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FIELD TRIP 12

PALEOBOTANY, PALYNOLOGY AND SEDIMENTOLOGY OF LATE CRETACEOUS – MIOCENE SEQUENCES IN OTAGO AND SOUTHLAND

Friday 27 – Sunday 29 November 2009

Leaders: Daphne Lee, Jon Lindqvist, Dallas Mildenhall*, Jennifer Bannister, Uwe Kaulfuss

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Paleobotany, palynology and sedimentology of Late Cretaceous – Miocene sequences in Otago and Southland

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The aims of this field excursion are to examine a variety of fossiliferous, mostly nonmarine sedimentary sequences ranging in age from Late Cretaceous to Miocene, and to use the plant fossils and information from palynology to reconstruct the vegetation and paleoenvironments, including changing paleoclimates. Terrigenous and biogenic sediments include coal measures, silcrete, lake silts, estuarine sediments, shallow marine sandstone, and diatomite. Otago and Southland have some of the best-preserved plant macrofossils of Late Cretaceous, Oligocene, and Early Miocene age in Australasia. In addition to yielding information on floral richness and diversity, the associations of exceptionally well-preserved leaf compressions with intact cuticle, ferns with sporangia, flowers with pollen still on the anthers, resin and wood, together with estuarine and shallow marine beds make it possible to glimpse and reconstruct past ecosystems at selected intervals during the past 70 million years.

Fig. 1 View looking south of conglomerates, sandstones and coal seams in Late Cretaceous Taratu coal measures at Shag Point.

ITINERARY

Day 1. Friday 27th November: The trip will leave Oamaru as soon as the conference ends. It will include a brief visit to Late Eocene marine Oamaru Diatomite, followed by a stop at Shag Point (Late Cretaceous coal measures). We will then drive through the Shag Valley (Waihemo Fault System, Oligocene limestone, Miocene volcanics) to the Maniototo. Stay at Ranfurly.

Day 2. Saturday 28th November: Visit the Ida Valley coal mine and Early Miocene lake sediments and associated fauna and flora including leaf fossils and stromatolites near St Bathans, followed by lunch at St Bathans. We will then drive south to Roxburgh (Early Miocene coal measures), and then visit Late Oligocene Pomahaka Estuarine Beds and the Early Miocene Landslip Hill silcrete (both near Waikoikoi). Stay at Gore.

Day 3. Sunday 29th November: We will investigate two sites near Gore: a new rocky shore locality in the Late Oligocene Chatton Formation, and the Late Oligocene/Early Miocene Gore Lignite Measures at Newvale Mine, Waimumu. We will then make a brief stop at Gabriels Gully (Late Cretaceous Blue Spur Conglomerate), and travel, via Lake Mahinerangi, to Foulden Hills near Middlemarch to collect plant fossils from an Early Miocene diatomite deposit.

Participants will arrive back at Dunedin airport in time for late flights north, or they can stay overnight in Middlemarch or Dunedin.

Day 1. Friday 27th November

Stop 1 Taratu Formation, Shag Point

Day 2. Saturday 28th November

Stop 2 Idaburn lignite mine, Manuherikia Group

Stop 3 Alluvial and lacustrine beds, Manuherikia River, Manuherikia Group

Stop 4 Alluvial beds, St Bathans, Manuherikia Group

Stop 5 Harliwich's Pit, Manuherikia Group

Stop 6 Waikoikoi Stream, Pomahaka Formation

Stop 7 Landslip Hill silcrete, Gore Lignite Measures

Day 3. Sunday 29th November

Stop 8 Cosy Dell pit, Chatton Formation

Stop 9 Newvale lignite mine, Waimumu, Gore Lignite Measures

Stop 10 Gabriels Gully, Lawrence, Blue Spur Conglomerate

Stop 11 Middlemarch, Foulden Hills Diatomite

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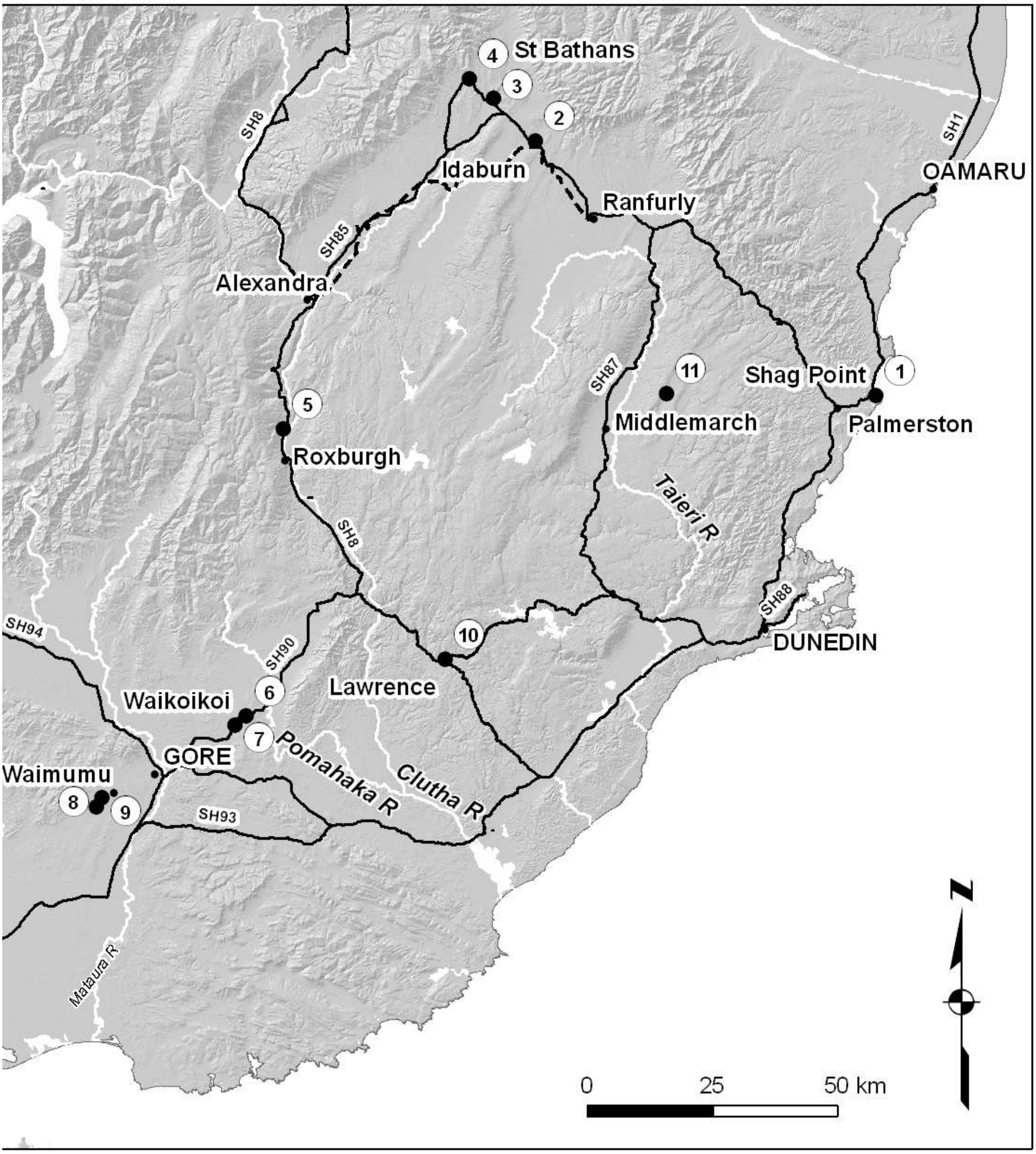

Fig. 2 Route map

Stop 1. Taratu, Herbert and Katiki Formations, Shag Point

At Shag Point the Taratu Formation beds form an anticlinal basin-inversion structure. The southern limb of this structure is downwarped against a branch of the northwest-trending Waihemo Fault System along which offset was probably normal, down to the north during Mid Cretaceous to early Paleocene extension. The northern shore of Shag Point is parallel to structural strike. Beds exposed along the southern Katiki Beach foreshore below the SH1-Shag Point road intersection form a gently plunging syncline and further north resume a regional strike, dipping to the northeast at about 5°.

Alluvial sediments at Shag Point are of Piripauan to Haumurian age (Late Cretaceous). Inland, the contact with underlying Horse Range Formation is marked at Pukehiwitahi (between Horse Range Road and SH1) by an increase in the ratio of quartz to greywacke + schist clasts from 1:10 to approximately 2:1 at the top of the exposure (Douglas 1970).

Taratu Formation exposed on the south and east shores of Shag Point (Fig. 1) consists of conglomerate-sandstone-mudstone-coal cycles. Immediately east of the road-end vehicle park, muddy sandstone overlying quartzose conglomerate displays large-scale inclined bedding characteristic of meandering channel point-bar accretion (Figs 3 & 4). Bituminous coals from the Shag Point area contain ~2 % sulphur and 5~10% ash. Six significant seams or seam groups have been logged in a 185 m prospecting shaft (Fig. 5). According to Mutch (1975) coal production from Shag Point mines started in 1848 and amounted to approximately 2 million tonnes.

Coal measures in the Taratu Formation at Shag Point are the type locality for several fossil plants described by Ettingshausen in 1887, although Sir James Hector in the 1870's was the first to illustrate fossil leaves from Shag Point in a series of unpublished lithographic plates on which the fossils were named, names that subsequently entered the literature (Mildenhall 1970). Ettingshausen thought the locality was Eocene, and attributed the plants to a wide variety of taxa including *Sequoia, Acer, Alnus, Ficus, Quercus, Fagus* and *Eucalyptus* (Pocknall & Tremain 1988) thus reinforcing his already outmoded theory of an identical Cretaceo-Tertiary world wide flora. Pole (1992, 1995) considered the Shag Point plant beds to be Campanian in age, and (re)described various gymnosperms, including araucarians, and angiosperms including *Nothofagus,* from the locality.

Characteristic Late Cretaceous palynomorphs from Shag Point include *Phyllocladidites mawsonii* (Cookson), *Microcachryidites antarcticus* Cookson, *Trichotomosulcites subgranulatus* Couper, *Nothofagidites kaitangata* (Te Punga) Romero and '*Tricolpites lilliei'* Couper, and it is the type locality for species described by Couper (1953, 1960) including *Podocarpidites otagoensis, Dacrydium microsaccatum* (= *T. subgranulatus*) and *Triorites fragilis* (Pocknall & Tremain 1988). The pollen assemblages fall into the mainly Maastrichtian Haumurian Stage and *Phyllocladidites mawsonii* Assemblage PM2 Zone of Raine (1984).

The Taratu coals and associated river deposits extend far offshore beneath the Great South Basin and are source rocks for oil and natural gas. It seems surprising to discover evidence of extensive forests at this time when the region was situated close to the South Pole (probably at a latitude of 70^{o}S). However, there was no ice on Antarctica around 70 Ma, the global climate was warm, and higher CO^2 levels may have enabled these forests to grow at much higher latitudes than today.

At Boat Harbour near the northeast extremity of Shag Point, Taratu Formation is overlain by marine beds. A 50 cm thick transgressive conglomerate lag is overlain by burrow-mottled fine-medium sandstone of Herbert Formation. Herbert Formation is overlain by bioturbated very-fine silty sand and siltstone of Katiki Formation which includes presumed estuarine sediments and possibly more-fully marine strata (massive, carbonaceous, bioturbated, slightly calcareous siltstones) that have produced plesiosaurs and mosasaurs. One relatively complete plesiosaur is the holotype and only known specimen of *Kaiwhekea katiki* (Cruickshank & Fordyce 2002).

For the Katiki Formation, the absence of calcareous foraminifera and ammonites suggests a setting with restricted access to the open sea, perhaps a sheltered embayment or an estuary floored with soft, soupy, oxygen-poor muds. Trace fossils, such as the branched *Thalassinoides* (shrimp burrow), *Teichichnus*, *Planolites*, and clusters of agglutinated foraminifera are abundant. Wood occurs frequently. Rare molluscs from sandier horizons include often-decalcified gastropods and bivalves and a few examples of the age-diagnostic belemnite *Dimitobelus*. These invertebrates indicate an age of Haumurian Stage, or latest Cretaceous.

Toward the north end of Katiki Beach, the Katiki Formation is overlain by Otepopo Greensand, which has long been viewed as probably Paleocene, but has recently produced at least one specimen of the Haumurian ammonite *Kossmaticeras bensoni*.

The Last-Interglacial Quaternary terrace succession at the road-end of Shag Point includes a spectacular bed of imbricate conglomerate blocks that Kennedy et al. (2007) interpret as a tsunami deposit (Fig 3 & 4).

Fig. 3 Late Cretaceous Taratu Formation and Quaternary terrace deposits exposed near the road-end car park, Shag Point. Photo JK Lindqvist.

Fig. 4 Shag Point road-end exposure. Kennedy et al. (2007) interpret imbricate conglomerate blocks overlying Taratu Formation siltstone and mudstone as a Last-Interglacial (Isotope Stage 5) tsunami deposit. A 20 cm high notebook, centre of view, shows scale. Photo JK Lindqvist.

Driving south from Shag Point we cross the Waihemo Fault System, a series of NE-dipping faults running NW-SE along the Shag River valley, across which the Kakanui Mountains and Horse Range have been compressed and uplifted. While the north eastern side of the fault system is now upthrown relative to the southwest, several lines of evidence suggest that, formerly, in the Late Cretaceous, the north eastern side was downthrown relative to the southwest. This is an example of tectonic inversion, where the sense of throw across the fault system has changed with time.

Just before crossing the Shag River, note steeply dipping Late Cretaceous sediments on the upper slopes of Pukehiwitai in the Horse Range. The classic 1892 report by geologist Alexander McKay entitled "*ON THE PROSPECTS OF FINDING COAL ON ROWLEY'S FARM, NEAR SHAG POINT RAILWAY STATION*" described the geology of this area. The legend goes that parliamentarians had complained that the reports of the Geological Survey were "too technical and of little use to the 'practical colonists' of New Zealand." In this report McKay replaced the geological jargon with commonplace terms and analogues: "*Synclines are of various kinds, regular and irregular, and so are onions, especially shalot onions; and there is hardly any kind of syncline that may not be illustrated by some kind of onion....*"

Puketapu, the hill to the east of Palmerston, is capped with Miocene volcanics overlying the Late Cretaceous to Tertiary sedimentary succession. The summit monument commemorates Sir John McKenzie (1839-1901), Minister of Lands in the 1890s who legislated for the breakup of the vast early land-holdings to provide farms for the expanding population, based in part on his experience of the infamous Highland Clearances forced by the landed proprietors of his native Scotland.

From Palmerston, we follow the Shag River inland, past Dunback and the turnoff to the large gold mine at Macraes, and take the winding Pigroot along the foothills of the Kakanui Range through to the Maniototo. Stop at Ranfurly for the night.

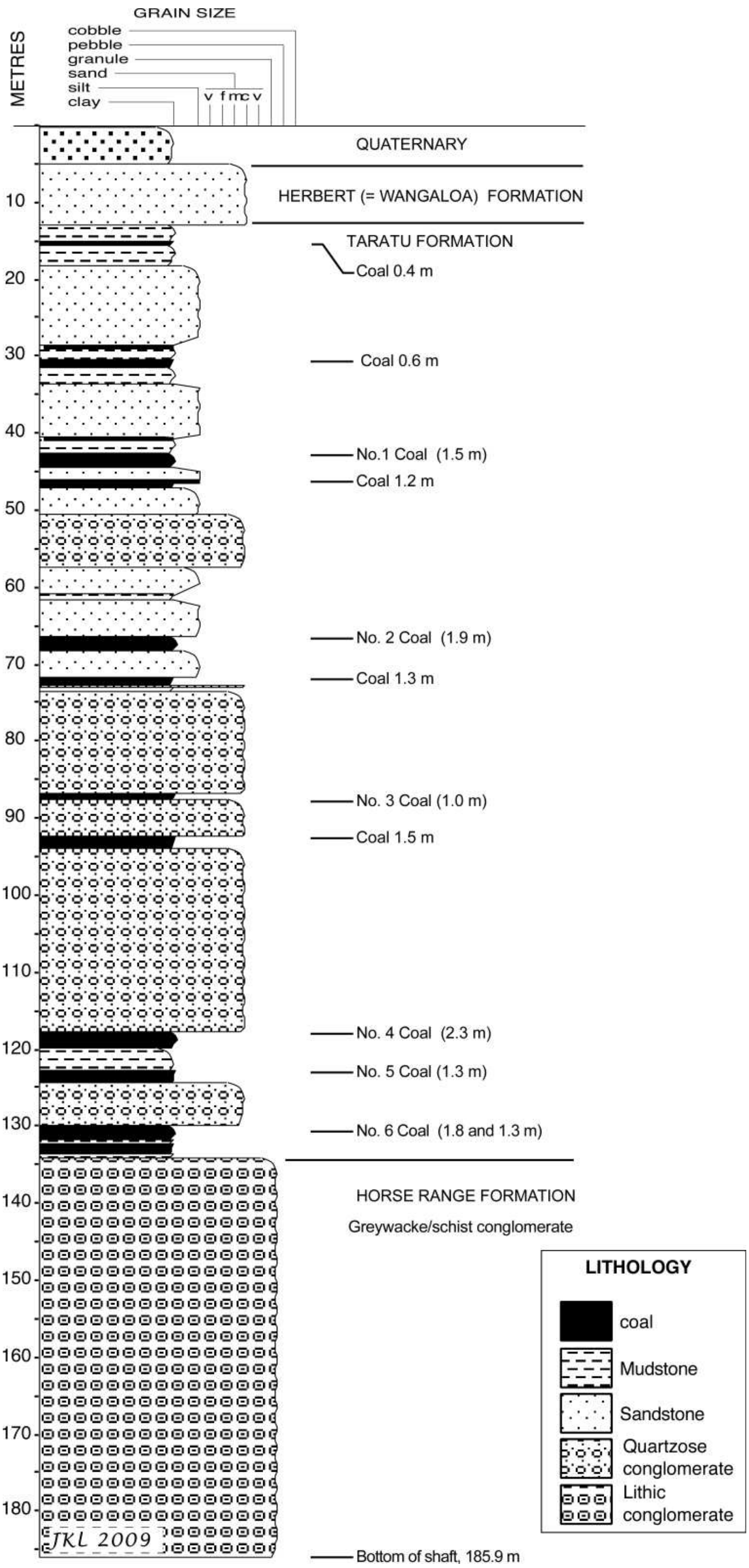

Fig. 5 Distribution and thickness of coal beds in the Queen Shaft, Shag Point (from data compiled by A.R. Mutch (unpublished).

Day 2. Ranfurly to Gore

We will be crossing three major river catchments of southern New Zealand – from the Taieri catchment in the Maniototo, to the Clutha, with its tributaries of the Manuherikia and Pomahaka, and finally the Mataura (Fig. 2). The trip takes us from Ranfurly through to the historic gold mining township of St Bathans, and then will head south to Alexandra criss-crossing the Middlemarch-Clyde Rail Trail.

From Ranfurly to south of Roxburgh, 'Central' is dominated by tor-studded landscapes formed in schist basement. Originally greywackes and argillites deposited in Permian-Triassic times in ocean basins and trenches off Gondwana, these rocks were metamorphosed into Otago Schist during the Jurassic. By the early Cretaceous, about 110 million years ago, the once deeply buried schist had been uplifted and eroded down to a low relief erosion surface ('peneplain') over most of Otago. The Otago Peneplain represents a gap of >60 million years in the rock record and the more-or-less flat topped, tor-studded mountains such as the Rock and Pillar Range, Dunstan and Old Man Range are remnants of this widespread erosion surface.

By the Early Miocene (23 to 20 million years ago), a plate boundary had developed through New Zealand. This led to uplift and a gradual increase in the New Zealand land area. Large braided rivers and eventually a vast inland lake system covered most of the Central Otago region (Fig. 6). The sediments deposited by these rivers and lakes are collectively termed the Manuherikia Group (Douglas 1986). Now preserved in several Central Otago NNE-trending thrust-fault controlled half graben, and as erosional remnants on schist horsts, Manuherikia Group typically comprises a basal succession of alluvial conglomerate, sandstone, mudstone and lignite (Dunstan Formation) overlain by palustrine and lacustrine sediments (Bannockburn Formation) comprising illitic mudstone and shale, along with thin sand and biogenic carbonate beds.

Although Dunstan Formation lignites are widespread in Central Otago, they are surprisingly hard to find. Often the best indications of the dozens of former coal workings are signposts for 'Coalpit Road' or 'Coal Creek'. Currently, the only active lignite mine is Harliwich's Pit (Stop 5) where opencast lignite is mined for local use.

The younger Bannockburn Formation sediments were deposited in the vast paleolake Manuherikia which at its maximum covered an area of about 5000 km^2 (more than the combined area of all modern New Zealand lakes). Up to 700 m of sediments accumulated in and around this lake basin, which, although fairly shallow, must have been slowly subsiding in order to hold the fine sands and muds carried in by meandering rivers. Fine-grained, white or pale brown lake sediments are well exposed in gold diggings and in road cuts St Bathans, in and around the rail trail in the Manuherikia valley, and elsewhere. Sometimes, as in road cuttings near the Roxburgh Hydro Dam, they are brick-coloured from 'baking' by burning lignite.

At the time of Lake Manuherikia, the Central Otago landscape was subdued with low hills. But about 15 million years ago, after the Australian-Pacific plate boundary had developed through New Zealand, the landscape began to change. New Zealand's land area began to increase, the sea retreated, and eventually tectonic uplift resulted in vast quantities of greywacke-derived gravels from the north and schist-derived gravels from the south and west filling in the lake. Often the Miocene lake sediments are tilted and deformed, with younger undeformed, flat-lying gravels lying unconformably above them, as seen near St Bathans.

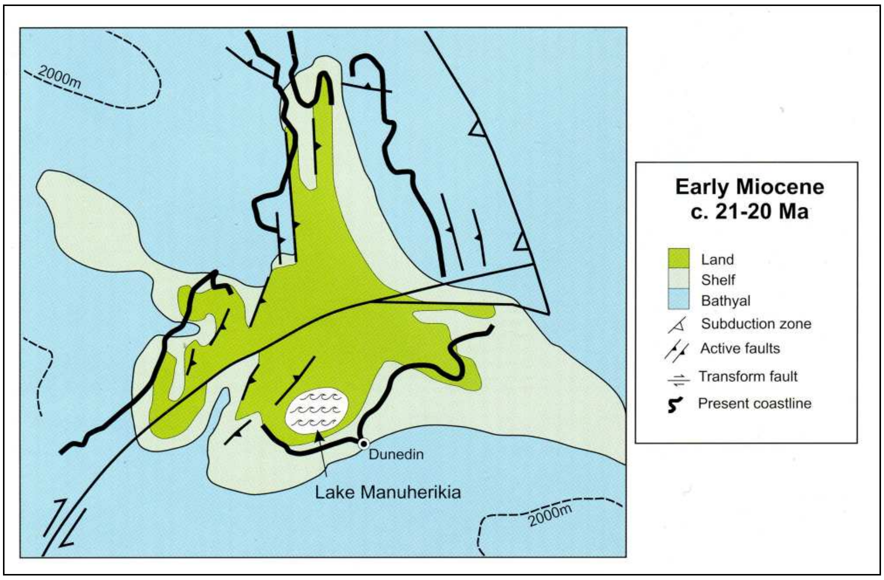

Fig. 6 Paleogeographic map of New Zealand in the early Miocene, showing the position of Lake Manuherikia. (Modified after Peter King).

Stop 2. Idaburn coal mine, Idaburn

This open cast mine was formerly operated by the Idaburn Coal Mining Company Limited. Here a lignite seam with well-preserved conifer wood is exposed in a pit wall.

Fig. 7 The opencast pit at Idaburn, with well-preserved conifer branches. Photos Beth Fox.

Stop 3. Manuherikia Group upstream of Manuherikia River bridge, Loop Road

Immediately north of Manuherikia River Bridge, a 300 m thick, south-dipping succession of alluvial plain and lacustrine sediments of the Dunstan and Bannockburn Formations is exposed (Fig. 8). The lower alluvial succession consists of quartz pebble and granule conglomerate, quartzose sandstone, and silty mudstone beds from 1-6 m thick. The white to pale greenish grey silty mudstone paleosol beds are markedly homogeneous, containing abundant 2-4 mm diameter and 5-15 cm deep mud-filled rootlet casts. At the top of the coarse grained alluvial succession is a fine-grained association of woody lignite, root-mottled carbonaceous mudstone, silty fine sand (commonly rootlet penetrated), micaceous lignitic shale, and greenish grey claystone. The claystone facies contains fish vertebrae, spines, and teeth. This assemblage forms a transition with overlying palustrine and lacustrine beds, and its component facies represent forested peat swamp (woody lignite), floodplain lake - open bay (laminated shale, fish bone-bearing claystone) and probable distributary splay (laminated silty sand) deposition.

Overlying the topmost lignite-bearing part of Dunstan Formation, the lower 8.8 m of Bannockburn Formation consists of fine silty sandstone, green claystone, calcareous mudstone and marl (Fig. 9). Fine-grained sandstones locally include quartz granules (<15 mm) and granules, marl pebbles, and fish vertebra and spines. Unionid bivalves (*Hyridella*), ostracods, tubular microbial carbonate and stromatolitic carbonate grains are locally present. Rare 8-10 mm diameter trace fossils of possible crustacean origin display inverted-Y junctions. Distinctive fine-grained cream - pale greenish grey marls and calcareous mudstones up to 40 cm thick contain 1-3 mm diameter branching rootlet casts, infilled with green clay. Marl beds intensely disrupted by plant root, animal burrowing, or desiccation brecciation are preserved as weakly-cemented nodules enclosed by mottled greenish grey clay. The micritic carbonate is thought to have been precipitated during the photosynthetic activities of cyanobacteria, charophytes and other aquatic plants in a lake margin (carbonate marsh) setting prone to seasonal flooding and desiccation. Interbedded green claystones containing abundant root traces probably represent shallow lake deposition within the zone of nearshore plant growth. The interbedded nature of these two facies indicates a rapidly oscillating shoreline. Associated sandstones, and intraformational rounded marl pebble and shelly bases to some sands, are interpreted as storm wave-sorted deposits.

The upper part of the lacustrine association is dominated by greyish green mudstone and laminated shale (Fig. 10) with subordinate silty mudstone, and shelly and microbial carbonate beds. Blocky weathering green mudstones contain abundant 1-2 mm wide vertical rootlet-like. Hyriid bivalve moulds and rarer shelly, locally paired, inflated valves are present. The green mudstone supported abundant aquatic plants and is interpreted as a nearshore facies, as in the palustrine association. Thin sharp-based shelly lags contain fish and bird bones, together with mollusc shell and algal carbonate fragments. Local concentrations of carbonate sand are composed of ostracods or gastropods, including sinistrally coiled (opening on the left) *Physa* sp. (Fig. 11A). Thin developments of stromatolites associated with carbonate sands (Fig. 11B) and composed of laminated microcrystalline calcite, are comparable with various forms described from other Manuherikia Valley localities (Lindqvist 1994).

Laminated shales, very dark grey - greenish grey when freshly exposed, contain fine organic matter and abundant mica flakes. Scattered fish vertebra, spines, and scales are commonly preserved, as are compressed hyriid bivalve moulds. Incomplete articulated fish specimens have been collected (McDowall et al. 2006). The shale beds, typically grading upward into green mudstone, are interpreted to have been deposited in the deeper lacustrine profundal zone, perhaps during times of higher lake levels and increased input of mica-rich sediment from tributary rivers.

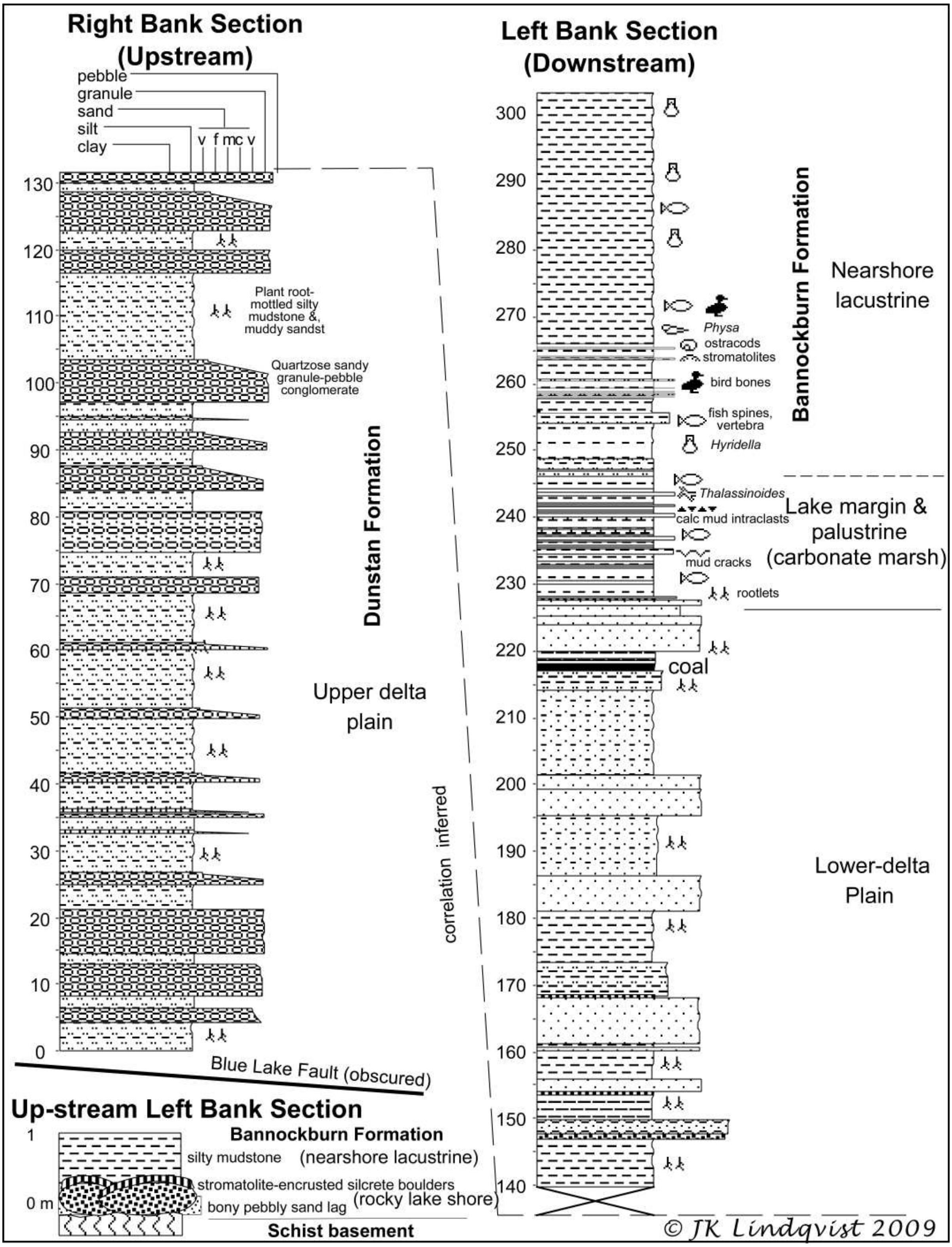

Fig. 8 Stratigraphic sections recorded upstream of Manuherikia River Bridge, St. Bathans Road.

Fig. 9 Paleobotanists Ian Raine and Liz Kennedy examining the lacustrine section above the Manuherikia Bridge. Photo DE Lee.

Fig. 10 Interbedded brownish grey shale and green mudstone in the Bannockburn Formation lacustrine section near Manuherikia River bridge. Rock hammer for scale, lower left. Photo JK Lindqvist.

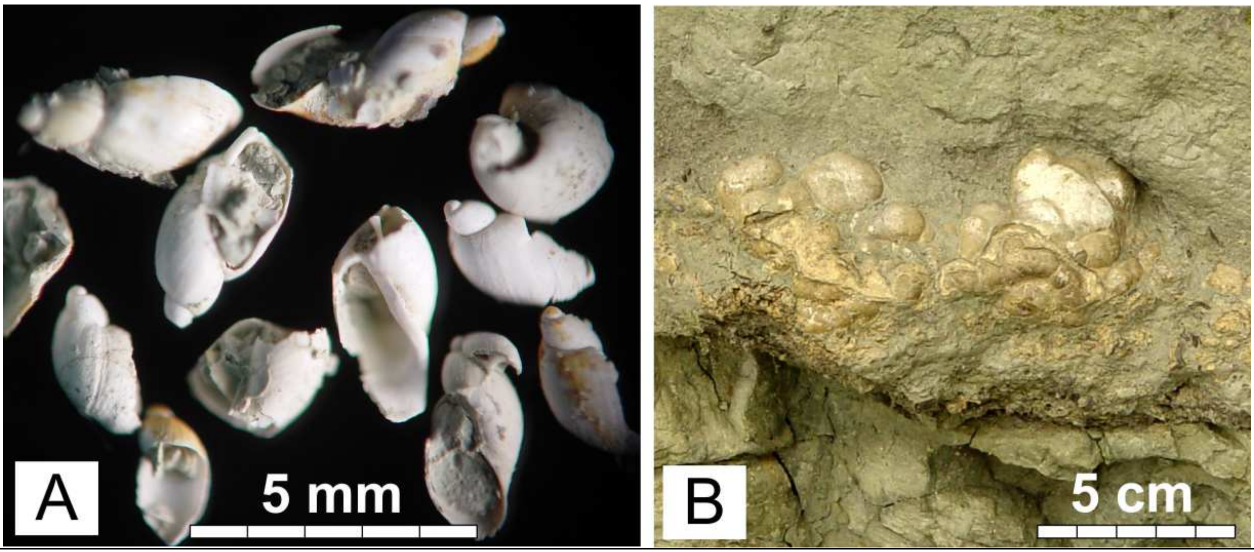

Fig. 11 A. Small sinistrally coiled freshwater gastropods (*Physa sp*.) from a 2-3 cm thick muddy shellbed. B. Stromatolite bioherm associated with laminated ostracod-rich carbonate sand. Photos JK Lindqvist.

Several outcrop samples examined for palynological age determination by DCM in 2008 contain a number of taxa not known to be either older than Altonian or younger than Clifdenian (e.g. *Haloragacidites amolosus* Partridge, *Latrobosporites marginis* Mildenhall & Pocknall , *Lymingtonia cenozoica* Pocknall & Mildenhall, *Rhoipites hekelii* Mildenhall & Pocknall). They indicate that these beds are in the *Spinitricolpites latispinosus* Zone (Crundwell *et al* in Cooper 2004) and are of Altonian-Clifdenian age.

All fossiliferous samples include an abundance of Casuarinaceae pollen, with a variety of *Nothofagus* pollen types (mainly *Fuscospora* and *Brassospor*a) increasing in abundance up sequence (cooler and wetter?). Podocarpaceae including *Dacrydium cupressinum, Dacrycarpus dacrydioides*, *Microcachrys*, *Phyllocladus* and *Lagarostrobos franklinii*, Araucariaceae, Asteraceae, Myrtaceae, Polypodiaceae, *Milfordia homeopunctata* (McIntyre) (Restionaceae) and various unidentified tricolporate pollen types are also common. The lake sediments are dominated by the freshwater colonial algae *Botryococcus* and *Pediastrum*. The pollen assemblage appears to be derived from a mixed beech/podocarp forest with she-oaks possibly flanking the depositional site. A site such as this fringing a large lake would result in much regional pollen being captured and so beech and probably other pollen may be derived from some distance.

The first fossil crocodile from New Zealand is a fragment of jaw collected by Mike Pole from near here (Molnar & Pole 1997; Pole et al. 2003). The bone is probably from an extinct group of mekosuchine crocodiles first recognised in Australia, and now known from other SW Pacific localities as well as New Zealand.

A team led by Trevor Worthy has been excavating near St Bathans since 2001. Their research is providing new insights into the terrestrial vertebrate fauna of New Zealand, especially birds and reptiles (Worthy et al. 2006). To date, they have reported 25 species of birds, including 5 genera of anatids, “making it the most diverse Neogene ‘duck’ fauna known worldwide” (Worthy et al.

2006: 36). Other birds include a diving petrel, a gull, small waders, a possible flamingo, a pelican, several rails, an eagle, a pigeon, and several parrots (Worthy et al. 2007; Worthy et al. 2008). Thick eggshell is most likely that of moa, although no moa bones have yet been discovered.
Other bones indicate the presence of frogs, and diverse skinks and geckos (Lee et al. 2009), as well as the first pre-Quaternary record of tuatara (Jones et al. 2009). The fauna also includes the first record of a small terrestrial mammal (Worthy et al. 2006b), as well as several species of bats.

Stop 4. Alluvial beds, St Bathans, Manuherikia Group

Blue Lake, at the foot of Mt St Bathans, is an important historical gold mining area, and unusual in that gold was mined here in an area of greywacke, rather than schist basement. Early Miocene erosion of schist hills further to the south produced quartz-rich river sediments which were transported northeast with their associated gold and deposited on greywacke bedrock in the St Bathans area. Carbonaceous mudstone interbedded with the quartz gravels can be disaggregated to reveal small conifer shoots and leaves (Pole 1997), ferns, numerous seeds and angiosperm leaf fragments. Some blocks have produced well-preserved angiosperm leaves including Lauraceae, Myrtaceae, and Elaeocarpaceae. A range of epiphyllous fungi have been found on some leaves, including a new spiny microthyriaceous cyst.

Fig. 12 Blue Lake at St Bathans infills a 70 metre deep hole left by removal of the 120 m high Kildare Hill by gold mining operations. Photo DE Lee.

Stop 5. Harliwich's Mine, Coal Creek, Roxburgh

The thickest lignite seam in the Central Otago region occurs in the East Roxburgh coalfield, and varies from 33-85 m thick (Douglas 1986). It is currently mined at the open cast Harliwich's Pit where the seam reaches 45 m. Resin, and woody stems and logs up to 6 m long, some in growth position, are locally abundant. According to Douglas (1986: 255), the McPherson Seam "represents deposits of a long-lived, peat-forming swamp that accumulated on the upper part of the Teviot delta plain."

Palynological samples from the East Roxburgh coalfield are dominated by Podocarpaceae (one sample), Myrtaceae or *Nothofagus* pollen. The Nothofagaceae include representatives of the *Fuscospora* group (*Nothofagidites lachlaniae*), *Lophozonia* group (*N. asperus*), and *Brassospora* group (*N. cranwelliae*). The Myrtaceae include forms resembling *Acmena*, *Metrosideros*, *Leptospermum* and *Eucalyptus*. Other common taxa include A*recipites otagoensis* (Couper), *Haloragacidites harrisii* (Couper), *Podocarpidites*, Palmae and Loranthaceae (Mildenhall & Pocknall 1989). Pteridophyte spores are rare. The spore-pollen assemblages were derived from a forest growing under humid, warm temperate conditions. However, occasional periods of drought and fire are suggested by the presence of charcoal, Gyrostemonaceae (*Gyropollis psilatus* Mildenhall & Pocknall) and *Mallotus*-*Macaranga* (*Nyssapollenites endobalteus* (McIntyre) pollen and periods of cooler climate when *Fuscospora* dominate and Podocarpaceae. The age is likely to be Altonian (Early Miocene), based on the occurrence of *Anisotricolporites truncatus* Pocknall & Mildenhall and *Acaciapollenites miocenicus* Mildenhall & Pocknall (Mildenhall & Pocknall 1989) and all samples fall into the *Spinitricolpites latispinosus* Zone. The only leaf macrofossils recognised from the locality are large fronds that resemble nikau (*Rhopalostylis*) from baked mudstones associated with the lignite and *Eucalyptus*-like leaves (Holden 1983).

This is the only currently working coal mine remaining out of many dozens that once operated in Central Otago.

Fig. 13 At Harliwich's Pit, a thick, gently dipping seam of lignite is exposed beneath white quartz sands. Photo DE Lee.

Stop 6. Pomahaka Formation, Waikoikoi Creek

Many New Zealand Cretaceous and Tertiary coal-bearing formations accumulated in coastal plain settings but few examples of significant peat development closely associated with shelly marine or brackish-marine facies have been documented. Remnants of fine-grained embayment facies containing inferred shallow-marine trace fossil associations occur in Brunner Formation, north Westland, the Waikato Coal Measures, and the transition zone between Taratu and Wangaloa formations, Kaitangata Coalfield. Fluvial-channel incision during sea-level fall and wave-erosion during marine transgression tend to obliterate shallow marine facies. Since high energy shoreface sandstones commonly overlie New Zealand coal-bearing formations (e.g. Island Sandstone overlying Brunner Coal Measures, and Wangaloa Formation overlying Taratu Formation in Kaitangata Coalfield) it is not surprising that estuarine successions are rare.

Pomahaka Formation, a ~30 m thick assemblage of shallow marine and freshwater swamp deposits, is the basal unit of the Late Oligocene-Miocene East Southland Group (Isaac & Lindqvist 1990). It is inferred to have accumulated in a tidal interdistributary bay setting. As well as providing an example of coal accumulation in a coastal marsh environment, Pomahaka Formation contains an important record of New Zealand's brackish water mollusc fauna (e.g. Beu & Maxwell 1990).

Formerly well exposed following Waikoikoi Stream realignment in the late 1970's, Pomahaka Formation is overlain by a channelised coarse grained sand silty clay succession that marks the onset of Gore Lignite Measures deposition and southward progradation of the East Southland coastal delta system. Small isolated flat-lying exposures of Pomahaka Formation have been mapped in the banks and bed of Pomahaka River to the north and east (Isaac & Lindqvist 1990, Wood 1956). Pomahaka Formation is exposed in the steeply dipping limbs of an antiformal decollement in the toe of Charters Road slump (Fig. 14). The beds strike consistently WNW-ESE and dips on each limb range from 35^0 to slightly overturned.

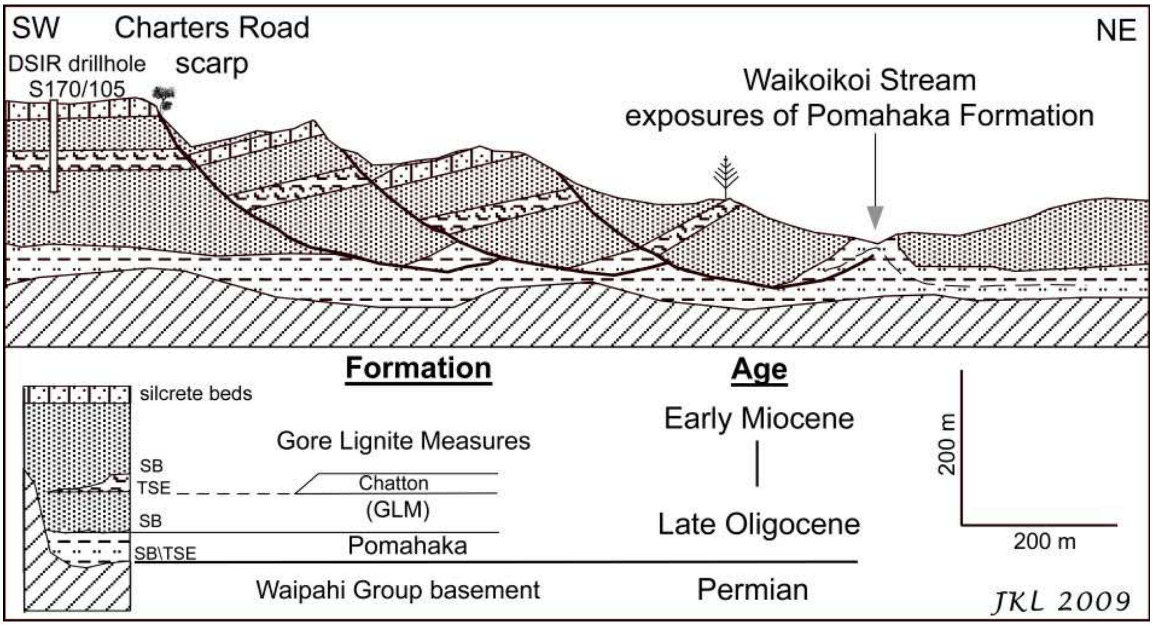

Fig. 14 Waikoikoi Valley cross section.

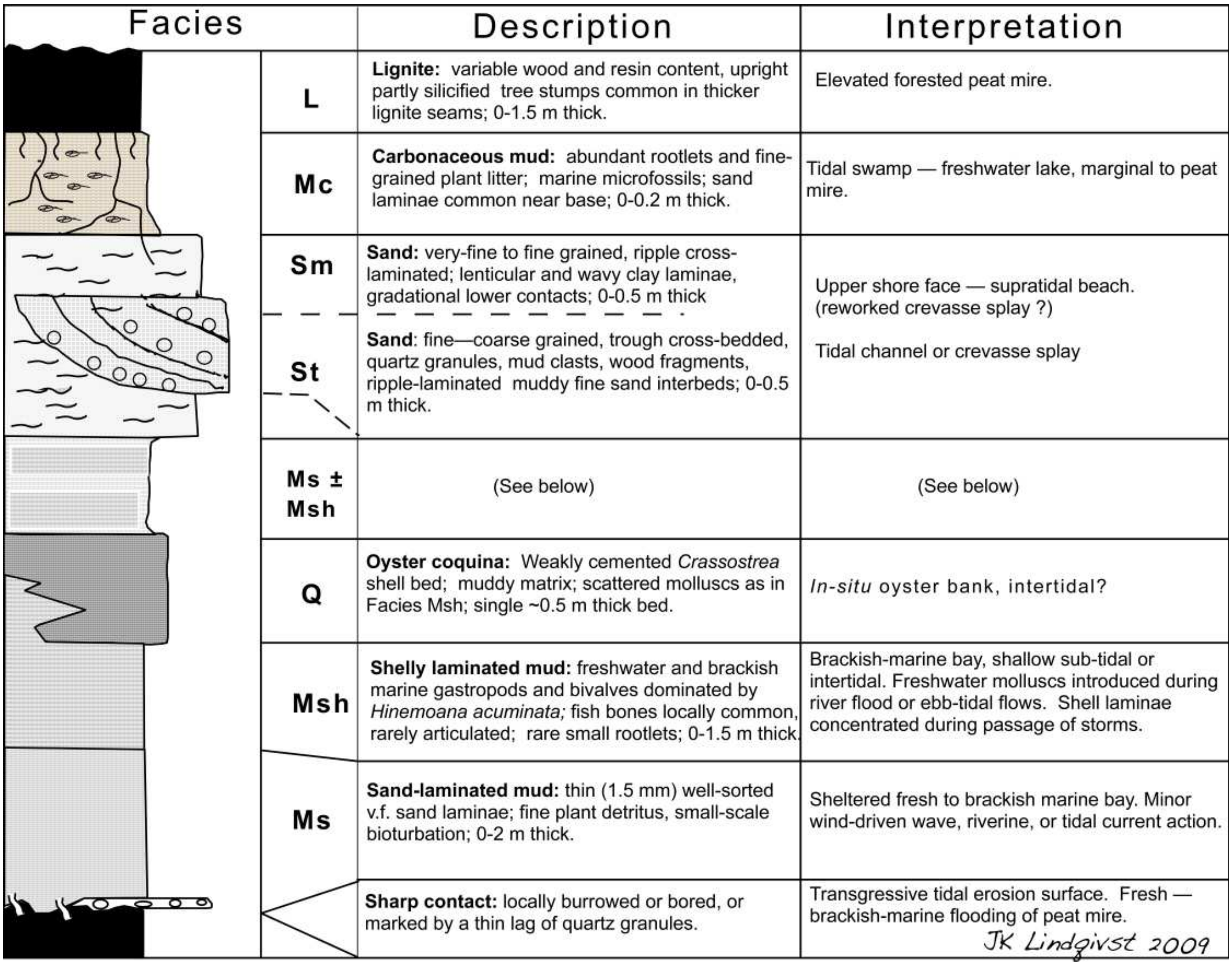

Fig. 15 An 'ideal' Pomahaka Formation facies sequence based on Waikoikoi Stream exposures (after Isaac & Lindqvist 1990).

The estuarine beds near Pomahaka were originally collected by James Hector in 1866. Wood (1956) probably collected a fauna from Hector's original Pomahaka River locality near the junction with Oyster Creek and used the term *Pomahaka Estuarine Bed* for 60 cm of shelly clay that he regarded as a lateral (east) equivalent of Chatton Formation. More recently Isaac & Lindqvist (1990) summarised the stratigraphic setting and sedimentology of Pomahaka Formation. Beu & Maxwell (1990) reaffirmed its Late Oligocene age (late Whaingaroan or Duntroonian Stage).

In exposures in the Pomahaka River, the Pomakaka Formation contains *in situ* tree stumps, resin, leaves with cuticle, concretions with crustaceans, and estuarine shellbeds (Euan Rodway pers. comm.). One large block of well-preserved silicified wood is araucarian, although wood anatomy alone cannot distinguish between *Agathis* and *Araucaria*.

Pocknall (1982) noted that the dominant *brassi* beech pollen component in the Pomahaka Formation is *Nothofagidites matauraensis*, whereas *N. cranwelliae* is generally the more abundant in Chatton Formation and Gore Lignite Measures. The pollen and spores from Pomahaka include a number of unusual species, and/or the first record of important elements in the modern New Zealand flora. One group of assemblages is dominated by *brassi* beech pollen, with common gymnosperms (Araucariaceae and Podocarpaceae), *Casuarinaceae*, and *Gunnera*. Pomahaka has the earliest record of the warmth-loving *Caesalpinia* and *Scaevola*, the latter now found only on the Kermadecs in the New Zealand region. According to Pocknall (1982), warmth-demanding taxa grew in specialised coastal habitats, while other species, adapted to damp conditions, grew on marshes away from tidal influence.

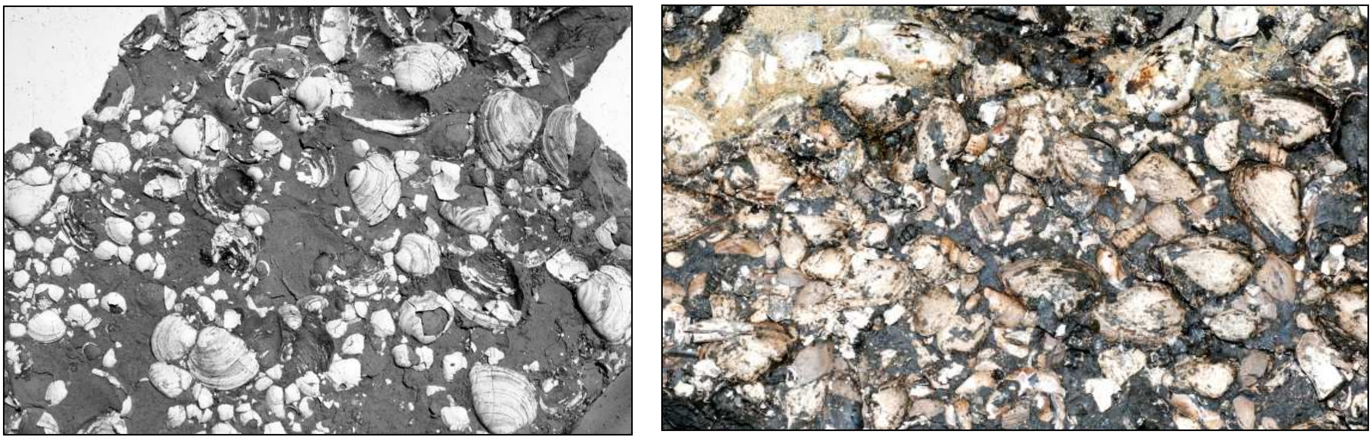

Fig. 16 Pomahaka Formation shell layers from Waikoikoi Stream (left) consisting mainly of current-oriented single valves of *Hinemoana acuminata*, and Pomahaka River (right), consisting of corbulids. The small intertidal gastropod *Batillona* is present in both. Photos JK Lindqvist and JG Conran.

Stop 7. Landslip Hill silcrete, Charters Road, Gore Lignite Measures

Silica-cemented quartzose sandstone and conglomerate forming resistant hilltop exposures and boulder accumulations at Landslip Hill are part of the Gore Lignite Measures. Holden (1984) suggested, on the basis of scanning electron microscope examinations of plant fossils and enclosing sandstones, that the Landslip Hill Beds were cemented soon after burial and therefore classifiable as silcrete deposits. Silcrete has been defined as '*a silica-indurated product of surface and near-surface diagenesis*.'

The silcrete is subhorizontally bedded, persists along strike for 2-3 km in the Charters Road scarp (Figs. 14 & 17) and at Landslip Hill to the south, and may form part of a single alluvial channel belt (Lindqvist 1990). It is underlain by uncemented sandstone, mudstone, and thin lignite. Exposures of leached sandy shellbeds belonging to Chatton Formation have been recorded in slump blocks on the lower slopes south of Waikoikoi Stream. Pomahaka Formation at the base of the exposed succession consists of thinly interbedded lignite, mudstone, sandstone and shellbeds (see Stop 7).

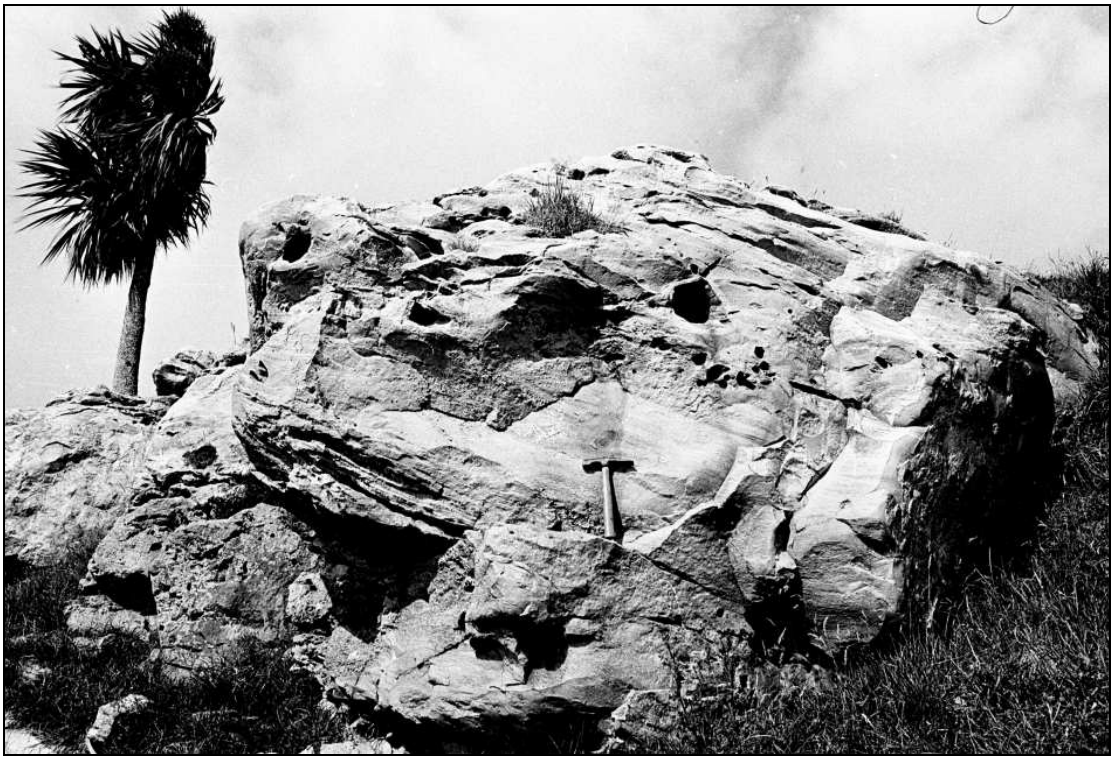

Fig. 17 Silica-cemented sandstone and conglomerate exposed on the west margin of Charters Road scarp. Large holes are moulds of transported tree trunks. (From Lindqvist 1990).

Lindqvist (1990) described five sedimentary facies: pebble conglomerate; trough cross-stratified coarse grained sandstone, planar and ripple laminated fine-medium grained sandstone, mottled sandstone pervaded by root structures, and silicified mudstone intraclast conglomerate from the Charters Road and Landslip Hill exposures.

Conglomerates consist of small pebbles and granules of mostly polycrystalline schistose quartz set in a matrix of fine-medium grained monocrystalline quartz sand. Breakage commonly occurs through, rather than around, individual quartz pebbles. Sand matrix is commonly cemented by aggregates of 1-15 µm wide quartz crystals oriented subnormal to the grain surfaces. In places the matrix is almost completely cemented by clear euhedral overgrowths that contrast with the 'dusty' appearance of detrital grains. Sandstones show various degrees of 'apparent' intergranular pressure solution at grain contacts which is difficult to reconcile with the moderate depth of burial (less than about 600 m) indicated by the lignite coal rank.

Plant fossils including leaves, fruit and wood have been collected from the outcrops and loose blocks of Landslip Hill silcrete since at least 1862, when James Hector was director of the Geological Survey of Otago. Hector collected further material in 1869, and commissioned James Park to acquire more specimens in 1886 (Campbell & Holden 1984). Many further collections have been made, several by amateur collectors, and material is housed in the Geology Department, University of Otago, at the Otago Museum, and elsewhere in New Zealand.

The plant remains include uncompressed three dimensional logs, stems, roots and rootlets, and a variety of fruits, some of which can be assigned to modern New Zealand taxa, and others which are no longer present in the local flora (Holden 1983). In his final publication (Campbell 2002), Doug Campbell described and illustrated several examples of fruit and 2-dimensional leaves from Landslip hill. These include fruit closely resembling dried drupes of *Corynocarpus* (karaka), and the modern New Zealand mangrove, *Avicennia*. In the same paper, leaves attributed to *Pomaderris*, *Nothofagus*, and *Pouteria* were figured.

Campbell & Holden (1984) described "cones" of *Casuarina* (she-oak) from Landslip Hill and named a new species, *C. stellata*, noting that its affinities were closest to *Gymnostoma*, living species of which are known from New Caledonia, NE Australia, Malesia and Fiji. The pollen flora of the Gore Lignite Measures is generally dominated by *Nothofagus* (especially *N. cranwelliae*) and *Casuarina* (*Haloragacidites harrisii*). According to Pocknall (1982) other families represented include podocarps and araucarians, palms, Chloranthaceae, Liliaceae, Loranthaceae, Myrtaceae, Proteaceae, Epacridaceae and Gunneraceae.

Day 3. Gore to Dunedin

Stop 8. Chatton Formation, Cosy Dell Farm

Fig. 18 New exposure of Chatton Formation, Cosy Dell lime pit, near Croydon, looking west towards the Hokonui Hills. Photo DE Lee.

At Cosy Dell, a new exposure of highly fossiliferous Chatton Formation is located close to the core of an eroded anticlinal structure that separates Waimumu and Croydon coalfields (Figs 18 & 19). Waimumu and Croydon coalfields are the smallest of six major lignite deposits in Eastern Southland (Isaac & Lindqvist 1990). They occupy a gently warped northeast-trending structural block, overthrust from the west along Bushy Park Fault by Murihiku basement rocks, and bordered to the east by Hedgehope Fault which also has reverse throw, up on the west. Several en echelon splinter faults cause local structural disturbance within the block.

Chatton Formation was named from shallow marine sandy shell beds exposed in the Chatton district some 12 km north of Gore (Marwick 1929). Drilling data and surface exposures in the Waimumu - Mataura region indicate that it was deposited as a transgressive system, onlapping and infilling a moderate-relief basement topography that locally included thin valley-floor coaly sediments. In the Mataura coalfield, recent drilling indicates that Chatton Formation, where present, is up to 8 m thick (Stein et al. 2009), whereas it exceeds 50 m in thickness in the Waimumu-Croydon area (Isaac & Lindqvist 1990).

In the vicinity of Cosy Dell Farm, Chatton Formation is known from exposures in Hedgehope Steam and in drillhole d1148 (Fig. 18) which intersected shallow Murihiku greywacke basement. Immediately downstream of Cosy Dell Farm a series of thin (2-10 cm) shellbeds interbedded with shelly quartzose sandstone, laminated glauconitic sandstone, and thin mudstone beds is patchily exposed in Hedgehope Stream. The mudstone beds are riddled with *Thalassinoides* while *Ophiomorpha* burrows are locally abundant in sandstone beds. Interpreted as a storm-influenced nearshore succession by Isaac & Lindqvist (1990), it has facies analogies with Wangaloa Formation exposed at Mitchells Rocks in Kaitangata Coalfield (Lindqvist 1986).

In the recently excavated Cosy Dell lime pit two shellbeds containing high diversity faunas dominated by robust thick-shelled molluscs are interbedded with shelly sands that contain scattered smaller thin-shelled bivalves and thin current-sorted concentrations (Fig. 19). The lower of the two main shellbeds includes abundant well-rounded Murihiku basement-derived andesites and granitoids, greywacke sandstone, and mudstone conglomerate pebbles, cobbles and boulders. *Teredo*-bored logs are also present, together with well-rounded shaley coal clasts of uncertain origin. The succession is assumed to closely overlie Murihiku basement. Although a straightforward storm-event depositional model appears applicable to the thin shell concentrations, the two main shell beds containing diverse faunas likely mark small but abrupt (?initially regressive) sea-level fluctuations, comparable to transgressive onlap shellbeds described from Wanganui Basin by Abbott & Carter (1994), Abbott (1998), and others.

The Chatton Formation has long been known to have a highly diverse assemblage of molluscs (e.g., Marwick 1929; Beu & Maxwell 1990). The new Cosy Dell farm exposure provides evidence for a rocky shoreline in the Duntroonian, with oyster-encrusted boulders and cobbles of fresh Murihiku basement, and a diverse range of rocky shore and intertidal animals including limpets, chitons, trochid gastropods, opercula, large benthic foraminifera, and a hermatypic coral. In addition, the fauna of some 150 species includes freshwater and estuarine molluscs, one of which lived on eelgrass. The abundance of *Teredo*-bored logs indicates an adjacent forested landmass (Stein 2009). The abundance of large, warm shallow-water species indicates a subtropical climate, and the geological setting and biota provide firm evidence for land in southern New Zealand in the Oligocene (cf Landis et al. 2008).

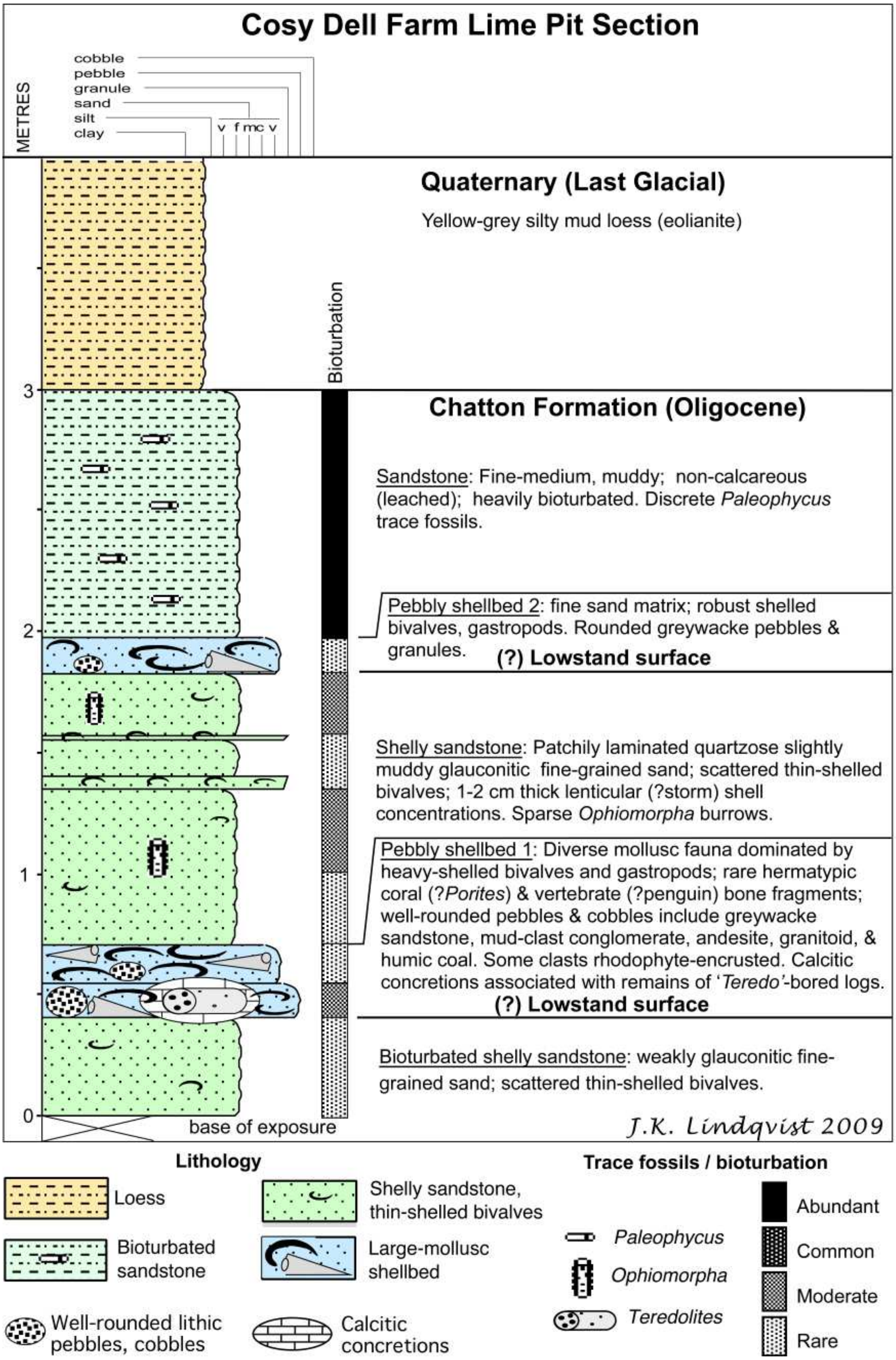

Fig. 19 Chatton Formation exposed at Cosy Dell Farm.

Stop 9. New Vale Mine, Waimumu, Southland

The Gore Lignite Measures accumulated on a low-lying coastal plain, at a latitude similar to that of present day southern New Zealand. There is no evidence for high relief, although there may have been low ridges in the hinterland hinterland, but the thickness of the Gore Lignite Measures hints at a large inland catchment and a slowly sinking depocentre. According to Isaac & Lindqvist (1990: 165), the Gore Lignite Measures were mainly deposited "in a range of fluvial channel, overbank splay, floodplain and swamp environments, as indicated by the presence of *in situ* terrestrial plant remains, lateral persistence of the multiple coal seams, common root-penetrated seat earths, large scale upward-fining clastic sequences typical of ... cyclothems, and the paucity of marine fauna. The depositional setting was a prograding deltaic plain, which advanced across a shallow marine shelf during Late Oligocene-Early Miocene time."

In the Waimumu Coalfield the Gore Lignite Measures consist of 10 major seams or seam groups separated by sandstone and mudstone which are overlain by 60 m or more of quartzose sandy conglomerate (Isaac & Lindqvist 1990). The opencast Newvale mine lies on the western limb of Waimumu-Croydon Anticline (Figs 20 & 21). Beds typically dip to the southwest at 3-5˚. As shown in cross-section (Fig. 20; drawn slightly oblique to maximum dip) the base of the main lignite W6 recovered in Newvale mine is approximately 175 m above Chatton shelly sandstone beds. Over most of the Waimumu exploration area W6 is a single low-ash coal. It is typically 9-12 m thick, reaching 17.5+ m in Newvale Mine. The 16-34 m thick W6-W7 clastic interval currently exposed in the mine highwall is dominated by fine-medium grained sand that includes climbing-ripple laminated intervals and clayey siltstone interbeds.

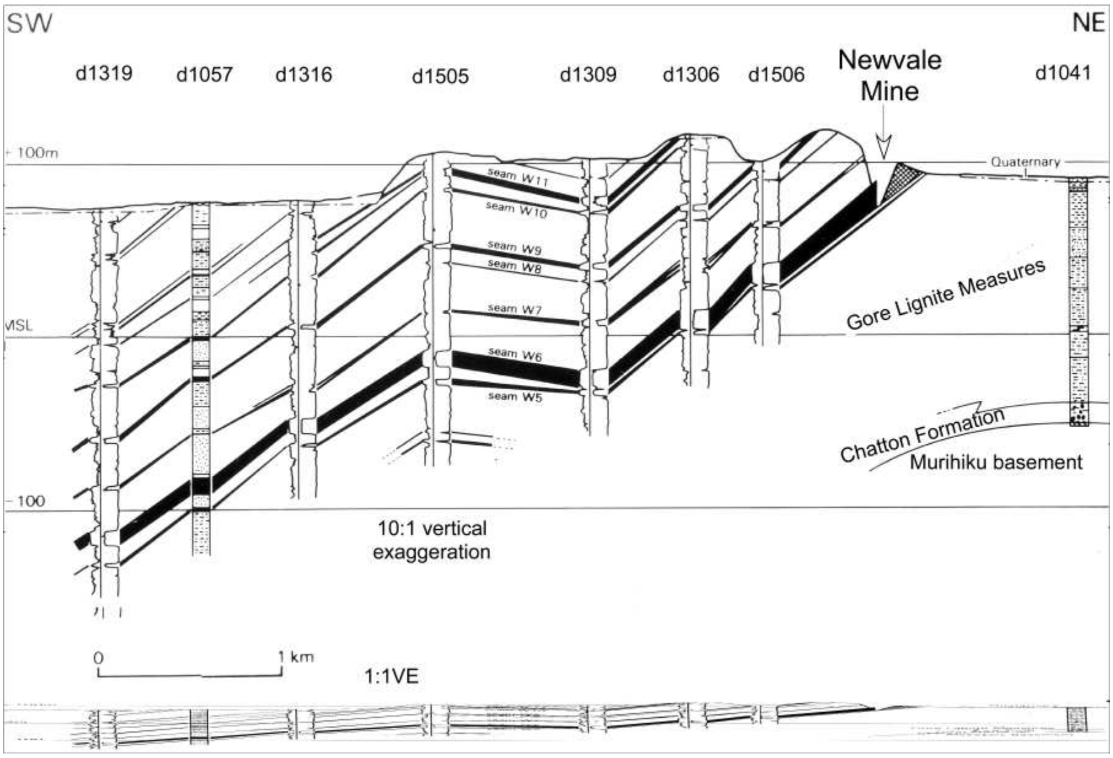

Fig. 20 Cross sections drawn slightly oblique to maximum dip shows the stratigraphic position of lignite W6 in Newvale Mine. Modified after Isaac & Lindqvist (1990).

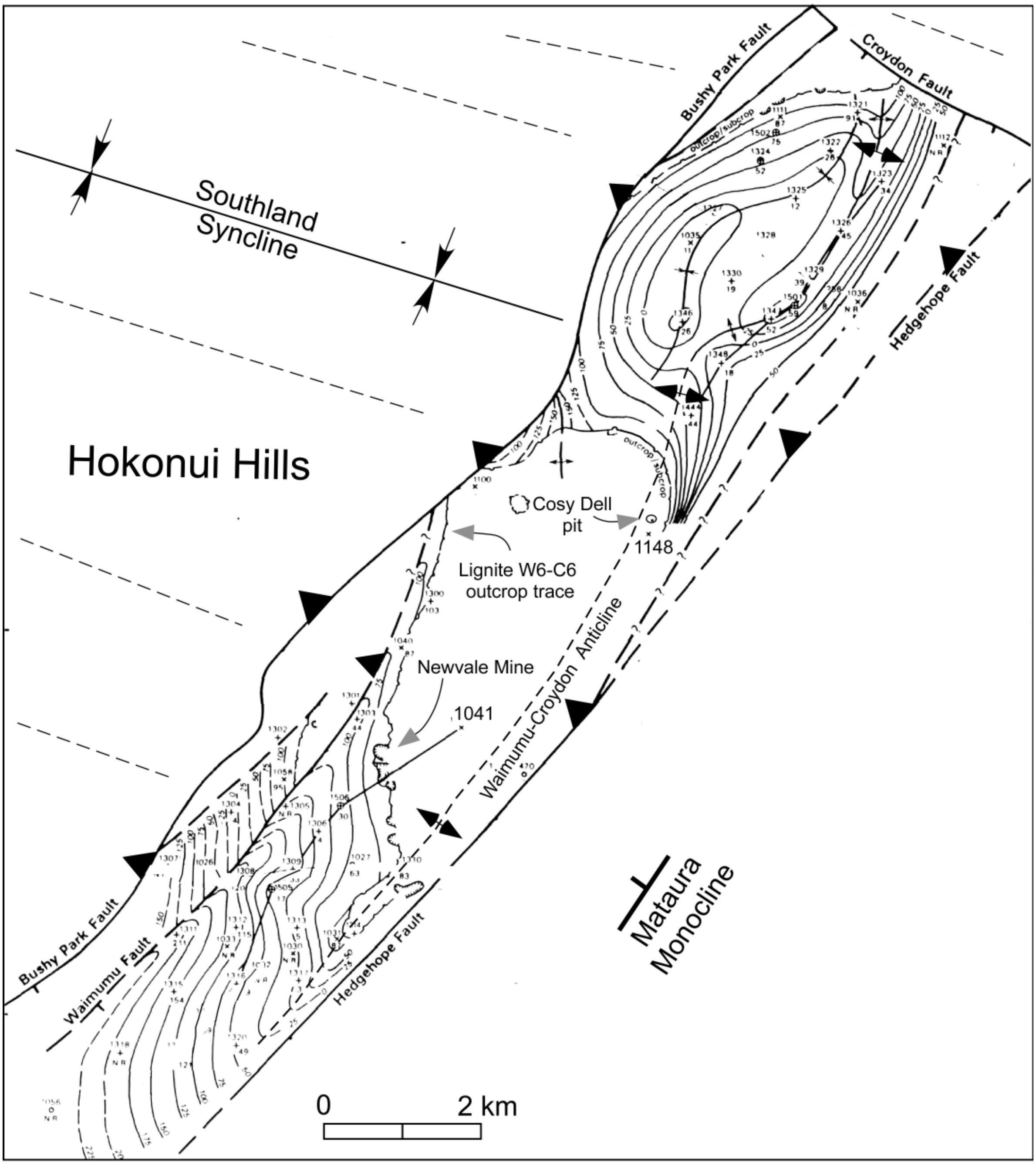

Fig. 21 Structural setting of Chatton Formation at Cosy Dell Farm and Gore Lignite Measures (bed W6) exposed in the Solid Energy Ltd Newvale Mine, Waimumu Coalfield. Map modified from Isaac & Lindqvist (1990).

The age of the Gore Lignite Measures is Late Oligocene or Early Miocene (Waitakian to Altonian Stage) based on studies of palynofloras of Oligocene and Miocene strata of Otago and Southland by Pocknall & Mildenhall (1984) and Mildenhall & Pocknall (1989). Palynofloras from Seam W6 in the Newvale Mine were placed in the *Proteacidites isopogiformis* Zone (Pocknall *in* Isaac & Lindqvist, 1990), which is regarded as equivalent to the lower part of the Otaian Stage (Crundwell et al. 2004, Fig. 12.6). However, given the close association between marine strata of Duntroonian to Waitakian age and the lower Gore Lignite Measures in the Waimumu area (Isaac & Lindqvist, 1990), we consider that the lignite is probably Waitakian (late Oligocene to early Miocene) in age. The coal typically contains large quantities of wood, some *in situ* stumps, and blocks and blebs of golden-brown resin are ubiquitous. At Newvale an unusual leaf litter bed occurs about 5 m below the top of the W6 seam (Fig. 22). It contains well-preserved macrofossils of Araucariaceae (*Agathis*) (Fig. 23) (Lee et al. 2007) and at least 4 conifers: *Dacrydium*, *Dacrycarpus*, *Phyllocladus* and *Halocarpus*. Leaves identified to date represent at least 8 angiosperm families: Araliaceae (cf. *Schefflera*), Casuarinaceae (*Gymnostoma*), Cunoniaceae, Nothofagaceae (*Nothofagus* Subgenus *Brassospora*), Ericaceae, Sapindaceae (cf. *Alectryon*), and one monocot, *Phormium* (Asparagaceae) (Fig. 24) (Ferguson et al. 2009). In addition, 6 leaf species of Proteaceae are present, including *Beauprea*, and the first extra-Australia macrofossil species of *Banksia* (Ray Carpenter pers.comm 2009). All of the macrofossils have exceptionally well-preserved cuticle, and pollen of many, but not all, are represented in palynological samples.

The commonest pollen type in the coal is *Haloragacidites harrisii* (Casuarinaceae). Although the pollen of the 4 extant genera of Casuarinaceae are quite similar, it seems reasonable to infer that some of the *H. harrisii* pollen represents *Gymnostoma.* The scarcity of Araucariaceae pollen is surprising considering the abundance of resin, and large numbers of *Agathis* leaves. However, *Agathis* pollen is known to have a poor preservational potential (Mildenhall 1985). Another mystery is the absence of *Banksia* pollen, although other Proteaceae have good correspondence between macrofossils and pollen. *Banksia* is mainly zoogamous and its pollen when found is usually in trace amounts in any New Zealand sequence.

Other palynomorphs that lack matching macrofossils include *Dictyophyllidites arcuatus* Pocknall & Mildenhall (*Dicranopteris* [Gleicheniaceae]), a fern that grows on wet, nutrient-poor soils. Other pollen such as *Milfordia homeopunctata* (McIntyre) Partridge (Joinvilleaceae/Restionaceae), *Rhoipites alveolatus* (Couper) Pocknall & Crosbie (*Euphorbia* [cf. *E. glauca*, Euphorbiaceae]), *Haloragacidites myriophylloides* Cookson & Pike (*Myriophyllum* [Haloragaceae]), *Tricolpites reticulatus* Cookson ex Couper (*Gunnera* [Gunneraceae]) came from herbaceous angiosperms that are unlikely to be preserved.

The leaf litter bed contains abundant cenobia of the fresh- to brackish-water, colonial green alga *Botryococcus* which often inhabits temporary pools to the exclusion of other algae. The leaf litter bed does not contain the diversity of palynomorphs relative to the diversity recovered from the sediments either side of the bed, including from Seam W6, which are dominated by pollen from the Myrtaceae, a pollen type that is very rare with the leaf litter bed.

The leaf layers represent litter horizons laid down in pools on the surface of a subtropical, domed ombrotrophic forest mire above the level of surrounding rivers. Highly acidic water ponded in tree-fall depressions is likely to have prevented microbial decay of the foliage (Gastaldo & Staub 1999; Ferguson et al. 2009).

Fig. 22 The surface of a leaf bed at Newvale Mine. The white substance is a paraffin wax. Photo JK Lindqvist.

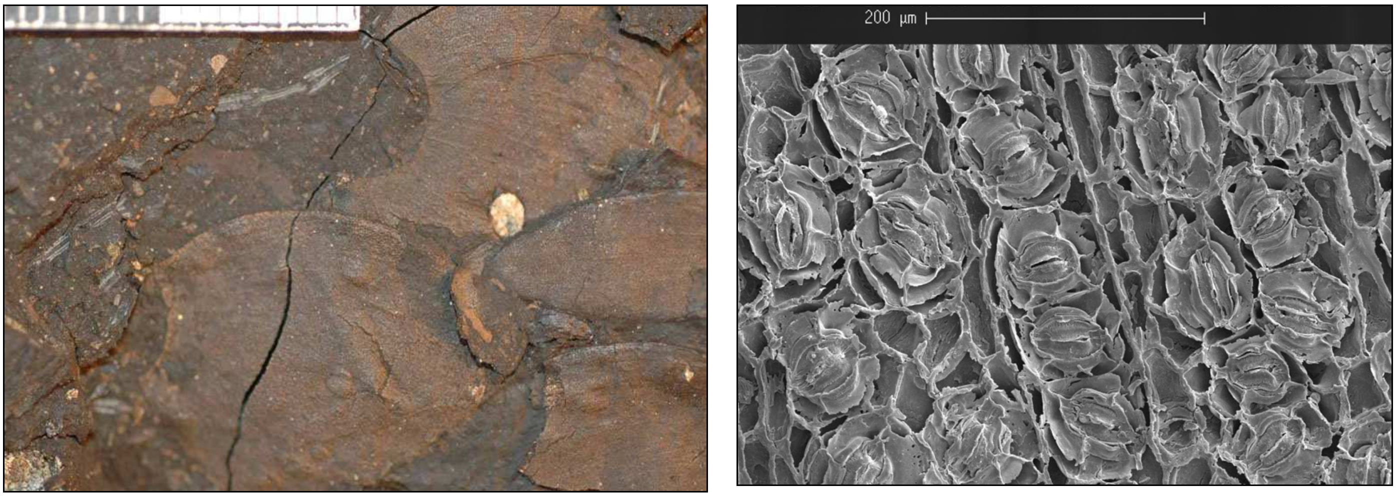

Fig. 23 Several detached *Agathis* leaves from Newvale, and an SEM photograph of an inner view, abaxial cuticle showing the characteristic discontinuous stomatal rows and the predominantly oblique orientation of stomata. Photos JM Bannister.

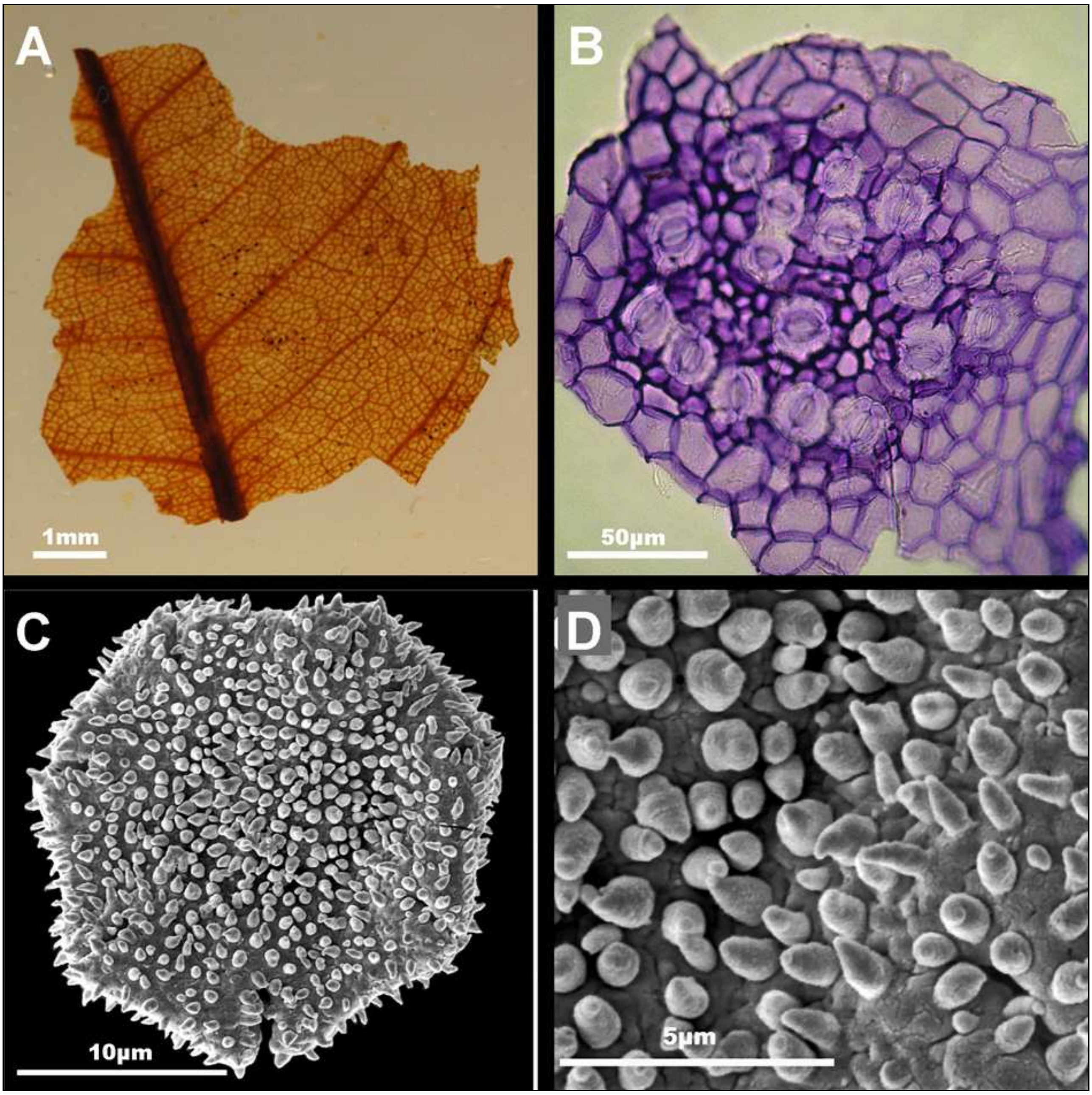

Fig. 24 A, B. *Nothofagus* Subgenus *Brassospora* leaf with venation, and cuticle showing stomata in tight areoles. C, D. Pollen grain of *Nothofagidites cranwelliae* (Subgenus *Brassospora* type) and close up of sculpture. (from Ferguson et al. 2009). Photos JM Bannister and R Zetter.

Stop 10. Blue Spur Conglomerate & Tuapeka Fault Zone, Gabriels Gully

On 4th June 1861, Gabriel Read wrote a letter to the Superintendent of Otago describing his discovery of gold near Blue Spur in a small tributary of the Tuapeka River now known as Gabriels Gully. This sparked a gold rush that changed the future of Otago. The first gold was acquired by panning, but this easily obtained alluvial gold soon ran out. The miners then turned to mining, crushing and sluicing of the host rock, the Blue Spur Conglomerate, a sedimentary rock faulted against the schist basement. Vast quantities of Blue Spur Conglomerate were removed, leaving steep cliffs and pinnacles. Deep layers of tailings now cover the site of the initial discovery. Unmined remnants of northeast-dipping Blue Spur Conglomerate abut the spectacularly exposed southwest-dipping Tuapeka Fault plane (Fig. 25).

DC Mildenhall (pers. comm. to JKL 1991) determined the age of Blue Spur Conglomerate as Late Cretaceous (?Piripauan) from pollen extracted from carbonaceous siltstone collected from 8 m above the basal contact exposed near the entrance to the Great Extended mine (Fig. 26). The sample (H44/f03) contained a poorly preserved palynoflora dominated by bi- and tri-saccate podocarps, especially *Phyllocladidites mawsonii* and *Podocarpidites ellipticus*. *Tricolpites lilliei* (Rt-Mh), *Proteacidites*, *Triorites fragilis* (Mp-Mh), *Tricolpites gillii* (Mp-Mh) indicate an age range of Teratan to Haumurian. The sample also included abundant charcoal, finely diminuted organic debris, and many unidentifiable macerated pollen grains.

Blue Spur Conglomerate consists of schist, greywacke and quartz clasts in sand matrix (Fig. 27). Remnant blocks littering the western slopes of Gabriels Gully are carbonate cemented. A major tributary of the drainage system that deposited Late Cretaceous Taratu Formation in the Kaitangata area and beyond in Great South Basin may have flowed down a paleovalley aligned along the Tuapeka Fault system. According to Els et al. (2003) imbrication of clasts in Blue Spur Conglomerate unequivocally indicates paleoflow towards the southwest, across the Tuapeka Fault Zone from the uplifted block.

Fig. 25 The fault plane separating the schist basement from the Blue Spur Conglomerate is the broad steep slope exposed by sluicing off the overlying gold-bearing rocks. Photo DE Lee.

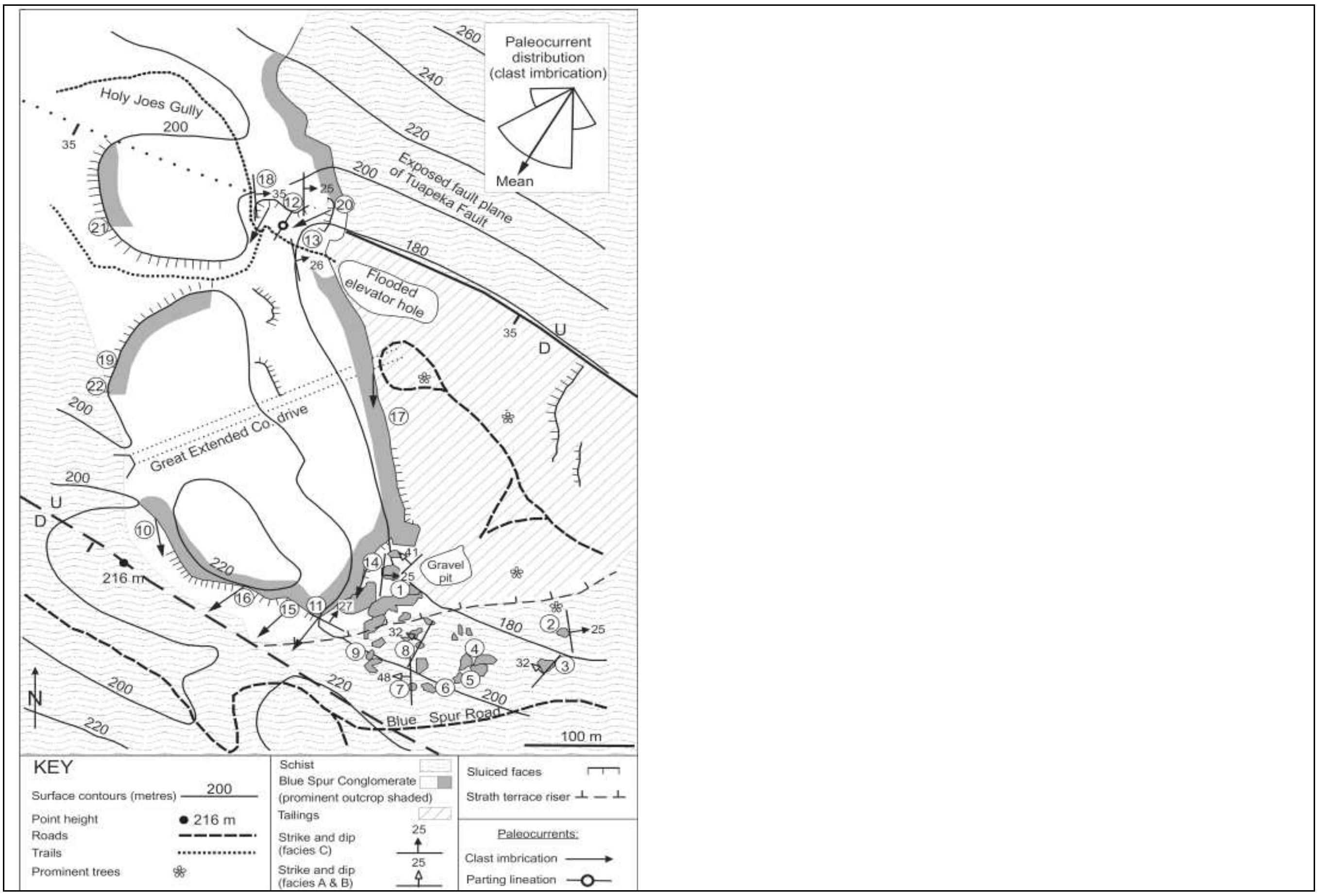

Fig. 26 Map of the Gabriels Gully area (from Els et al. 2003, fig 2).

Fig. 27 Sluiced outcrops of Blue Spur Conglomerate. Photo DE Lee.

Stop 11. Diatomite fill of Foulden Maar, Waipiata Volcanic Field

Foulden Hills Diatomite accumulated in a small ~1.5 km diameter maar lake that formed during basaltic volcanism. Except for exposures of basanite dated at 23.2 Ma by $^{40}Ar/^{39}Ar$, and remnants of a Paleogene sandstone and conglomerate cover, the diatomite body is surrounded by Otago Schist (Fig. 28).

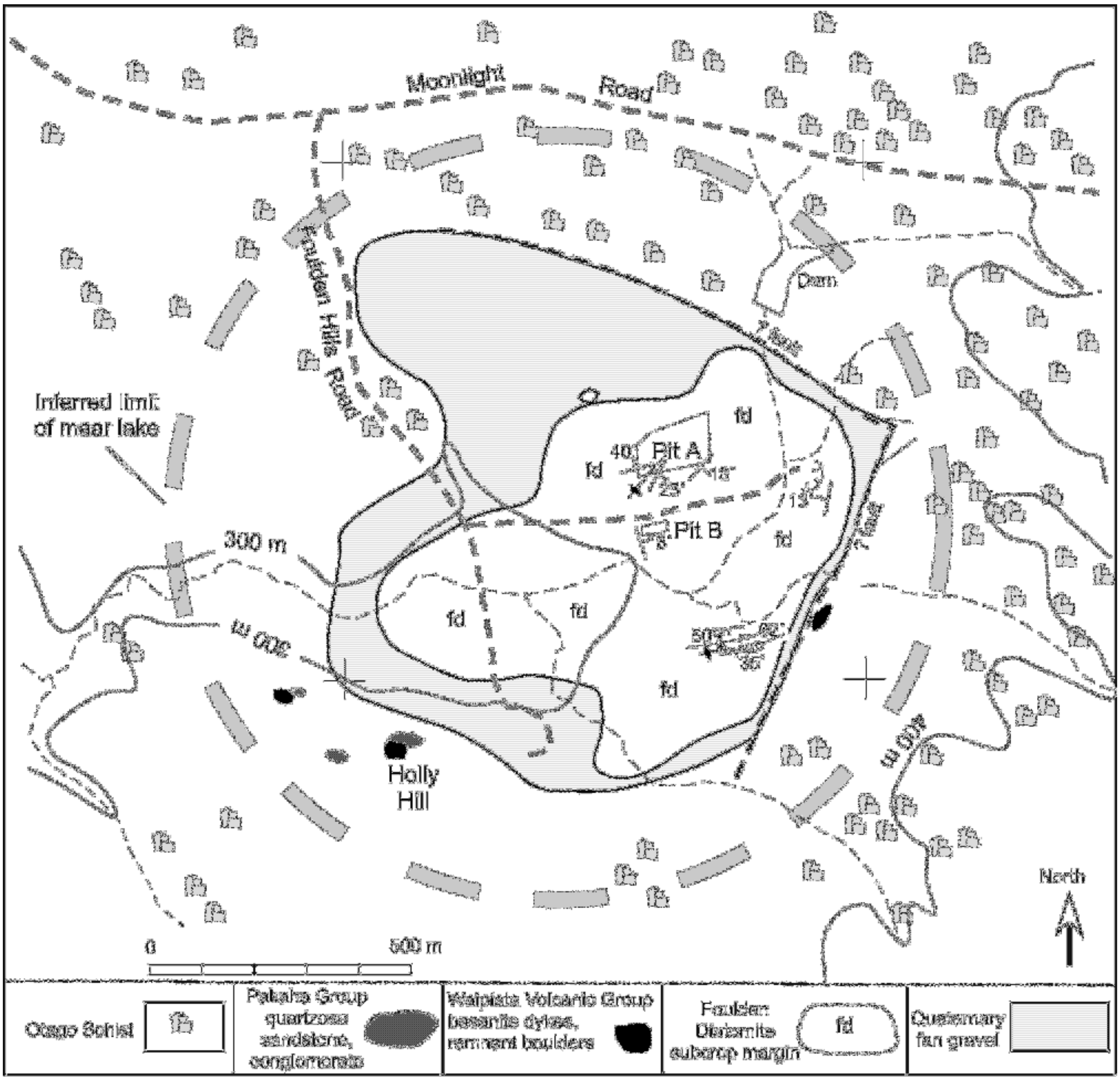

Fig. 28 Map showing the sub-surface distribution of Foulden Hill Diatomite (after Lindqvist & Lee 2009).

Recent drilling shows that the total diatomaceous sediment thickness exceeds 120 m. Two diatomite facies are exposed in mining test pits (Lindqvist & Lee 2009) (Fig. 29). A thinly laminated facies, comprising some 60% of the exposed section consists of dark brown and white couplets of average thickness 0.5 mm. Both brown and white laminae are mainly composed of frustules of a single small pennate diatom (*Encyonema jordanii*) along with 1-2 % of siliceous sponge spicules. Dark laminae also contain abundant 5-7.5 µm diameter siliceous chrysophycean stomatocysts and organic matter.

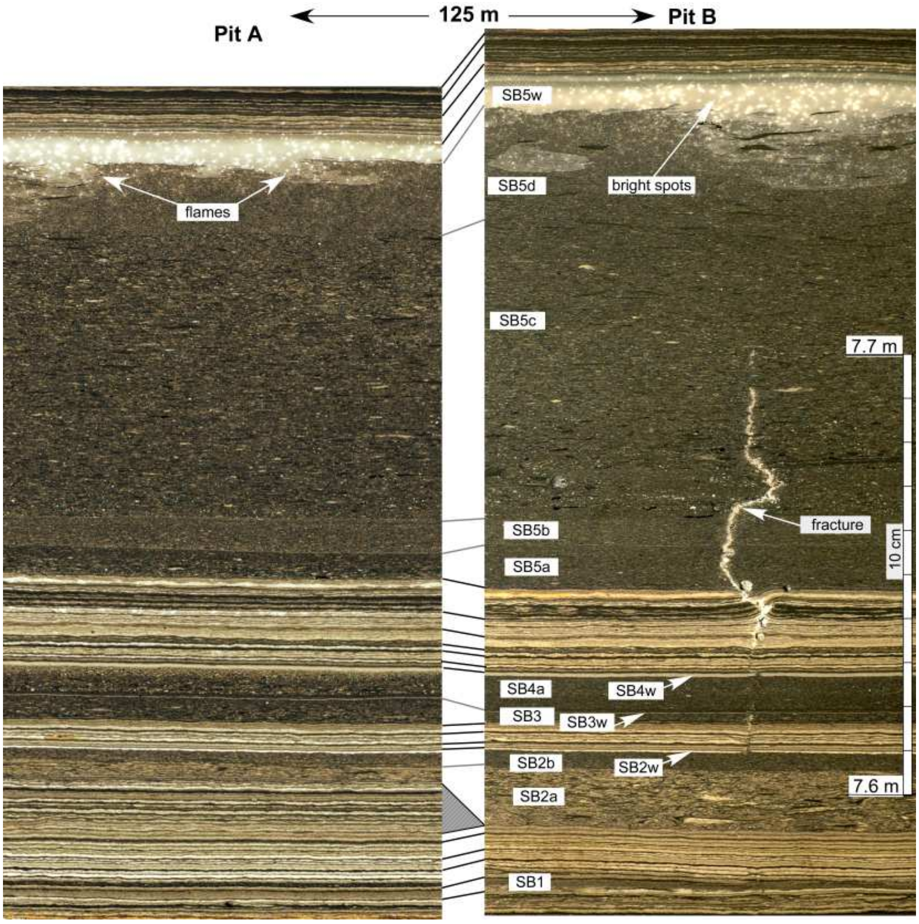

Fig. 29 Correlations of laminated facies and speckled beds (SB1 etc) between Pit A and Pit B. Note the continuity of sub-mm thick laminae between the two sites.
See Lindqvist & Lee (2009) for details.

The lake was a closed system with almost no terrigenous siliclastic sediment input. Decalcified, but complete skeletons of *Galaxias* occur throughout (Fig. 30) (Lee et al. 2007).

Fig 30 *Galaxias effusus* Lee, McDowall & Lindqvist

The area surrounding the lake was blanketed by a seasonally dry, ever green subtropical forest and all of the plant remains in the diatomite must have blown or fallen directly into the lake.

The plant macrofossils include two ferns, one with *in situ* spores (*Davallia*), a large-leaved conifer (*Podocarpus*) (Fig. 31), and a wide variety of monocot and dicot angiosperm leaves with well-preserved cuticles. Flowers, including two with *in situ* pollen, are present, as well as seeds and fruit.

There are at least 6 species of monocots, including the first organically preserved orchid leaves, the first fossil records of subfamily Epidendroideae, and the first Southern Hemisphere records for family Orchidaceae (Conran et al. 2009). About 40% of the leaves are from several genera of Lauraceae. Other families include Araliaceae, Cunoniaceae, Elaeocarpaceae, Euphorbiaceae, Menispermaceae, Myrsinaceae, Myrtaceae, Proteaceae, Sapindaceae and Sterculiaceae (Pole 1996; Bannister et al. 2008).

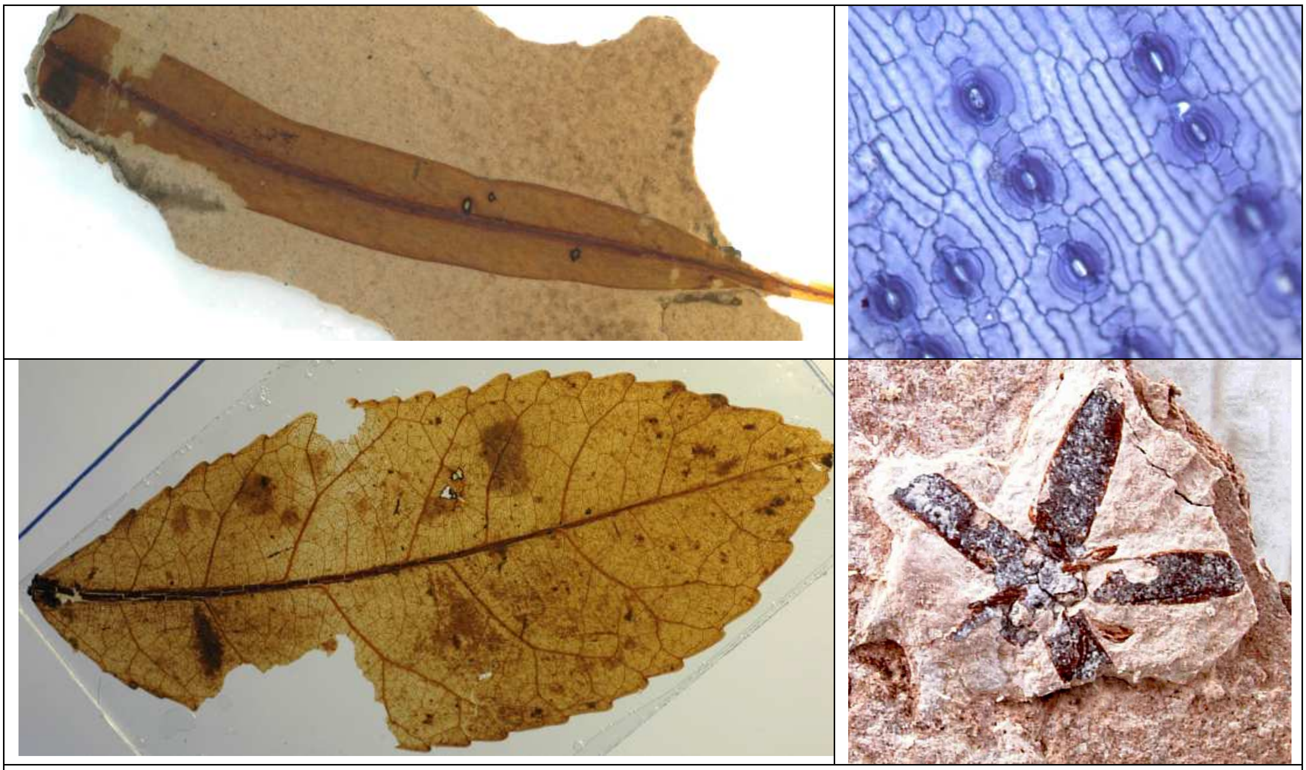

Fig. 31 *Podocarpus* leaf and cuticle (upper); Elaeocarpaceae leaf and *Fouldenia staminosa* (lower). Photos JM Bannister.

Fruiting bodies of wood-rotting fungi are found on small twigs; epiphyllous fungi occur on some leaf surfaces, but are uncommon. Saprophytic hyphae and spores are found in the dark layers and on decaying leaves. Some of the plants and animals have close living representatives in the modern New Zealand biota, but many of the fossil taxa are now locally extinct.

At least 4 different families of terrestrial and aquatic insects are present (Fig. 32) (Harris et al. 2007; Lee et al. 2009). These include two types of scale insects in life position and a flat bug (Hemiptera),winged ants (Hymenoptera), termites (Isoptera), and beetles and their larvae (Coleoptera). There is also one spider fossil.

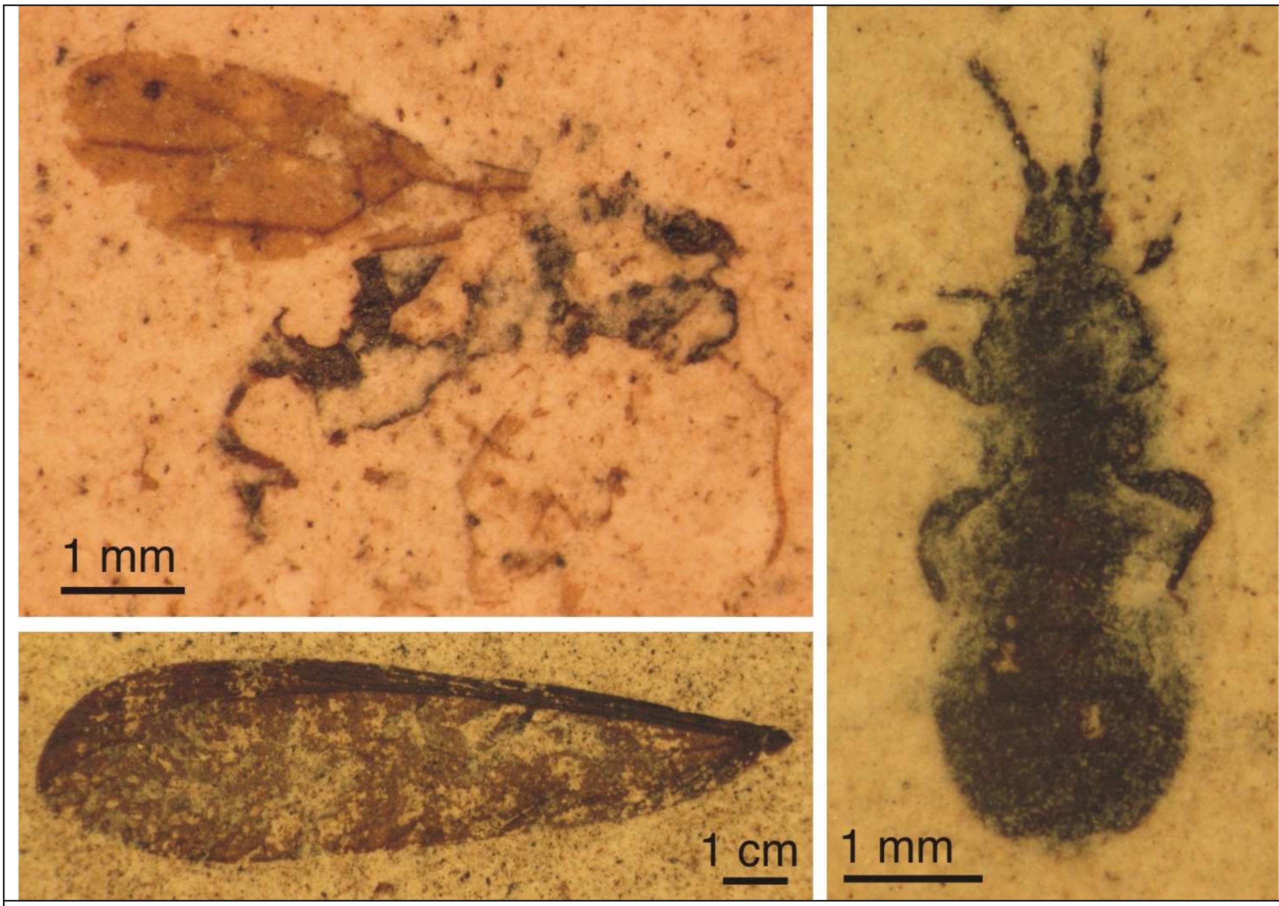

Fig. 32 Winged ant (Formicidae) (upper left); termite wing (Stolotermitidae) (lower left), and flat bug (Aradidae) from the Foulden Maar Diatomite. Photos U Kaulfuss.

Laterally continuous pinstripe lamination, widespread absence of bioturbation, and excellent fish and plant preservation indicate that the profundal lake and floor were anoxic. Periodic variations in couplet thickness of ~3-10 years compare with Quaternary records of El Niño-Southern Oscillation variability and indicate that the Early Miocene low altitude New Zealand climate was strongly seasonal.

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