultimately, the tectonic activity associated with the Kaikoura Orogeny resulted in an influx of sand and gravel from braided streams, causing Lake Manuherikia to shallow. This formed the conformable, or possibly locally unconformable, Maori Bottom Group sediments.

AGE

The oldest beds are found at the base of the sequence at Gimmerburn, near Ranfurly. Here the basal ± 20 m contains *Acaciapollenites myriosporites* (Cookson), *Proteacidites annularis* Cookson, *P. isopogiformis* Couper and *P. stratosus* Pocknall & Mildenhall, all indicative of the early Miocene (Otaian-Altonian) *Proteacidites isopogiformis* Zone of Pocknall and Mildenhall (1984). This zone assignment is supported by the absence of *Tricolpites latispinosus* McIntyre, and palynomorphs characteristic of the *T. latispinosus* Zone. In Southland the *T. latispinosus* Zone overlies the *P. isopogiformis* Zone (Pocknall and Mildenhall, 1984).

The youngest sediments are at Lowburn, Gimmerburn and Ranfurly, and could be as young as late Miocene (Taranaki Series). These assemblages are characterised by a low diversity of taxa with a wide age range. Pollen of herbaceous and shrubby taxa are prominent and include Chenopodiaceae (especially at Lowburn), and Compositae (Tubuliflorae and Liguliflorae), although *Haloragacidites harrisii* (Couper) (*Casuarina*) and *Nothofagus* species remain dominant. These assemblages are similar to late Miocene assemblages recorded from central New Zealand, especially Blind River and Palliser Bay (Mildenhall and Pocknall, 1984). Late Miocene assemblages are usually dominated by *Nothofagus fusca* beech and podocarps, reflecting the onset of colder climatic conditions; however, *Casuarina* and *Nothofagus brassi* beech are occasionally dominant (Mildenhall, 1980). Compositae (Liguliflorae) are generally regarded as first appearing in the late Miocene (Couper, 1960; Mildenhall, 1980) giving a maximum age for the assemblages.

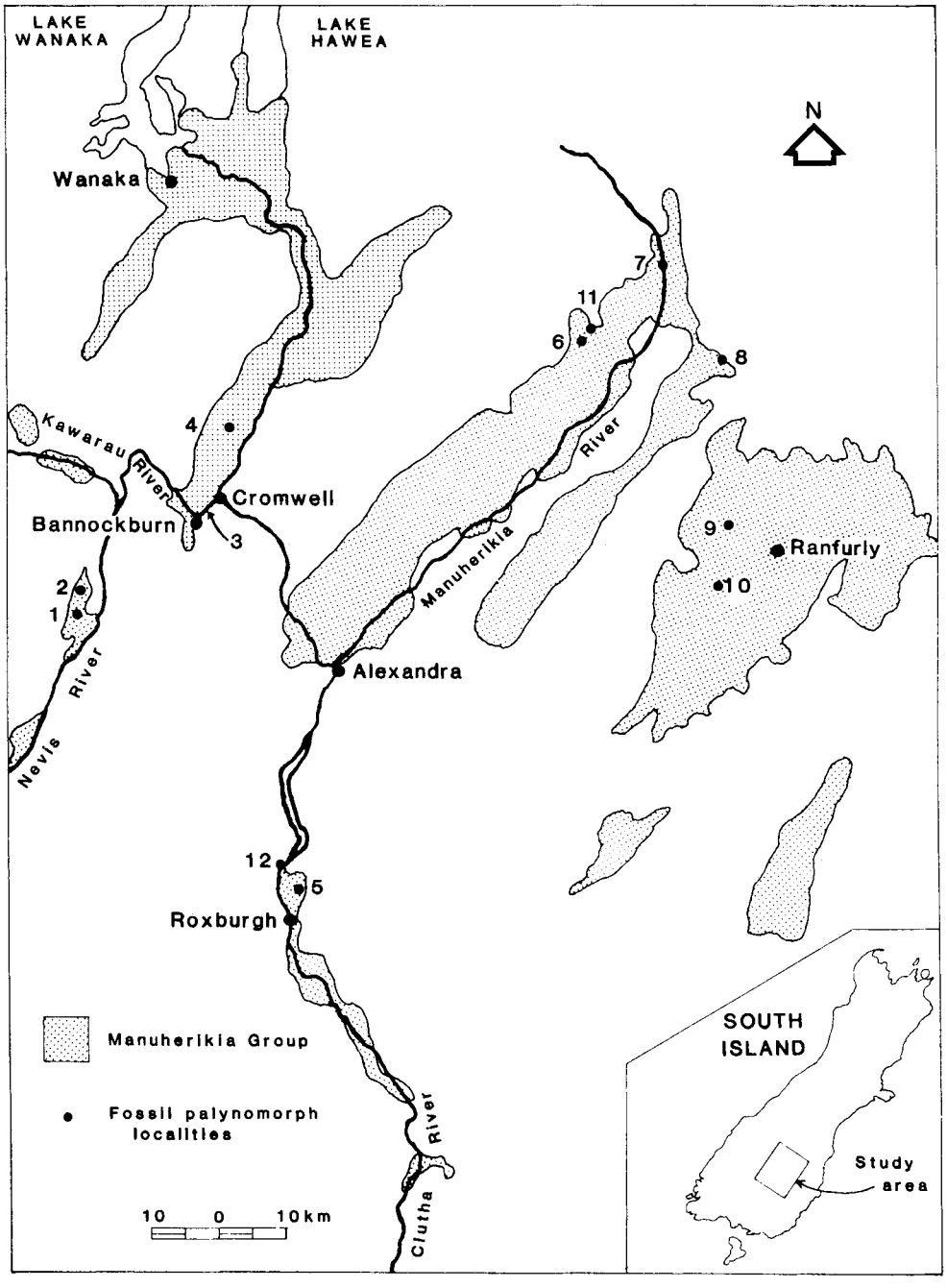
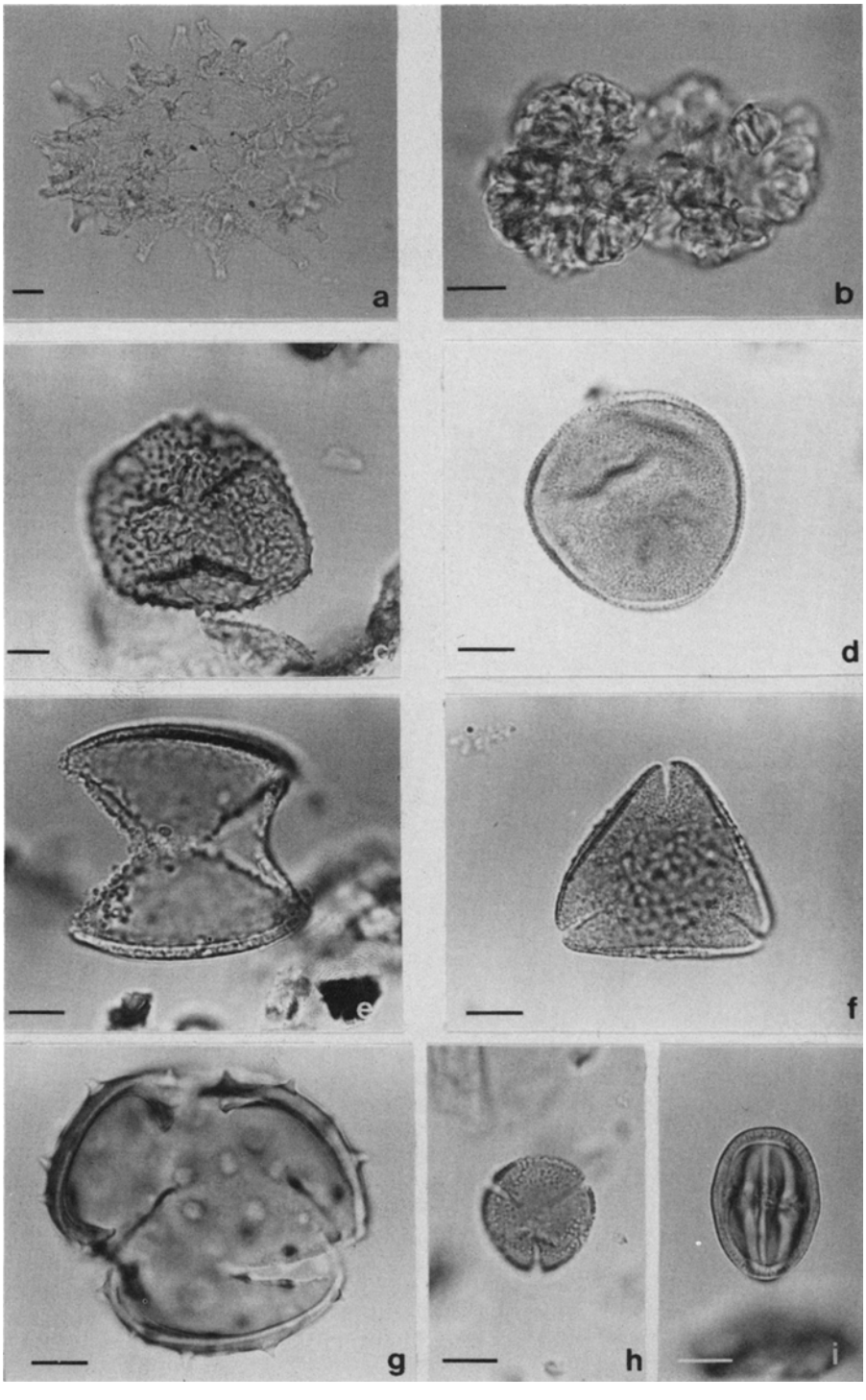


Fig. 1—The region between Roxburgh and Lake Hawea showing the main fault angle depressions containing Manuherikia Group and Maori Bottom Group sediments. The main rivers, lakes and towns are also indicated. Unstippled areas are primarily uplifted schist and greywacke basement blocks forming basin and range topography. The numbers refer to localities as follows. 1—Nevis; 2—Shale Creek; 3—Kawarau River section; 4—Lowburn; 5—Roxburgh East; 6—Cambrians; 7—Hawkdun; 8—Home Hills; 9—Ranfurly; 10—Gimmerburn (Haughton's Hill); 11—Vinegar Hill section; 12—Harliwichs Coal Mine. All except 3, 6, 11 and 12 are drillholes.



All other sediments of the Manuherikia Group fall into the early Miocene *Tricolpites latispinosus* Zone of Pocknall & Mildenhall (1984). Most assemblages differ from the

Taranaki Series assemblages in their high diversity of warm temperate plants, and the presence of numerous taxa not found in sediments younger than early Miocene (Altonian). The following taxa are important in determining the age range of the Manuherikia Group (see Figs 2, 3).

Acaciapollenites species (Fig. 3l): late Oligocene to middle Pleistocene (Waitakian to Okehuan).

Anisotricolporites truncatus Pocknall & Mildenhall (Fig. 2h): early Miocene (Altonian).

Assamiapollenites inanis Pocknall & Mildenhall: late Oligocene to early Miocene (Duntroonian to Altonian).

A. incognitus Pocknall & Mildenhall (Fig. 2d): early Miocene to Pliocene (Otaian to Waipipian).

Beaupreaidites verrucosus Cookson (Fig. 2f): late Cretaceous to early Miocene (Haumurian to Altonian).

Compositae (Tubuliflorae) (Fig. 3f): late Oligocene to present day (Waitakian onwards).

Dicrassipollis balteus Pocknall & Mildenhall (Fig. 2i): late Oligocene to early Miocene (Duntroonian to Altonian).

Glencopollis ornatus Pocknall & Mildenhall: early Miocene to early Pliocene (Otaian to Opoitian).

Haloragacidites haloragoides Cookson & Pike: early Miocene to present day (Otaian onwards).

H. myriophylloides Cookson & Pike: early Miocene to present day (Otaian onwards).

H. amolosus Partridge: early Miocene to Pliocene (Otaian to Waipipian).

Nuxpollenites species (Fig. 3b, c): early Miocene (Otaian to Altonian).

Proteacidites annularis Cookson (Fig. 3h): Paleocene to early Miocene (Teurian to Altonian).

P. isopogiformis Couper (Fig. 3j): late Oligocene to early Miocene (Waitakian to Altonian).

P. stratosus Pocknall & Mildenhall (Fig. 3g): middle Eocene to early Miocene (Bortonian to Altonian).

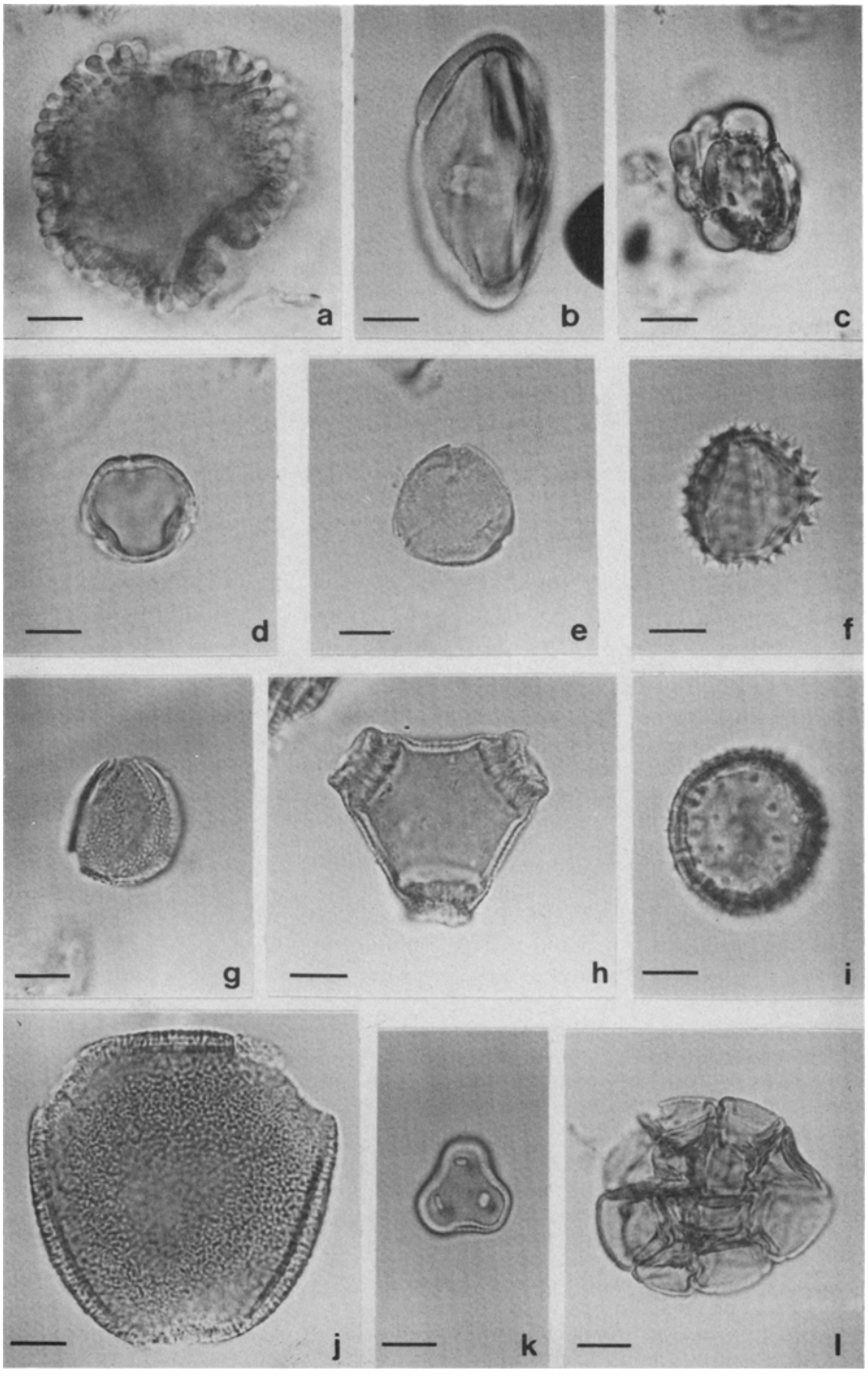
Symplocoipollenites austellus Partridge (Fig. 3e): early to middle Miocene (Otaian to Lillburnian).

Tetracolporopollenites costatus Pocknall & Mildenhall: early Miocene to Pliocene (Otaian to Waipipian).

Tricolpites latispinosus McIntyre (Fig. 2g): early Miocene to Pliocene (Altonian to Waipipian).

Although most assemblages appear to have been deposited *in situ*, two taxa, *Anacolosidites luteoides* Cookson & Pike (Fig. 3k) and *Quadraplanus* sp. appear to have been derived from older sediments. Both were found at Home Hills and are well preserved. The known or accepted range of *A. luteoides* in both New Zealand and Australia is Paleocene to Eocene (Mildenhall, 1980; Stover and Partridge, 1973), and *Quadraplanus* is normally characteristic of late Cretaceous assemblages in Australia (Stover and Partridge, 1973; Helby *et al.*,

Fig. 2 (opposite)—Photomicrographs of some key algae, spores and pollen from Miocene Manuherikia Group, Central Otago. Photomicrographs taken on Zeiss Universal Photomicroscope 838. Co-ordinates are given of all specimens illustrated from strew slides (L number). Single mounts (SM number) lack co-ordinates. Locality numbers refer to Fig. 1. Scale bar in all photomicrographs equals approximately 10 μm. (a) *Pediastrum*. L9760/2, co-ordinates 1002/039. Locality 10. (b) *Botryococcus*. L9760/2, co-ordinates 1135/145. Locality 10. (c) *Rudolphisporis rudolphi*. L11562/1, co-ordinates 1033/159. Locality 5. (d) *Assamiapollenites incognitus*. L11556/2, co-ordinates 1177/047. Locality 5. (e) *Dicolpopollis* cf. *D. metroxylonoides*. L11440/2, co-ordinates 1198/226. Locality 8. (f) *Beaupreaidites verrucosus*. L11433, SM4212. Locality 8. (g) *Tricolpites latispinosus*. L11404, SM4213. Locality 7. (h) *Anisotricolporites truncatus*. L11575/1, co-ordinates 1088/129. Locality 5. (i) *Dicrassipollis balteus*. L11433/2, co-ordinates 1092/119. Locality 8.



1987). It is problematical as to whether these two taxa are recycled. Both *A. luteoides* and *Quadraplanus* are usually rare throughout their range, and are unlikely to be found in the absence of additional, more common, taxa.

PALEOECOLOGY AND PALEOCLIMATE

The Central Otago lignites, including beds of both Manuherikia Group and Maori Bottom Group, can be divided into two suites on the basis of age and paleoclimate. There is a younger, cooler suite of assemblages at Lowburn, Gimmerburn and Ranfurly, and an older and predominantly warmer suite of assemblages at the base of the Gimmerburn and Ranfurly sequences and at all other localities studied, except Lowburn.

The Lowburn sequence is dominated by pollen of Chenopodiaceae and *Casuarina*. The colonial freshwater algae *Botryococcus* and *Pediastrum* are also common, and indicate a wet meadow or lacustrine environment. At the top of the Ranfurly and Gimmerburn sequences *Nothofagus fusca* beech and *Casuarina* are common, with Myrtaceae and *Sphagnum*, suggesting that flood plain, levee and swamp environments were represented. Moist, cool temperate climatic conditions are suggested by the dominance of *Nothofagus fusca* beech over *Nothofagus brassi* beech. At Lowburn the presence of genera like *Epilobium* and *Stellaria*, the abundance (58%) of herbaceous taxa, the lack of species diversity and the absence of warm temperate to subtropical taxa all suggest cool temperate climate conditions. Abundant *Casuarina*, *Myriophyllum*, *Haloragis*, Cyperaceae, Sparganiaceae and Chenopodiaceae with *Pediastrum* and *Botryococcus* all indicate a moist environment. Moist, cool temperate conditions also prevailed during deposition of the younger parts of the Ranfurly and Gimmerburn sequences as evidenced by the low species diversity, abundant Compositae and *Sphagnum*, less abundant Myrtaceae, and Podocarpaceae and *Nothofagus fusca* beech more common than *Nothofagus brassi* beech.

All the older sequences contain pollen assemblages characterised by high species and assemblage diversity, numerous taxa suggestive of warm temperate, moist conditions, *Nothofagus brassi* beech dominant over *Nothofagus fusca* beech, and generally low percentages of taxa characteristic of cool temperate situations, common in the younger material.

Occasional samples of *T. latispinosus* Zone age indicate cooler conditions, especially those with pollen of podocarps (*Phyllocladus, Podocarpus*) and *Nothofagus fusca* beech dominating. Also, some samples show evidence of periodic drought, especially those which contain abundant pollen of Gyrostemonaceae and *Mallotus/Macaranga* type. At Vinegar Hill, Douglas (1985b) reported the presence of desiccation cracks in muddy sediments, although no evaporite mineral precipitation has yet been located. Fluctuating water levels in permanent and ephemeral lakes are recorded by changes in the associated pollen assemblages, especially in the fluctuations of the colonial algae, and the presence of aquatic and semi-aquatic herbaceous taxa.

The following taxa are considered to be important indicators of the changes in climatic conditions in Central Otago during the deposition of the Central Otago lignites (see Figs 2, 3).

The colonial green algae, *Pediastrum* (Fig. 2a) and *Botryococcus* (Fig. 2b), are found abundantly in Central Otago. They occupy open, fresh-water environments and often form algal blooms and sapropelic accumulations in small lakes and ponds, for which warm temperate conditions are necessary. They have an additional economic importance in

Fig. 3 (opposite)—Photomicrographs of some key pollen from Miocene Manuherikia Group, Central Otago. Photomicrographs taken on Zeiss Universal Photomicroscope 838. Co-ordinates are given of all specimens illustrated from strew slides (L number). Single mounts (SM number) lack co-ordinates. Scale bar in all photomicrographs equals approximately 10 μm. Locality numbers refer to Fig. 1. (a) *Ilexpollenites anguloclavatus*. L9577/1, co-ordinates 1171/138. Locality 11. (b) *Nuxpollenites* sp. aff. *Diplopeltis*. L11417/2, co-ordinates 1191/058. Locality 7. (c) *Nuxpollenites varicosus*. L11554/1, co-ordinates 1033/117. Locality 5. (d) *Nyssapollenites endobalteus*. L11417/2, co-ordinates 1152/069. Locality 7. (e) *Symplocoipollenites austellus*. L11413/1, co-ordinates 1078/095. Locality 7. (f) *Tubulifloridites antipodica*. L9760/1, co-ordinates 1052/049. Locality 10. (g) *Proteacidites stratosus*. L9765/2, co-ordinates 1081/099. Locality 10. (h) *Proteacidites annularis*. L9765/2, co-ordinates 1153/141. Locality 10. (i) *Micrantheum spinyspora*. L8579, co-ordinates 1180/074 (specimen from Glentanner Formation of Pliocene age; Miocene specimens could not be photographed because of poor preservation and orientation). Locality Pukaki drainage canal. (j) *Proteacidites isopogiformis*. L9765/2, co-ordinates 1182/109. Locality 10. (k) *Anacolosidites luteoides*. L11435, SM4227. Locality 8. (l) *Acaciapollenites myriosporites*. L9756, SM4232. Locality 10.

that they are oil-secreting organisms, and have contributed greatly to the development of the Central Otago oil shales.

The genera *Ricciaesporites* and *Rudolphisporis* (Fig. 2c) are spores of liverworts and hornworts. They are frequent in Central Otago, indicating moist, humid conditions in fluviatile and lacustrine environments. They tend to occupy bare soil and damp rock faces.

Phyllocladidites mawsonii (Cookson) and *P. paleogenicus* Cookson & Pike (Podocarpaceae) are frequent in Central Otago and are common in some samples. High frequency peaks of *P. paleogenicus*, usually coinciding with the presence of *P. mawsonii*, may represent cooler periods during the deposition of the lignites.

One specimen of *Dicolpopollis* (Palmae) (Fig. 2e) was located at Home Hills. This genus has an affinity with the tropical sago palm (*Metroxylon*) which is common in Papuan swamps. Truswell *et al.*, (1985) also compare this pollen type with *Calamus*, another palm genus of tropical to subtropical distribution.

The family Gyrostemonaceae is frequent and often abundant in Central Otago. Pollen grains similar to the modern genera *Didymotheca*, *Codonocarpus* and *Gyrostemon* form up to 35% of total pollen in some samples. In modern vegetation, members of the Gyrostemonaceae are important elements in sclerophyll woodlands and shrublands in Australia (Luly *et al.*, 1980), and therefore indicate arid conditions. There is sedimentological evidence for periods of drought during the deposition of the fluviatile/lacustrine beds.

Ilex (Aquifoliaceae) (Fig. 3a) is a genus rarely found as fossils in Central Otago, which is unexpected since it is most common in late Oligocene to early Miocene sediments in the southern part of New Zealand, for example at Clifden (McIntyre, 1968). *Ilex* is a tree or shrub which, with few exceptions, requires a relatively wet and equable climate (Martin, 1977). The periodic droughts in Central Otago during the Miocene may have been frequent enough to inhibit the development of *Ilex* as a prominent component of the vegetation. *Ilex* is insect-pollinated, so very little of its pollen is dispersed by air. Scarcity of this pollen therefore does not necessarily indicate a scarcity of the parent plants. Its presence at Vinegar Hill suggests either high humidity at this site or lower susceptibility to drought.

Diplopeltis (Sapindaceae) (Fig. 3b) pollen at Home Hills and Hawkdun suggests relatively dry, warm conditions (Kemp, 1976; Bint, 1981). The same samples contain Gyrostemonaceae but also mesophytic taxa like Restionaceae, Sparganiaceae and Cyperaceae.

Nyssapollenites endobalteus (Fig. 3d) has an affinity with *Mallotus* and *Macaranga* (Euphorbiaceae), and suggests dry conditions. Samples containing relatively abundant *N. endobalteus* are found frequently in Central Otago. *Mallotus* and *Macaranga* are tropical genera characteristic of forest margins, secondary regrowth sites, and under breaks in the forest canopy (Martin, 1974). They do grow in moist situations in southeast Asia (D. Walker *pers. comm.*, 1985), but the associated palynomorphs in the Central Otago assemblages do not suggest a southeast Asian affinity for the vegetation.

Symplocoipollenites austellus (aff. *Symplocos*; Symplocaceae) (Fig. 3e) is found rarely at Shale Creek and Hawkdun. *Symplocos* has a tropical and subtropical distribution (Martin, 1978). Apparently the family Symplocaceae was far more widespread during the Miocene than at present, and its presence in Central Otago indicates a warm, humid climate at that time.

Cupanieidites species are frequent in Central Otago (but never more than 1% of total pollen) and are allied to several genera in the Sapindaceae (Tribe Cupanieae). Many of the genera (*e.g. Cupaniopsis*) have tropical distributions in America, Australia, and Polynesia, although the tribe can also be found as far south in Australia as northern New South Wales. Their variety and high frequency in Central Otago indicate a range of climates from moist, warm temperate to tropical conditions.

Striasyncolpites, a genus with a botanical affinity to *Liparophyllum* (Gentianaceae), or *Villarsia* (Menyanthaceae) is found in Roxburgh East. It is present in samples containing

cool-climate assemblages including abundant sedges, grasses, *menziesii* beech, composites, *Phyllocladus* and *Libocedrus*. Similar striate pollen grains are associated with cool-climate assemblages in Tasmania (M.K. Macphail, *pers. comm.*, 1985).

Anacolosidites luteoides (Fig. 3k), if *in situ*, represents pollen of *Anacolosa* (Olacaceae), a genus of African, Madagascan and Indomalayan distribution, and indicates warm temperate conditions.

Micrantheum spinyspora (Euphorbiaceae) (Fig. 3i) has been found occasionally at Kawarau River, Roxburgh East and Home Hills. *Micrantheum* is a small shrub found today on the east coast of Australia, in temperate South Australia, and in mainly sclerophyll vegetation in Tasmania (Martin, 1974). All Central Otago records are from temperate to warm temperate assemblages.

By drawing attention to just some of the several hundred taxa found in the Central Otago lignites, it can be seen that the early- to mid-Miocene climate fluctuated. It was generally moist and warm temperate, but with intervening cooler and drier phases. No indication of the frequency of the periods of drought can be made at this stage, because of the lack of suitable complete sedimentary sequences and the difficulty of precise correlation in the short sequences examined to date.

DISCUSSION AND CONCLUSIONS

The fluctuating climate and depositional environments of the Central Otago lignites imply variable rates of sedimentation and periodic erosion. In such an environment unconformities are difficult to detect unless there is a clear lithological difference or a change in the tectonic regime, *e.g.* tilting between deposition of separate sedimentary layers. Since the spore-pollen assemblages show pronounced differences between environments, they are also of little use in determining the presence of unconformities unless there is a marked age difference between them. For example, at Gimmerburn and Ranfurly, the tops of the sequences are apparently much younger than the basal parts of the same sequences. At Lowburn, the assemblages seem much younger than those to the east and west. However, no other physical evidence of clear unconformities has been found in Central Otago, where the sedimentation of the Manuherikia Group and the lower part at least of the overlying Maori Bottom Group appears to be essentially continuous.

Most of the Central Otago lignites are regarded as early Miocene (Altonian) in age, but little is known about the older Otaian Stage, which cannot be readily differentiated from Altonian. The younger middle Miocene stages, Clifdenian and Lillburnian, are also difficult to differentiate palynologically and, although both may be represented in Central Otago, a time range of Altonian-Clifdenian is accepted for the Central Otago lignites. The youngest sediments, at Lowburn, Ranfurly and Gimmerburn, appear to be of Late Miocene Taranaki Series age (*i.e.* Tongaporutuan or Kapitean stages). A widespread unconformity may separate the oldest and youngest sediments, or alternatively the interval may well be unsampled in areas where sedimentation was continuous.

Charcoal is found in a number of samples from Lowburn, Roxburgh East, Hawkdun, Home Hills, and Ranfurly. Fire appears to have been important at these localities, particularly in samples representing swampy environments. This may represent spontaneous combustion, common in blanket peats, as well as fire caused by lightning. The charcoal is occasionally quite abundant, particularly at Roxburgh East, Hawkdun and Home Hills, and is found predominantly in samples in which *Nothofagus* is the dominant pollen type. Gyrostemonaceae pollen is typical of samples containing charcoal at Home Hills and Hawkdun. There could be a positive correlation between the periodicities of aridity and of fire, although there were also mesophytic taxa in the same samples, which suggests that moisture was still freely available.

According to Kemp (1981), the development of grasslands and open woodlands with increasing aridity in the central Australian Miocene would have encouraged the increase in frequency of fires. The evidence for this aridity is an increase in grass pollen together with the increase or appearance of pollen of Compositae, Myrtaceae, especially *Eucalyptus*,

Acacia and possibly some species of *Casuarina*. These taxa are also prominent in the New Zealand Miocene. The apparent higher frequency of fires in the early to middle Miocene of Central Otago contrasts with the apparent lack of fires in the Oligocene to early Miocene of Southland. The two sets of coal measures may be separated by the low to higher fire frequency boundary postulated for Australia by Kemp (1981) and placed in the early Miocene.

The evidence for aridity in the Central Otago lignites contrasts with other evidence suggesting that moist, humid, warm temperate conditions existed for much of that time. Abundant *Botryococcus* and *Pediastrum* indicate that large, relatively permanent lakes must have been a feature of the Miocene Central Otago landscape, although desiccation cracks (Douglas, 1985b) indicate that the lakes were susceptible to drying up, at least at the margins. When it comes to trying to find evidence of aridity it has to be remembered that there is a bias towards preservation in wet environments (Kemp, 1981). Therefore, the meagre evidence for possible aridity in Central Otago, as, for example, the presence, frequency or abundance of pollen of Gyrostemonaceae, *Mallotus/Macaranga*, grasses, composites, *Acacia*, *Eucalyptus*, *etc.*, and charcoal associated with mesophytic taxa, probably indicates far greater development of arid grassland/shrubland than can ever be found in the fossil record.

In summary, the Central Otago lignites were deposited in a fluviatile/lacustrine environment under a climatic regime that was predominantly humid, moist and warm temperate but subject to periodic drought. The vegetation at the time of accumulation of the lignites was diverse and constantly changing, due to fluctuating climate, tectonic activity, constant alteration of sedimentary environments and soil parent material, and fires. The spore-pollen assemblages were derived from vegetation growing on a number of different fluviatile and lacustrine environments, as previously published by Douglas (1985a, b). From the presence of several stratigraphically important taxa, I conclude that the sediments young westwards; the oldest sediments are in the Gimmerburn area, and the youngest in the Lowburn area. It is also possible that there were breaks in the sedimentary sequences.

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