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L. J. Brown , D. D. Wilson , N. T. Moar & D. C. Mildenhall

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Stratigraphy of the late Quaternary deposits of the northern Canterbury Plains, New Zealand

L. J. BROWN
New Zealand Geological Survey
Department of Scientific and Industrial Research
P.O. Box 30 368
Lower Hutt, New Zealand

D. D. WILSON
7 Paulus Terrace
Cashmere
Christchurch, New Zealand

with an Appendix

Pollen assemblages from late Quaternary deposits in Canterbury

N. T. MOAR
Botany Division
Department of Scientific and Industrial Research
Private Bag
Christchurch, New Zealand

D. C. MILDENHALL
New Zealand Geological Survey
Department of Scientific and Industrial Research
P.O. Box 30 368
Lower Hutt, New Zealand

Abstract Stratigraphic correlations of late Quaternary subsurface deposits of the Canterbury Plains, New Zealand, are revised and defined using well logs, radiocarbon dates, and pollen analyses. Three new members—**Bleak House, Riverview,** and **Courtenay**—are proposed for the postglacial fluvial Springston Formation. Riccarton Gravel (last glaciation) and Bromley Formation (last interglaciation) are revised. Five new formations are defined for coastal subsurface deposits to depths of about 170 m. **Heathcote** and **Shirley Formations** are proposed for older possibly interglacial terrestrial and marine deposits. Interbedded subsurface gravel deposits representing deposition during predominantly glacial periods are assigned stratigraphic names—**Linwood, Burwood** and **Wainoni Gravels,** and tentatively correlated with outwash deposits of the inland Canterbury Plains.

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Keywords Canterbury Plains; Christchurch; Quaternary; well logs; ground water; C-14; palynology; Waimakariri River; Heathcote Formation; Shirley Formation; Linwood Gravel; Burwood Gravel; Wainoni Gravel; new stratigraphic names; Springston Formation; Riccarton Gravel; Bromley Formation.

INTRODUCTION

Suggate (1958) described formations for the Quaternary deposits underlying Christchurch in terms of two sets of glacial deposits, intervening "last interglacial" and subsequent "postglacial". He correlated the glacial deposits with those described by Gage (1958) in the Waimakariri River valley. Further development of correlations across the Canterbury Plains (Suggate 1963) and revision of glaciations (Suggate 1965) led to changes adopted in the 1:250 000 geological mapping of part of the Canterbury Plains by Suggate (1973) and 1:63 360 mapping of coastal North Canterbury by Brown (1973).

Additional geological mapping of the plains' surface west of Christchurch (Wilson in press), and examination of several hundred well logs and samples from coastal Canterbury wells, provides a basis to extend Suggate's (1958, 1963, 1965) Quaternary stratigraphy of the plains.

The gravel deposits of the Canterbury Plains are proved (in three petroleum exploration bores) to be over 500 m thick (Wilson 1985). Coastal North Canterbury wells penetrate gravel strata interbedded with silt, clay, peat, and shelly sand and clay, down to explored depths of 223 m. The fine

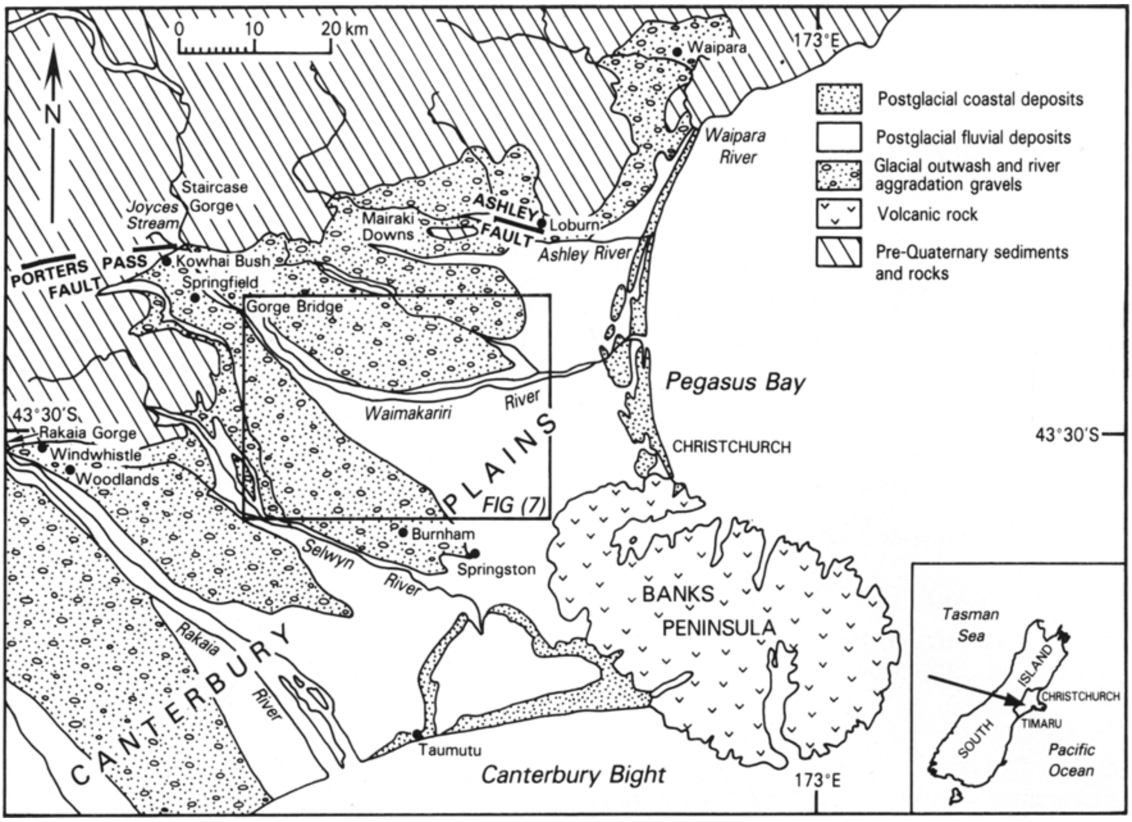

Fig. 1 Quaternary surface deposits of the northern Canterbury Plains

sediments form aquicludes and aquitards separating gravel deposits which form aquifers. The gravel strata are inferred to represent deposition during glacial periods by rivers building coalescing fans across the Canterbury Plains. Inland reworking and coastal redeposition of gravel occurred during milder interglacial periods as river profiles adjusted to sea-level changes.

Definitive assigning of subsurface gravel strata to Suggate's (1965, 1985) Quaternary glacial stages and correlation with outwash deposits of the inland Canterbury Plains is rejected for two reasons. It is impossible to recognise erosion intervals within deposits penetrated by wells in inland Canterbury, and the gravel deposits near the coast are likely to include interglacial reworked gravel as well as glacial outwash gravels. Correlation of gravel strata between wells is made on the basis of the gravel aquifers and the intervening fine-sediment strata, and may not be conclusive. Gravel strata and the intervening fine sediments, some containing peat and shellbeds, are formally recognised and named for the gravel aquifers and the interbedded aquicludes and aquitards, and tentative correlations are suggested with Suggate's (1965, 1985) glacial stages.

Outline of geology

The Canterbury Plains extend over a 50 km wide and 160 km long area from Timaru to the Waipara River and east to Banks Peninsula (Fig. 1). They are formed by a series of coalescing alluvial fans built by the Waimakariri River and other Canterbury rivers emerging from the Southern Alps and foothills. The rock in the mountain catchments of the Canterbury rivers is almost entirely indurated Mesozoic sandstone and mudstone ("greywacke and argillite"). In the Waimakariri River valley, glaciers extended downvalley to close to the western margin of the plains and possibly out onto the plain for the Avoca advance (Gage 1958) (Table 1); sea level was as low as 150 m below present sea level (Chappell 1983), and glacial outwash alluvial fans built out to beyond the present-day coast.

Table 1 Nomenclature and tentative correlations of late Quaternary stratigraphic units of the northern Canterbury Plains.

Waimakariri glacial advances	Canterbury Plains			Coastal North Canterbury			Climatic event
Gage (1958)	Oborn & Suggate (1959)	Suggate (1963)	Suggate (1965 & 1973)	Suggate (1958)	Brown (1973)	This paper	(Suggate 1965 & 1985)
			Christchurch	Christchurch	Christchurch	Christchurch (coastal marine associated deposits)	
		Springston	Springston	Yaldhurst surface	Springston	Springston (fluvial deposits)	
					Yaldhurst Member	Yaldhurst Member	
					Halkett Member	Halkett Member	Aranui Postglacial
						Courtenay Member Riverview Member Bleak House Member	
Poulter (not recognised on Canterbury Plains)			St Bernard				
Blackwater 1–2	Springston	Burnham	Burnham	*Riccarton Gravel	Burnham		
				Halkett surface	*Riccarton Gravel	*Riccarton Gravel (fluviatile gravel)	Otira Glaciation
Otarama	Burnham	Windwhistle	Windwhistle	Darfield surface			
				*Bromley	*Bromley	*Bromley (coastal marine associated deposits)	Kaihinu Interglacial
Woodstock	Woodlands	Woodlands	Woodlands		Woodlands	†*Linwood Gravel (fluviatile gravel)	Waimea Glaciation
						†*Heathcote (coastal marine associated deposits)	Karoro Interglacial
Avoca	Hororata (part)	Hororata (part)	Hororata (part)		Hororata (part)	†*Burwood Gravel (fluviatile gravel)	Waimaunga Glaciation
						†*Shirley (coastal marine associated deposits)	Scandinavia Interglacial
Avoca	Hororata (part)	Hororata (part)	Hororata (part)		Hororata (part)	†*Wainoni Gravel (fluviatile gravel)	Nemona Glaciation
						*Unnamed (?coastal marine associated deposits)	Unnamed interglacial

* Subsurface formations † New formations

Rising interglacial and postglacial sea level resulted in transgressions of the sea westward over the land with swamp, estuary, lagoon, and beach deposits accumulating over the alluvial fans. Entrenchment of rivers into their glacial outwash and postglacial fan deposits in response to the rising and stable sea levels, as well as a continuing supply of material from the Southern Alps, provide the sediment for progradation. The Canterbury Plains coast from Taumutu (north of the Rakaia River mouth) to the Waipara River has prograded during the last 6000 years of relatively stable high sea level. In the Waimakariri River, the present-day transition point from upstream downcutting to downstream fan building, occurs about 18 km from the sea, having migrated downstream some 27 km in the 14 000 years of postglacial time (Wilson 1973, 1985). Flood control and shingle extraction since European settlement have also forced adjustment of the Waimakariri River bed (Griffiths 1979).

Subsurface deposits

Water wells in coastal North Canterbury penetrate a sequence of gravel, sand, and silt interbedded with silt, clay, and shell often with peat. The deepest known peat beneath the Canterbury Plains is at a depth of 215 m (about 180 m below present-day sea level) in well M35/w1039* at Islington (Fig. 2, 3). As the lowest eustatic sea levels of the glacial periods of the last 300 000 years are unlikely to have exceeded 150 m below present-day sea level (Chappell 1983), tectonic subsidence with possibly compaction must be invoked to explain the deep peat layers.

Compaction of peat, silt, and clay deposits is demonstrated by postglacial deposits at the coast. Near-surface gravel deposited in channels during incursions by Waimakariri River floods into the coastal swamp area, forms ridges on the present-day surface as a result of consolidation of adjacent peat, silt, and clay deposits following drainage and dewatering. The amount of compaction depends on sediment lithologies and thickness—thick subsurface peat layers influence the depositional attitude of the overlying sediments and may affect correlation between wells.

Surface effects of tectonism are shown by several aspects of the geology of northern Canterbury Plains. The Ashley Fault on the north bank of the Ashley River near Loburn dislocates gravel of the last glaciation. The Porters Pass Fault to the west of the Canterbury Plains near Kowhai Bush also has postglacial movement. The moderately young high-level gravels of Mairaki Downs show slight folding of bedding planes (Fig. 1).

In the strata underlying the coastal Canterbury Plains, however, it is impossible to detect specific downwarping, uplift, or dislocation of strata. Speight (1943) noted that volcanic rock is buried at the northern margin of Banks Peninsula. Wells encounter volcanic rock rubble below sea level up to 1 km from Banks Peninsula (see well M36/w975 at Beckenham, Fig. 2). These rubble deposits which are up to 216 m below present-day sea level (well M36/w1107 at Ferrymead, Fig. 2), possibly accumulated in a littoral marine environment and are usually overlain by fine sediment deposits. Like the deep peat layers, these beach deposits suggest compaction and subsidence since deposition.

*Number assigned to well by the North Canterbury Regional Water Board when the record is filed within the specific NZMS 260 (1:50 000) sheet.

STRATIGRAPHY

Previous Quaternary stratigraphy for coastal North Canterbury subsurface formations and the proposed sequence are tentatively correlated in Table 1 with the glacial and interglacial sequence of Suggate (1965, 1985). Table 2 summarises the main details of the new and revised stratigraphic units. These are described in order of increasing age rather than the conventional method of decreasing age. Increasing age corresponds to increasing depth and is considered more appropriate for describing stratigraphic units as penetrated by wells.

CHRISTCHURCH FORMATION
(Suggate 1958)

No change is needed in the definition of the Christchurch Formation of Suggate (1958), apart from metrication of numbers for three wells designated as type sections (Table 2 and Fig. 4). The formation overlies the Riccarton Gravel and Burnham Formation in the east, and interfingers with the contemporaneous fluvial Springston Formation in the west. It comprises beach, estuarine, lagoonal, dune, and coastal swamp deposits of gravel, sand, silt, clay, shell, and peat, deposited during and after the rise of sea level since the end of the Otira Glaciation about 14 000 years ago. The basal beds of Christchurch Formation consist of swamp and estuarine silt and peat.

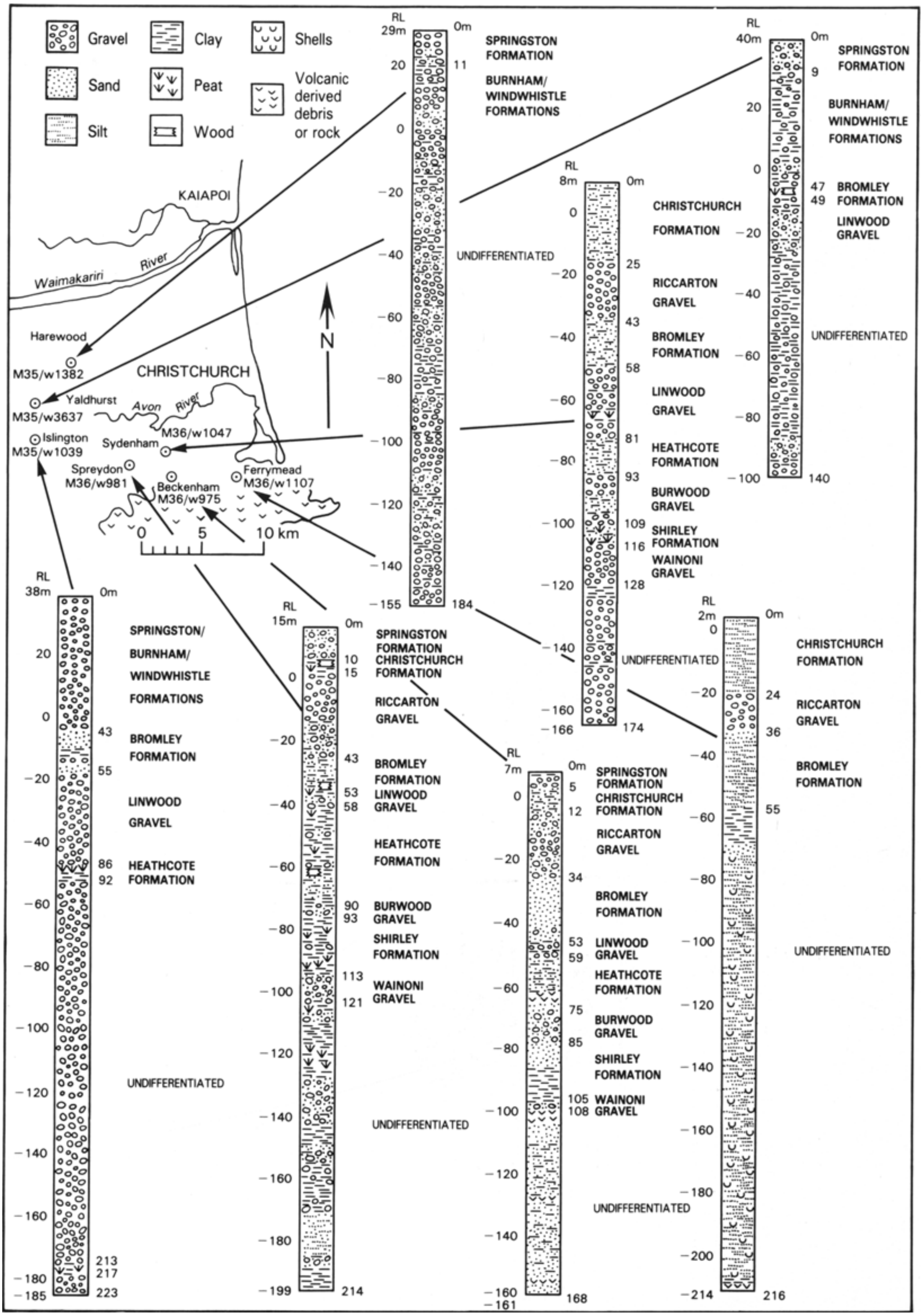

Fig. 2 Stratigraphy of deposits penetrated by deep wells about Christchurch.

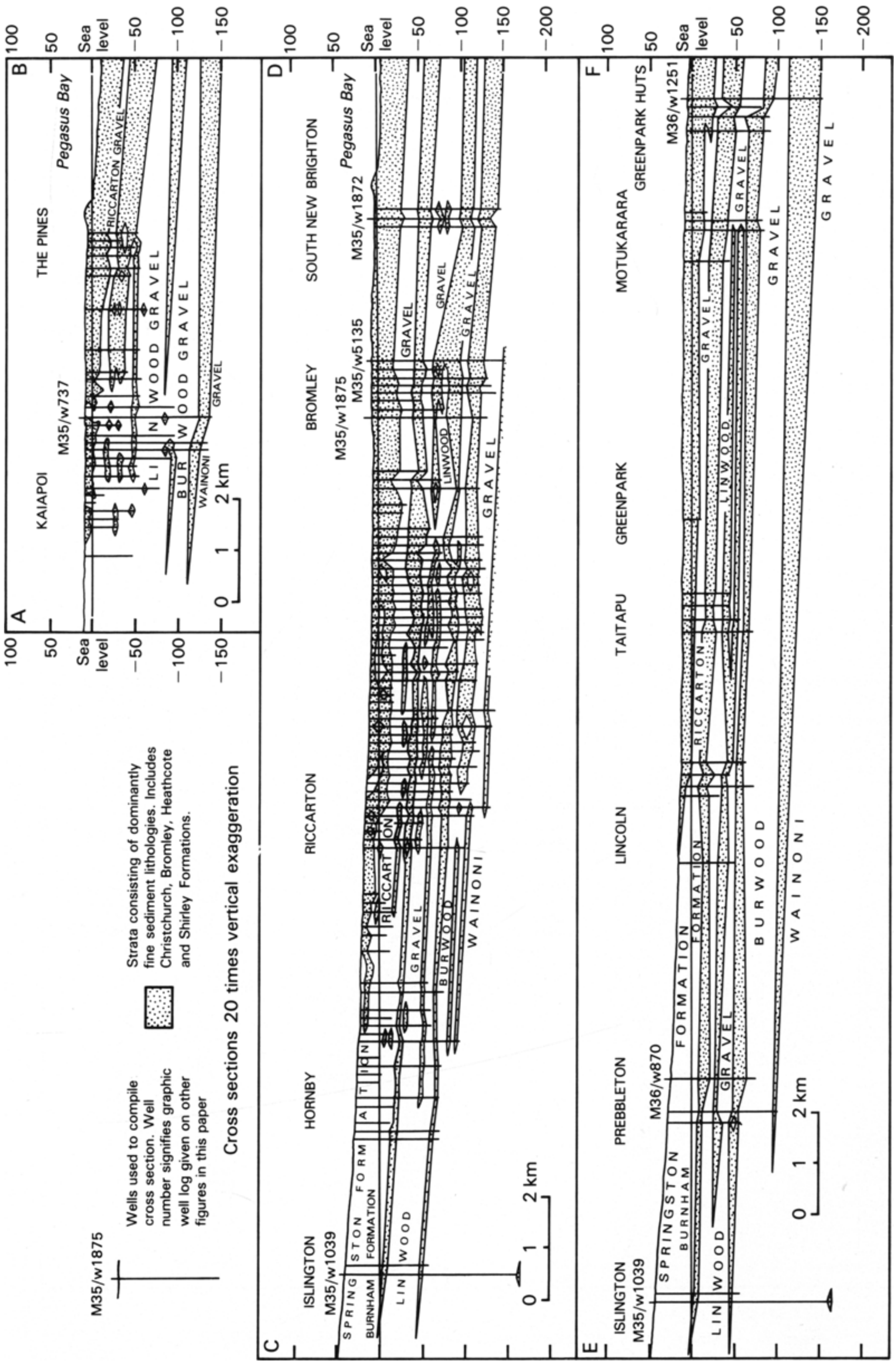

Fig. 3 Section lines across coastal Canterbury Plains: cross section A–B through Kaiapoi; cross section C–D through Christchurch; cross section E–F Islington to Lake Ellesmere. See Fig. 4 for location.

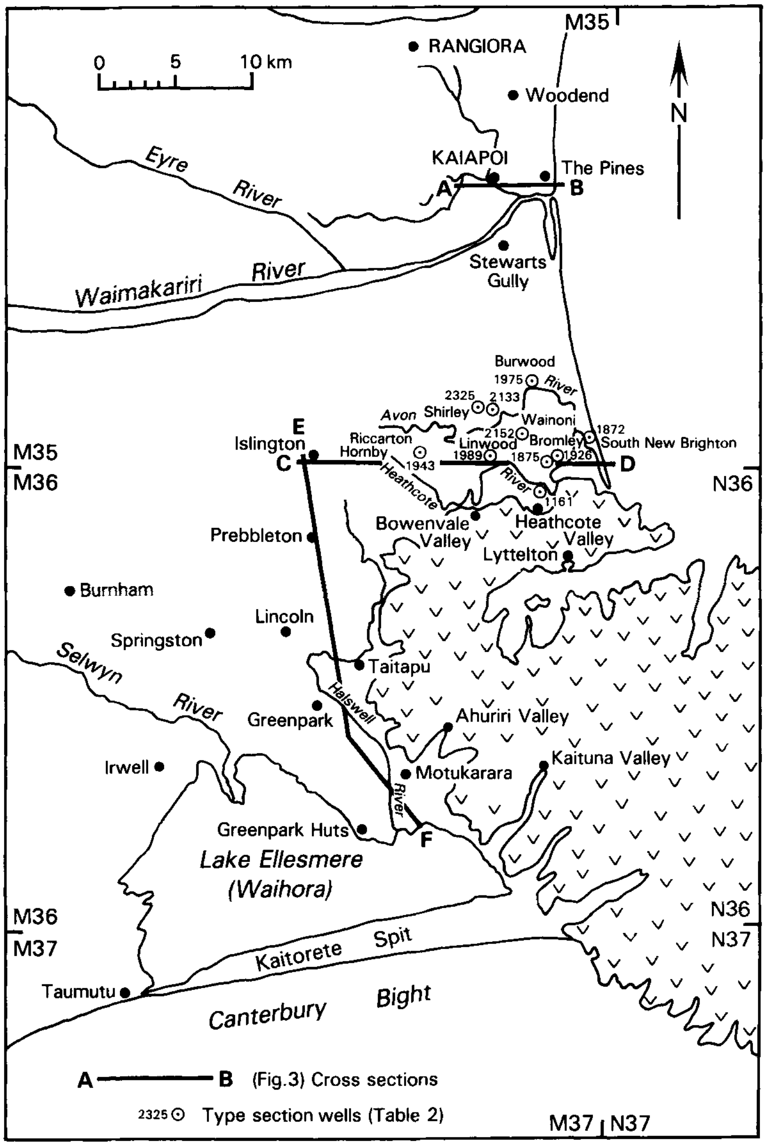

Fig. 4 Canterbury Plains adjacent to Banks Peninsula, showing locations of cross sections given in Fig. 3 and type section wells given in Table 2.

Progradational surface or uppermost layers of Christchurch Formation include fixed dune sand and drained interdune swamp and estuarine deposits, and they crop out along the North Canterbury coast from the Waipara River mouth to the Rakaia River mouth. Subsurface deposits extend inland (Fig. 5, 6). The maximum inland extent of the postglacial marine transgression occurred about 6500–6000 years ago, judged by radiocarbon-dated estuarine shells (NZ120A,* 6200 ± 120 years B.P., Riccarton; NZ4711A, 6600 ± 140 years B.P., Northcote), when sea level had risen to a level similar to that of the present day. Its thickness varies from a few metres to at least 40 m at the New Brighton coast.

Kaitorete Spit, a beach barrier, encloses Lake Ellesmere (Fig. 4). Subsurface beach gravels and sand cannot be recognised with certainty in well logs. However, between Woodend and Stewarts Gully, 4–5 km inland from the North Canterbury coast, a subsurface deposit of coarse sand, locally called the "Kaiapoi grit", is probably a beach sand; its top is 0–5 m below mean sea level near Kaiapoi (5–10 m below ground surface). The Kaiapoi grit

* New Zealand Radiocarbon Dating Laboratory sample number. Old half life uncorrected for secular effects in years before present.

Table 2 Northern Canterbury Plains late Quaternary stratigraphic units.

Formation	Type section	Geographic distribution	Lithologic content	Thickness	Depositional environment
Christchurch Formation (Suggate 1958)	Well M35/w1872* South New Brighton M35/886417 Well M35/w2325† Richmond M35/825438 Well M35/w1943‡ Riccarton M35/783416	North Canterbury coast—Waipara River to Rakaia River mouth	Predominantly blue gravel, sand, shelly, sand and silt, clay, peat, and wood	Maximum thickness of 40 m from ground surface at New Brighton coast	Beach, lagoonal, dune, and coastal swamp sediments deposited as a result of post-glacial marine transgression and progradation
Springston Formation (Suggate 1963)	Gravel pit Springston M36/673348 Type localities:	Canterbury Plains —floodplains immediately adjacent to rivers on inland plains but fanning out towards coast	Well sorted rounded gravel with dominantly sand matrix but sometimes lenses of silt and clay	Maximum thickness of 20 m to west of Christchurch	Degradational lag deposits and aggradational fan deposits of river gravel and overbank silt and coastal flood channels
Yaldhurst Member (Suggate 1958)	Yaldhurst M35/663515				
Halkett Member (Suggate 1958)	Halkett M35/551451				
Courtenay Member	Courtenay domain L35/458497				
Riverview Member	Riverview homestead L35/426511				
Bleak House Member	Bleak House homestead L35/381554				
			EROSION INTERVAL		
Burnham Formation (Oborn & Suggate 1959 and Suggate 1963)	Gravel pit Burnham M36/527332	Canterbury Plains	Moderately sorted and rounded gravel in a sand matrix sometimes oxidised to a brown colour		Glacial outwash derived river deposits

			? INTERSTADIAL		
Windwhistle Formation (Suggate 1965)	Inland Canterbury K35/044416	Inland Canterbury Plains	Moderately sorted and rounded gravel in a sand and silt matrix generally oxidised to a brown colour		Glacial outwash derived river deposits
Riccarton Gravel (Suggate 1958)	Well M35/w1943† Riccarton M35/783416	Subsurface coastal North Canterbury —Leithfield Beach to Irwell	Blue and brown gravel with some sand and silt layers and rare peat deposits (?interstadial)	Maximum thickness of 30 m beneath Christchurch	Glacial outwash derived river deposits
			EROSION INTERVAL		
Bromley Formation (Suggate 1958)	Well M35/w1875§ Bromley M35/849414 Well M35/w1926¶ Bromley M35/861420	Subsurface coastal North Canterbury —Leithfield Beach to Irwell	Blue-grey gravel, sand, silt, clay, shelly clay, and peat. Some brown gravel, and brown and yellow clay layers	Maximum thickness of 30 m beneath Heathcote Valley–Ferrymead. Depth range about 40–60 m below ground surface	Beach, lagoonal, dune, and coastal swamp sediments associated with rising, high, and declining sea level
			EROSION INTERVAL		
Woodlands Formation (Suggate 1965)	Gravel pit Woodlands Homestead —near Rakaia Gorge K35/099428	Inland Canterbury Plains	Unbedded rounded and subrounded gravelly till up to boulder size but averaging coarse gravel, and yellow-brown silt sand matrix		Glacial outwash derived river deposits
Linwood Gravel	Well M35/w1989 Linwood M35/876413	Subsurface coastal North Canterbury—Leithfield Beach to Irwell	Brown gravel with matrix of brown sand and clay with blue clay and sand layers and occasional peat layers	Maximum thickness of about 40 m. Depth range about 60–100 m below ground surface	Glacial outwash derived river deposits
			EROSION INTERVAL		
Heathcote Formation	Well M36/w1161 Heathcote M36/854386	Subsurface coastal North Canterbury—Leithfield Beach to Irwell	Blue-grey gravel, sand silt, clay, shelly clay, and peat. Some brown gravel and brown and yellow clay layers	Maximum thickness of about 30 m. Depth range about 70–100 m below ground surface	Beach, lagoonal, dune, and coastal swamp sediments associated with rising, high and declining sea level

(*Continued on next page*)

Table 2 (*Continued*)

Formation	Type section	Geographic distribution	Lithologic content	Thickness	Depositional environment
			EROSION INTERVAL		
Hororata Formation (Suggate 1965)	30 m high bluff Racecourse Hill L35/316537	Inland Canterbury Plains	Unstratified rounded and subrounded weathered gravel mainly 50–150 mm diameter with a few subrounded boulders to 600 mm, overlain by thick loess-like silt.		Glacial outwash derived river deposits
Burwood Gravel	Well M35/w1975 Burwood M35/844453	Subsurface coastal North Canterbury—Leithfield Beach to Irwell	Brown gravel with matrix of brown sand and yellow and brown clay and silt. Yellow clay layers common	Maximum thickness of about 20 m. Depth range about 100–120 m below ground surface	Glacial outwash derived river deposits
			EROSION INTERVAL		
Shirley Formation	Well M35/w2133 Shirley M35/827442	Subsurface coastal North Canterbury—Leithfield Beach to Irwell	Blue, brown and yellow gravel, sand, silt, and clay with interbedded peat and wood, and shelly layers	Maximum thickness of about 30 m. Depth range about 120–150 m below ground surface	Beach, lagoonal, dune, and coastal swamp sediments associated with rising, high, and declining sea level
			EROSIONAL INTERVAL		
Wainoni Gravel	Well M35/w2152 Wainoni M35/843425	Subsurface coastal North Canterbury—Leithfield Beach to Irwell	Brown gravel with matrix of brown sand and yellow and brown clay and silt. A few layers of blue gravel, yellow clay and brown clay, sand, and silt	Maximum thickness of about 20 m. Depth range about 150–170 m below ground surface, at New Brighton coast	Glacial outwash derived river deposits

*Old well no. S84/w122.
†Old well no. S84/w555 (S84/w120A).
‡Old well no. S84/w236.
§Old well no. S84/w138.
¶Old well no. S84/w211.

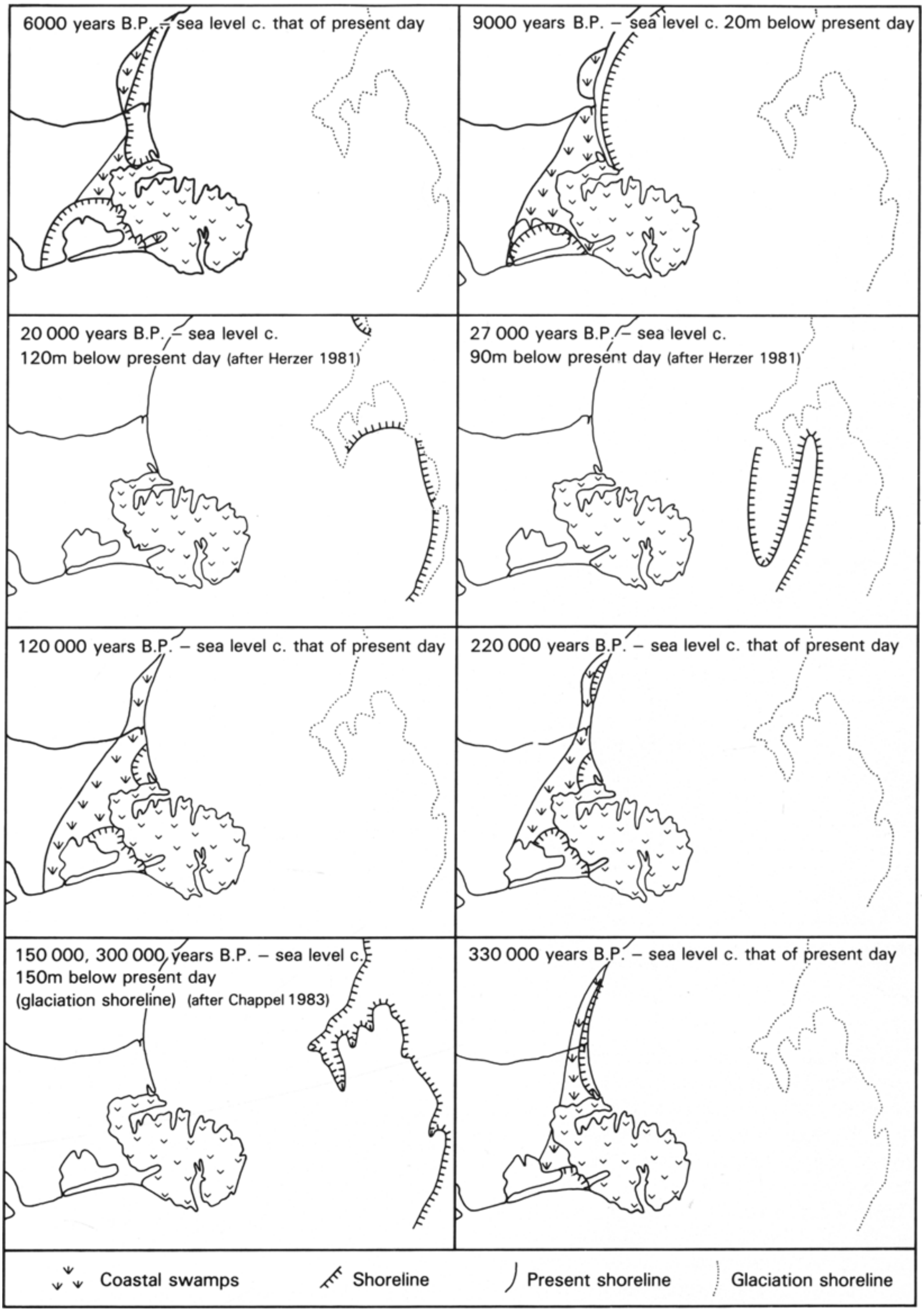

Fig. 5 Position of North Canterbury shorelines at various times during the late Quaternary.

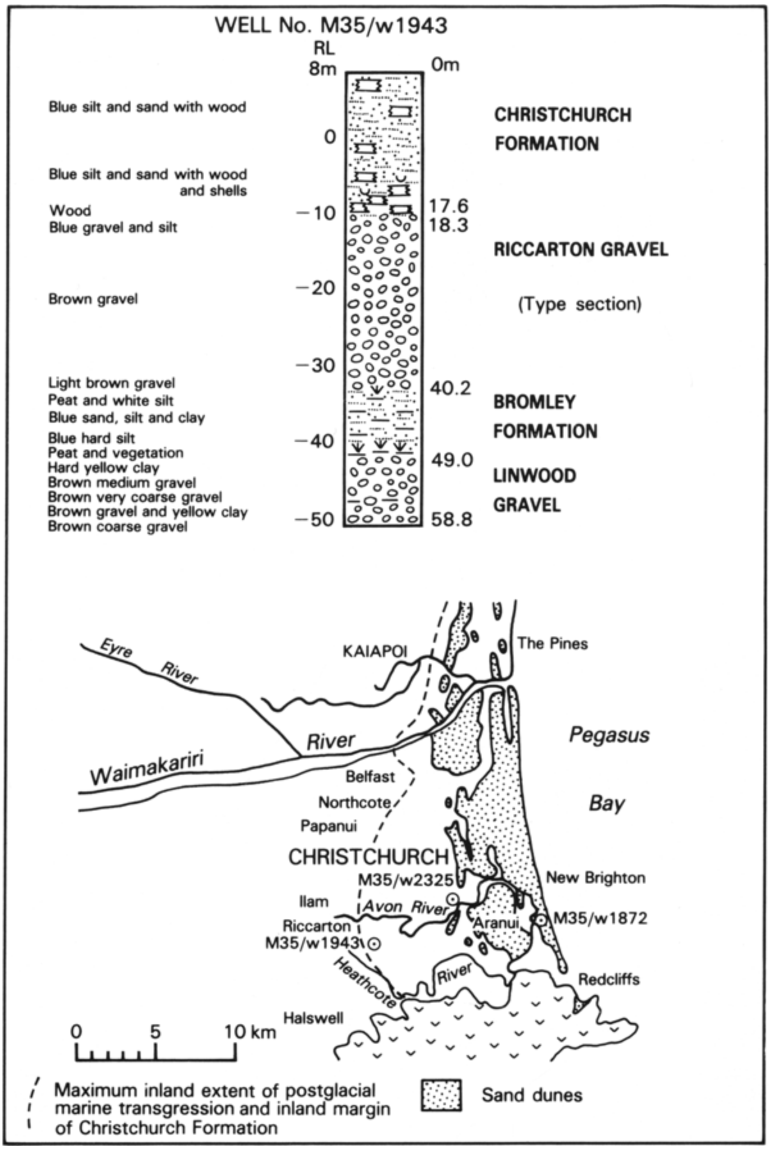

Fig. 6 Christchurch Formation distribution and Riccarton Gravel type section in M35/w1943, Riccarton.

dips to the south and has a maximum thickness of 6 m, from 5 to 11 m below mean sea level (10–16 m below ground surface) at Stewarts Gully 6 km to the south of Kaiapoi. It has been worked as a sorted aggregate supply near Kaiapoi, where the overburden is thinnest (Brown 1973).

Gravel-filled channels within and on the fine sediments of Christchurch Formation represent deposits of the Waimakariri River formed with changes of course and rivermouth position in the postglacial period. These gravels are assigned to the Springston Formation.

SPRINGSTON FORMATION
(revised after Suggate 1963)

The type section for Springston Formation is a gravel pit (M36/673348)* near Springston, 19 km southwest of Christchurch, in the lower part of the fan of the Waimakariri River. The pit exposes 6 m of fresh gravel of Springston Formation, overlying a

*All sheet districts and grid references are based on the national thousand-metre grid of the 1:50 000 topographical map series (NZMS 260).

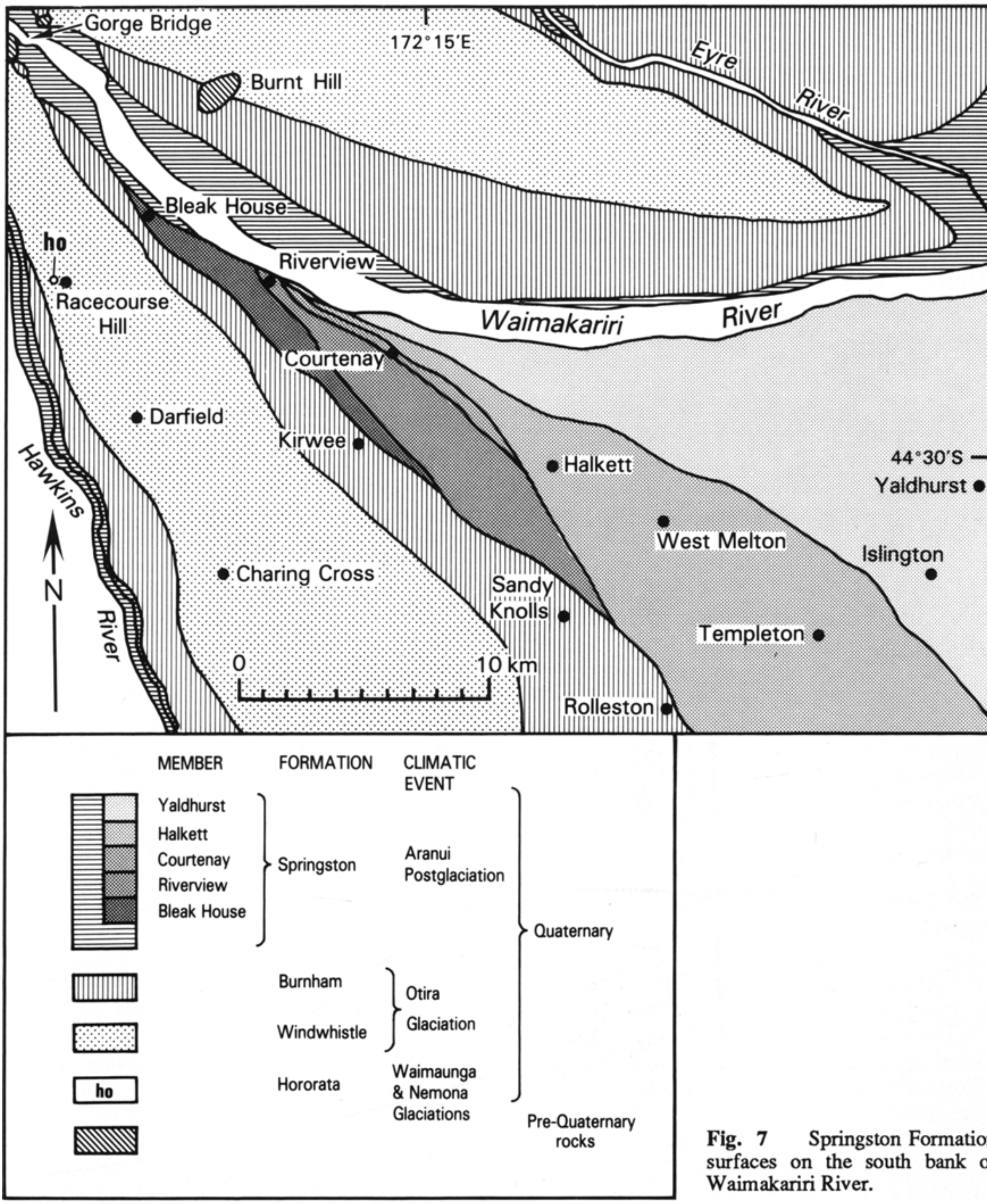

Fig. 7 Springston Formation surfaces on the south bank of Waimakariri River.

silt band resting on iron-stained gravel of Burnham Formation.

Springston Formation represents fluviatile deposition that followed glacial retreat at the end of the Otira Glaciation about 14 000 years ago, although the earliest (Bleak House) member (Fig. 7) may have been formed between 18 000 and 14 000 years ago as a result of the retreat of ice prior to the smaller ice advance that deposited the St Bernard Formation (see Table 1). Springston Formation comprises all postglacial fluvial deposits, except those of present-day river channels and floodplains that are periodically reworked by floods. Included are the thin veneers of gravel and silt lag deposits that cap successive degradational terraces of Canterbury rivers cut below the level of the Burnham Formation, the wedge-shaped alluvial fan deposits that widen, thicken, and overlap downstream from these terraces, and gravel-filled channels and overbank silt that accumulated at the inland margin of the Christchurch Formation.

Springston Formation has a maximum thickness of 20 m as shown in water wells located to the west of Christchurch. It overlies Burnham Formation, and, where postglacial coastal progradation has occurred from Leithfield Beach almost to the Rakaia River mouth, is interbedded with Christchurch Formation. Inland it is difficult to distinguish Springston Formation from the underlying Burnham Formation in the gravel with sand, silt, and clay matrix penetrated by wells.

Springston Formation caps a series of degradation terraces, on the south bank of the Waimakariri River downstream from the Gorge Bridge, merging eastwards into aggradation deposits (Fig. 7). The terraces mark pauses in progressive river entrenchment, and Springston Formation on them is merely a lag deposit. The lag deposits under each surface are differentiated as members of the Springston Formation for mapping purposes (Wilson in press). There is a progressive downstream reduction of gradient from one surface to the next. The thin lag deposits of Springston gravel overlie older gravel in the upstream reach; they are easily mapped (Fig. 7) because the inner and outer boundaries are marked by terrace edges. The downstream aggradation fan deposits of each degradation terrace are more difficult to distinguish because they overlap as the gradient flattens (see Wilson 1985, fig. 3, 4). The presence or absence of loess and dune sand, soil characteristics, degree of weathering of the gravel and matrix, and some radiocarbon-dated near-surface wood and peat provide the basis for differentiation.

The oldest surface on Springston along the Waimakariri River occurs near Bleak House homestead (Fig. 7). The surface has an average width of 1.5 km; its boundary with Burnham Formation is a terrace riser 5 m high at the upper end which decreases to zero over about 4 km. About 12 m of gravel is exposed in a cliff fronting the river at L35/381554. There is no obvious sedimentation break in this exposure, but 2 m of creamy sandy gravel at the top appears to be much finer than gravel of similar colour below. This is capped by 1 m of loess. The 2 m of finer gravel is considered to represent the Springston lag deposit and is designated **Bleak House Member.**

A topographically lower, and thus younger, Springston surface nearly 2 km wide, extends southeast from Riverview homestead at L35/426511. The surface is separated from the older Bleak House surface by a terrace riser about 5 m high at its upper end, diminishing in height downstream. The deposits at the terrace riser fronting the Riverview surface are creamy sandy gravel from top to bottom. No contact with underlying older gravel is exposed. The deposit is designated **Riverview Member** of the Springston Formation.

A later postglacial surface is recognised at the Courtenay domain, separated from the older Riverview surface by a terrace riser 4 m high at the upper end, diminishing in height downstream. The deposit beneath the surface is given the status of a member of the Springston Formation and is called **Courtenay Member.**

A series of surfaces, each separated from its neighbour by a terrace riser not exceeding 2 m high, mark successively younger stages of incision of the Waimakariri River below the Courtenay surface. The surfaces, which include the site of Halkett township at M35/551451, are more uneven than older surfaces because they are capped by numerous sand dunes. The dunes probably bordered successive positions of a southern channel of the Waimakariri River. These surfaces are the Halkett surface of Suggate (1958, 1963), and the deposits immediately underlying the surface are designated the Halkett Member of the Springston Formation (Brown 1973).

The youngest Springston surface is a triangular area with its apex near Courtenay, its northern boundary at the floodplain of the Waimakariri River, and its southern boundary fanning southwards to include Yaldhurst township (Fig. 7). The surface is barely above flood level of the present Waimakariri River and forms aggradation deposits southeast of M35/663515. Dunes are present but are fewer than on the composite Halkett surface. During development of the Yaldhurst surface, the Waimakariri has occupied courses linking with the Avon, Heathcote, and Halswell Rivers (Islington Channel). These old flood-overflow routes extend east to interfinger with, and overlie, Christchurch Formation. Peat has accumulated in swamps along the junction of the Springston and Christchurch

Formations. This surface is the Yaldhurst surface of Suggate (1958, 1963), and the fluvial deposits beneath the surface are designated the Yaldhurst Member of the Springston Formation (Brown 1973).

BURNHAM FORMATION
(Oborn & Suggate 1959, Suggate 1963, 1965)

Burnham Formation is named and described in a pit (M36/527332) from Burnham, 30 km southwest of Christchurch. The Burnham Formation originated from outwash streams during the Blackwater 1 and 2 glacial advances (Gage 1958) in the late Otira Glaciation, about 25 000—18 000 years ago. It is the last significant outwash laid down to form the Canterbury Plains.

Burnham Formation is composed of moderately sorted and rounded gravel in a sand and silt matrix. The matrix is oxidised to a brown colour in exposures. Gravel of the Burnham Formation is notably tighter and stands better in vertical faces than the Springston Formation. When Burnham and the older Windwhistle gravels are seen in superposition, Windwhistle gravel can be distinguished from the former by slightly more weathering of its matrix. In exposures adjacent to the present-day river floodplains and towards the coast, Burnham Formation is usually unconformably overlain by fluvial gravel deposits of the Springston Formation. The unconformity cannot be recognised in most well logs due to the limited sample available for visual comparison; there may also be areas where complete continuity of deposition occurs with merging of Burnham into Springston Formation. Although the correlation of Riccarton Gravel with Burnham Formation (Brown 1973) is retained (see Riccarton Gravel), Riccarton Gravel may include Windwhistle Formation in its lower part.

Darfield surface (Suggate 1958)

Suggate (1963) considered the Darfield surface of the Canterbury Plains to result from the Blackwater glacial advances rather than from the older Otarama advance as he had previously (Suggate 1958) suggested.

Recent mapping (Wilson in press) shows that the Darfield surface no longer complies with the original definition as the surface on the Burnham Formation (see Fig. 7). East of the Hawkins River, areas mapped as Burnham Formation by Suggate (1973) have been subdivided into Burnham and Windwhistle Formations by Wilson (in press). It is suggested that the use of the name Darfield surface be discontinued.

WINDWHISTLE FORMATION (Suggate 1965)

Windwhistle Formation was deposited during an early Otiran ice advance, possibly about 70 000–40 000 years ago. Suggate (1965) described the formation from Windwhistle, a locality 5 km east of the Rakaia Gorge bridge, in the Rakaia River sector of the Canterbury Plains. The ice advance that resulted in the Windwhistle Formation was correlated with Gage's (1958) Otarama advance in the Waimakariri River valley, on the basis of similar relations to the Burnham Formation which is recognised in both the Waimakariri and Rakaia sectors of the plains. Windwhistle Formation is well exposed in the steep cliffs on both banks of the Waimakariri River between Staircase Gorge and the Gorge Bridge. A subsurface equivalent of Windwhistle Formation is not distinguished from that of the Burnham Formation or the Riccarton Gravel in wells on the Canterbury Plains.

RICCARTON GRAVEL
(revised after Suggate 1958)

Riccarton Gravel is normally the gravel stratum immediately underlying Christchurch Formation in wells adjacent to the North Canterbury coast. Suggate (1958) described the Riccarton Gravel from a type section penetrated by well M35/w1943 at Riccarton (M35/783416). The Riccarton Gravel type section was the gravel strata from 17.6 to 40.2 m below ground surface (Fig. 6). A thin layer of blue gravel was recorded at the top of the Riccarton Gravel overlying brown gravel; the blue colour was attributed to reduction of iron in the presence of organic matter.

Riccarton Gravel is a subsurface deposit with no surface outcrop. The known thickness of Riccarton Gravel ranges from a few metres to at least 30 m. It was interpreted as fluviatile gravel, deposited on an eroded surface of older estuarine and marine beds in the east and on older fluviatile beds in the western suburbs of Christchurch. Compilation from well logs of contours at the base of Christchurch Formation shows a drainage pattern on the Riccarton Gravel surface indicating a significant break in deposition between Riccarton Gravel and Christchurch Formation (Suggate 1958).

There is probable overlapping in age of Riccarton Gravel and Burnham Formation—both represent fluvial deposition during the late Otira Glaciation. Riccarton Gravel cannot be recognised more than a few kilometres inland of the coast as it is difficult to distinguish Riccarton Gravel, Springston, and Burnham Formations in well logs. In the east, mainly adjacent to Banks Peninsula, it cannot be clearly distinguished owing to its partial or complete removal by erosion before the deposition of Christchurch Formation (see well M36/w1161, Fig. 10).

BROMLEY FORMATION
(revised after Suggate 1958)

The Bromley Formation was proposed by Suggate (1958) to comprise last interglacial deposits underlying the Riccarton Gravel beneath Christchurch. It was interpreted as estuarine and marine gravel, sand, silt, and peat, described in logs of wells located at the coast adjacent to Banks Peninsula. Suggate (1958) designated the Bromley Formation as the strata below the Riccarton Gravel typically shown in two wells located in the Bromley suburb of Christchurch—well M35/w1875 (47–134 m) and well M35/w1926 (53–143 m). He made no subdivision of the clay, sand, and gravel below the Riccarton Gravel. Additional data and work now provide a basis for subdividing and correlating these strata from well to well. By analogy with the Christchurch Formation and Riccarton Gravel the silt, clay, peat, and shelly clay and sand, penetrated by wells adjacent to the coast, are recognised as formations, as are the intervening gravels. It is now proposed that the Bromley Formation be restricted to the sand, clay, shelly clay, peat, silt, and interbedded gravel unit immediately underlying the Riccarton Gravel and associated with rising and high sea level in an environment similar to that which produced the postglacial Christchurch Formation. Figure 8 shows the well logs used as Bromley Formation type sections by Suggate (1958). Redefinition of the Bromley Formation makes the base of the Bromley Formation in M35/w1875 the base of the yellow clay at 63.7 m, and in M35/w1926 the base of the clay at 71.6 m. The thicknesses of Bromley Formation in these two wells are 20 m and 17 m but beneath the Heathcote Valley and Ferrymead suburbs of Christchurch it reaches 30 m.

The western limit of Bromley Formation is indicated by wells penetrating peat, wood, clay, and silt deposits close beneath Riccarton Gravel, from Sefton in North Canterbury (6 km from the present coast) through to Irwell adjacent to Lake Ellesmere, 1 km from the present coast (Fig. 8). The swamp and associated deposits grade into or abut silt, sand, and gravel and overlie silt, sand, and gravel. Erosion prior to deposition of the Riccarton Gravel and Burnham Formation may have made the western limit of the Bromley Formation difficult to recognise.

Nonfinite radiocarbon ages are up to >49 700 years old, and finite ages, range from 40 000 to 27 900 years old for Bromley Formation or last interglacial organic material (Table 3) which should be >80 000 years old. It is pertinent that sample M36/f6515* from Lincoln is regarded as indicative of a podocarp forest similar to those of the post-glacial and hence is probably last interglacial (see Appendix 1), yet it has a 39 500 + 2700 -2000 years B.P. age (NZ1930A). A nearby sample M36/f1 from only 5 m deeper has an age of >48 300 years B.P. (NZ4260A). Contamination, as was shown by Goh et al. (1978) for peat at Timaru, is a factor to be considered. Even the youngest radiocarbon date, 27 900 years B.P. (NZ4 850A), is improbable as it is from the same peat bed and only 3 m above a date of >36 800 years B.P. (NZ5174A) (see Fig. 8). The radiocarbon dates listed in Table 3 are rejected as being too young due to contamination. Although pollen evidence of interglacial conditions is inconclusive (see Appendix 1) for the site at Prebbleton and for other sites, the associated sediments are correlated with Bromley Formation or last interglacial deposition.

Peat samples from other Canterbury Plain localities (Table 4) have also been radiocarbon dated and examined for pollen (see Appendix 1, Table 5). Wells adjacent to the present Ashburton River mouth penetrated fluvial gravel overlying peat (NZ3964A, NZ5290A, and NZ5291A, Table 3) (Fig. 8). Peat is also interbedded with loess in shallow depressions on the surface of the downlands south of Saltwater Creek near Timaru (Tonkin et al. 1974) and in test bores at Timaru Harbour (NZ693A; Table 3) (Fig. 8). No conclusive evidence as to age or climatic conditions is apparent from these studies, although the pollen record from the Timaru (Saltwater Creek) peat (Goh et al. 1978) suggests a milder climate than the present (Appendix 1).

WOODLANDS FORMATION (Suggate 1965)

Woodlands Formation, named after Woodlands homestead near the Rakaia Gorge, consists of boulder clay, and was attributed by Suggate (1965) to the Waimea Glaciation. A section near Woodlands homestead was described and the

*New Zealand Fossil Record File number.

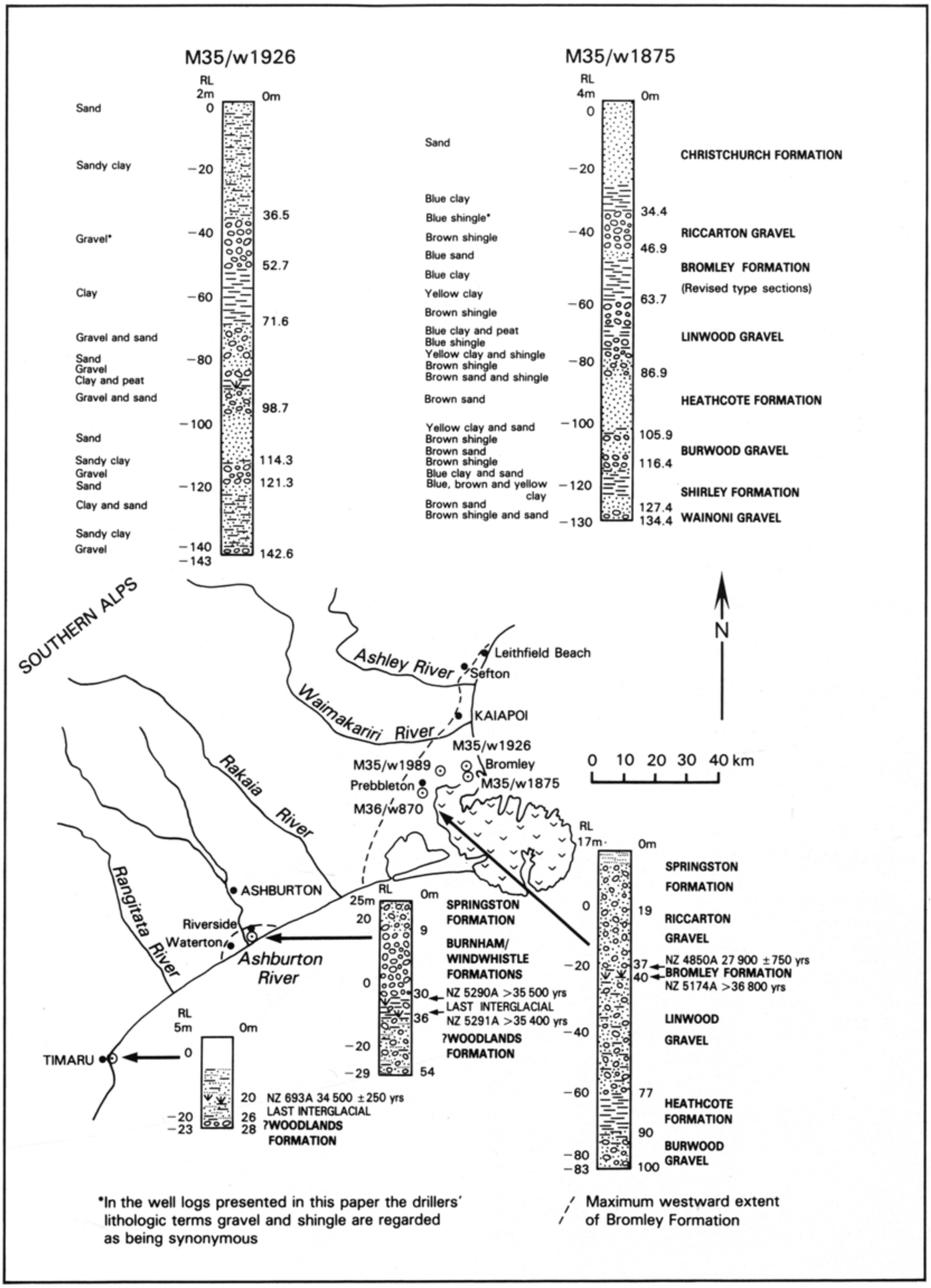

Fig. 8 Bromley Formation type section in M35/w1875 and 1926, Bromley, and distribution.

Table 3 Organic material from strata associated with pre-Holocene deposition.

Age (years B.P.)[1]	NZ^{14}C no.[2]	NZ Fossil Record File no.[3]	Well no. if from well[4]	Sample	Locality	Grid reference NZMS 260 (metric)	Depth from surface (m)	Altitude with ref. to M.S.L. (m)	Formation
27 900 ±750	4850A	M36/f12	M36/w870	peat	Prebbleton	M36/710355	37	–17	Bromley
31 000 +1100 –900	1269A	J39/f7703	–	peat	Timaru	J39/692409	5	+30	–
34 500 ±250	693A	K39/f7586	N.A.	peat	Timaru	K39/710452	Offshore	–15	–
34 600 +2750 –5700	1294A	M36/f6513	M36/w151	wood	Springston	M36/639309	26	–4	Bromley
>35 300	5195A	M35/f5	M35/w2273	wood/peat	Sockburn	M35/741411	42	–18	Bromley
>35 400	5291A	L37/f2	N.A.	peat	Riverside	L37/184877	36	–11	–
>35 500	5290A	L37/f1	N.A.	peat	Riverside	L37/184877	30	–5	–
>36 800	5174A	M36/f11	M36/w870	peat	Prebbleton	M36/710355	40	–20	Bromley
39 400 +2650 –2000	3964A	K37/f9502	N.A.	peat	Waterton	K37/073800	42	–20	–
39 500 +2700 –2000	1930A	M36/f6515	M36/w1961	peat/wood	Lincoln	M36/677296	23	–10	Bromley
40 000 +5700 –3300	3966A	M36/f6517	M36/w168	wood	Springston	M36/623305	25	+4	Bromley
>40 000	25A	M35/f9505	M35/w2054	peat	Bryndwr	M35/775447	58	–44	Bromley
>43 000	121A	M35/f9524	M35/w1987	peat	Riccarton	M35/778419	42	–32	Bromley
>45 000	99A	M35/f9516	M35/w2054	peat	Bryndwr	M35/775447	46	–32	Bromley
		M35/f24	M35/w3637	peat	Yaldhurst	M35/699437	47	–7	Bromley
>45 000	94A	–	–	peat	Joyces Stm	L35/242686			–
>48 300	4260A	M36/f1	M36/w583	wood	Lincoln	M36/672297	26	–15	Bromley
>49 700	2323A*	J39/f7703	–	peat	Timaru	J39/692409	5	+30	–
		M35/f11	M35/w2790	peat	Aranui	M35/862429	63	–58	Bromley
		M35/f19	M35/w5135	peat	Bromley	M35/856402	62	–60	Linwood Gr
		M36/f8	N.A.	peat	Templeton	M36/667367	60	–22	Heathcote
		M36/f10	M36/w937	peat	Halswell	M36/743368	61	–45	Heathcote
		M35/f20	M35/w5135	peat	Bromley	M35/856402	81.5	–79.5	Heathcote
		M35/f21	M35/w5135	peat	Bromley	M35/856402	82	–80	Heathcote
>44 100	715A	M36/f7560	M36/w1161	shell	Heathcote	M36/852386	93	–91	Heathcote
		M35/f22	M35/w5135	peat	Bromley	M35/856402	111	–109	Shirley
		M35/f9	M35/w1975	wood/peat	Burwood	M35/844453	134	–131	Shirley
		L35/f3	L35/w186	peat	Kirwee	L35/488462	82	+170	–
		M35/f23	M35/w5135	peat	Bromley	M35/856402	154	–152	Unnamed

*NZ1269 after treatment for contamination (see Goh et al. 1978).

[1] Old half life uncorrected for secular effects.

[2] New Zealand Radiocarbon Dating Laboratory sample number.

[3] New Zealand Fossil Record File number based on the metric (NZMS 260) system.

[4] Number assigned to well by the North Canterbury Regional Water Board when the record is filed within the specific NZMS 260 (1:50 000) sheet.

Table 4 Wood identifications for samples from strata asociated with pre-Holocene deposition.

Age (years B.P.)[1]	NZ^{14}C no.[2]	NZ Fossil Record File no.[3]	Well no. if from well[4]	Locality	Grid reference NZMS 260 (metric)	Depth from surface (m)	Altitude with ref. to M.S.L. (m)	Identification
34 600 +2750 −5700	1294A	*M36/f6513	M36/w151	Springston	M36/639309	26	−4	*Leptospermum* sp.
>35 300	5195A	*M35/f5	M35/w2273	Sockburn	M35/741411	42	−18	*Dacrycarpus dacrydioides* *Leptospermum ericoides*
>36 800	5174A	*M36/f11	M36/w870	Prebbleton	M36/710355	40	−20	Not identifiable
39 500 +2700 −2000	1930A	*M36/f6515	M36/w1961	Lincoln	M36/677296	24	−11	*Dacrycarpus*
		K37/f9501	N.A.	Waterton	K37/073800	27	−5	*Leptospermum* sp.
39 400 +2650 −2000	3964A	K37/f9502	N.A.	Waterton	K37/073800	42	−20	root (fibrous)
40 100 +5700 −3300	3966A	*M36/f6517	M36/w168	Springston	M36/623305	25	+4	*Podocarpus totara/hallii*
>48 300	4260A	*M36/f1	M36/w583	Lincoln	M36/672297	26	−15	*Podocarpus totara/hallii*
		†M35/f9	M35/w1975	Burwood	M35/844453	134	−131	*Leptospermum* sp.

*Bromley Formation †Shirley Formation

[1]Old half life uncorrected for secular effects. [2]New Zealand Radiocarbon Dating Laboratory sample number.

[3]New Zealand Fossil Record File number based on the metric (NZMS 260) system.

[4]Number assigned to well by the North Canterbury Regional Water Board when the record is filed within the specific NZMS 260 (1:50 000) sheet.

Woodlands Formation correlated with the deposits of the Woodstock advance of the Waimakariri glacier of Gage (1958).

Woodlands Formation may be represented by gravel penetrated by wells near the coast of North Canterbury, but continuity cannot be demonstrated, and the Linwood Gravel (see below) is separately named for the gravel underlying the Bromley Formation.

LINWOOD GRAVEL FORMATION
(new formation)

Gravel forming a flowing artesian aquifer beneath Bromley Formation adjacent to the present coast, both north and south of Banks Peninsula, is designated Linwood Gravel. Inland it cannot be distinguished in the continuous sequences of gravel penetrated by wells.

Strata penetrated from 59.4 to 78.9 m below ground surface by well M35/w1989 at Linwood (M35/826413) are proposed as the type section of the Linwood Gravel (Fig. 9). The top of the Linwood Gravel is at a depth of about 60 m and the base at about 100 m. The thickness ranges from 10 to about 40 m. It is thinnest beneath the southern suburbs of Christchurch adjacent to Banks Peninsula.

Linwood Gravel is predominantly brown gravel with a varying proportion of brown sand and clay matrix. Interbedded blue clay and sand up to 5 m thick are widespread. Because of the absence of shellbeds at the coastal margin, the interbeds are regarded as having been deposited during a period of predominantly cold climate and low sea-level. Pollen analysis from a peat layer within the Linwood Gravel from a well (M35/w5135) at Bromley (M35/856402) (see Fig. 12 and Appendix 1) also suggests deposition in a cold climate.

HEATHCOTE FORMATION (new formation)

Heathcote Formation occurs in wells from Leithfield Beach to the west shore of Lake Ellesmere (Fig. 10). It is named after the southern Christchurch suburb of Heathcote Valley where the type section well is located. Heathcote Formation comprises estuarine and marine sediments underlying the Linwood Gravel. Sediments are dominantly blue-grey sand, silt, and clay interbedded with peat and shelly layers. Some wells also show gravel and brown and yellow clay layers.

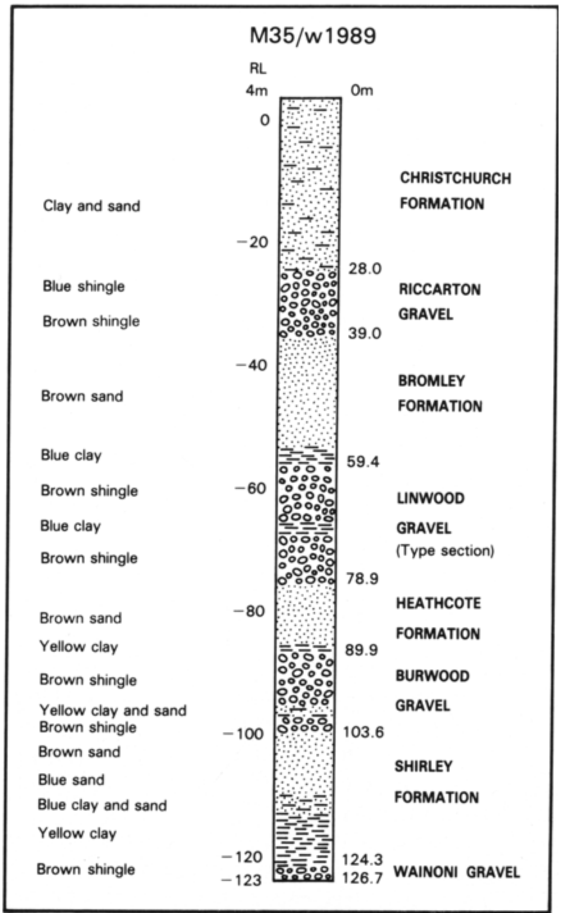

Fig. 9 Linwood Gravel type section in M35/w1989, Linwood. See Fig. 8 for location.

The formation's top is about 70–100 m below ground surface. The strata penetrated from 75.5 to 94.7 m below ground surface by well M36/w1161 at Heathcote Valley (M36/854386) are proposed as the type section of the Heathcote Formation (Fig. 10).

The estuarine and marine facies of Heathcote Formation grade laterally westwards into lagoon, estuary, and swamp deposits of peat, sand, and silt. Blue-grey colour, from iron reduction by the interbedded organic matter, alternates with brown oxidised iron-stained sand and silt. Yellow silt or clay deposits are more commonly recorded in well logs than in the Bromley Formation.

HORORATA FORMATION (Suggate 1965)

Hororata Formation is named from Hororata on the western edge of the Canterbury Plains, 55 km west of Christchurch. Hororata Formation is defined by Suggate (1965). The type section is a bluff in the Hawkins River near Racecourse Hill (L35/316537) on the Waimakariri River sector of the Canterbury Plains. It may include deposits of more than one glaciation. Age is uncertain, and it was tentatively correlated with the Waimaunga and possibly Nemona Glaciations (Suggate 1965) (Table 1).

Like the Woodlands Formation, Hororata Formation may be represented by gravel deposits penetrated by wells in coastal North Canterbury but again, continuity cannot be demonstrated, and the Burwood and Wainoni Gravels (see below) are separately named for gravel strata at the coast.

BURWOOD GRAVEL FORMATION
(new formation)

Gravel forming a flowing artesian aquifer underlying Heathcote Formation adjacent to the present coast both north and south of Banks Peninsula is designated Burwood Gravel. Burwood Gravel is a subsurface deposit with no recognised surface outcrop. Inland it is impossible to distinguish in the continuous sequences of gravel penetrated by wells.

The strata penetrated from 104.9 to 122.5 m below ground surface by well M35/w1975 at Burwood (M35/844453) are proposed as the type section of the Burwood Gravel (Fig. 11).

Burwood Gravel is mainly brown gravel in a matrix of brown sand and yellow and brown clay and silt. Yellow clay layers up to a few metres thick are common. Its top is about 100 m beneath the eastern suburbs of Christchurch. The maximum thickness of the formation is about 20 m.

SHIRLEY FORMATION (new formation)

Shirley Formation is known only from wells adjacent to Pegasus Bay from Leithfield Beach to Redcliffs and south of Banks Peninsula on the western shore of Lake Ellesmere (Fig. 12). It is penetrated beneath the Burwood Gravel from about 120 to 150 m below ground surface. It consists of sand, silt, and clay with interbedded peat and wood layers. Sediments are blue, brown, and yellow with a significantly greater proportion of the last two than in the Bromley and Heathcote Formations. Shelly layers within Shirley Formation are penetrated by wells adjacent to Pegasus Bay especially underlying the Christchurch suburbs of North New Brighton, Burwood, and Shirley. This estuarine and marine facies of Shirley Formation grades laterally

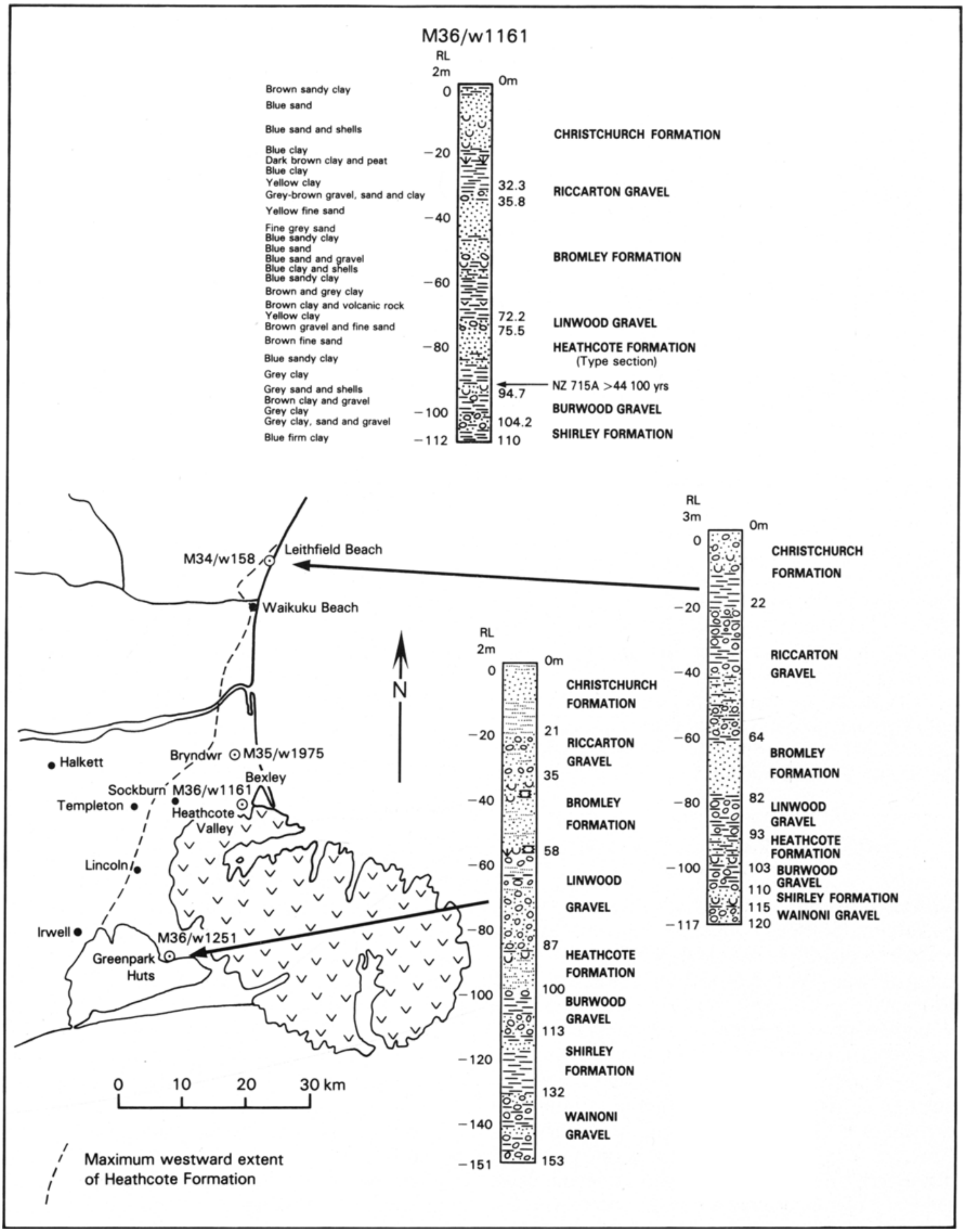

Fig. 10 Heathcote Formation type section in M36/w1161, Heathcote, and distribution.

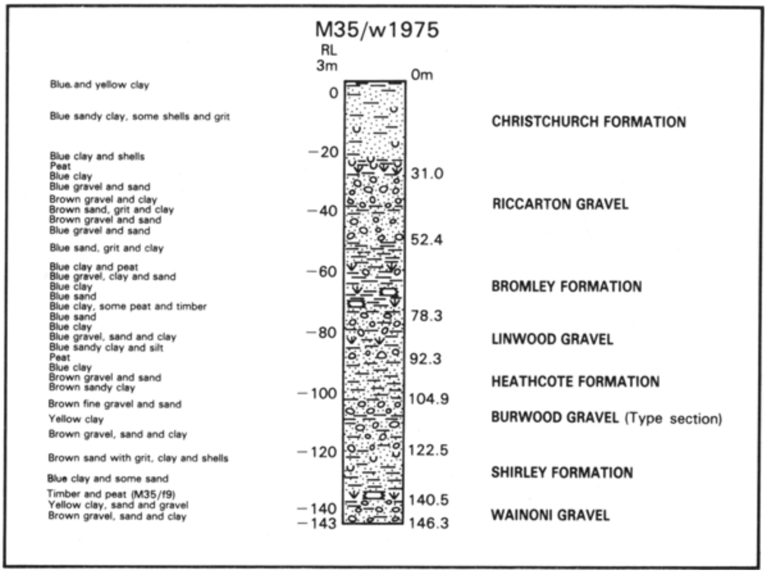

Fig. 11 Burwood Gravel type section in M35/w1975, Burwood. See Fig. 10 for location.

westwards into peat, sand, and silt deposits. The only well deep enough to penetrate Shirley Formation to the south of Banks Peninsula (well M36/w1251, Fig. 10) encountered blue sand, silt, and clay from 113 to 132 m below ground surface, but no organic material.

The strata penetrated from 113.3 to 135.6 m below ground surface by well M35/w2133 at Shirley (M35/827442) are proposed as the type section of the Shirley Formation (Fig. 12).

WAINONI GRAVEL FORMATION
(new formation)

Gravel providing a flowing artesian aquifer underlying Shirley Formation adjacent to the present coast from Leithfield Beach to Bromley and south of Banks Peninsula on the west shore of Lake Ellesmere (well M36/w1251) is designated Wainoni Gravel. Its extent is uncertain because of the limited number of deep wells. Wainoni Gravel is a subsurface deposit with no recognised surface outcrop. It is probably of similar origin and derivation to Riccarton, Linwood, and Burwood Gravels. Inland from the coast it is impossible to distinguish Wainoni Gravel in the continuous sequence of fluvial gravel deposits penetrated by wells. The strata penetrated from 133.1 to 141.4 m below ground surface by well M35/w2152, at Wainoni (M35/843425), are proposed as the type section of Wainoni Gravel (Fig. 13). Wainoni Gravel is dominantly brown with a few bands of blue gravel, yellow and brown clay, sand, and silt. Wells in the eastern suburbs of Christchurch encounter Wainoni Gravel at about 140–150 m below ground surface. Those which penetrate to the base suggest that the thickness of the gravel is between 10 and 15 m beneath Christchurch.

Deeper subsurface Canterbury Plains deposits

In the vicinity of Christchurch a few wells have drilled through the Wainoni Gravel into brown and blue clay, silt, sand, and peat which in turn are underlain by a gravel aquifer (Fig. 2). These wells are over 150 m deep. They appear to have been unsuccessful in locating high-yielding aquifers at depth, so in some wells (e.g., M36/w981 and M36/w1047 at Spreydon and Sydenham) the casings were pulled back and the wells screened and developed in Wainoni Gravel or shallower aquifers. Well M36/w981 was drilled to 214 m below ground surface and penetrated alternating gravel and clay, silt, and sand from the base of the Wainoni Gravel at 121 m. Aquifers within the gravel strata were of low permeability because of the high content of clay, silt, and sand matrix. A peat sample (M35/f23, Table 5) from a well at Bromley (M35/w5135, Fig. 12) at 154 m below ground surface, yielded a pollen assemblage suggesting deposition in a freshwater coastal sedge swamp surrounded by shrubland and podocarp forest under cool temperate conditions

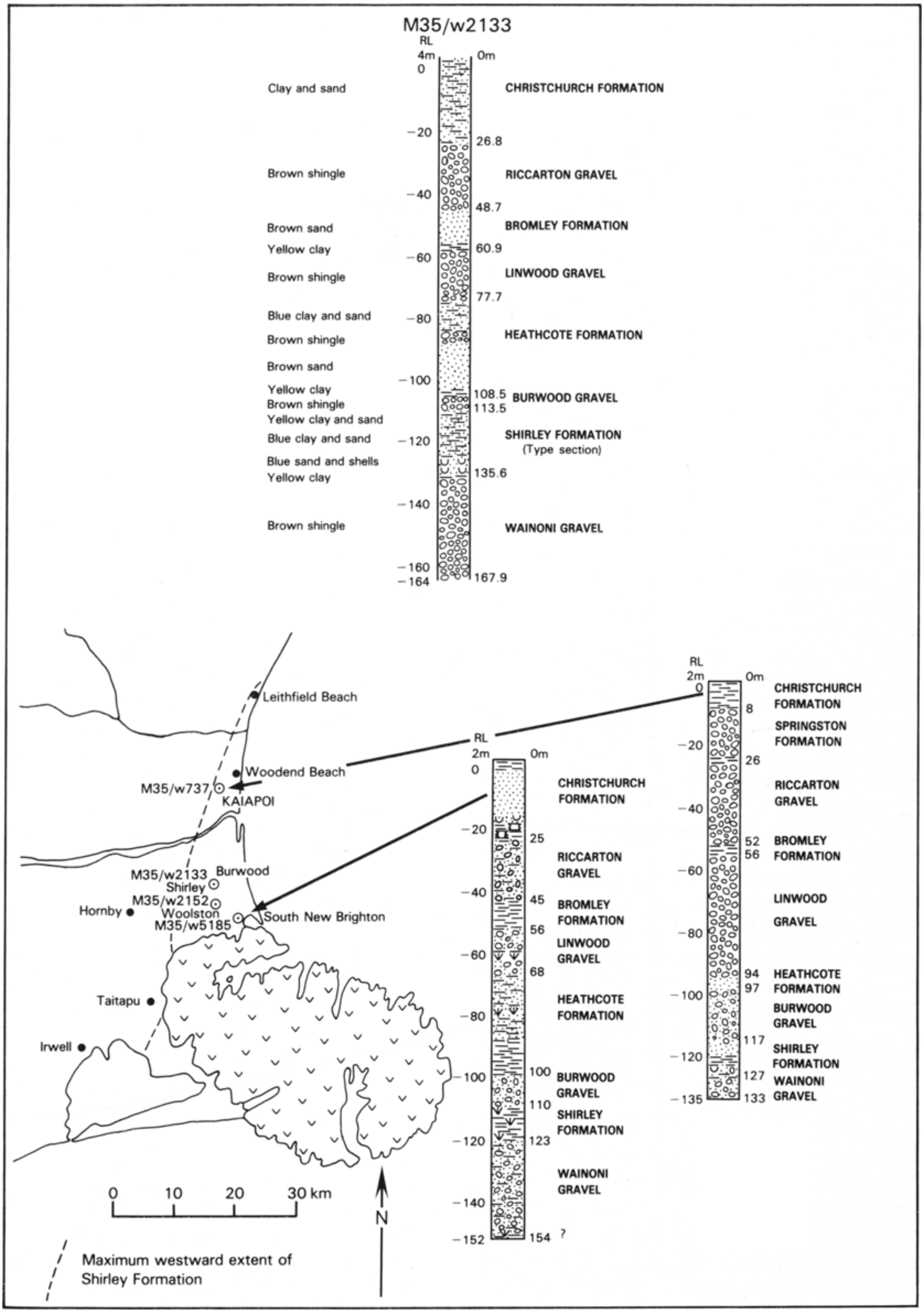

Fig. 12 Shirley Formation type section in M35/w2133, Shirley, and distribution.

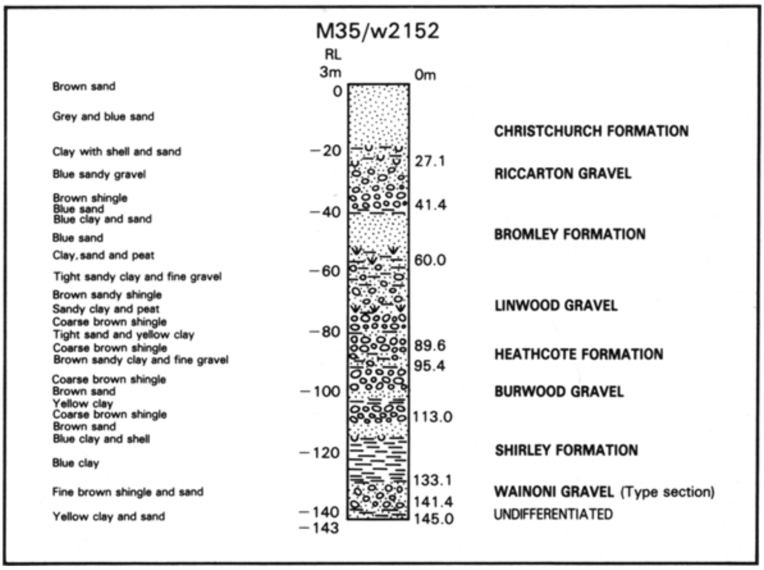

Fig. 13 Wainoni Gravel type section in M35/w2152, Wainoni. See Fig. 12 for location.

(see Appendix 1). Formal recognition of the strata as a formation is considered inappropriate until more information on the extent, lithology, depositional environment, and aquifers is obtained from deep wells.

The impossibility of recognising the distinct gravel formations and the lack of fine sediment or organic material to allow stratigraphic correlation in wells on the western edge of Christchurch, where predominantly gravel strata are penetrated, has already been mentioned. Only limited and tentative correlation can be made (Fig. 2, 3). Well M35/w1039 at Islington intersected peat and wood at a depth of 175–177 m below sea level, too deep to be correlated with the Shirley Formation in the coastal wells or with unnamed peat, clay, and sand strata at about 150 m below sea level in a few deep wells beneath Christchurch (Fig. 3, section C–D).

Banks Peninsula margin of subsurface deposits

The persistence of gravel strata to the present coast, with only relatively minor thinning eastwards, suggest they extend offshore. However, to the immediate north and south of Banks Peninsula, coastal wells penetrated a higher proportion of fine sediment relative to gravel than did coastal wells further north of Christchurch.

Well M36/w1107, located at Ferrymead adjacent to Banks Peninsula (Fig. 2), penetrated Christchurch Formation (to 22 m below sea level) and Riccarton Gravel (22–34 m below sea level). Sand, silt, and clay (34–71 m below sea level, including Bromley Formation at 34–53 m) are underlain by shelly, mainly blue sand and clay from 71 to 212 m below sea level. Prolonged estuarine or nearshore deposition is suggested by these lithologies (as observed by Speight 1911). Other shallower wells in the Ferrymead–Heathcote Valley area (see well M36/w1161, Fig. 10) also penetrated strata showing a predominance of clay, sand, and shelly layers with intervening gravel either thin or absent.

Riccarton Gravel, the only gravel formation of significant thickness in the Ferrymead–Heathcote Valley area, is thinner than Riccarton Gravel penetrated by wells to the northwest at Bromley and Woolston. This suggests that the coastal plains adjacent to Banks Peninsula lay on the fringe of the depositional environment for fluvial gravel of the Canterbury Plains. The lack of unconformities or abrupt changes in lithology in the well logs suggests the area was isolated from the effects of erosion. The presence of these thick deposits of fine-grained often shelly strata implies that the thinness of the fine-grained formations to the northwest of Banks Peninsula is likely to result from erosion below successive gravels, just as erosion of the Bromley Formation prior to deposition of the Riccarton Gravel has been demonstrated (Suggate 1958). Peat in the fine-grained formations contains pollen from vegetation mostly associated with cool climate, in comparison with the temperate climate of the postglacial period (see Appendix 1). The predominance of peat containing cool-climate pollen suggests temperate-climate interglacial peat deposits were commonly eroded (probably when sea level was declining during the transition from interglacial to colder climate glacial periods), and thus are underrepresented.

CORRELATION WITH SOUTH ISLAND INTERGLACIAL–GLACIAL SEQUENCES

The comparison of lithologies recorded in well logs has permitted tentative correlation of the subsurface gravel formations of the northern coastal Canterbury Plains with the outwash deposits of the Canterbury Plains to the west (as in Table 1), and has led to acceptance of the fine sediments (including estuarine and offshore deposits) of the postglacial Christchurch Formation as an analogy for the recognition of deeper fine-grained interglacial formations. Definitive correlation between the subsurface gravel and the intervening fine sediment sequences, and the climatic stages of the Quaternary, however, is impossible without well logs demonstrating continuity across the Canterbury Plains for the gravels, and definitive dating of the fossils within the fine-grained interglacial formations.

Radiocarbon dates and pollen analyses, when considered in isolation, are inconclusive and often conflicting, and as such do not support definite correlation. However, sequences derived from a comparison of well logs (see Fig. 3) show a broad uniformity of distribution of lithologically related sediments, which could only have occurred in response to a recurring pattern of depositional environments. The climatic cycles of the Quaternary provide the most probable cause, with alternating glacial and interglacial conditions and associated changes in sea level, and river and coastal processes, influencing sediment accumulation and their contained biota.

Other less important influences (because they are less rapidly effective) on sediment accumulation and preservation are tectonic subsidence and consolidation. These factors are difficult to quantify.

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APPENDIX 1

Pollen assemblages from late Quaternary deposits in Canterbury

N. T. MOAR
D. C. MILDENHALL

INTRODUCTION

The late Quaternary pollen record from the Canterbury Plains is not extensive. Most data come from buried silty, often thin, organic layers, and there are no continuous sequences which can be used as standards for either glacial or interglacial periods.

The postglacial (Aranuian Interglacial) is best known, and pollen, macrofossils, and charcoal come from numerous sites (Cox & Mead 1963; Molloy et al. 1963; Moar 1969, 1971; Molloy 1969). Records of interglacials are few; a buried peat from Timaru, South Canterbury (Moar 1973; Goh et al. 1978) and an interglacial/glacial transition at Joyces Stream, near Springfield, inland Canterbury (Moar & Gage 1973). There are only two known lowland sites of Otiran Glacial age. Both are late Otiran (Moar 1980).

In this study, samples from thin layers of silty peat, some with poorly preserved and recycled pollen, were taken from wells drilled in and around Christchurch. The pollen from these are interpreted against a background of information already derived from the sites noted above and from a shallow spring-fed mire near Motukarara, 20 km south of Christchurch.

RESULTS

The pollen analyses are presented in Table 5. Not all samples submitted for analysis are included because of poor preservation or because pollen was so scarce that reliable counts were impossible.

The pollen data from Motukarara are complemented by the identification of macrofossils. These are leaves and twigs of *Dacrycarpus dacrydioides*, seeds of *Coprosma*, *Elaeocarpus*, and *Prumnopitys taxifolia* and *Lophomyrtus obcordata* cupules; remains of the same plants are reported from a number of other sites in the Christchurch district (Moar 1958, 1971) (Table 4).

Recycled dinoflagellate cysts, pollen grains, and spores derived from Cretaceous or early Tertiary sediments are recorded from three samples. One, from the Bromley Formation (M35/f24), contains only a few grains; a second from the Shirley Formation (M35/f22), and a third from an unnamed interglacial (M35/f23) contains as many as 3% and 1%, respectively, of the total pollen counted. Charcoal (or fine coal chips) and *Proteacidites* pollen are common to all three. The recycled dinoflagellate cysts, pollen, and spore types recorded are listed below.

	M35/f22	M35/f23	M35/f24
Deflandrea	+		
Haloragacidites harrisii (Couper)	+	+	
Microcachryidites antarcticus Cookson	+		+
Nothofagidites matauraensis (Couper)			+
Palmae	+		
?*Paripollis*		+	
Phyllocladidites mawsonii (Cookson)	+	+	
Proteacidites pallisadus (Couper)		+	
Proteacidites	+	+	+
Rhoipites alveolatus (Couper)	+		
?*Sphagnum*		+	+
Trichotomosulcites microsaccatus (Couper)		+	
?*Triorites subspinosus* (Couper)	+		
Vitreisporites pallidus (Reissinger)		+	

DISCUSSION

Details of the Motukarara site are especially relevant to understanding the pollen analyses from the peat layers recovered during drilling operations. The pollen spectra (Table 5) and macrofossils from this site are typical of coastal sites in Canterbury and reflect the swampy nature of the area during the Aranuian.

The long history of swamp forest in the region is indicated by analysis of a buried peat from a pit excavated in a paddock on a Lincoln College farm (New Zealand Soil Bureau 1968). The peat, about 9000 years old (NZ493A, 8895 ± 130 years B.P.), contains, in addition to pollen, abundant twig and leaf remains of *Dacrycarpus dacrydioides* and *Prumnopitys taxifolia*, numerous utricles of *Carex* spp., *Coprosma* fruits, and a cupule of *Lophomyrtus obcordata*.

The presence of *Dodonaea*, *Tetrapathaea*, *Tupeia*, and *Typha* pollen, and glochidia and massulae of *Azolla*, in the Motukarara peats emphasise the temperate conditions which prevailed there during the late Aranuian. Burrows (1986) described a modern equivalent of lowland forest growing in the Ahuriri Valley, about 1 km from the Motukarara site, in which occur *Dodonaea*, *Prumnopitys ferruginea*, *P. taxifolia*, *Tetrapathaea*, and *Tupeia*. Remnants of similar forest are found throughout Canterbury as at Kaituna Valley, Banks Peninsula and Riccarton Bush, Christchurch.

Table 5 Pollen analyses from late Quaternary deposits, Canterbury Plains.

Climatic event and formation	Aranui postglacial Springston Formation						?		Kaihinu Interglacial Bromley Formation								Waimea Glaciation Linwood Gravel	Karoro Interglacial Heathcote Formation				Scandinavia Interglacial Shirley Formation		Unnamed interglacial Unnamed formation
Fossil record number and site locality‡	M36/f7590 Motukarara						K37/f9502 Waterton	L37/f1 Riverside	M36/f6515 Lincoln			M35/f5 Sockburn	M36/f11 Prebbleton	M35/f24 Yaldhurst	M35/f9505 Bryndwr	M35/f11 Aranui	M35/f19 Bromley	M35/f20 Bromley	M35/f21 Bromley	M36/f8 Templeton	M36/f10 Halswell	M35/f9 Burwood	M35/f22 Bromley	M35/f23 Bromley
Depth below ground surface (m)	0.65	0.90	1.60	2.80	3.20	3.65	42	30		23		42	40	47	58	63	62	81.5	82	60	61	134	111	154
Dacrycarpus	5	25	8	1		+			36	19	42	18	5	7	1	+	+		+			41	2	4
Dacrydium cupressinum	*	*	1	1	1	1	1		*	+	*			4	3			*	+		*		*	
Elaeocarpus	3	*	1								*	1												
Libocedrus				*											*									
Metrosideros									*		*				*							18		
Nothofagus fusca-type	12	9	6	11	9	10	42	1	16	7	1	3	4	11	15		+	2	1	1	2	2		1
Nothofagus menziesii							2								*							*	2	
Podocarpus totara	2	2	2	4	4	5						1										1		
Podocarpus	19	8	1			3			16	49	40	46	25	31	39		5	4	1	1	1		22	35
Prumnopitys ferruginea	1		3	1	1	2									*									
Prumnopitys taxifolia	7	12	7	12	20	18																		
Weinmannia										+	+	+										5		
Ascarina															*									
Alectryon																							+	
Carpodetus	+	*	2							+		1											*	1
Dodonaea		*	2	8	21	26					3	2	1			+	+							
Fuchsia		+																+				*	+	+
Griselinia		*	6		1						+													
Halocarpus bidwillii						+	2				+				1							*		
Hoheria	*		3	5	4	7										+			1					*
Knightia														*				2	+			*		+
Lophomyrtus	13	1	4	2	2	1						+		+	*									
Melicytus														+								20		
Myoporum						+																		
Myrtaceae									4				3											
Paratrophis	+		1	2						+	+		1											
Phyllocladus	1		1	2	2	1	7	+	*	2	2	1	5	2	13	+	9	*	8	2	1	2	3	+

Pittosporum	*		4																					
Plagianthus		3					2	1	2	2	+	1	2	+	1		24	15	8	1	+	*	*	3
Pomaderris														*										*
Pseudopanax	10	23	13	1	1	1			*	*	1		1	7	5		1	2	+		1	1		
Carmichaelia				*																				
Compositae	*			1	2	3	4	8	*		*		4	*	*		3	1	7	*	2	*	6	2
Coprosma	4	3	7	18	13	11	20	1	2	2	*	4	13	21	6	+	54	48	55	5	9	11	62	41
Coriaria									20	15	4			4				+						+
Dracophyllum														+	*			+						1
Gaultheria																		*						
Hebe		1													+				1				+	+
Leptospermum-type	16	3	6	21	1	2	23		4	4	3	17	28	3	8			15	5	83	84	8		
Loranthus																							+	
Muehlenbeckia	1	1	6	5		5	1	86			+		5	5	+		+	*		1	1	1	1	6
Myrsine	3	6	13	5	14	6		3	1		2	4	3	4	1		5	9	11	3	+	*	+	*
Pimelea																							+	+
Pseudowintera						+																	*	+
Rubus		1	1		1									*	+			+			+	1		
Tetrapathaea			*		1	+			+	+	+													
Elytranthe																								+
Tupeia	1		*	*	3	3												+	+				+	
Acaena														+										
Astelia	+	+	4											+				4			3	1		
Calystegia																		1						
Caryophyllaceae													*											
Chenopodiaceae		+				+				+								+	+			1	1	
Cordyline																								2
Crassula				*																				
Cruciferae				1															1					
Epilobium						+										+	1		+					
Geranium						+																		+
Geum																		2						
Gramineae	*	*	*	3	5	1	29	3	*			1	6	1	2		4	1	1	2		*	+	2
Haloragis											+			4				+	1				1	+
Hydrocotyle				*								+												
Libertia																		+						
Plantago									*															
Ranunculus		+													1									
Rumex																	8	14	+					
Stellaria																			+					+
Umbelliferae						+		*	*					*				+	1				+	
Cyperaceae	1		4	54	31	7	651	3	12	11	*	11	34	143	259		158	89	186	13	8	5	31	261
Empodisma									*						1		3	21	121				8	4

(*Continued next page*)

Table 5 (*Continued*)

Climatic event and formation			Aranui postglacial Springston Formation				?					Kaihinu Interglacial Bromley Formation				Waimea Glaciation Linwood Gravel		Karoro Interglacial Heathcote Formation			Scandinavia Interglacial Shirley Formation		Unnamed interglacial Unnamed formation
Fossil record number and site locality‡			M36/f7590 Motukarara				K37/f9502 Waterton	L37/f1 Riverside		M36/f6515 Lincoln		M35/f5 Sockburn	M36/f11 Prebbleton	M35/f24 Yaldhurst	M35/f9505 Bryndwr	M35/f11 Aranui	M35/f19 Bromley	M35/f20 Bromley	M35/f21 Bromley	M36/f8 Templeton	M36/f10 Halswell	M35/f9 Burwood	M35/f22 Bromley	M35/f23 Bromley
Gunnera							4				+								+					
Leptocarpus																						2		
Phormium			2	5	8	+				+		1	4	3			3	5	8		1	*		1
Typha	*	1	*	1	4	184					*			+	+		41	1					+	
Azolla						+	1					1					1							
Myriophyllum						4	14												10	3				
Potamogeton							2				*													
Adiantum																	43							
Anthocerotales																	+	1	+				+	
Cyathea smithii-type										1	*	6		1	14		28	22	15		+	*	3	5
Dicksonia fibrosa											1			+			2		+			*		
Dicksonia squarrosa										1		5				+	+	6	1				1	+
Gleichenia												1			1			65	6		13		+	1
Histiopteris											2	1					1	+			+			
Lindsaea																		+						
Lycopodium														1				+	1				+	+
Monolete	*		*	2	12	3	1	1	14	76	2	25	37	164	123		81	71	70	30	11		+	3
Ophioglossum														+					+					
Paesia														+			+	1	+				+	+
Phymatosorus					1				*		*			+			11	+	1					+
Pteridium													1			*								
Schizaea fistulosa															1									
Sphagnum														+										+
Trilete	1			1		1			*	4	*	3	5			1								
Recycled pollen														+									7	1
Unidentified pollen														13	10		6	13	4				4	5

Data are based on total woody pollen counted so that pollen of woody plants is presented as a percentage of total pollen of woody plants; ferns, lycopods, bryophytes and pollen of herbaceous plants are presented as actual counts.
‡See Tables 3–5 for details of sample localities. * Represents frequencies of <1%. +Presence noted after count completed.

The Motukarara pollen analyses also record the late Aranuian decline of *Dodonaea* which is comparable to the *Ascarina* decline discussed by McGlone & Moar (1977). The only radiocarbon date, NZ1820A, 1890 ± 80 years B.P., comes from a moa bone lying between 0.85 and 0.95 m in the Motukarara mire. It is not known whether the bone is as old as the peat matrix in which it was embedded, but it provides a minimum date, close to that for *Ascarina*, for the eclipse of *Dodonaea*. A similar marked decline of *Dodonaea* pollen occurs in a pollen diagram from a site in coastal hill country near Cass Road, Waipara (Moar unpub.) The *Dodonaea* decline reflects the adverse effect of increased frost and drought considered to account for the scarcity of *Ascarina* after about 2000 years ago.

Moar (1971) described pollen spectra from an Aranuian site near Timaru which compare with those from Motukarara except for the absence of *Azolla, Dodonaea,* and *Tetrapathaea*. *Azolla* and *Tetrapathaea* are recorded in the last interglacial site at Timaru (Moar 1973; Goh et al. 1978) well south of the present limit for the latter.

The pollen spectra from the Lincoln well samples (M36/f6515, Table 5) record the dominance of podocarp forest. That this forest is interglacial is emphasised by the presence of *Dodonaea, Tetrapathaea,* and *Tupeia* pollen, although the absence of *Dodonaea* from the upper samples suggests that the mildest part of the interglacial was over when the sediments were deposited. *Coriaria* pollen, recorded from the Lincoln, Yaldhurst, and Bromley sites, is indicative of some form of disturbance. This does not affect the view that the sites were interglacial, for *Coriaria* seeds are recorded in a number of buried Aranuian peats as at Lincoln and in Christchurch (Moar 1958).

The interglacial character of other sites (Tables 3, 5) is less obvious. The presence of *Dodonaea* pollen in the Bromley Formation peat (Kaihinu Interglacial) at Prebbleton (M36/f11), Sockburn (M35/f5), and Aranui (M35/f11) and in the Shirley Formation (Scandinavia Interglacial) at Burwood (M35/f9, Fig. 12), *Ascarina* pollen at Bryndwyr (M35/f9505) (Kaihinu Interglacial), and pollen of other warmth-demanding plants nevertheless confirms that temperate climates prevailed at those times. Pollen was probably washed into these sites with silt and is therefore often poorly preserved. Analysis of a sample (M35/f19) from the Linwood Gravel (Waimean Glacial) suggests it is similar to samples (M35/f20, M35/f21) from the base of the Heathcote Formation (Karoro Interglacial). The presence of *Azolla, Dodonaea* (trace), and *Typha* indicate interglacial conditions, but the dominant woody pollen, *Coprosma* (54%), *Plagianthus* (24%), and *Phyllocladus* (9%), suggest early interglacial rather than full interglacial conditions. A sample (M35/f23) from an unnamed interglacial contains a trace of *Dodonaea* pollen in an assemblage dominated by sedge pollen and in which *Coprosma* and *Podocarpus* are the dominant woody types.

A Shirley Formation (Scandinavia Interglacial) sample (M35/f22) is dominated by *Coprosma* pollen. The pollen grains are clumped together, as though still in the anthers, and are regarded as overrepresented, indicating a dense local shrubland in a forested landscape. The presence of *Ascarina, Typha,* and *Tupeia* pollen supports the view that the site is an interglacial one. In other sites also (e.g., Heathcote Formation, Karoro Interglacial; M36/f8), high frequencies of *Leptospermum*-type pollen suggest a dense local growth which screened out regional pollen. Neither *L. scoparium* nor *Kunzea ericoides,* both with *Leptospermum*-type pollen, occur above the forest limit, although both tolerate local extremes of climate. Molloy & Ives (1972) emphasised the tolerance of both species to dry windy environments and showed that they have been present on the inner Canterbury Plains for thousands of years.

Nothofagus pollen is present in all but one site (M35/f11), and the pollen frequencies are low enough to suggest long-distance dispersal (Myers 1973). However, *Nothofagus* leaves (cf. *N. cliffortioides*) have been recovered from 1000 year old buried peats at Bowenvale Valley, Christchurch (Moar 1958), so that the source of the pollen at Motukarara need not have been too distant. The high frequency for *Nothofagus* pollen from the Waterton site (K37/f9502) is puzzling. Beech forest (*Nothofagus*), shrubland, and grassland occupied the area rather than the mixed podocarp forest characteristic of the other sites. If the Waterton site is assigned interglacial status, it must be close to the transition from interglacial to glacial. Since there is no coastal site in Canterbury with a similar pollen spectrum, the age of the Waterton site must remain uncertain.

CONCLUSION

Most of the samples from the Canterbury Plains have been tentatively assigned to either the last (Kaihinu) or earlier interglacials by Brown & Wilson (above). The pollen data support this view, but they cannot yet be used to separate one interglacial from another, the ages of which still depend upon their relative position in the stratigraphic column. Thus the samples from the Lincoln well with their records of warmth-demanding plants are considered to be closer to full interglacial conditions than those others in which woody vegetation is represented by beech forest or shrubland. A more detailed appraisal depends upon study of long, continuous sequences yet to be discovered in the Canterbury Plains.