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Field Trip Guides

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GEOLOGICAL SOCIETY OF NEW ZEALAND
ANNUAL CONFERENCE 2003
FIELD TRIP 9

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

Saturday 6th – Monday 8th December 2003

Leaders

Daphne Lee, Jon Lindqvist, Barry Douglas,
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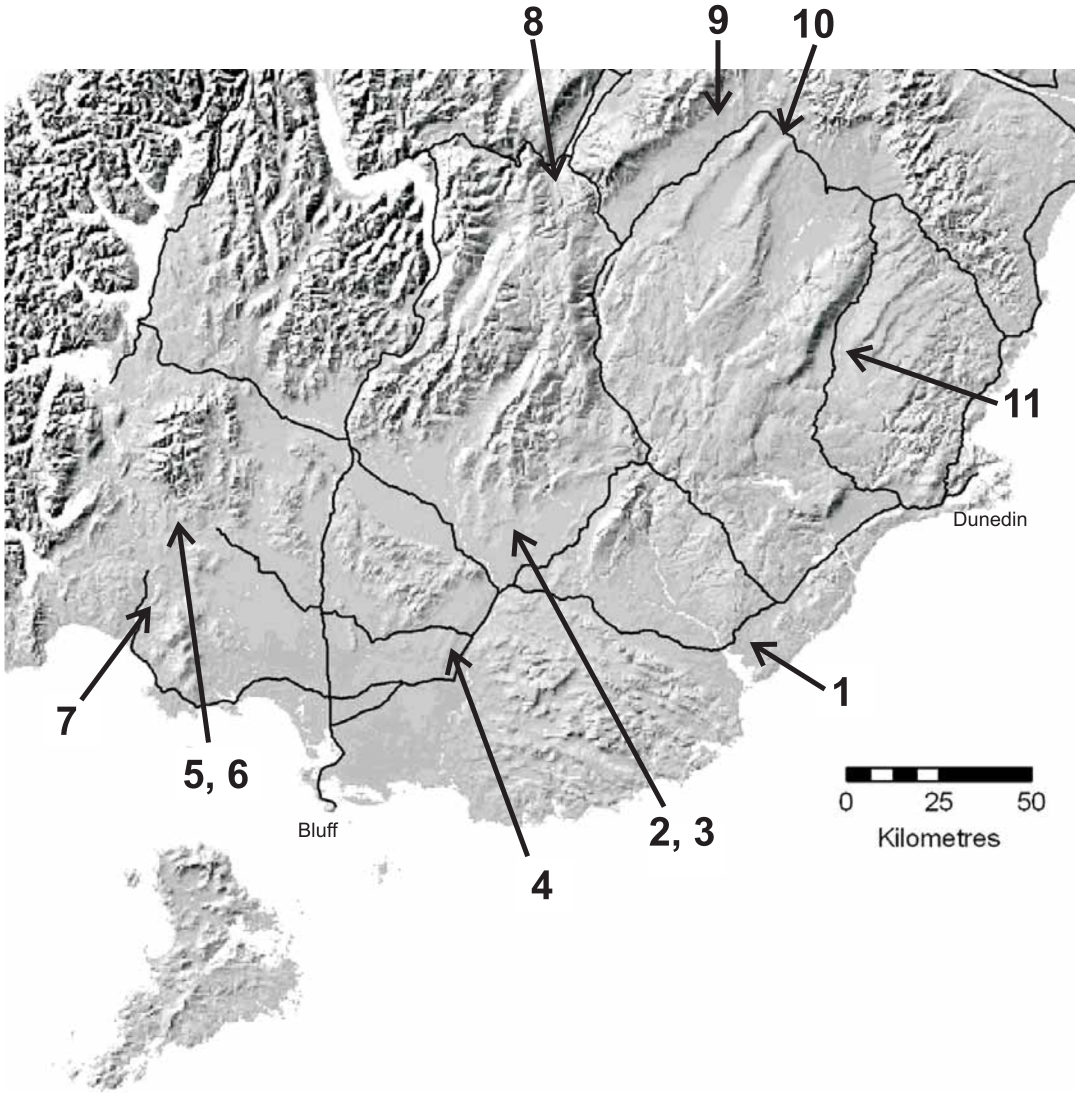
INTRODUCTION

The aims of this field excursion are to examine a variety of generally fossiliferous 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, an *in situ* fossil forest, lake beds, estuarine sediments, and diatomite. Otago and Southland have some of the best-preserved plant macrofossils of Late Cretaceous, Late Eocene, Oligocene, and Early Miocene age in Australasia. In addition to yielding information on floral richness and diversity, the associations of exceptionally well-preserved epiphyllous fungi, ferns with sporangia, a flower with pollen still on the anthers, resin, vast numbers of leaves with preserved cuticle, and trees preserved in life position make it possible to glimpse and possibly reconstruct past ecosystems at intervals during the past 70 million years.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ITINERARY

Day 1. Saturday 6th December: Depart from Geology Department, University of Otago at 8.30am. Drive south to Tuatapere, with stops at Kaitangata, Waikoikoi, Mataura and Ohai. Bed and breakfast in Tuatapere.

Day 2. Sunday 7th December: Visit Pikopiko fossil forest and adjacent modern *Nothofagus* forest remnant near Tuatapere, travel north to Kingston, brief stops to look at Quaternary sediments and landforms in the Lake Wakatipu Basin. Bed and breakfast in Cromwell.

Day 3. Monday 8th December: Bannockburn lacustrine and fluvial sediments, through Cromwell Gorge to St Bathans; arriving back at Dunedin Airport late afternoon, in time for flights north.

Day 1 (Saturday 6th)

Stop 1 Kai Point opencut coal mine, Taratu Formation

Stop 2 Landslip Hill silcrete, Gore Lignite Measures

Stop 3 Pomahaka Formation, Waikoikoi Stream

Stop 4 Mataura lignite mine, Gore Lignite Measures

Stop 5 Ohai No. 16 extension mine, Morley Formation/Beaumont Formation

Stop 6 Nightcaps opencut mine, Morley Formation/Beaumont Formation

Day 2 (Sunday 7th)

Stop 7 Pikopiko fossil forest, Beaumont Formation, Nightcaps Group
Quaternary features en route to Bannockburn

Day 3 (Monday 8th)

Stop 8 Manuherikia Group, Bannockburn

Stop 9 Fluvial and lacustrine beds, Manuherikia Group, Vinegar Hill

Stop 10 Idaburn lignite mine, Manuherikia Group

Stop 11 Foulden Hills Diatomite

STOP 1 KAI POINT OPENCUT MINE, KAITANGATA COALFIELD

Mine Operator: Kai Point Coal Company , Limited

Geological Unit: Taratu Formation (Ongley 1924)

Aim: To examine Late Cretaceous (Haumurian) fluvial facies and plant material in a 90m thick succession, incorporating the Kaituna and Barclay Seams

STRATIGRAPHIC AND STRUCTURAL SETTING

The Cretaceous – Cenozoic succession in Kaitangata Coalfield shown in the schematic west-east pre-inversion cross section through the Kaitangata coalfield (Figure 1.2), consists of 4 stratigraphic units, Henley (Breccia) Formation) (mid Cretaceous), Taratu Formation (Late Cretaceous – Paleocene), Wangaloa Formation (Late Cretaceous – Paleocene) and Abbotsford Formation.

The coal occurs within the Taratu Formation, a fluvial gravel dominated unit some 500m+ thick, thickest east of the Castle Hill fault, in the Kaitangata Coal Sector. West of the Castle Hill fault, in the Benhar Coal Sector, only the upper part of the Taratu Formation is represented, positioned directly on basement.

Harrington (1958), divided the Taratu Formation into 17 coal horizons based on the recognition of fine grained coal-bearing intervals separated by coarse grained (usually conglomeratic) sequences. Harrington's model, in view of modern understanding of coalfield architecture, is now far too simplistic and unworkable for correlating coal bed units. His concept that fluvial sedimentary strata are essentially tabular units of considerable lateral extent, even though they may vary in thickness, is unrealistic, particularly in the multi-seam structurally deformed setting at Kaitangata, where seam thickness and character may vary considerably within short distances. Uncertainties associated with seam correlation can influence almost every aspect of resource estimation.

COAL RESOURCES OF KAITANGATA COALFIELD

The Kaitangata area has been an important source of coal for local use, with a number of mines (mostly underground) in operation since 1859. Within the Kaitangata Sector, exploration by New Zealand Coal Resources Survey (1981-1985) for the Ministry of Energy, identified a total in-ground resource of 322 million tonnes of coal, of which 101 million tonnes were considered recoverable by opencut methods, and 115 million tonnes were considered recoverable by underground mining. A further 887 million tonnes of coal, mostly of lignite quality, were identified in the Benhar Sector of the coalfield, within the upper part of the Taratu Formation.

Coal in the Kaitangata Sector is of sub-bituminous C rank, with seams near the top of the Taratu Formation being close to lignite A (classification) and seams near the base borderline sub-bituminous B and C coals. On a bed moisture basis, most of the coal has a specific energy between 18 MJ/Kg and 20.5 MJ/Kg, an ash content of 4% - 11% and a medium to high (1.5% to 4.5%) sulphur value. Highest sulphur levels occur within the upper coal seams (Barclay and younger), and are attributed to peat swamp development in a marginal marine location.

A revised stratigraphic division of Taratu Formation based on sequence stratigraphic modeling of the coalfield (developed in 1993 by Douglas) is presented for the strata outcropping at the Kai Point mine (refer to the stratigraphic section Figure 1.3).

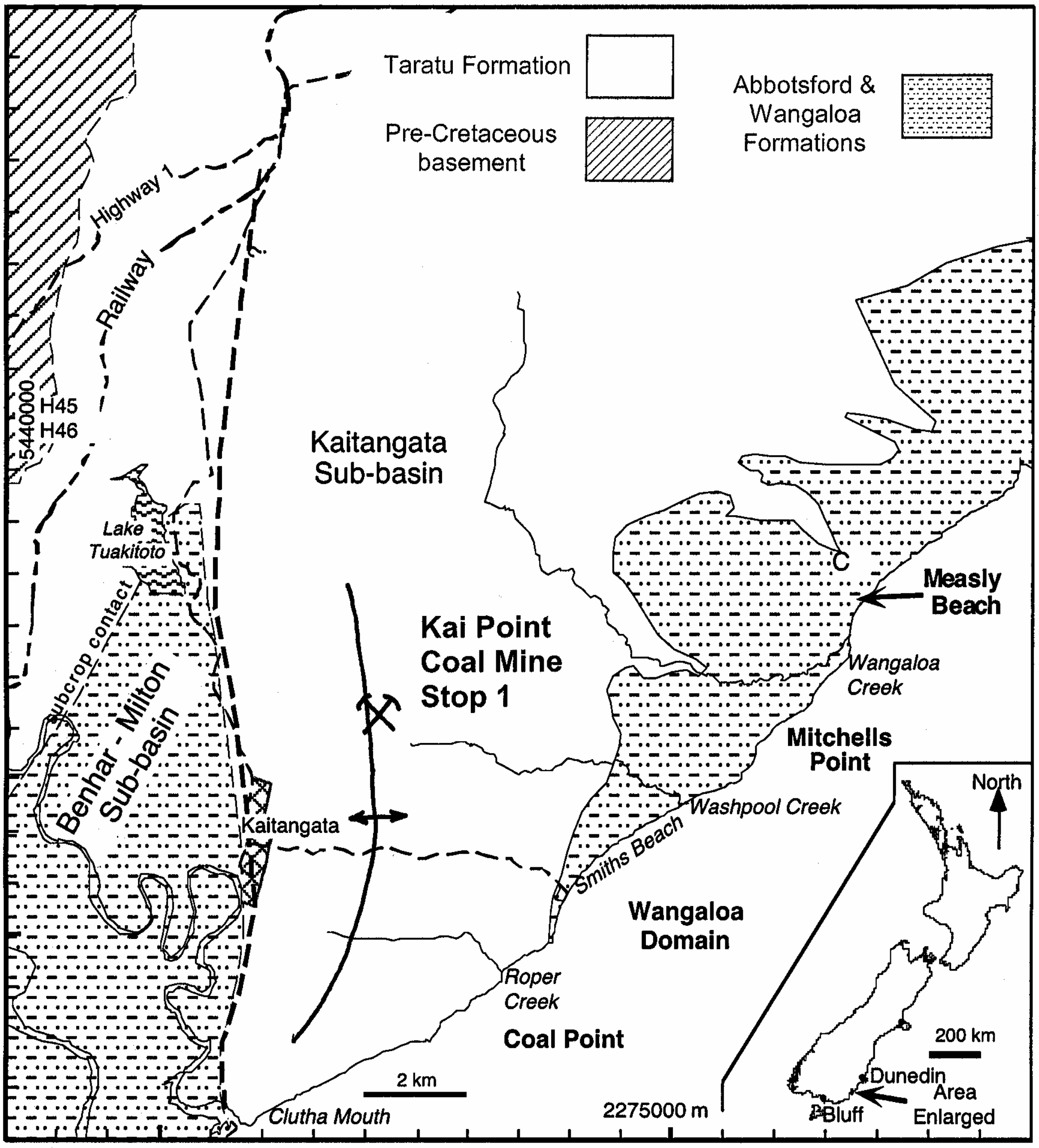


Figure 1.1 Generalised geological map of Kaitangata Coalfield

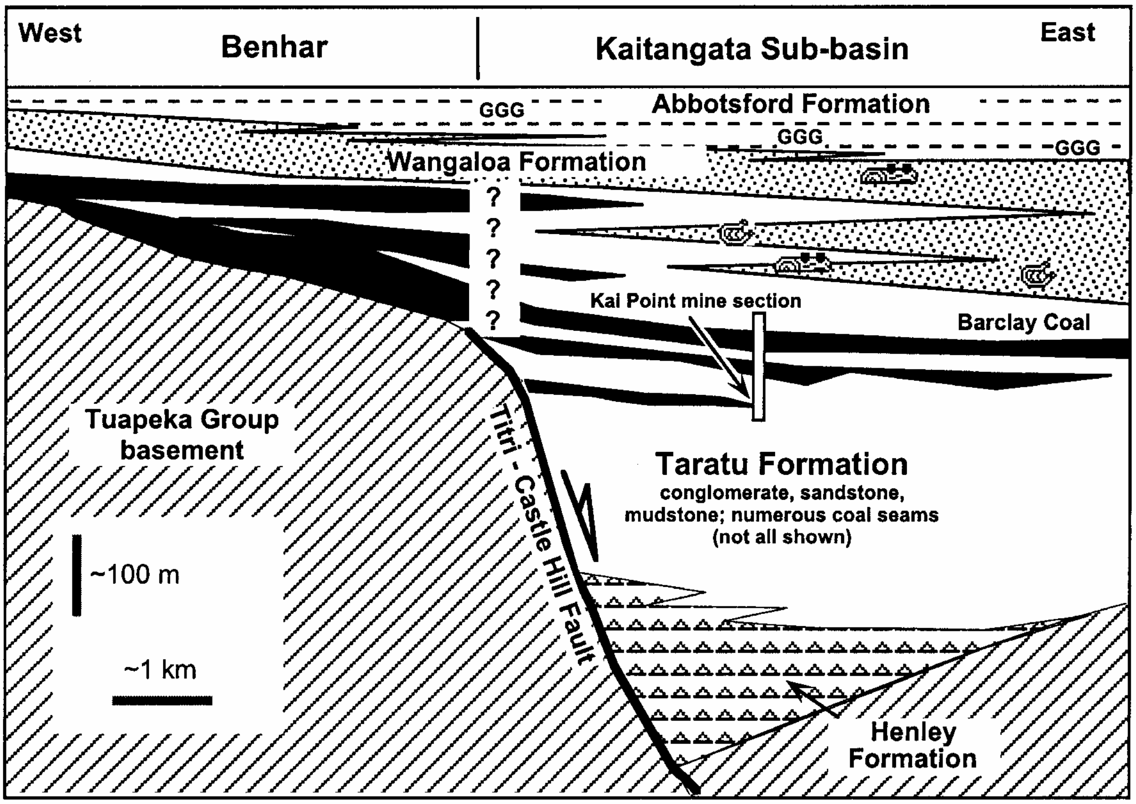


Figure 1.2 Schematic west-east cross section through the Kaitangata coalfield showing pre-inversion stratigraphic relationships inferred from drillhole and outcrop geology, and position of the Kai Point opencut mine.

RECOGNITION OF A SEQUENCE STRATIGRAPHIC MODEL AT KAI POINT MINE

Sequence stratigraphic modeling is used to delineate the sedimentary succession into conformable rock sequences bounded by unconformities of mappable regional scale. The sedimentary fill of each major sequence reflects changes in sediment supply, accommodation space and hydraulics of the Taratu fluvial system as controlled by tectonics, climate and base level changes. These changes produce distinct packages of genetically related strata referred to as system tracts. Lowstand, transgressive and highstand systems tracts identifiable within each sequence are regionally correlatable. A representation of all tracts is recognizable in the Kai Point mine area.

Sequence Boundary: A pronounced sequence boundary defined by an unconformable regionally extensive, incised, erosion surface separates the regionally extensive Barclay Seam from an overlying thick succession of gravelly, laterally amalgamated fluvial channel sandstones (previously described as the Washpool Member).

Lowstand systems tract: Lowstand systems tracts overlie the sequence boundaries. At Kai Point mine and in nearby boreholes, this tract is initially represented by a succession at least 30-40m thick of amalgamated, multi-lateral, multi-storey sandy gravelly channel units. In the highwall above the Barclay Seam, they are partially epsilon stratified. Upward changing trends in fluvial stacking patterns and channel geometry that are allocyclic, are evident. These are indicated by reduced degree of channel connectedness, increased sinuosity of channels, and lower channel gradient.

Transgressive systems tract: Transgressive systems tracts overlie lowstand systems tracts. At Kai Point mine, the upper part of this system is represented in the lowermost strata exposed in the mine area, on the highbanks cut for the main access road to the mine pit. This tract is dominated by fine grained alluvial plain strata (typically flood-basin mud and well-drained swamp mud), interbedded (sometimes frequently), with sand and sandy gravel of single-story high sinuosity (meandering) channel and crevasse splay deposits, and coals of subregional extent.

Highstand systems tract: This is magnificently exposed in the mine pits for the Kaituna and Barclay Seams and in the highwall between these seams (Fig 1.4). At the Kai Point mine this tract is characterised by fine-grained flood-basin and well-drained to poorly-drained swamp muds, single-story sinuous channel sands, crevasse splay sands and coal seams of regional extent. A zone of maximum flooding may be indicated by mixing of fluvial and marine waters, and may be evident from flaser mud drapes in tidally influenced channel deposits. These deposits can be traced with various degrees of certainty to coeval marine strata (Wangaloa Formation) locally interdigitating with deposits of the Taratu Formation.

The regionally extensive Barclay Seam occurs within the highstand systems tract. It overlies fine-grained (muddy) well-drained and poorly-drained swamp deposits, indicative of a prolonged phase of rising base level. The extent, longevity and preservation of the peat-forming mires that developed these seams indicate raised groundwater tables of regional extent, and confined channel facies sedimentation. The association of inferred high water levels with marine flooding is supported by the occurrence of dolomite cemented concretions (Figure 1.5).

Sequence stratigraphy modeling provides a predictive genetic stratigraphic framework of critical importance to the assessment of fossil fuels, and at Kaitangata, it has particular relevance to immediately offshore coeval strata with hydrocarbon reservoir potential.

AGE OF TARATU FORMATION

Palynomorphs of Taratu Formation samples from Kai Point mine and Wangaloa Coast have been identified within the Late Cretaceous (Haumurian) miospore zone PM2. Only in the uppermost part of the Taratu Formation, have palynomorphs been identified belonging to the earliest Tertiary (Teurian) miospore zone PM3.

Plant Fossils

"The Kaitangata coal field is one of the few places in the Australasian region with common, well-preserved latest Cretaceous plant macrofossils" (Pole & Douglas 1999). The plant samples studied come from grey or very carbonaceous mud which separates coal seams, rather than from the coal itself, and the leaves probably represent vegetation from clastic swamps rather than the peat-forming swamps. The plant material occurs as well-preserved cuticle in the form of dispersed fragments. At least 13 different gymnosperms and a similar number of angiosperms have been recognised.

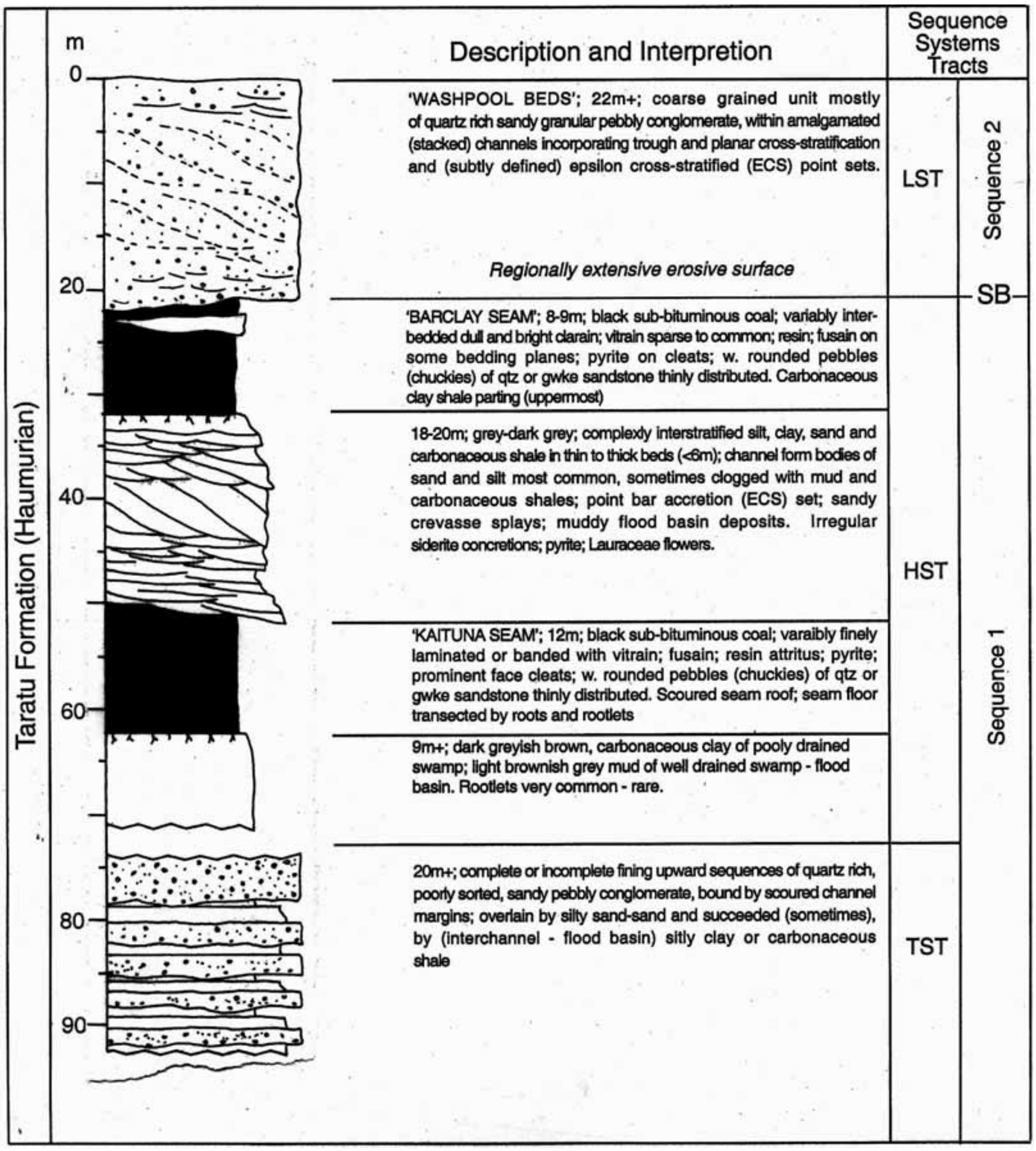


Figure 1.3 Stratigraphic section in the Kai Point Coal Ltd mine (Douglas 2001). Systems Tracts identified; LST, lowstand systems tract; TST, transgressive systems tract; HST, highstand systems tract; SB, sequence boundary.

Figure 1.4 Kai Pont opencut mine, 1994. Highstand sytems tract, incorporating Kaituna Seam (lowermost); 20m thick (highwall) interval of fine grained (sandy and muddy) sediments with high sinuosity channel forms (ECS sets) crevasse splay and flood-basin features; and the overlying Barclay Seam.

From well-preserved but fragmentary plant debris at Kai Point coal mine, Pole & Douglas (1999) described a diverse flora consisting of two cycads (*Macrozamia* and *Pterostoma*), a species of *Gingko* and other possible ginkgophyte taxa, and ten conifer taxa. The conifers include *Araucaria* sp, another araucarian which can be compared to *Dacrycarpus*, two other podocarps, *Kaia and Kakahuia*, and representatives of Family Taxodiaceae which are placed in recently described endemic genera including *Otakauia, Paahake, Waro* and *Maikuku* (Pole 1995, Pole & Douglas 1999). Angiosperms include one representative of Lauraceae, and another with affinities to Chloranthaceae and Monimiaceae. The plant communities may have included both deciduous (e.g. *Ginkgo*) and evergreen components (the conifers), based on the relative thickness of the cuticle. On a local scale there appears to have been distinct spatial separation between conifer and angiosperm dominated vegetation. Ecologically, the vegetation was probably similar to present day northern hemisphere “taiga”, a boggy forest of conifers and angiosperms. Temperatures were cool or cold, and conditions ideal for peat accumulation.

There is still debate about the paleolatitude of New Zealand in the late Cretaceous, although 70 million years ago, New Zealand probably lay between 70^0 to 75^0 S (Lee *et al.* 2001).

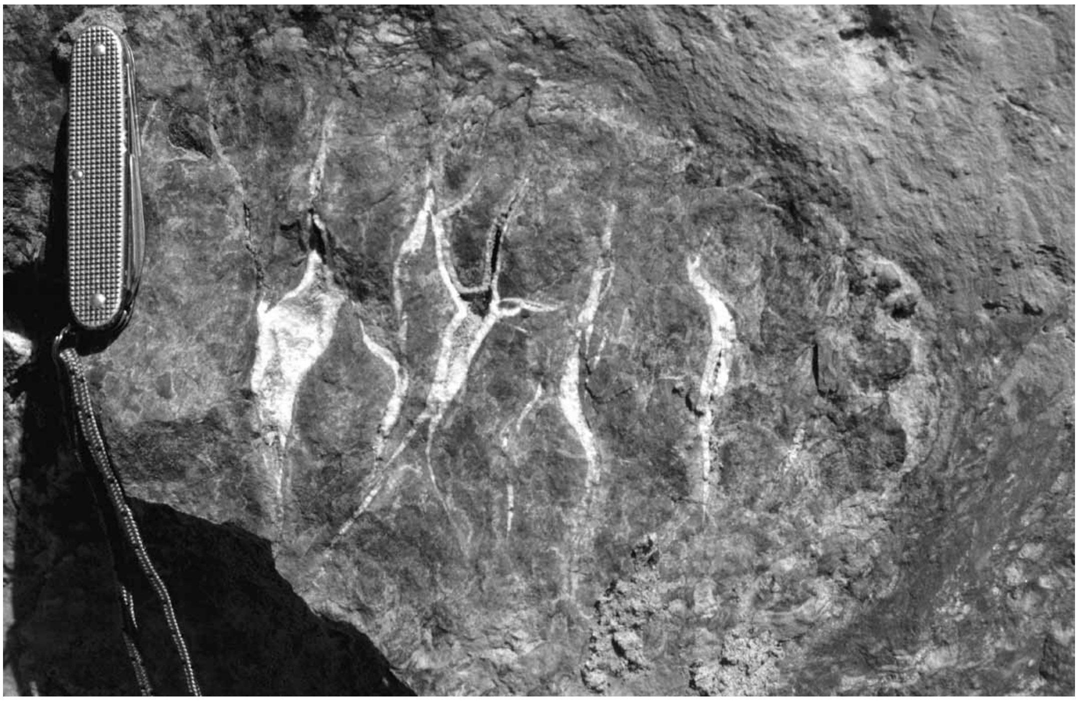


Figure 1.5 A dolomite-cemented concretion from Kaituna clastic interval. Septarian cracks are lined with sucrosic dolomite.

STOP 2 LANDSLIP HILL SILCRETE, CHARTERS ROAD

Geological Unit: Gore Lignite Measure (Wood 1956)

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. 2.1 & 2.2) 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 (Fig. 2.1). 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 3).

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. In his final publication (Campbell 2002), Doug Campbell described and illustrated fruits closely resembling dried drupes of *Corynocarpus* (karaka), and the modern New Zealand mangrove, *Avicennia*. In the same paper, leaves attributable to *Pomaderris*, *Nothofagus*, and *Pouteria* were figured. Campbell and 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. cranwellae*) and *Casuarina* (*Haloragacidites harrisii*). According to Pocknall (1982) other families represented include podocarps and araucarians, palms, Chloranthaceae, Liliaceae, Loranthaceae, Myrtaceae, Proteaceae, Epacridaceae and Gunneraceae.

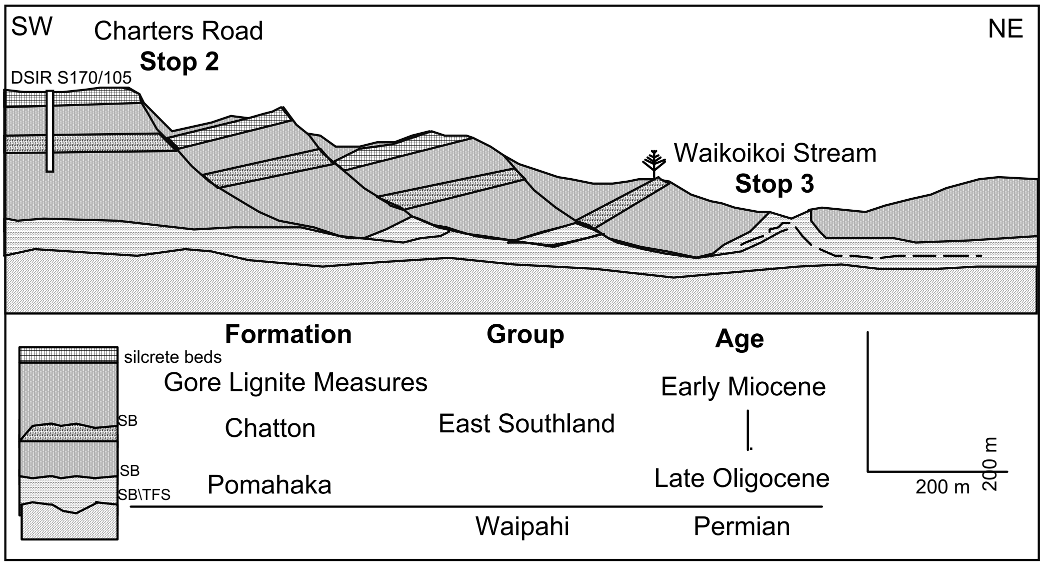


Figure 2.1 Waikoikoi Valley cross section.

Figure 2.2 Silica-cemented sandstone and conglomerate exposed on the west margin of Charters Road scarp. Large holes are moulds of transported tree trunks.

STOP 3 WAIKOIKOI CREEK

Geological Unit: Pomahaka Formation (Hector 1884)

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, Fig 3.2). 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 was temporarily exposed in the steeply dipping limbs of an antiformal decollement in the toe of Charters Road slump (Fig. 2.1). The beds strike consistently WNW-ESE and dips on each limb range from 35^0 to slightly overturned.

Hector (1866) suggested an estuarine environment of deposition based on the presence of bivalves analogous to the modern New Zealand low intertidal—shallow sub tidal 'cockle' *Austrovenus (Chione) stutchburyi* (Fig. 3.1). Hector's mollusc collection was described and/or revised by Hutton, Suter, Finlay and Marwick.

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 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 (New Zealand late Whaingaroan or Duntroonian Stage).

Plant fossils

Pocknall (1982) noted that the dominant *brassi* beech pollen component in the Pomahaka Formation is *Nothofagidites matauraensis*, whereas *N. cranwellae* is generally the more abundant in Chatton Formation and Gore Lignite Measures. The pollen and spores from these beds 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), *Casuarina*, 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.

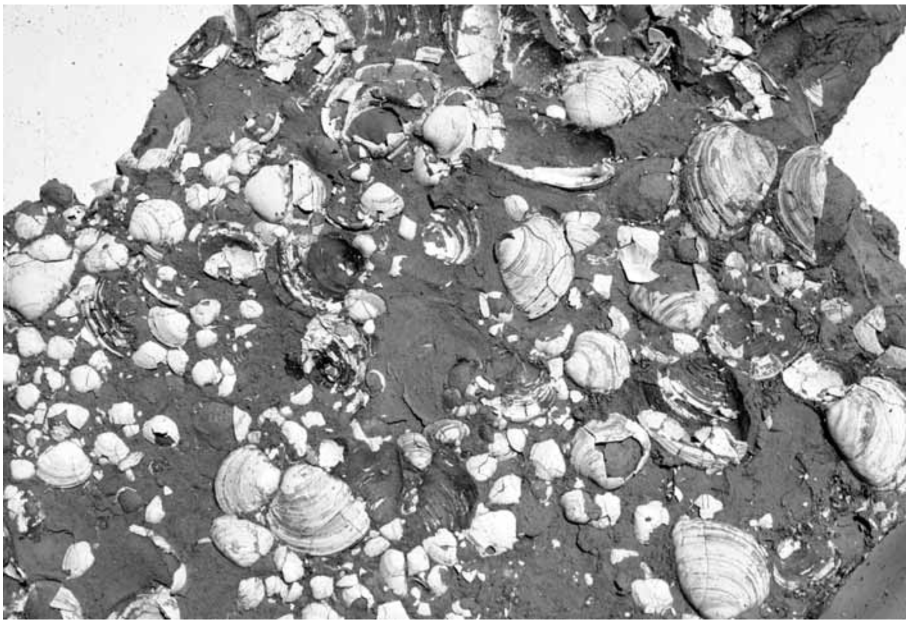
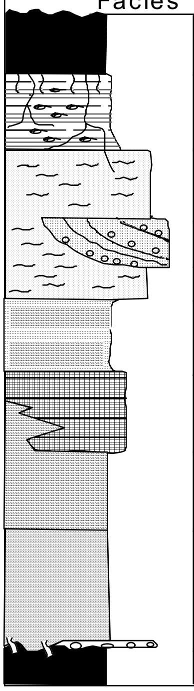


Figure 3.1 A Pomahaka Formation shell layer collected from Waikoikoi Stream composed mainly of current-aligned single *Hinemoana acuminata* valves.



Facies	Description	Interpretation
L	**Lignite:** variable wood and resin content, upright partly silicified tree stumps common in thicker lignite seams; 0-1.5 m thick.	Elevated peat mire, forested when well developed.
Mc	**Carbonaceous mud:** abundant rootlets and fine-grained plant litter; marine microfossils; sand lamine common near base; 0-0.2 m thick.	Tidal swamp - freshwater lake, marginal to peat mire.
Sm	**Sand:** very-fine to fine grained, ripple cross-laminated; lenticular and wavy clay laminae, gradational lower contacts; 0-0.5 m thick	Upper shoreface - supratidal beach. (reworked crevasse splay ?)
St	**Sand**: fineÑ coarse grained, trough cross-bedded, quartz granules, mud clasts, wood fragments, ripple-laminated muddy fine sand interbeds; 0-0.5 m thick.	Tidal channel or crevasse splay
Ms ± Msh	(See below)	(See below)
Q	**Oyster coquina:** Weakly cemented *Crassostrea* shell bed; muddy matrix; scattered molluscs as in Facies Msh; single 0.5 m thick bed.	*In-situ* oyster bank, intertidal?
Msh	**Shelly laminated mud:** freshwater and brackish marine gastropods and bivalves dominated by *Hinemoana acuminata;* fish bones locally common, rarely articulated; rare small rootlets; 0-1.5 m thick.	Brackish-marine bay, shallow sub-tidal or intertidal. Freshwater molluscs introduced during river flood or ebb-tidal flows. Shell laminae concentrated during passage of storms.
Ms	**Sand-laminated mud:** thin (1.5 mm) well-sorted v.f. sand laminae; fine plant detritus, small-scale bioturbation; 0-2 m thick.	Sheltered fresh to brackish marine bay. Minor wind-driven wave, riverine, or tidal current action.
	Sharp contact: locally burrowed or bored, marked in places by a thin layer of quartz granules.	Minor erosion surface with coarse clastic lag. Fresh - brackish-marine flooding of peat mire.

Figure 3.2 An ‘ideal’ Pomahaka Formation facies sequence based on Waikoikoi Stream exposures (after Isaac & Lindqvist 1990).

STOP 4 MATAURA LIGNITE MINE, MATAURA COALFIELD

Mine Operator: Solid Energy New Zealand, Limited

Geological Unit: Gore Lignite Measures (Wood 1956)

Late Oligocene - Middle Miocene lignite-bearing sediments extend over 2700 km^2 of East Southland shallow sub-surface. At Mataura a 250-300 m thick coal-bearing succession comprising 10 major seams or seam groups separated by sandstone and mudstone is overlain by 60 m+ of quartzose sandy conglomerate (Fig. 4.1). The beds dip gently west. Shelly mudstone and sandstone (Chatton Formation) interposing between the lignite-bearing succession and Jurassic basement locally infills shallow "lows" that represent small west-facing inlets of an Early Miocene East Southland embayment. Of the ca. fourteen areas containing significantly thick, laterally extensive lignite identified in East Southland and Central Otago, Mataura is the largest and most intensively drilled. Its lignite resource exceeds $2x10^9$ tonnes to a depth of 200 m (Isaac & Lindqvist 1990).

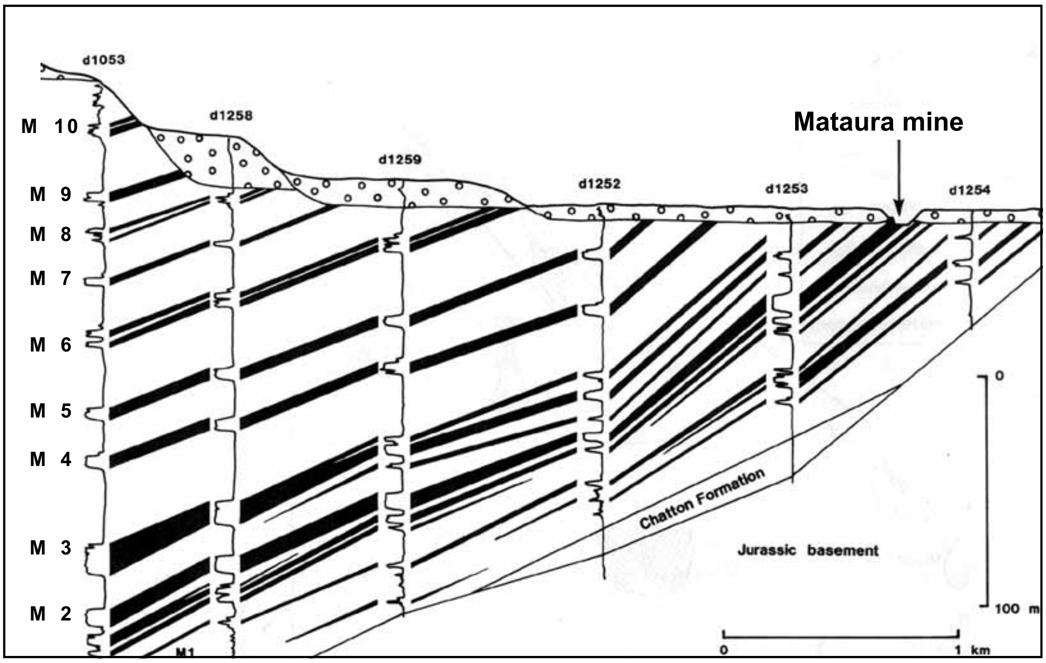


Figure 4.1 Northwest-southeast cross section through part of the Mataura Coalfield including the Mataura Solid Energy Ltd mine. After Lindqvist & Isaac (1991). Vertical exaggeration = 10:1.

Presently owned by Solid Energy Ltd, Mataura mine formerly supplied the Carter-Holt-Harvey Ltd paper mill. The main seam in the pit (M2C) has a mean thickness of 5.2 m, maximum 8.0 m. In common with other huminite-rich Southland lignites, it shows well developed lithotype banding on a decimetre scale and good preservation of resinous bark residue on compressed woody litter. Fresh lignite contains 40-44% water, less than

5% mineral matter, and up to 0.4% sulphur. Dark brown carbonaceous mudstone partings between individual splits of seam M2 typically include siltstone and fine sandstone lenses and laminae, and locally abundant 2-3 mm diameter rootlets. Sand-filled *Thalassinoides*-like burrows have been found in the M2b-M2c parting.

Sulphur distribution in the lower splits of M2 seam indicates likely brackish conditions, as sulphur content rises sharply to nearly 3% immediately beneath the partings. The upper contact of lignite M2c is commonly gradational through 0.3-0.7 m of muddy lignite to several metres of upward-coarsening mudstone to sandstone cycles. The interval between M2 and the overlying M3 seam (Fig. 4.1) is dominated by the lowermost of several major upward-fining sandstone to mudstone units, everywhere present between the higher seams interpreted as stacked meandering channel fills of a lower delta coastal plain (Isaac & Lindqvist 1990).

Silica-cemented vertical stumps confined to two stratigraphic intervals at 1 m and 4.5 m above the base of the M2c lignite were described by Lindqvist & Isaac (1991) (Fig. 4.2). The 0.15-0.4 m (max 0.8 m) diameter stumps are spaced at 2-6 m intervals along the coal face. Only the lowermost 0.6-0.8 m of each tree, including the proximal few dm of the sub-horizontal root system, is silicified. The upper few dm of preserved trunk generally merges abruptly into the woody lignite matrix, as does the remainder of the root system.

Figure 4.2 Silicified *Podocarpus* stumps in Seam M2c, Mataura lignite mine.

Incompletely replaced wood matrix imparts a very dark brown to black colour to freshly broken silicified material that quickly oxidises to a pale grey siliceous “patina”. Fallen compacted tree trunks 0.3-0.7 m in diameter formerly exposed in the floor of the working mine are not silicified.

Six silicified stumps examined by Lindqvist & Isaac (1991) are conifers resembling modern *Podocarpus hallii* (totara). Annual growth ring boundaries are well defined and the multiple-layered tracheid wall structure is well replicated where no early compactional crushing has occurred. Chalcedonic and opaline quartz are present in both silicified wood and late-stage cross-cutting veins. Siderite and vivianite are also locally present in vein fills. Lindqvist & Isaac (1991) also recorded silicified hyphae of wood-rot fungi of the Basidiomyceti group, as well as possible endophytic tissue of a parasitic plant, perhaps an epiphytic orchid, in the silicified *Podocarpus* wood.

Totara wood is well known for its resistance to fungal and bacterial decay and boring insects. The two well defined stump horizons suggest that paleoenvironmental conditions suitable for the establishment and subsequent preservation of the podocarp forests were attained only rarely. The maximum diameters of the trees (0.3 - 0.8 m) and their average growth ring widths (0.16 - 1.0 mm) indicate individual trees persisted for at least 500 years. Although silicified wood is common in coal-bearing sequences and some silcrete deposits it is rarely reported from coal seams. In considering the question of why the stumps are silicified whereas the enclosing lignite is almost free from macroscopic silica cement, Lindqvist & Isaac (1991) suggested the high longitudinal permeability of wood could have imparted a vertical differential permeability between the stumps and surrounding peat. The presence of relatively impermeable humified peat layers around the stumps would have effectively channeled formation water through the stumps during early compaction. It is likely that the stumps provided a ready conduit for silica-saturated meteoric groundwater or formation water released during compaction.

Podocarp pollen is also well-represented in the Gore Lignite Measures (Pocknall & Mildenhall 1984), and includes fossil representatives of many important modern New Zealand taxa such as rimu (*Dacrydium cupressinum*), totara (*Podocarpus totara)*, *Phyllocladus* (tanekaha) (all recognised from wood and pollen, Pocknall *in* Isaac & Lindqvist, 1990), kahikatea (*Dacrycarpus dacrydioides*), *Halocarpus* and *Libocedrus*, (Pocknall & Mildenhall, 1984). In addition, there are a number of podocarps now lost from the New Zealand flora, including *Microcachrys* (now restricted to Tasmania), and extinct forms.

Fossil Resin from Mataura: *Agathis*, *Araucaria* or *Wollemia*?

As well as tree trunks, large pieces of fossil resin are commonly found in the lignite. At the present time the only New Zealand tree to produce such large lumps of resin is the kauri, *Agathis australis*. Pocknall (1989) commented that some of the araucarian wood in the Gore Lignite Measures undoubtedly belongs to *A. australis* or a very close relative. Evans (1937) microsopically examined wood from Mataura and found that it could not be distinguished from that of *A. australis,* and that resin taken from the wood had been analysed (with other resins). Agathic acid was isolated and it was concluded that it was kauri resin. A further chemical analysis of various fossil coal resins by Brandt (1939) also found agathic acid. Brandt also concluded that the resins had come from *A. australis* or a near relative, although he did not test resin from Mataura.

Lambert et al. (1993) reported on the results of NMR analysis of both modern and fossil resins from New Zealand and Australia, including resin from Mataura. They concluded that the NMR signal from *Agathis* was distinct from that of *Araucaria* and that most of the fossil resins, including resin from Mataura, were from *Agathis*. In a further paper in 1999 they added that the newly discovered Wollemi Pine, *Wollemia*, gave the same NMR signal as *Agathis*. Of interest is that recent DNA work (Stockler et al. 2002) has shown that *A. australis* was on the earliest diverging line of *Agathis*, and leaf cuticular micromorphology features (Daniel 1989) suggest that an extinct New Zealand species, *A. seymouricum* from the Cretaceous is more similar to *A. australis* than any other living or fossil species of *Agathis*. The conclusion made is that both DNA and leaf cuticle features indicate a continued presence of *Agathis* in New Zealand since the Cretaceous. Note that pollen of *Wollemia* is indistinguishable from the fossil pollen form-genus *Dilwynites* which has a fossil record extending back to the late Cretaceous in New Zealand.

A wide variety of angiosperms are present in the lignite horizons, although few identifiable leaves have been found. The Mataura pit contains one of the earliest records of pollen of the climbing shrub *Freycinetia (Lateropora glabra) (*Pocknall & Mildenhall, 1984). The Gore Lignite Measures contain a diverse range of pollens referable to taxa no longer present in the New Zealand region (see Lee *et al*. 2001). These include *Strasburgeria* and *Beauprea* (now found only in New Caledonia), and at least 10 types of Proteaceae, modern examples of which have brightly coloured flowers with complex pollination systems and equally diverse pollinators. Since the pollen types from the Eocene-Miocene proteaceans closely resemble those of their modern relatives, the inescapable conclusion is that the New Zealand flora during this period had brightly coloured exotic flowers such as those of modern species of *Isopogon, Telopea, Xylomelon, Petrophile, Embothrium*, etc, and probably a much more diverse array of pollinators than it does today. Lee *et al.* (2001) attribute the loss of these floral elements to cooling in the Late Miocene.

STOP 5 OHAI NO. 16 OPENCAST EXTENSION, OHAI COALFIELD

Mine Operator: Solid Energy New Zealand Limited.

Geological Units: Beaumont Formation, Morley Formation

Aim: Observation stop to view the magnificent exposure of Morley Formation and overlying Beaumont Formation in the southern highwall of the mine pit (Figure 5.1).

Development of this mine recommenced this year by stripping the highwall of the old Ohai No.16 opencast. Opencast production is presently from the 8-9m thick Morley No.2 Seam, at the floor of the pit. The seam dips 10-15 SSWº.

Strata exposed in the southern highwall portray Morley Formation coal-bearing sediments (enclosing Morley No.2, Morley No.1 and Star Seams), and overlying Beaumont Formation. The unconformable contact between Cretaceous Morley Formation and Eocene Beaumont Formation is located closely above the Star Seam.

Beaumont Formation strata above the unconformity are mostly sandy and muddy carbonaceous beds, and locally contain the fresh water mussel *Velesunio*.

Regional sedimentologic-stratigraphic models for the wider Ohai Coalfield are only crudely developed, and do not meet requirements for future coal exploration and development. Shearer (1992) has identified a stratigraphy for the highwall of the old Ohai No.16 highwall (essentially the No.16 extension highwall), consisting of S and C unit associations. Seven S units (of sandy fluvial channels) and six C units (fine grained, often carbonaceous with coals) were recognised by Shearer. These are broadly recognised on the present highwall.

Figure 5.1 Ohai No. 16 opencast extension, October 2003. Production is from the Morley No. 2 seam on the pit floor. Morley No. 1 and Star Seams outcrop higher in the highwall (far right), and are overlain by Beaumont Formation.

STOP 6 NIGHTCAPS OPENCUT MINE, OHAI COALFIELD

Mine Operator: Ohai Coals Limited for Straith Industries Limited

Geological Units: Beaumont Formation, Morley Formation

Aim: To examine Morley Formation coal seams, the scoured unconformity between Upper Cretaceous and Eocene sediments, and the biota and facies of overlying Beaumont Formation.

Three coal beds (UM1, UM2 and UM3) of the Upper Morley Coal Seam are mined from the base of the presently slumped eastern highwall. The coal beds are separated by thin carbonaceous muddy beds, and have a combined coal bed thickness of 8m. The base of the greenish conglomerate bed scoured into the roof of the UM1 Seam defines the regional unconformity between Upper Cretaceous (Haumurian) Morley Formation and Late Eocene (Kaiatan – Runangan) Beaumont Formation. The age is defined from samples taken from this mine in 1986 and identified by J I Raine. The UM1 Seam is within miospore zone PM2 (sample D45/f247). The higher muddy units above the conglomerate bed, are identified within the *Notofagus matauraensis* zone (samples D45f249 and D45f250).

Above the unconformity, the c. 209m exposure of Beaumont Formation strata incorporates a generally upward fining succession, from conglomerate (lowermost), through sandy beds, mudstone, carbonaceous shalestone to coal uppermost. The freshwater mussel *Velesunio* occurs within concretions in the muddy beds.

Figure 6.1 Nightcaps mine, May 1997. View north, showing exhumed roof of UM1 Seam (Morley Formation) adjacent to the eastern highwall (right of photo). The regional unconformity is defined on the surface between the coal roof and the overlying greenish conglomerate bed. Beaumont Formation sediments overlie the Morley Formation and are represented uppermost in the section by a coal seam (upper right).

STOP 7 PIKOPIKO FOSSIL FOREST, WAIAU RIVER

Geolgical Unit: Beaumont Formation

Fossil forests are rare in New Zealand. Two requirements for the preservation of fossil forests are the protection of *in-situ* trees from bioerosion and microbial decay by either rapid burial or groundwater rise, and early introduction of mineralising fluids into the wood structure. The rarity of fossil forests (trees preserved in growth position and with a forest-like distribution) in the New Zealand record suggests that these conditions were not often attained. The best known South Island example is the Jurassic forest at Curio Bay where silicified stumps and large logs are displayed on the beach platform at low tide (Pole 1999, 2001). In the Curio Bay example, early-diagenetic silica cement was probably derived from the alteration of associated volcanigenic sediments.

Another striking example of a fossil forest with trees still spaced in life position is exposed on the east bank of Waiau River, 6 km upstream from Tuatapere township, Waiau Basin, Southland (Fig. 7.2, 7.3). Some 50 tree stumps are preserved on a bedding plane now exposed in the bed of the Waiau River. The trees are spaced at 2-5m apart, and cover an area of 30m by 120m. The stumps are now represented by calcite-cemented concretions up to 60cm in diameter, and 80cm in height. Preservation of the original cell structure is generally poor, but occasional specimens exhibit details of wood structure.

The fossil forest and associated leaf beds occur in the lower part of the coal-bearing alluvial sediments of the Beaumont Formation, which, together with overlying lacustrine sediments of Orauea Mudstone, are now included in Nightcaps Group (Bowen 1964; Turnbull *et al.*, 1989). Both formations are regarded as potential sources of petroleum in Waiau Basin .

Pocknall & Turnbull (1989) recorded 100 m of sandstone, mudstone, and thin coals (Beaumont Formation) overlain by ~225 m of mudstone and minor graded sandstone turbidites (Orauea Mudstone). A comparable transgressive alluvial plain to lacustrine facies succession was penetrated in a 248 m deep Tui-1 drillhole near Tuatapere (Lindqvist & Beggs 1999) (Fig. 7.1). The Beaumont Formation at Pikopiko consists of 2-5 m thick coarse - medium grained arkosic sandstone units overlain by silty sandstone carbonaceous mudstone and root-bioturbated silty mudstone paleosols (Fig. 7.2). Sedimentary facies sequences indicate cyclic sedimentation in a sandy meandering river and vegetated floodplain setting. Organic matter concentrations are restricted to thin coals and laminated shales rich in plant detritus that probably accumulated in transient floodplain lakes. Their sparse occurrence, and the small quantities of carbonaceous matter preserved in paleosol beds, indicate that the vegetated floodplain environment, although prone to frequent overbank flooding events was generally well-drained rather than constantly swampy.

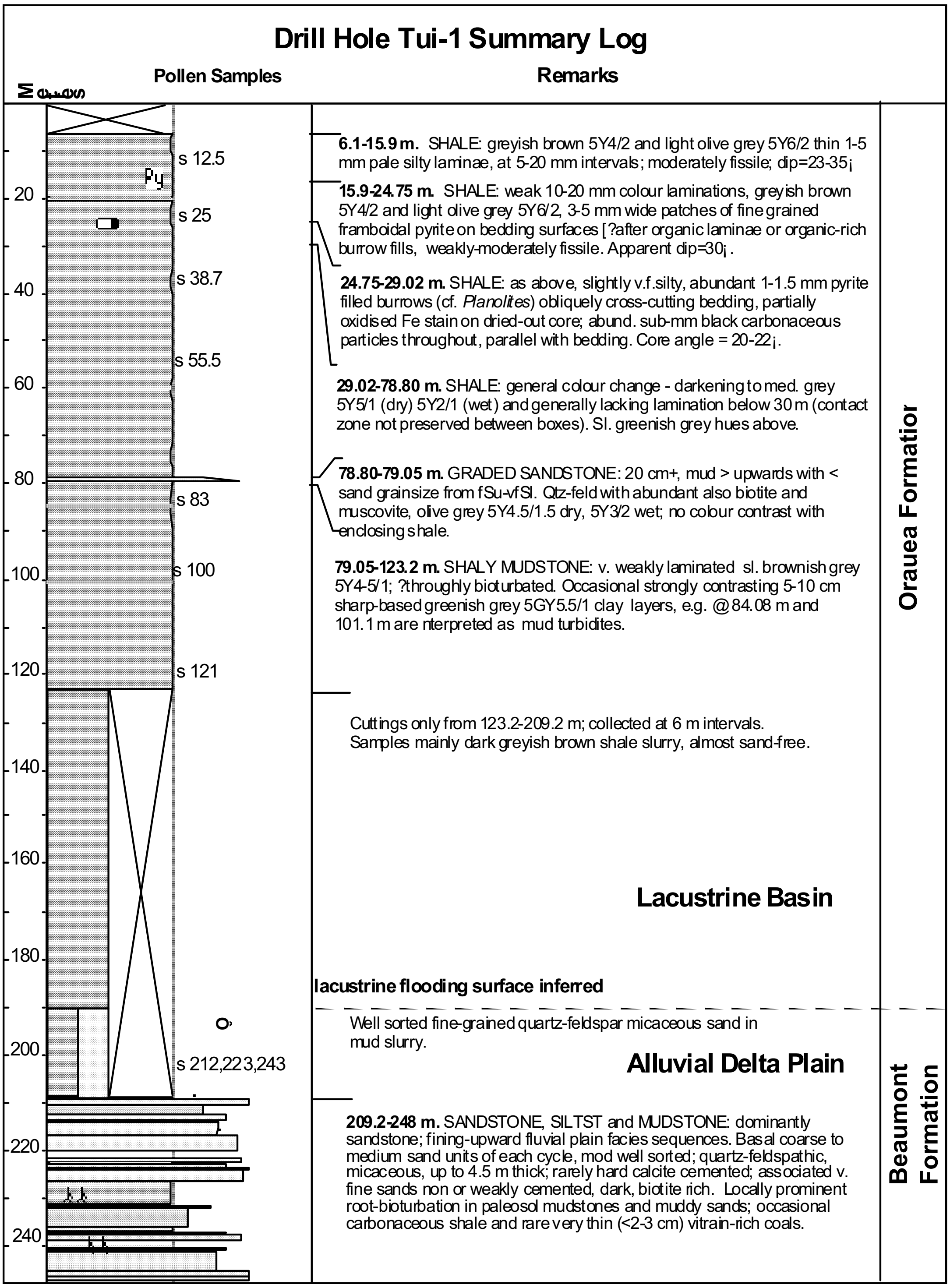


Figure 7.1 Summary log of a cored hole (DSIR Tui-1) near Tuatapere (after Lindqvist & Beggs 1999).

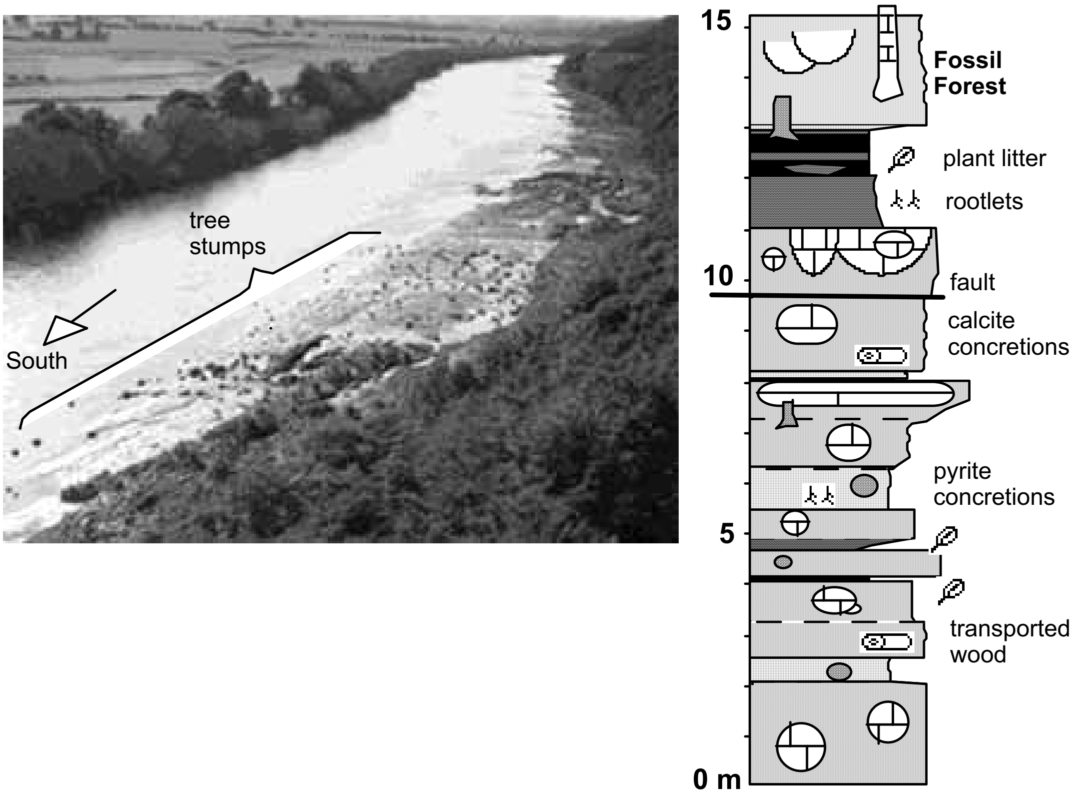


Figure 7.2 Aerial photograph and log of the Pikopiko outcrop section on the east bank of Waiau River. Photo (taken from a microlight) courtesy of H. Marshall and G. Quinn.

Figure 7.3 Pikopiko fossil forest. Tree stumps are represented by columnar calcite-cement sandstone concretions, some with a partially preserved wood core or outer layer.

The plant remains include a diverse variety of angiosperm leaves, at least 6 types of fern fronds, some with intact sporangia (Fig. 7.4), bark, and wood. The leaves which include *Nothofagus*, ?*Metrosideros* and a liane (possibly *Smilax*), are moderately well preserved, and have yielded several different types of epiphyllous fungi that grew on the leaf surfaces. This is the first time that such fungi have been identified from New Zealand, and the diversity of fungal types indicates that the prevailing climate was humid and at least warm temperate. In addition to the leaves, stems and wood, a large slab of bark with very distinctive lenticels closely resembles bark of modern araucarians.

The age of the Beaumont Formation near Pikopiko was considered to be Kaiatan, on the basis of "the persistent dominance of *N. matauraensis* over *N. flemingi*" (Pocknall & Turnbull 1989:377). However, examination of a new palynological sample from one of the fern-bearing horizons (D45/f367) suggests that the age is no older than Runangan, on the basis of relatively abundant *Nothofagidites matauraensis*. Similarly, lack of index species of Late Oligocene and younger suggests that the sample is no younger than Whaingaroan (pers. comm. I. Raine and E. Kennedy). It is likely, on other stratigraphic evidence, that the age is Runangan to early Whaingaroan,

The list of spore and pollens from Pikopiko provided by I. Raine and E. Kennedy can be found in Table 7.1 (together with their possible botanical affinities). The sample provided a rich yield of miospores, with good preservation, but some, possibly biogenic corrosion. As might be expected from the abundance of both fern macrofossils, and epiphyllous fungi in the sample, there was a moderate number of fungal spores and hyphae, but fern spores were dominant, overwhelmingly *Laevigatosporites* sp., with *Cyathidites* the second most abundant taxon.

Table 7.1: Pollen and spore list from a mudstone sample underlying Pikopiko Fossil Forest (D45/f367).

SPORITES:

Taxonomic Name	**Comments**	**Possible Botanical Affinity**
Baculatisporites sp.	finer pattern than B. disconformis	Osmundaceae
Baculatisporites disconformis		Osmundaceae
Biretisporites sp.		Hymenophyllaceae
Cibotiidites tuberculiformis		Dicksoniaceae
Cyathidites minor		Cyatheaceae
Echinosporis sp.		?
Foveotriletes lacunosus		Lycopodiaceae
Gleicheniidites circinidites		Gleicheniaceae
Laevigatosporites ovatus	dominant, including aggregates	? Blechnaceae
Lycopodiumsporites sp. cf. Lycopodium volubile	imperfectly reticulate, zonate	Lycopodiaceae

Taxonomic Name	Comments	Possible Botanical Affinity
Microfoveolatosporis sp.	Psilotum/Tmesipteris type 2	Psilotaceae
Osmundacidites sp.	densely packed verrucae	Osmundaceae
Peromonolites sp.	densus?	?
Peromonolites densus		Blechnaceae
Polypodiaceoisporites cf. tumulatus		Pteridaceae
Polypodiidites sp.		Polypodiaceae
Polypodiidites minimus		Davalliaceae
Punctatosporites sp.	large, Tmesipteris/Psilotum type 1	Psilotaceae
Stereisporites antiquasporites		Sphagnaceae
Todisporites sp.		Osmundaceae

POLLENITES:

Taxonomic Name	Comments
? Fuchsia	uncertain if 2-pored, could be Epilobium
Corsinipollenites oculusnoctis	Jussiaea/Epilobium type.
Cupanieidites orthoteichus	Sapindaceae (Cupanieae)
Dilwynites granulatus	Wollemia
Ephedra notensis	Ephedraceae
Gothanipollis sp.	Loranthaceae
Gothanipollis perplexus	Loranthaceae
Liliacidites sp.	Liliaceae
Malvacipollis subtilis	Euphorbiaceae
Myricipites harrisii	Casuarina
Myrtaceidites parvus	?Metrosideros
Nothofagus (Fuscospora)	Fuscospora - type
Nothofagus brachyspinulosa	Fuscospora - type
Nothofagus flemingii	Fuscospora - type
Nothofagus cranwelliae	Brassospora-type
Nothofagus matauraensis	Brassospora-type
Periporopollenites sp.	
Podocarpidites ellipticus	Podocarpaceae
Proteacidites cf. parvus	Proteaceae
Proteacidites minimus	Proteaceae
Proteacidites pseudomoides	Carnarvonia-type (Proteaceae)
Rhoipites alveolatus	?Gunneraceae
Rhoipites sp.	
Tetracolporites oamaruensis	
Tricolpites spp.	
Tricolporites sp.	pollen aggregate
Triorites minor	
Triporopollenites ambiguus	Telopea-type (Proteaceae)

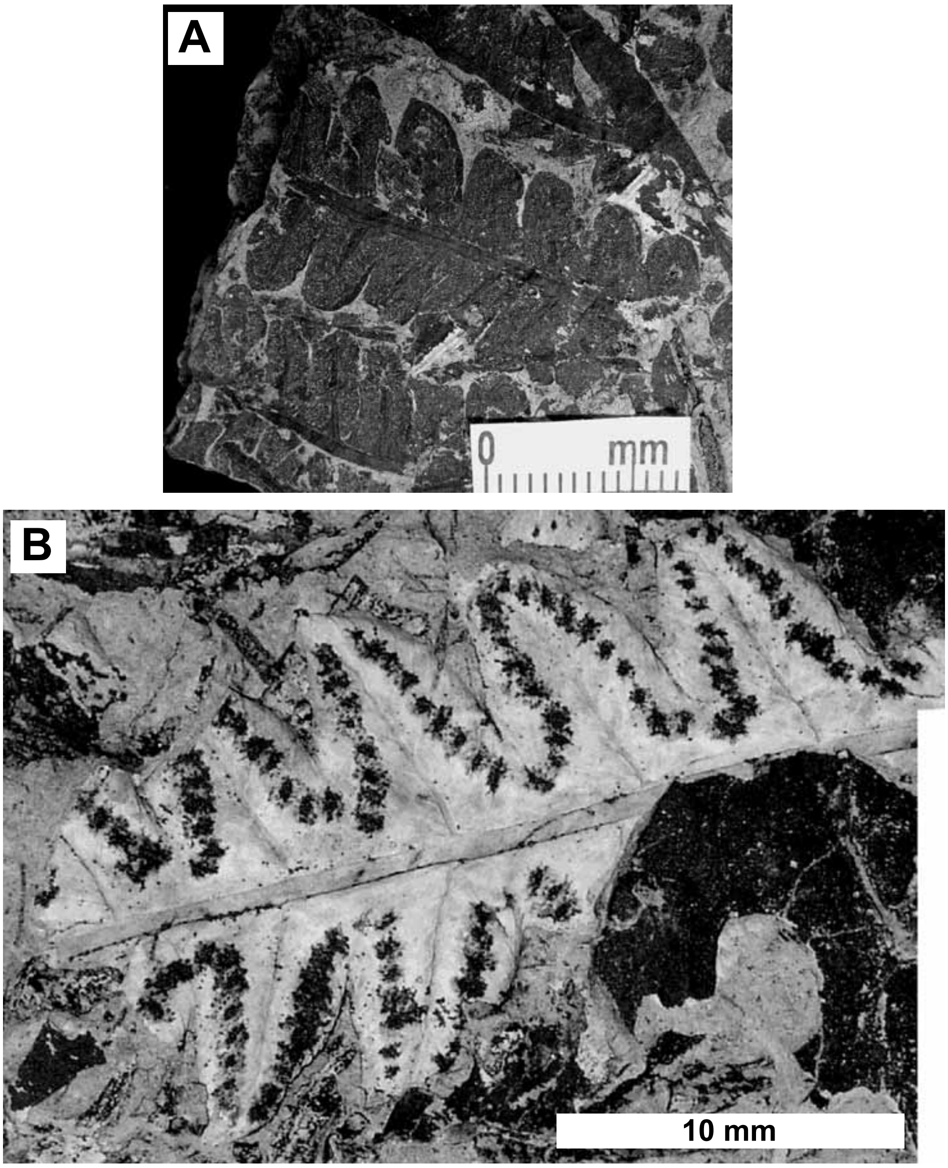


Figure 7.4 Two of the fern macrofossils at Pikopiko include fertile material. A is a species of *Todea* (Osmundaceae) and B a species of *Cyclosorus* (Thelypteridaceae).

STOP 8 BANNOCKBURN INLET

Geological unit: Cromwell Submember, Kawarau Member, Dunstan Formation (Douglas 1986)

Aim: To examine the vegetation of Lower-Middle Miocene swamp and interdistributary bay facies immediately landward of the Lake Manuherikia shoreline.

REGIONAL STRATIGRAPHY AND PALEOGEOGRAPHIC SETTING OF MANUHERIKIA GROUP SEDIMENTS

Manuherikia Group consists of fluvial lignite-bearing Dunstan Formation, and an overlying Bannockburn Formation that consists entirely of lacustrine sediments. A refined stratigraphy (Douglas 1986) subdividing Dunstan Formation into genetic units of regional extent is presented in Figure 8.1.

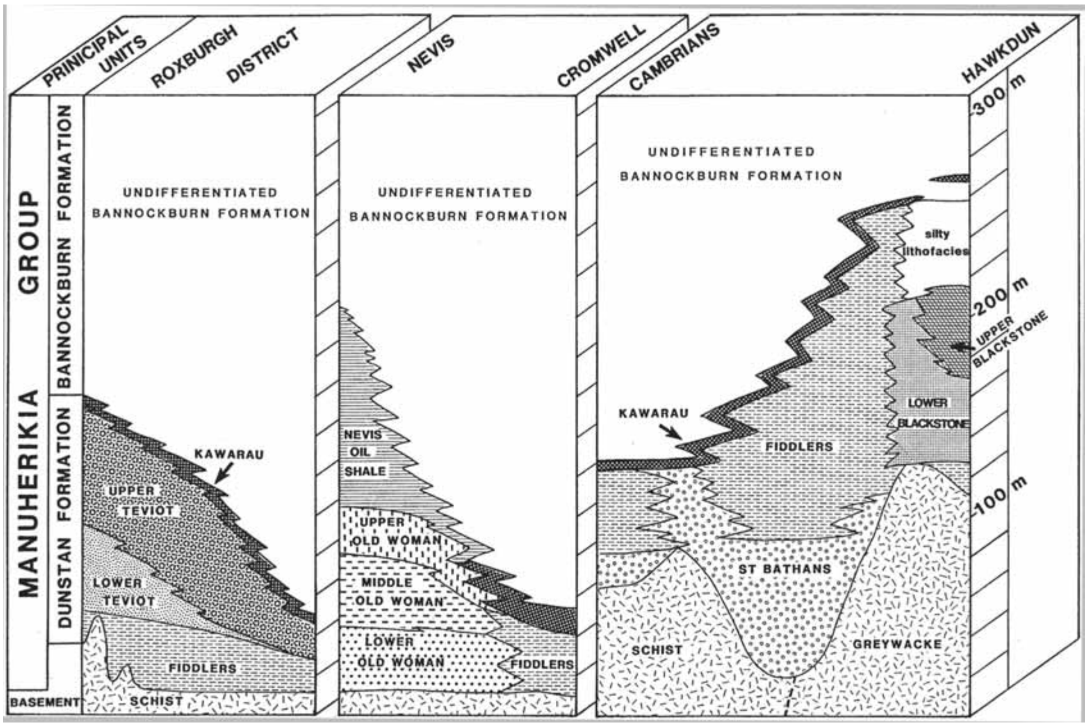


Figure 8.1 Stratigraphic relationships of major Manuherikia Group units.

The earliest Dunstan Formation sediments in Central Otago were deposited by braided river systems that occupied the valley floors of a desolate, irregular, schist and greywacke landscape. The East Otago lower to mid Tertiary marine transgression reached the Naseby district during the Late Oligocene and is not known to have extended further west. The East Otago marine margin was prograding eastward when sedimentation of Manuherikia Group strata commenced inland during the Early Miocene.

The St Bathans member braided channels transported large volumes of deeply weathered regolith material to, and from, the Central Otago catchment, probably to the east coast paralic and shelf environments. A northwest to west source for sediment in the St Bathans paleovalley is indicated.

Roughly coinciding with the dissipation of the braided channel system (during the Early Miocene), a network of sandy, low-gradient meandering channels and muddy flood-basins extended over most of the Central Otago area. They formed the Fiddlers Member alluvial plain (seen at Stop 10).

Fine-grained sediment appears to have been transported towards a depocentre formed from coalescing flood-basins. A long-lived (Early to Late Miocene) large freshwater lake (Lake Manuherikia) ultimately formed, extending over more than 5,600km^2 (Figure 8.2) and accumulating a sediment pile (Bannockburn Formation) up to 700m thick (Douglas 1986). The low channel gradients across the alluvial plain and the large volume of fine to medium sands and mud imply a continual sediment source from a land area of low to moderate relief.

Manuherikia Group sediments that originally covered Central Otago were highly deformed by Kaikoura orogenic events, and are now predominantly preserved in north to north-east trending Central Otago basins, bounded by uplifted schist and greywacke basement ranges (Figure 8.3). Evidence for the former regional continuity of Manuherikia Group is provided by the similarity of local depositional patterns of strata in adjacent basins (Figure 8.4), and by remnant fault-bounded outliers on the range tops.

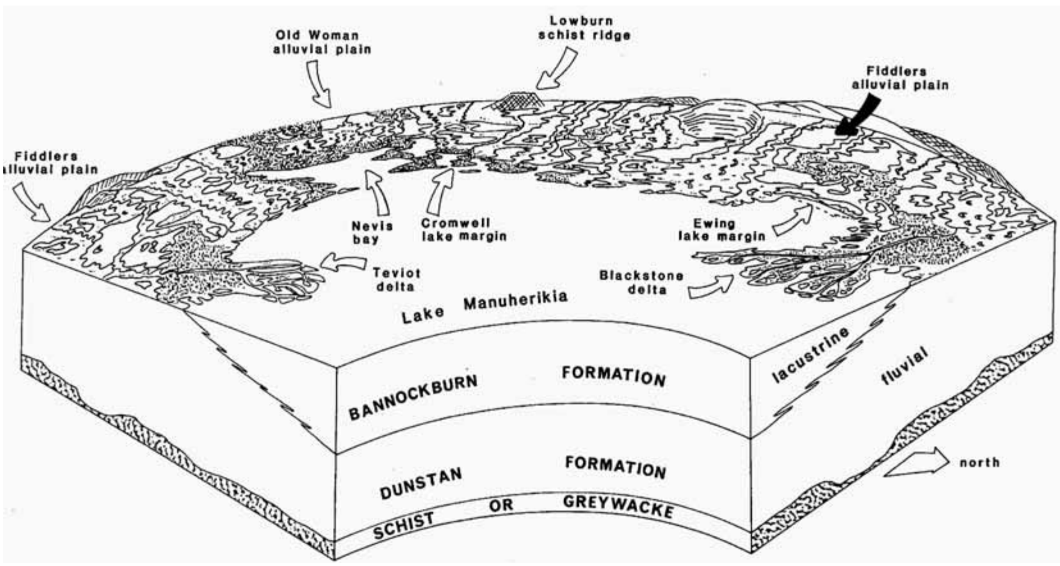


Figure 8.2 Schematic reconstruction of Early to Middle Miocene depositional environments in Central Otago (Douglas 1986).

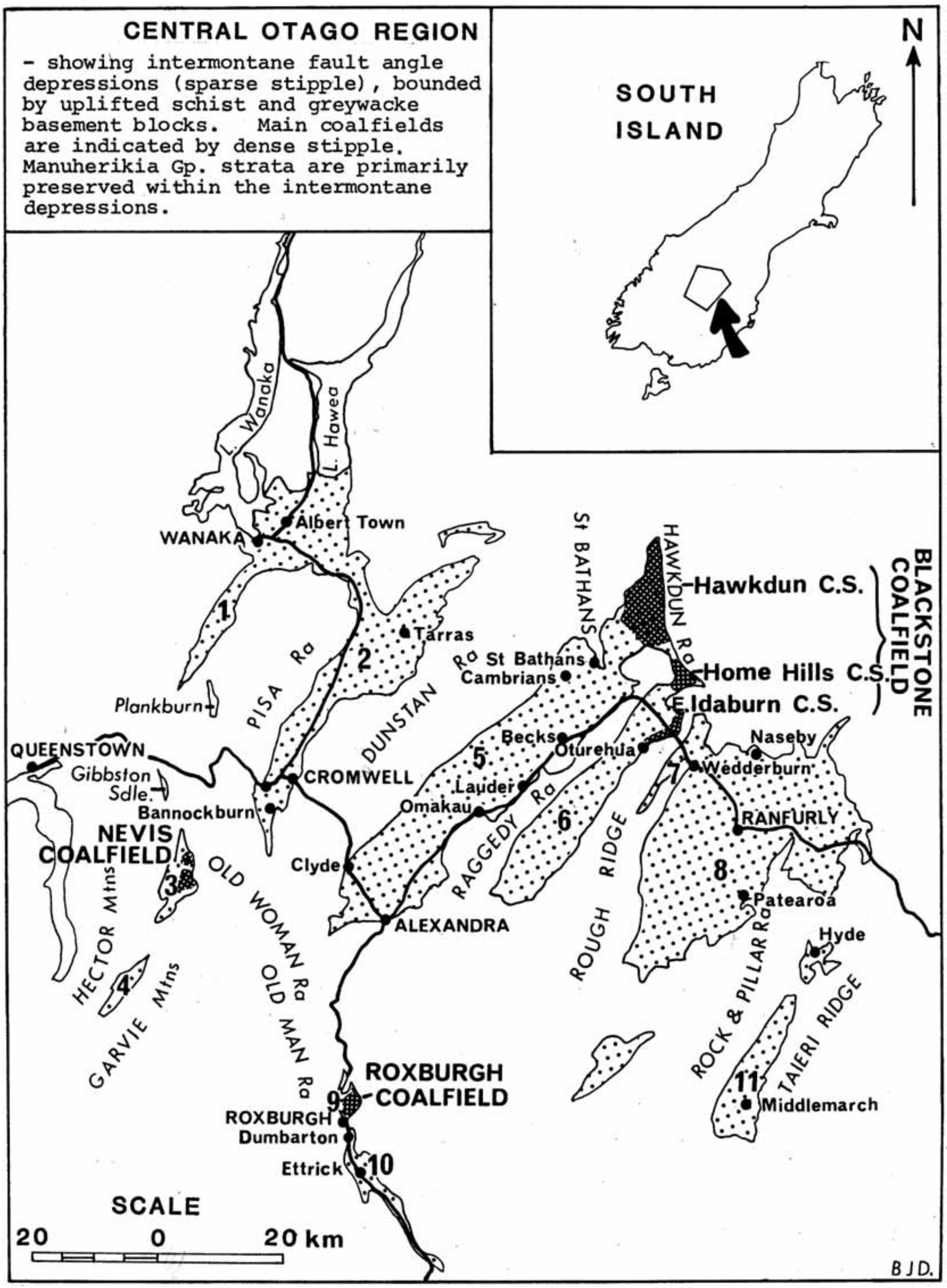


Figure 8.3 Map of Central Otago structural basins: 1, Cardrona Valley; 2, Upper Clutha Valley; 3, Lower Nevis Valley; 4, Upper Nevis Valley; 5, Manuherikia Valley; 6, Ida Valley; 7, White Sow Valley; 8, Maniototo Valley; 9, Roxburgh Basin; 10 Ettrick Basin, 11 Middlemarch Basin.

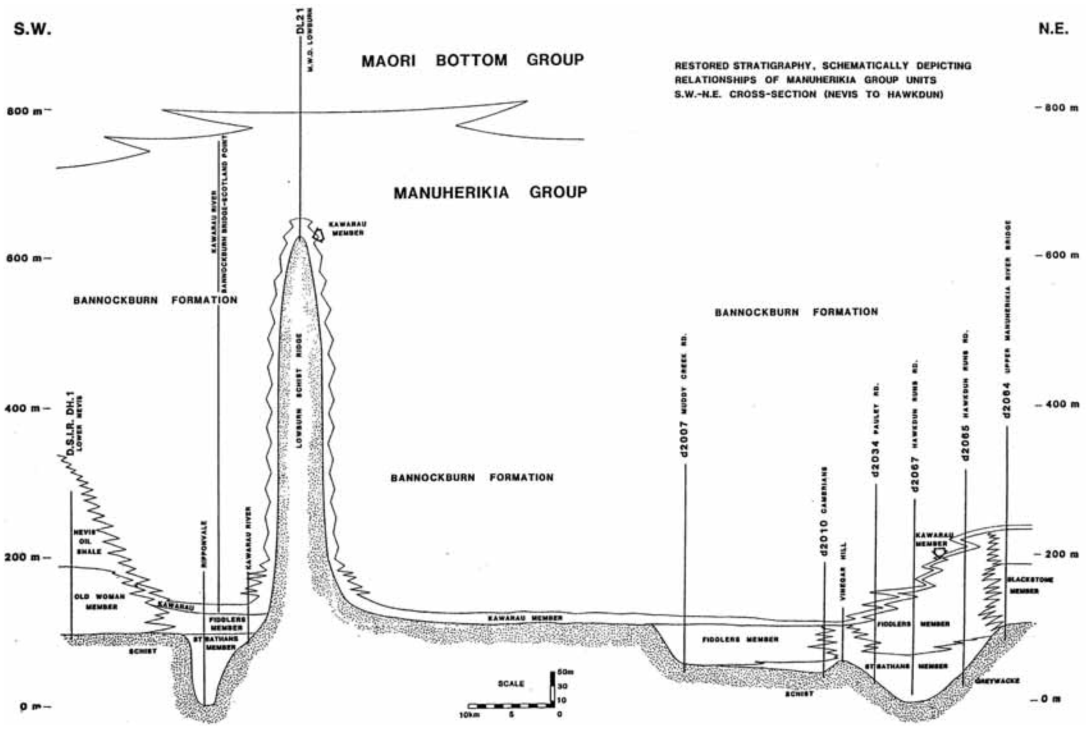


Figure 8.4 Restored stratigraphy, schematically depicting relationships of Manuherikia Group units. SW – NE cross-section (Nevis to Hawkdun).

Bannockburn Inlet

Cromwell Submember consists predominantly of richly carbonaceous lithologies of lignite, carbonaceous mud, richly organic shale (e.g. Nevis Oil Shale), silt, and less commonly of non-carbonaceous mud and sand. These lithologies occur as thin beds arranged into cyclic sequences. Two sequences, A and B, are recognized as closely associated lithogenetic units of lake margin fluvial facies. These sequences are cyclic and occur intercalated with strata of shallow water lacustrine origin that are assigned to the Bannockburn formation (refer to the stratigraphic columns Figures 8.5 and 8.6), from the nearby, now submerged Kawarau River section).

Sequence A consists of lignite (Lithofacies St, peat-forming herbaceous swamp to forest swamp material) and richly carbonaceous mud (Lithofacies Spd, poorly drained muddy swamp deposits). Sequence B consists of moderately carbonaceous rooted mud (Lithofacies Swd, well-drained swamp), thinly bedded or interlaminated silts and muds (Lithofacies LIBwd, well-drained interdistributary bay) and richly organic clayshales and mudshale (Lithofacies Ibpd, poorly drained interdistributary bay).

The geographic setting of poorly drained muddy swamps, peat-forming herbaceous and forest swamps, that encroached over well drained swamps, enveloping infilled or "starved" interdistributary flood-basins and interdistributary bays is illustrated in the paleogeographic model (Figure 8.7) of the fluvial lake margin.

Stratigraphic column (Figure 8.5) of the Cromwell submember records a major overall transgressive succession of lacustrine sediments on-lapping lower alluvial plain swamp-dominated environments. In the upper part of the column section, minor (thin) regressive fluctuations of the lake shoreline represented by short-lived swamp facies, are repeated at least five times.

In the wider Cromwell area, variations in the order and thickness of the lithofacies portrayed in the stratigraphic colums (Figures 8.5 and 8.6) are attributed to an intricate shoreline of complex interfingering facies. In the Bannockburn area, for example, the nearshore facies were locally influenced by distributary-channel sediments discharging into the lake.

Plant fossils

In Central Otago in the early-middle Miocene, the diverse flora included a number of sclerophyll taxa such as *Acacia, Beauprea, Diplopeltis, Gyrostemon, Micrantheum* as well as rainforest taxa such *Ilex, Mischocarpus* and *Symplocos*. Co-existing with these now locally extinct angiosperms were araliads, *Fuchsia, Gunnera, Metrosideros*, *Nothofagus fusca* and *menziesii* types, *Phormium*, *Ripogonum* and *Weinmannia*, as well as many, as yet, unassigned taxa (see Pole 1993c). Pole *et al.,* (2003) note that more than ten conifer taxa are now known from Central Otago, as well as at least three ferns and a cycad. Mildenhall & Pocknall (1989) listed nearly 200 pollen and spore types from the Central Otago area.

Campbell & Holden described a new species of *Casuarina*, *C. avenacea* from Bannockburn and *Casuarina* "cones" and *Nothofagus* leaves are moderately common in a siltstone unit in the roadcut below the Bannockburn Hotel. Campbell *et al*. (2000) described the first fossil divaricate from equivalent beds in the Nevis Oil Shale and suggested that the influence of moa browsing on the New Zealand vegetation was at least this old. Discovery of probable moa egg shell elsewhere in Lake Manuherikia sediments confirms the long history of ratites in New Zealand.

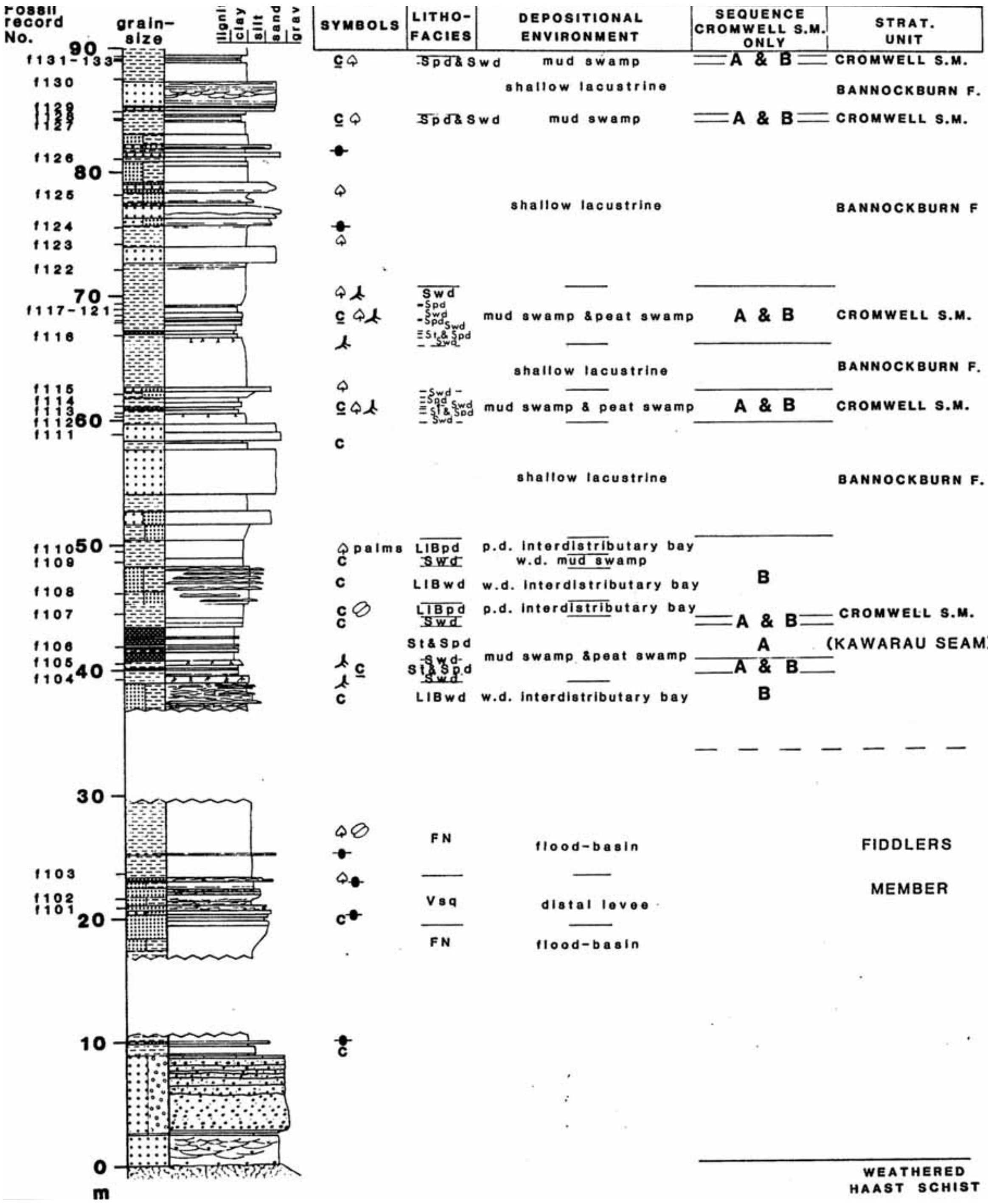


Figure 8.5 Stratigraphic column and interpretation of strata at the type section of the Cromwell Submember at GR F41/099646.

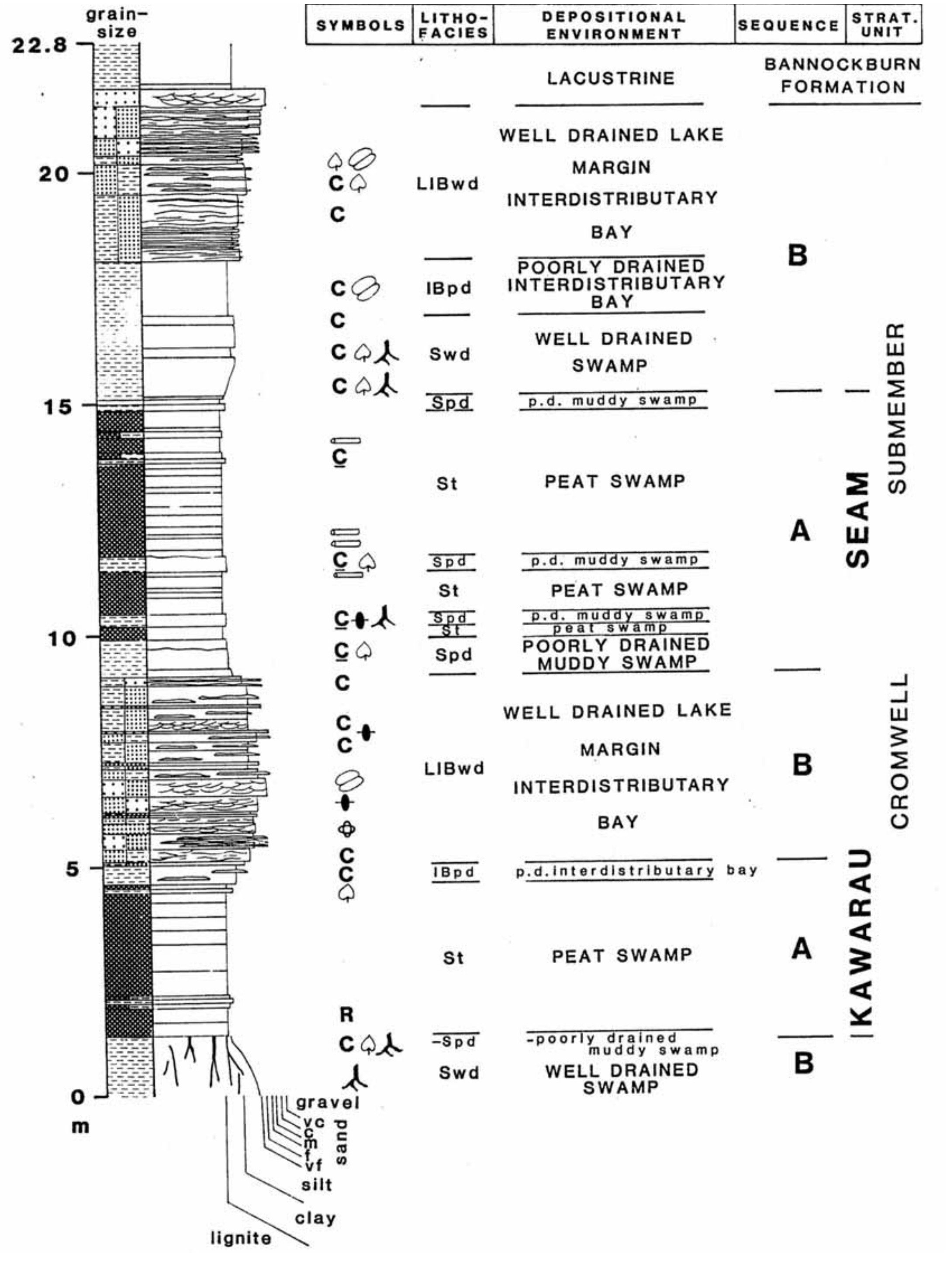


Figure 8.6 Stratigraphic column and interpretation of Cromwell Submember at the type locality of the Kawarau seam at GR F41/096637.

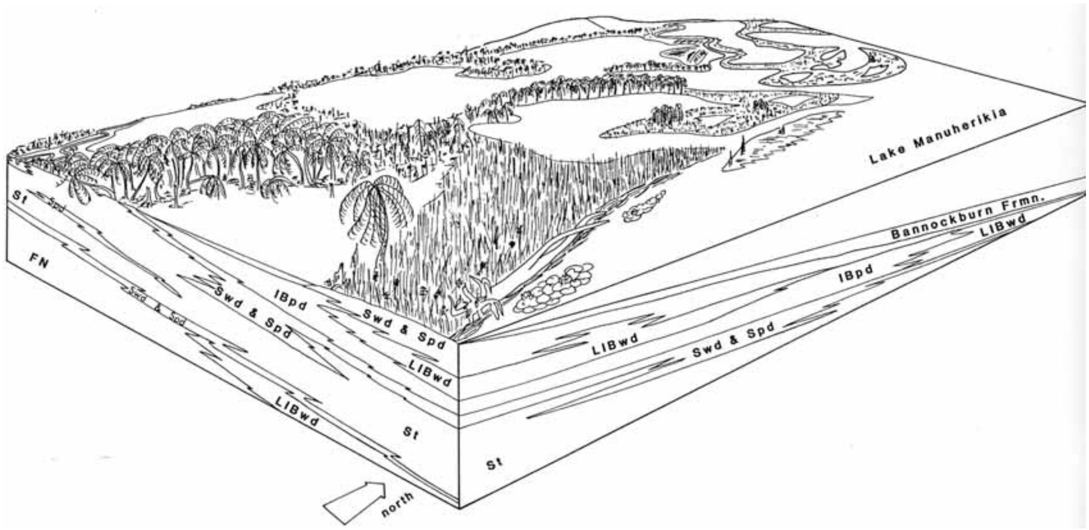


Figure 8.7 Reconstruction of the fluvial-lake margin environment as interpreted from Cromwell Submember lithofacies exposed in the Cromwell-Bannockburn district.

STOP 9 VINEGAR HILL, MANUHERIKIA GROUP

Geological Units: St Bathans Member, Dunstan Formation (Douglas, 1986)
Ewing Submember, Kawarau Member, Dunstan formation (Douglas, 1986)
Lauder Member, Bannockburn formation (Douglas, 1986).

Aim: To examine braided channel facies of St Bathans Member, and littoral-sublittoral lacustrine facies and biota of Bannockburn Formation.

STRATIGRAPHIC AND STRUCTURAL SETTING

Alluvial gold mining primarily by sluicing, but also from hydraulic elevating methods by a number of mining groups between 1878 and 1948 dissected and exposed Manuherikia Group strata on the Vinegar Hill schist ridge. The 70m thick succession of gold-bearing Dunstan Formation and overlying Bannockburn Formation strata exposed and portrayed in Figure 9.1, dip westward off the ridge between en-echelon segments of the Dunstan Fault.

STRATIGRAPHIC AND PALEOGEOGRAPHIC SETTING

St Bathans Member braided plain. The lowermost 47m of the Vinegar Hill succession (Figure 9.1) is assigned to St Bathans Member. Strata are dominated mostly by Sequence E and F type braided channels with minor interfingering of fine grained (predominantly muddy) overbank flood-basin deposits.

Fine grained flood-basin sediments accumulated directly on a kaolinitised schist basement. Clay minerals composing the mudstones are illite and kaolinite with minor smectite. The immediately overlying succession consists of stacked cycles of Sequence E channels. Their bed form of massive or crudely to well defined horizontal stratification, and their profile without any significant downcutting, are indicative of shallow almost unconfined, channels with unstable frequently switching (longitudinal) bars, subject to prolonged periods of high discharge.

Stacked Sequence F channel cycles predominate higher in the succession (27 – 44m above basement). They are characterized by a pronounced incised (erosive) channel form, abundant clay intraclasts and upward fining texture from sandy gravel to mud. They resemble abandoned channel fill deposits, and are similar to channels described from the distal braided part of the Donjek River, elevated above the major active channel zone.

The change in channel pattern from Sequence E to F reflects a lowering of the overall channel gradient associated with the encroachment of Fiddlers Member flood-basin facies and Kawarau Member lake margin facies.

Ewing Submember (Kawarau Member), lake margin fluvial facies. Mostly represented by a 5.5m succession, it includes beds of well sorted coarse silt to fine sand (interpreted as washover deposits), gently inclined and parallel stratified sand to gravelly sand (beach deposits), very dark brownish gray richly organic shale (back-barrier bay deposits), and dark brown carbonaceous mud (poorly drained swamp deposits).

In contrast to the Cromwell Submember (at Stop 8), these beds were deposited in a more wave agitated lake margin environment.

Lauder Member, Bannockburn Formation, nearshore lacustrine facies. Nearshore lacustrine sediments are located in the upper 20m of the Vinegar Hill section. They are dominated by greyish green mudstone and laminated shale. The shale beds have sharp basal contacts, grade upwards into green mudstone, and appear to lack desiccation cracks. The mudstone is intercalated with pebbly sand and muddy sand laminae and beds, normally less than 0.2m thick. These beds often contain algal fragments, fresh water molluscs (*Hyridella* and gastropods), ostracods, fish, egg shell fragments and vertebrate bones that were concentrated in this shallow sublittoral to littoral zone of Lake Manuherikia by wave reworking.

Polygonal desiccation cracks in muddy sediments indicate very shallow and emergent periods of lake water level recession. Rootlet structures are common.

Oncoids (a term used for rounded stromatolites that rolled about during growth) are represented at Vinegar Hill in a single bed. Fine grained laminated carbonate (calcite) composing the stromatolite incorporates small amounts of terrigenous sand and ooids. Small-scale unconformities show that stromatolite growth was frequently interrupted by current-rolling and abrasion, or periodic desiccation. The presence of narrow (1-3mm) fissures containing coated sand-sized grains (ooids) subsequently healed by succeeding layers, suggests that stromatolites growth was affected by emergence and desiccation cracking. Calcified cyanobacterial filaments in the oncoids (Lindqvist, 1994) provide evidence for the likely role of photosynthesis in carbonate precipitation.

Fish remains are common. At least two types of fish *Galaxias* (McDowall and Pole, 1997) and *Gobiomorphus* (R M McDowall *pers. comm. to JKL*) are known from Bannockburn Formation. A diverse range of bird bones, including ducks occur in the littoral zone at Vinegar Hill (Douglas et al. 1981; Douglas 1986) and at several other locations (in Lauder Member) in the St Bathans – Upper Manuherikia valley area. A small crocodilian has been identified (Molnar and Pole, 1997), and the first Tertiary records of sphenodontids and bats from New Zealand have been identified from Vinegar Hill and nearby locations (J McNamara, T Worthy, A Tennyson *pers. comm.,* to Douglas and Pole 2002

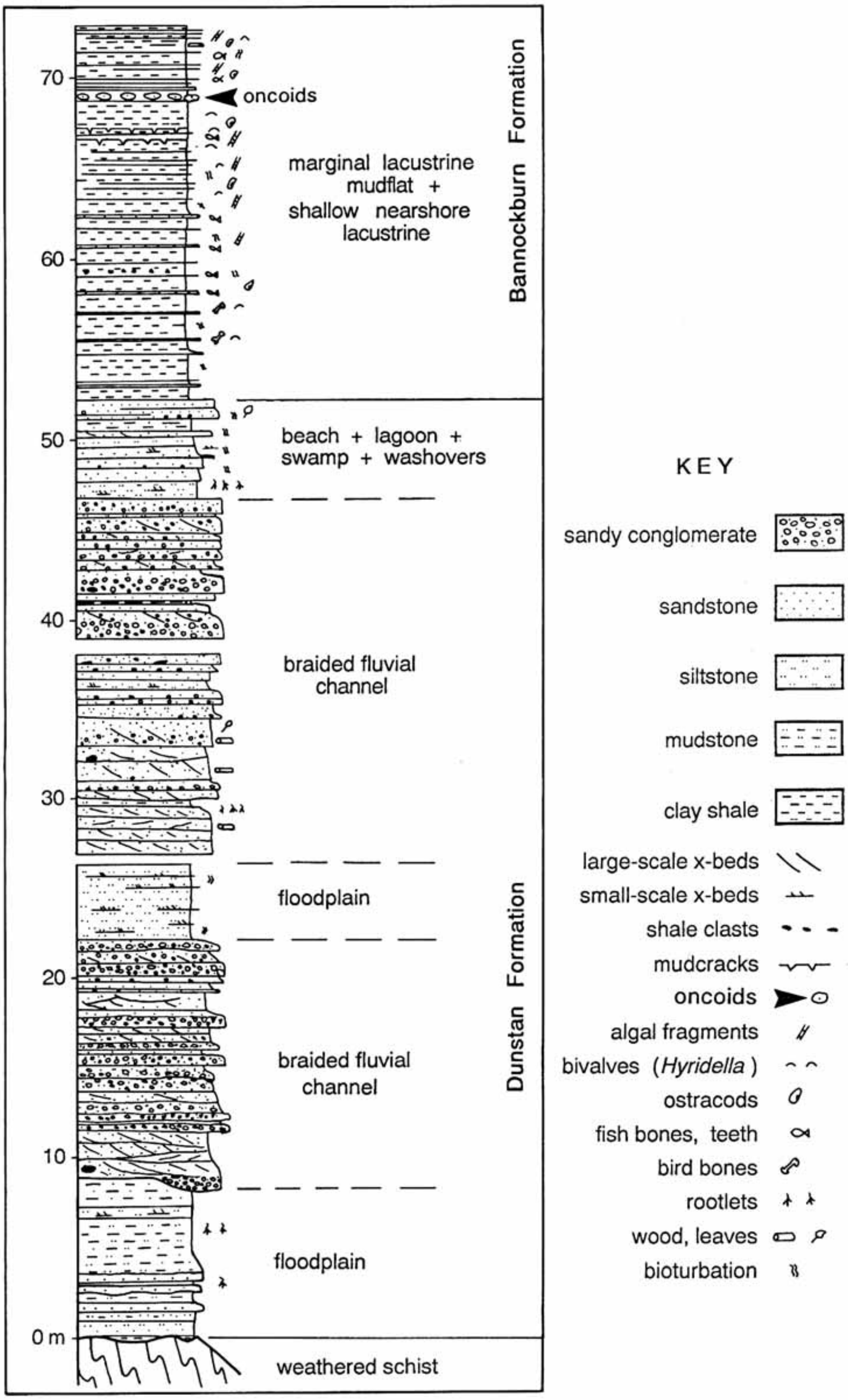


Figure 9.1 Composite stratigraphic column for the Vinegar Hill sections. From Lindqvist (1994).

STOP 10 IDABURN COAL MINE, IDABURN

Former Mine Operator: Idaburn Coal Mining Company Limited.

Geological Unit: Fiddlers Member, Dunstan Formation (Douglas 1986), Manuherikia Group. Type Section of Oturehua Seam.

Aim: To examine a meander channel sequence, and the plant composition of the Oturehua Seam.

STRATIGRAPHIC AND PALEOGEOGRAPHIC SETTING

The pattern of fluvial plain drainage portrayed by the Fiddlers Member in the northern Idaburn district is areally widespread, and formed the principal depositional style of Dunstan Formation architecture.

Regionally Fiddlers Member varies from a few metres to c. 150m thick and primarily consists of a fine-grained non-carbonaceous mud-dominated succession, punctuated by subordinate interbeds of silts, very fine sands, carbonaceous muds and occasional lignite beds.

The regional pattern of Fiddlers Member sedimentation indicates a widespread low-gradient flood-basin dominated plain, peripheral to an enlarging lake (Lake Manuherikia). There were relatively few primary river channels. Channels are all identified with high sinuosity (meandering) geometry, borded by levee and crevasse splay sands and poorly drained swamps. Peat swamps were geographically restricted, favouring development on sandy or silty platforms over infilled flood-basins, where the water table was sufficiently shallow, and the vegetation protected from the choking effect of overbank flood sediments.

INTERPRETATION OF SEQUENCES IN THE IDABURN COAL MINE

Strata cropping out in the highwall of the Idaburn Coal Mine are described and illustrated in Figures 10.1 and 10.2.

Sequence C: Peat forming herbaceous swamp and forest swamp, and poorly drained muddy swamp

Herbaceous and arboreal swamp associations are indicated by well-preserved plant litter. The varied composition of coal beds indicate periodic replacement of plant associations due to fluctuating water table controlled by changes in the drainage pattern, or, to forest swamp fires.

Specific factors that support this interpretation include:

a) Relatively high fusain content of some beds may provide evidence of swamp fires.

b) Abundant woody (xylitic) remains in some horizons, including tree trunks and stumps indicate periods of densely populated forest swamp.

c) Beds rich in densely packed litter composed almost entirely of fern-like rachis, indicative of a relatively open canopy and possibly high water level stands.

d) Fine grained lighter (dark brown) lithotypes, characterised by high pollen concentrations and comparatively devoid of woody (xylitic) detritus are generally associated with open water swamp environments.

e) Very fine quartz sand dispersed through or intercalated with the lignite as discontinuous laminae represents influxes of flood derived sediment into the peat swamp. A distinctive sandy parting correlated with a sandy split in the Oturehua Seam I d2013 suggests a wedge shaped parting thickening westwards towards a probably splay.

f) Lithotypes dominated by an herbaceous flora of reed-like taxa, probably associated with high water levels.

Suspended richly organic sediment accumulated in an open water, poorly drained swamp (Lithofacies Spd), between a peat-forming swamp dominated by an arboreal association (Lithofacies St), and an accretionary channel overbank zone (Sequence E).

Figure 10.1 Oturehua Seam in the Idaburn coal mine, 1977. See Figure 10.2 for details.

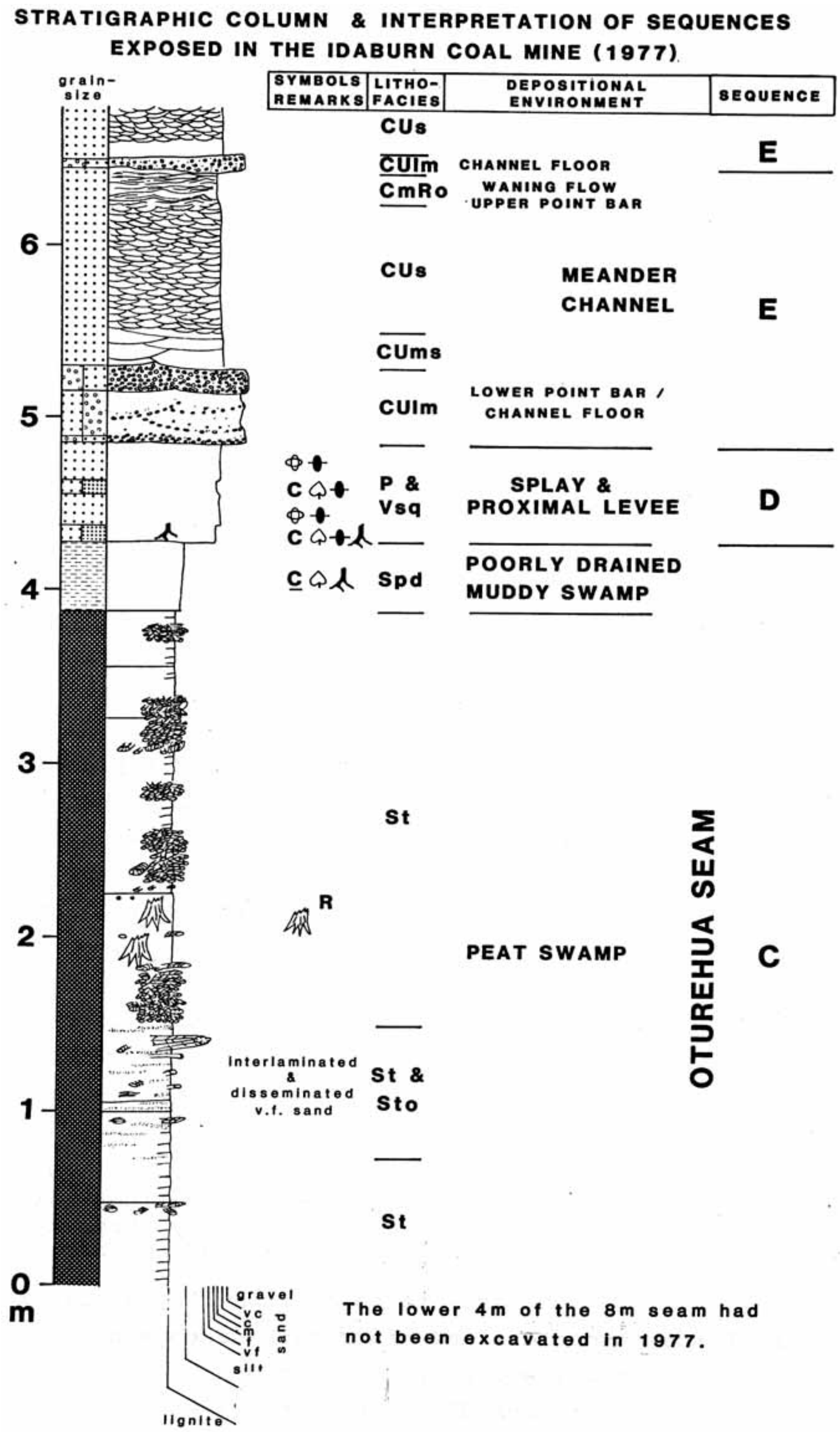


Figure 10.2 Stratigraphic column & interpretation of sequences in the Idaburn coal mine (from Douglas 1986).

Sequence D: Accretionary channel overbank deposits (splay and proximal levee)

Sandy beds of Sequence D represent overbank splay and proximal levee deposits bordering the stream channel (Sequence E) and adjoining a poorly drained swamp, Lithofacies Spd (Sequence C). Carbonaceous detritus was possibly derived from vegetation colonizing levee surfaces, which was inundated and uprooted by floodwaters. Sands with burrow structures and rootlets interbedded with featureless sands attest to a fluctuating discharge flow. During periods of low sedimentation, the sediments were extensively burrowed (destroying sedimentation structures), and the levee surface (at least partially) colonized by vegetation.

Sequence E: Meander Channel

The sandy succession represented by Sequence E is reminiscent of many upward fining cycles first recognised from the Old Red Sandstone. The erosive base of Sequence E is overlain by gravelly sands, succeeded by sediments which illustrate upward fining and a change in amplitude and type of sedimentation structures. The progression from large scale trough cross-stratified sets to very small scale trough cross-stratified sets (Lithofacies Culm to Cums) to finer grained ripple laminated sediments (Lithofacies CmRo) is attributed to waning flow on the point bar of a meandering channel.

The absence of muddy overbank sediments capping Sequence E suggests significant erosion by down-cutting of a younger channel migrating back across a former meander path. Channel meander belt deposits are interpreted from regional data (of stacked channel sequences).

The abandonment or migration of the channel belt and re-establishment of a stable flood-basin environment is recognised from E log data in a nearby borehole d2013, one kilometre west of the Idaburn Coal Mine. In d2013 muds overlie sands stratigraphically equivalent to the sands overlying the Oturehua Seam in the4 Idaburn Coal Mine.

STOP 11 FOULDEN HILLS DIATOMITE NEAR MIDDLEMARCH

Diatomite at Foulden Hills occupies a small half-graben structure closely overlying schist basement. Nearby basaltic volcanics indicate the diatomite may be a maar lake deposit. Over most of the area of exposure the diatomite dips to the east at 15-20^{o}, leveling out and dipping gently westward near its east margin (Fig. 11.1). The total thickness probably approaches 75~100 m. Silica content averages ~85% (Gordon 1954).

The exquisitely laminated (varved) diatomite is presently exposed in several small pits and trenches (Figs. 11.2, 11.3). Below an uppermost white (?) oxidised zone several meters thick much of the diatomite consists of 0.1 mm~1 mm thick organic-poor and organic-rich couplets. A time-frequency analysis and other research is in progress. Individual white-dark couplets probably record winter-summer changes in biological productivity and sedimentation rate rather than fluctuations in detrital mineral input. Conspicuous 5~10 year cycles (Fig. 11.3) may reflect El Nino-Southern Oscillation and sunspot activity-related changes in lake temperature and productivity, analogous to those identified in Green River Formation by Fischer & Roberts (1991) and Ripepe *et al* (1991). Higher-order cycles are also present.

The well-preserved lamination and absence of bioturbation indicate a very sparse benthos and anoxic lake bottom conditions. The deposit has yielded a diverse flora of mostly angiosperm leaves, and rare fossil fish (*Galaxias sp.*). The diatom flora is dominated by a small species of *Cymbella*, although other species are present, along with freshwater sponge spicules. Pole (1993) described a single species of conifer, a broad-leaved *Podocarpus* from the locality, and there are at least 28 species of mainly broad-leaved angiosperm fossils representing more than 10 different families (Pole 1996). Some of the leaves are very large (up to 15cm long), and cuticle is often preserved. *Vizella*-type fungal hyphae are present in at least one cuticle sample. One 2cm diameter fossil flower with five perianth segments (two damaged), and at least five long anthers, with pollen still present *in situ*, is yet to be described.

Couper (1958) listed 26 species of pollen, including an abundance of at least two species of *Nothofagus brassii*-type pollen (*N. cranwelliae, N. matauraensis*), *Casuarina*, an extinct form of *Dysoxylum* (Meliaceae) and *Mischocarpus* (Sapindaceae). Surprisingly, no *Nothofagus* leaves have been found, although *N. brassospora* pollen dominates the pollen flora. The taxa identified by Pole (1996) include *Ripogonum scandens* (supplejack), and representatives of Lauraceae, Myrtaceae, Myrsinaceae, Sapindaceae, Winteraceae. Many of the elements of the Foulden Hills flora such as pecies of *Mallotus* or *Macaranga*, *Ardisia* and *Zygogonum* are now extinct in New Zealand, and their closest living relatives occur in New Caledonia, Lord Howe Island, or Queensland.

The age of the diatomite is Early Miocene (Altonian) from pollen evidence, which closely matches the c. 20 Ma radiometric age from nearby volcanics (Coombs *et al*. 1976). Assuming an average varve thickness of 0.5 mm, a detailed record of perhaps 150,000 to 200,000 years may be preserved in the diatomite.

Figure 11.1 Diatomite exposed in a small pit close to the eastern margin of the Foulden Hills deposit.

Figure 11.2 The diatomite shows mm-thick varves of white (organic-poor) and dark (moderately organic) layers, as well as several longer-period orders of cyclicity.

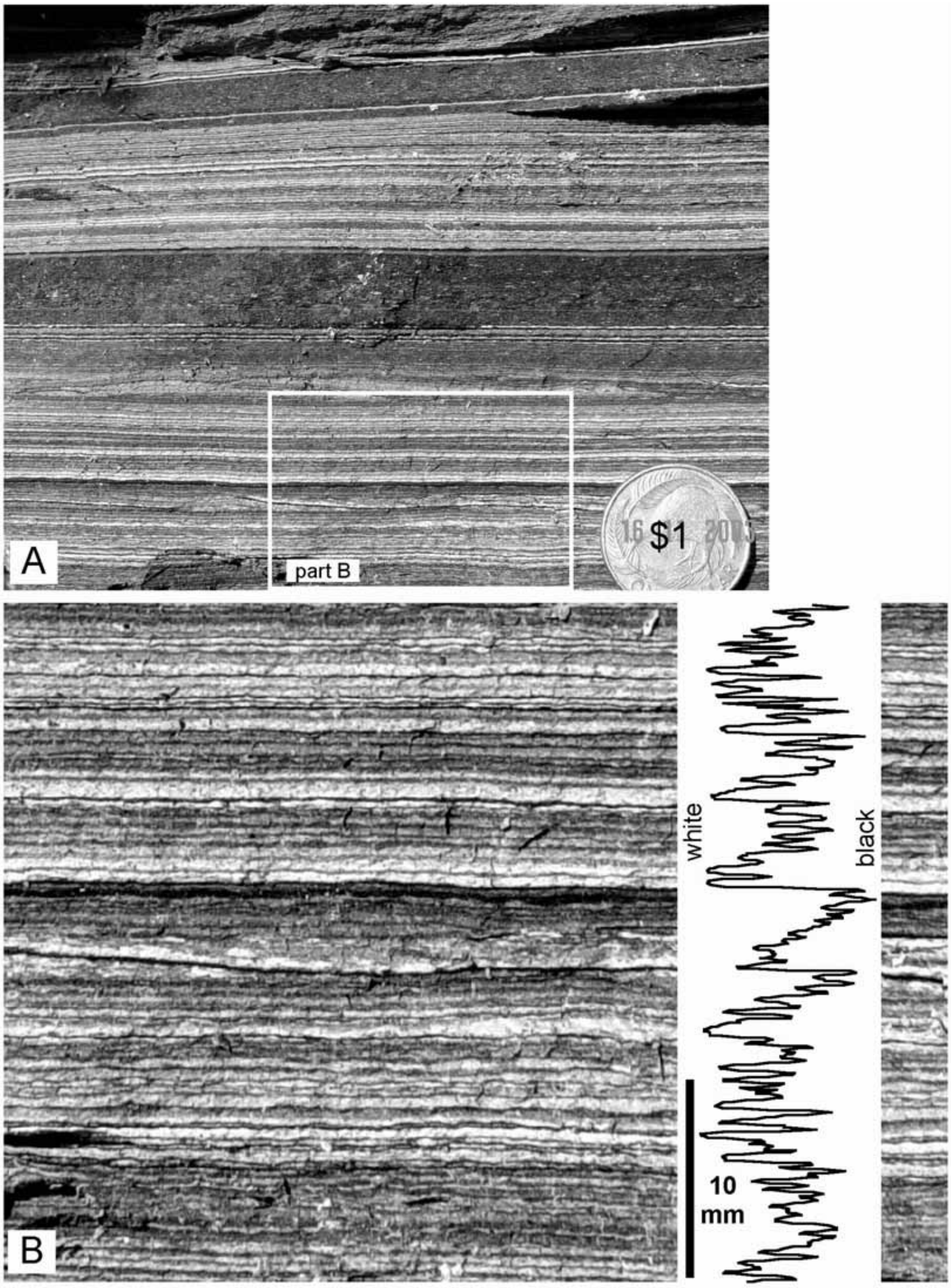


Figure 11.3 (A) Diatomite varves. The cm-thick mottled dark intervals include very thin white laminae. Do they represent extended periods of long hot summers? **(B)** A grey-scale plot shows 5~10+ year cycles of progressively increasing dark-layer thickness and reduced white-layer thickness. Average varve thickness is about 0.5 mm.

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