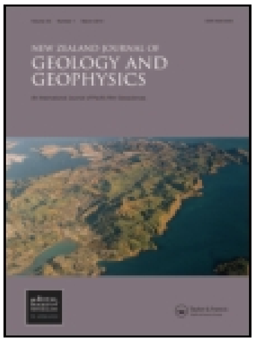

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Late Quaternary geology of the Wairau Plain, Marlborough, New Zealand

L. J. Brown

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Late Quaternary geology of the Wairau Plain, Marlborough, New Zealand

L. J. BROWN
New Zealand Geological Survey, DSIR
P.O. Box 30 368
Lower Hutt

with an Appendix

Faunas and paleoecology of Dillons Point Formation

A. G. BEU
New Zealand Geological Survey, DSIR
P.O. Box 30 368
Lower Hutt

Abstract The late Quaternary deposits of Wairau Plain are subdivided on the basis of mapping, test drilling, radiocarbon dating, and macropaleontology (paleoecology). Otira (last) Glaciation fluvial gravel, sand, and clay deposits (correlated with the Speargrass Formation of the upper Buller River valley) are capped by a surface which extended at least to the present-day coast and possibly into Cloudy Bay. Postglacial deposits overlying Speargrass Formation are grouped into 2 contemporaneous formations described in this paper.

Dillons Point Formation (new name) consists of marine embayment and estuarine sediment and fauna, deposited over the land surface during the postglacial marine transgression and the subsequent regression. The maximum inland transgression occurred about 6000 to 7000 years ago before a barrier spit (Boulder Bank) was formed part of the way across Cloudy Bay. Progradation of the coast occurred outside the northern end of the Boulder Bank simultaneously with the infilling of the lagoons and estuaries behind the Boulder Bank.

Rapaura Formation (new name), a postglacial fluvial gravel, sand, silt, and clay deposit, is derived mainly from erosion of the Speargrass Formation as a result of alternating aggradation and degradation by the Wairau River. Rapaura Formation lenses out against, and interfingers with, Dillons Point Formation.

Macrofaunas from Dillons Point Formation (mainly drillhole samples) are detailed in an appendix and the paleoecology is discussed.

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Keywords Quaternary; stratigraphy; postglacial environment; tectonics; water well data; paleoecology; Wairau River; Wairau Plain; Marlborough; Dillons Point Formation; Rapaura Formation; new stratigraphic names

INTRODUCTION

Marlborough consists of a series of northwest-tilted blocks forming mountain ranges, hills, and drowned valleys (Marlborough Sounds) separated by major transcurrent faults along which are developed fault-angle depressions. Wairau River lies in the fault-angle depression formed along Wairau Fault, a continuation of the Alpine Fault (Fig. 1). The valley and plain of Wairau River separate upper Paleozoic schist and greywacke in the north, from Mesozoic greywacke in the south. Tectonic activity is a major influence on the geology of the Wairau Plain. Northwest tilting of the block (Awatere Block) between the Wairau and Awatere Faults (Fig. 1) has resulted in the main tributaries of Wairau River being on the southern side of the Wairau valley.

In the lower reaches of the Wairau valley, alluvial deposits laid down by Wairau River and its tributaries during periods of glacial advance in the inland mountain ranges have been eroded and redeposited during warmer interglacial periods. Higher level and dissected alluvial deposits on the southern margin of the Wairau valley and plain are remnants of former glacial outwash deposits.

Postglacial aggradation by the Wairau River has partially dammed the tributaries joining it from the north. These southward flowing tributaries have also been affected by northwest tilting of the block (Marlborough Sounds Block) north of Wairau Fault. As a result, Tuamarina River has an extensive swamp (Para Swamp) at the southern end of the Tuamarina valley; the Areare Creek (Okaramio valley) and Pukaka Stream disappear into swamps which drain into the Wairau River, and Waikakaho River has established a meandering course at the mouth of its valley.

Over the greater part of the lower Wairau valley and plain, postglacial aggradation has formed fluvial

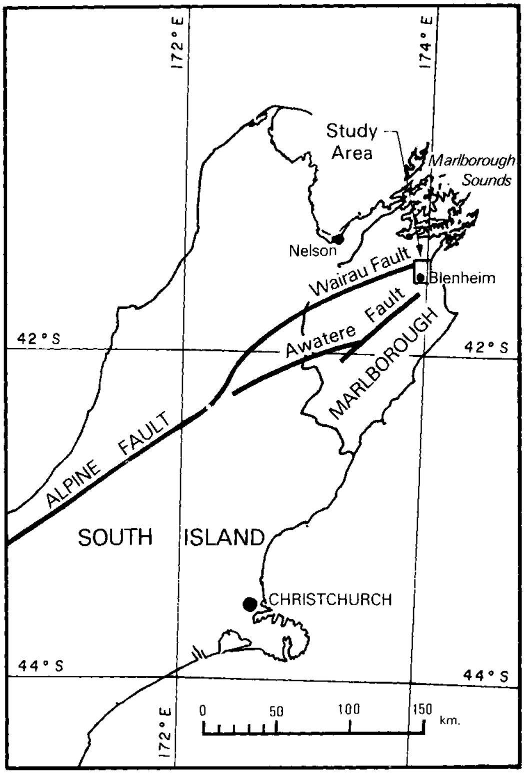


Fig. 1 Northern South Island, New Zealand, showing the study area in relation to the Wairau and Awatere Faults.

deposits on top of glacial outwash deposits. Near the modern coast, postglacial swamp, lagoonal, estuarine, and beach deposits overlie fluvial and glacial outwash deposits. The Wairau Plain is the surface developed on the postglacial and last glaciation deposits of the lower Wairau valley from "The Narrows" (just upstream of the Waihopai River junction) to Cloudy Bay (Fig. 2).

PREVIOUS WORK

The geology of the Wairau valley was summarised by Lensen (1962) and Beck (1964). Quaternary tectonics have been considered by Cotton (1954), Eiby (1973), and Lensen (1976). Various workers have discussed the evolution of the coastal part of the Wairau Plain. Cotton (1913) and Jobberns (1928) supposed that the lower plain formed as a delta of the Wairau River, whereas Wild (1915), Jobberns (1935), and Pickrill (1976) suggested that the plain formed as a result of infilling with sand, silt, and clay (by the Wairau River) of a lagoonal system, a remnant of which survives to the present day as the Wairau Lagoons, partially enclosed by a barrier spit (Boulder Bank).

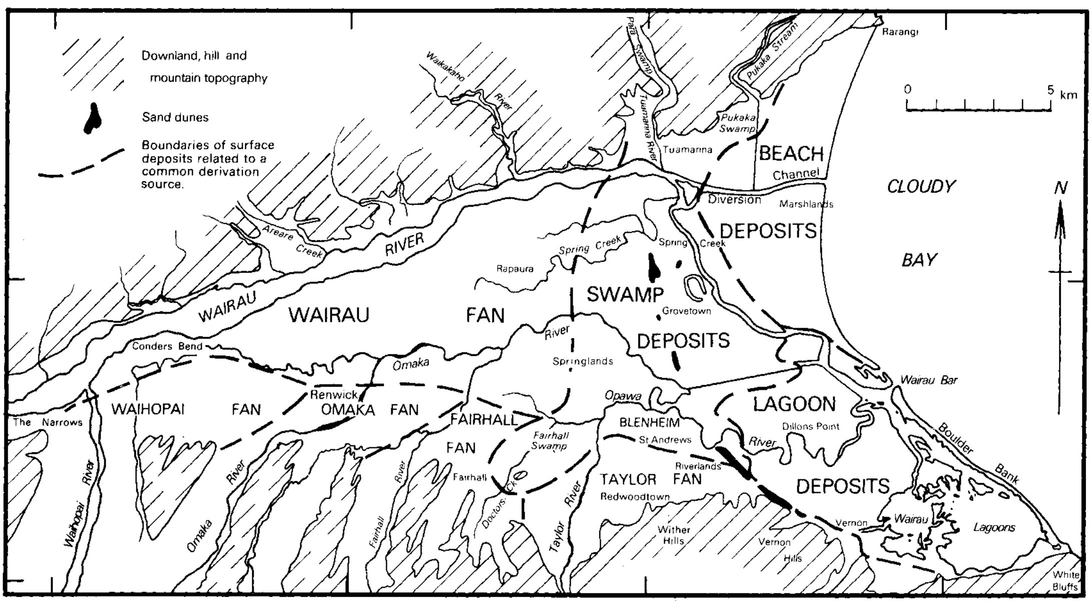
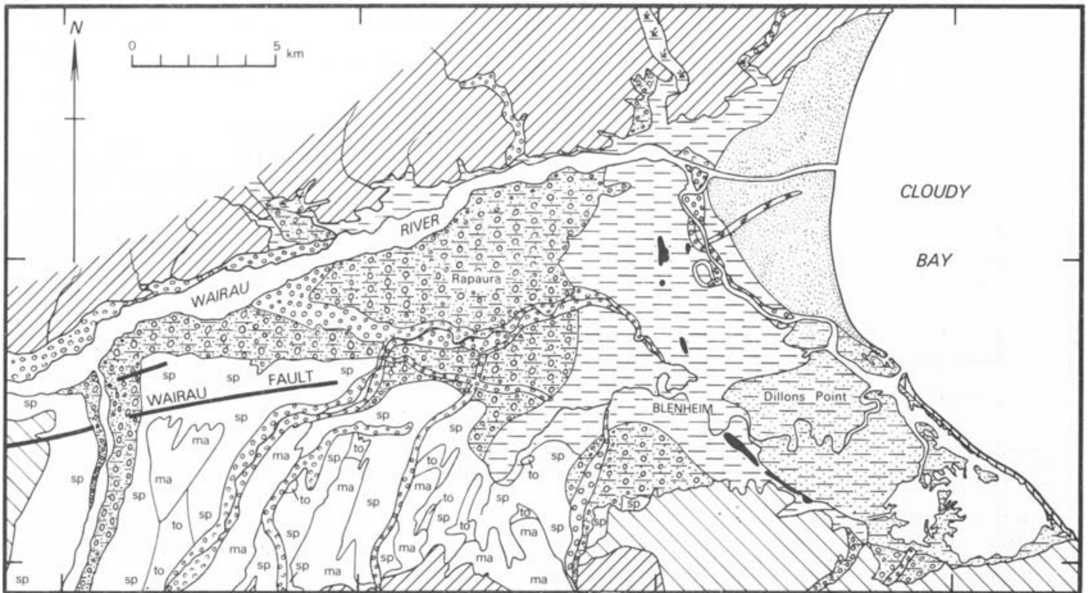


Fig. 2 Deposits of the Wairau Plain related to their parent rivers or origin.



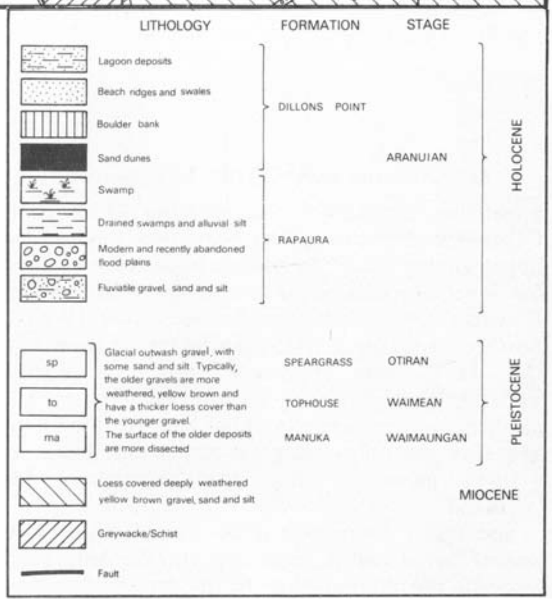


Fig. 3 Geological map of Wairau Plain.

STRATIGRAPHY

Figure 3 is a map of the surface geology of the Wairau Plain, and Fig. 4 illustrates the subsurface sequence. The late Quaternary stratigraphy of the Wairau Plain can be summarised thus:

Formation	*Derivation*	
Dillons Point*	Coastal and lagoon deposits	Contemporary postglacial
Rapaura*	Fluviatile and swamp deposits	Contemporary postglacial
Speargrass	Glacial outwash gravel	Otira Glaciation
Tophouse	Glacial outwash gravel	Waimea Glaciation
Manuka	Glacial outwash gravel	Waimaunga Glaciation

*New formation names

MANUKA AND TOPHOUSE FORMATIONS
(Suggate 1965)

Fan deposits laid down by the rivers flowing to the Wairau Plain from the south are dissected and mantled with loess to produce a "rolling" topography. These are correlated with glacial outwash deposits (Tophouse and Manuka Formations, Suggate 1965) of the Wairau and Buller valleys. In Fig. 3 the separation of Tophouse and Manuka Formations at the surface is based on the Manuka Formation having a thicker loess cover and being more dissected with more weathered (brown/yellow) gravel, sand, and clay content than the younger Tophouse Formation.

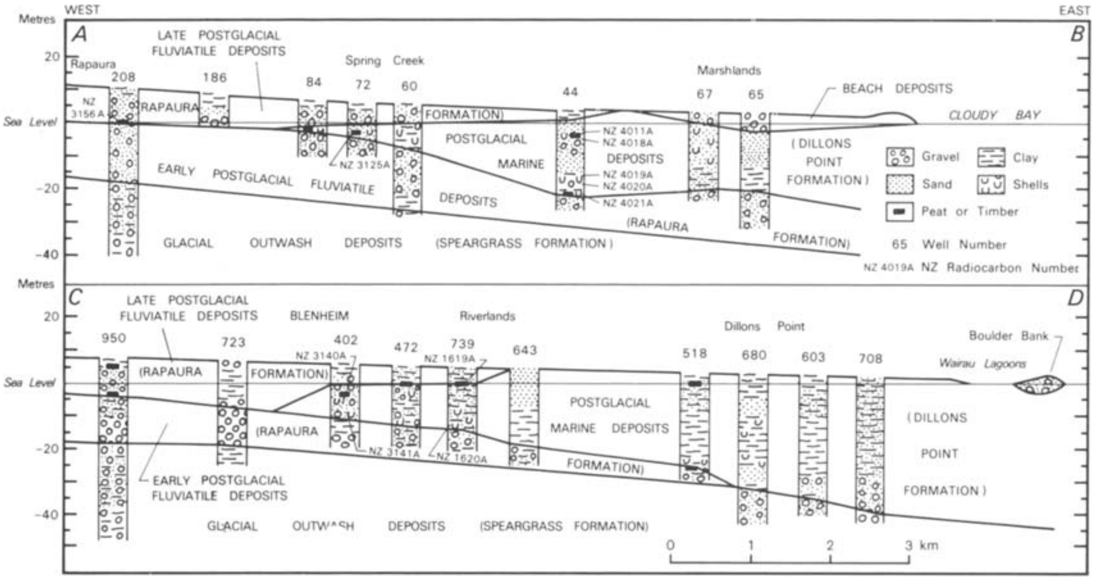


Fig. 4 Stratigraphic columns from well data, Wairau Plain. Positions of section lines A–B and C–D are shown in Fig. 5.

SPEARGRASS FORMATION (Suggate 1965)

Speargrass Formation, representing Otira (last) Glaciation deposition, has been described in the upper Buller valley; its surface is correlated with a low-level aggradation surface of the Wairau valley (Suggate 1965). The aggradation surface (Wairau Surface of Wellman 1955) can be traced from near the old Rainbow Homestead down the Wairau valley to Renwick on the Wairau Plain (Fig. 5). The surface is well preserved and flat, and the underlying gravel is generally blue-grey, rather than brown or yellow, indicating that little weathering has occurred.

Speargrass Formation is correlated with poorly sorted fluvial gravel, sand, and clay deposits which underlie the Wairau Plain to the present-day coast and possibly extend into Cloudy Bay. A series of bores drilled for the Marlborough Regional Water Board, to test the groundwater resources and the geology of the subsurface deposits of the Wairau Plain, showed vertical variation in permeability with essentially decreasing permeability with depth of a continuous sequence of gravel, sand, and clay beneath the postglacial deposits. No lithological trends were detected that might allow subsurface deposits (other than postglacial) to be subdivided and correlated with the surface stratigraphy. The base of Speargrass Formation is not obvious in the lithologies encountered by the bores. This monotony of the subsurface deposits is consistent with deposition in an environment dominated by net aggradation by the Wairau River.

The surface boundary between Speargrass Formation and postglacial fluvial deposits is marked by a degradational terrace with a maximum height of 6 m in the vicinity of Renwick (grid reference P28/798664* [S28/133999], Fig. 6). Further down the plain this erosional break is detected as a slight undulation and change in surface gradient on a relatively flat surface. In bores, Speargrass Formation can be distinguished from the overlying postglacial fluvial deposits by more clay and silt in the matrix, which is reflected in a lower permeability in the gravels and its being more difficult to drill. These criteria are the basis for distinguishing the Speargrass Formation surface (Fig. 5) and the subsurface division in the cross sections (Fig. 4).

The gradient of the Speargrass Formation surface is about 1:300 compared with 1:400 for the present-day Wairau Plain surface. The smooth contouring of the Speargrass Formation buried surface (Fig. 5) is a simplification of what is probably a series of steps arising from sequences of buried terraces and undulations. Degradation of the surface in early

*Grid references are based on the national thousand-metre grid of the 1:50 000 topographical map series (NZMS 260). These are followed by the equivalent grid references from the 1:63 360 map series (NZMS 1) in square brackets.

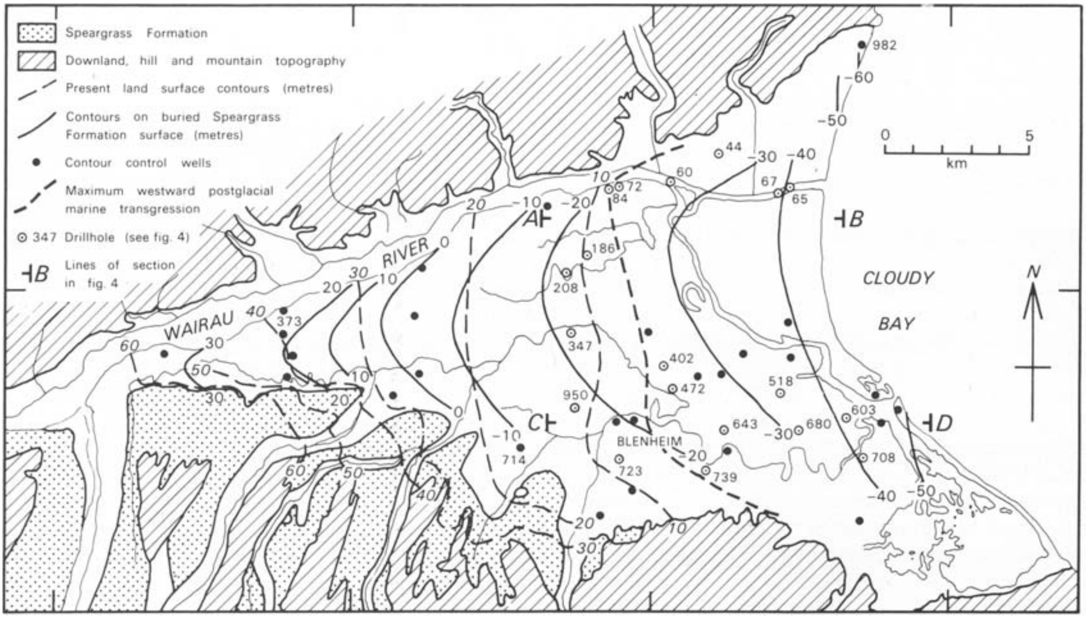


Fig. 5 Contours on Speargrass Formation surface.

Fig. 6 Speargrass Formation terrace degradational face, Renwick (grid ref. P28/798664). Rapaura Formation surface in foreground.

postglacial time was followed by periods of aggradation and degradation as the Wairau River criss-crossed the plain under the influence of a variable river load, a fluctuating but generally rising sealevel, and tectonic movement. The gravel immediately overlying Speargrass Formation (Fig. 4) through to the present coast was deposited during the early postglacial period, when Wairau River was cutting into the Speargrass Formation of the Wairau valley and inland Wairau Plain, and aggrading downstream with material derived from upstream entrenchment.

Within the Speargrass Formation there is a lateral increase in permeability (reflected in water yield from wells) towards the coast. This is probably due to the presence within Speargrass Formation of buried channels of gravel formed when the river washed out most of the finer sediment during deposition. Deposition and sorting in this coastal area would be influenced by the greater width of the valley and a coastline several kilometres beyond the present coast. On the southeastern margin of the Wairau Plain a significant quantity of sand and silt derived from material washed down from the Wither and Vernon Hills is present within the Speargrass Formation, reducing permeability.

RAPAURA FORMATION (new name)

Rapaura Formation is the unit proposed for the postglacial fluvial gravel, sand, silt, and clay deposits of the Wairau River and other rivers forming tributaries or flowing onto the Wairau Plain.

Rapaura is Maori for "running waters" (Insull 1952). The Rapaura Formation is named from the Rapaura locality about 5 km northwest of Blenheim on the Wairau Plain (Fig. 2).

The warmer climate at the end of the Otira Glaciation, about 14 000 years ago, reduced the area of ice and snow and allowed regeneration of vegetation at higher altitudes in the Wairau River catchment. A diminishing supply of easily eroded rock material resulted in a lower sediment load in the Wairau River. As a result, the Wairau River had sufficient energy to cut into the Speargrass Formation aggradational surface and remove gravel, sand, and silt to build alluvial deposits to the present coast to form the Wairau Plain surface.

Type section

The type section for Rapaura Formation is in a gravel pit operated by the Marlborough County Council near the intersection of State Highway 6 (Blenheim–Nelson) and Rapaura Road (grid reference P28/785679 [S21/216046]), Upper Rapaura. The pit is in a former flood channel of the Wairau River which was last occupied in 1861 when the river overflowed at Conders Bend and spilled into Omaka River. The water table is about 7 m below ground surface.

The pit exposes 6 m of rounded to subangular, poorly sorted gravel up to cobble size (Fig. 7, 8), but does not penetrate to the base of the formation. Rare sand lenses, up to 10 cm thick, are generally less than 1 m in length. Grey-brown sand dominates the matrix with a minor amount of clay and silt. The parent material of the gravel and matrix is almost exclusively greywacke, with rare schist pebbles. The

Fig. 7 Rapaura Formation type locality, Marlborough County Council pit, Upper Rapaura (grid ref. P28/785679).

Fig. 8 Rapaura Formation type locality showing detail of dominant gravel with sand lenses and sand-clay-silt matrix.

formation is about 20 m thick, in a bore (P28/w373)* adjacent to the type locality, and reaches a maximum thickness of about 30 m in another bore near Rapaura.

Distribution

In the valleys of the Wairau River and its tributaries, reworking of Speargrass Formation adjacent to the river has produced degradation surfaces and terraces mantled by reworked gravel, sand, and silt (Rapaura Formation). Downstream from "The Narrows" near the Waihopai River junction through to Renwick, the Wairau River entrenched into the former Speargrass Formation surface in early postglacial time. With the rapid rise in postglacial sealevel, to the present-day relatively stable level, a transition from degradation to dominantly aggradation occurred on this part of the Wairau Plain. Postglacial aggradation by Wairau River and the rivers flowing onto Wairau Plain from the south has always been dominant in the area from Renwick to Spring Creek and Blenheim. Little sediment is contributed from the hills to the north. From Spring Creek, south to Blenheim, Rapaura Formation interfingers with the postglacial coastal Dillons Point Formation (see below). Channels of fluvial gravel, sand, and silt within the sand, silt, and clay of Dillons Point Formation mark flood incursions by the Wairau River into the lagoonal or marine environment.

A narrow swampy area that extends northeast for 3 km from the western bank of the Wairau River near Spring Creek to Marshlands, where it appears to be truncated by beach ridges (Fig. 3), is an abandoned Wairau River course. A freshwater bivalve (P28/f15†, *Hyridella menziesi*) collected from an excavation in this swamp, gave a radiocarbon age (NZ4551A‡) of 1080 ± 70 years B.P.

The Taylor River has formed a postglacial fan of gravel, sand, and silt on which the Redwoodtown suburb of Blenheim is located (Fig. 2).

Subsurface Rapaura Formation is divided (Fig. 4) into an upper and lower unit, on the basis of depth, lithology, permeability, and ease of drilling. The upper unit was deposited since the postglacial maximum inland incursion of the sea (i.e., during the last 7000 years) in a dominantly aggradation phase of the Wairau River. The lower unit was formed in the early postglacial (i.e., 14 000–7000 years ago) during the inland degradation–coastal aggradation period of deposition. The lower unit extends to the present coast and underlies postglacial marine and lagoon deposits (Dillons Point Formation). The contrast in permeability and penetrability that is the basis for this division of the subsurface Rapaura Formation is not always visually apparent in the disturbed and washed samples obtained from bores put down by the cable-tool percussion drilling method. No definite distinct irregularities can be recognised on the Rapaura

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

†New Zealand Fossil Record File number based on the metric (NZMS 260) system. See Table 2.

‡New Zealand Radiocarbon Dating Laboratory sample number. Old half life uncorrected for secular effects. See Table 1.

Formation surface than can be attributed to the surface contact or transition between these 2 postglacial fluvial regimes. In contrast, Suggate (1963), when discussing Springston Formation, the Canterbury Plains equivalent of Rapaura Formation, was able to recognise 2 distinct postglacial fans in the Waimakariri sector of the Canterbury Plains (Halkett and Yaldhurst Surfaces). These also were postulated to be a result of the change from the period of rapid rise of postglacial sealevel, to the period of substantially stable sealevel of the last 4000–5000 years.

Present-day surface

The Rapaura Formation is overlain by soils developed from alluvial silt deposited by overbank flooding of Wairau River and its tributaries. The soils become denser and deeper at localities remote from the source of flooding (Harris & Birrell 1939). This has provided the basis for the subdivision of the Rapaura Formation surface deposits as mapped in Fig. 3. Very rapid and recent deposition on the Wairau Plain is illustrated by wood sample (P28/f6505, *Dacrycarpus dacrydioides,* Kahikatea), from a depth of 10.5 m below ground surface in a test bore (P28/w208) located east of Rapaura (grid reference P28/873709 [S21/216046]) dated (NZ3156A) at <200 years B.P. The tree trunk from which this sample was obtained was presumably deposited in a scour hole in a river bed.

Alluvial silt deposited during intermittent flooding by the Wairau River forms a 2–3 m thick layer over Dillons Point Formation in the area from Tuamarina to Riverlands. Also in this area swamps were formed as a result of local rain, spring flow, and water from the Omaka, Fairhall, Tuamarina, Taylor, and Pukaka Rivers and Doctors and Spring Creeks banking up behind the prograded coastal deposits and the Wairau Lagoons.

Blenheim was originally named Beavertown because at the beginning of European settlement of the Wairau Plain in the mid-nineteenth century, the surveyors had to live on logs in the swamps, like beavers. Grovetown (originally named Big Bush) was the site of a forest of about 40 ha and was an "island" in the swamp. Other forests were at Tuamarina and adjacent to the Pukaka Swamp. In the latter, numerous trees (P28/f14 *Leptospermum ericoides,* kanuka; *Leptospermum scoparium,* manuka; *Podocarpus totara/halli,* totara) have been buried in a silty peat deposit in what appears to be the position of growth. Another buried forest occurs in the former Fairhall Swamp. A wood sample (P28/f8584, *Podocarpus totara*) encountered by a well (P28/w714) near Fairhall (grid reference P28/856647 [S28/196979]), at a depth of 9 m from ground surface, gave a radiocarbon age (NZ1934A) of 240 ± 60 years B.P., which suggest rapid infilling. These historical and buried forests illustrate that some areas of the Wairau Plain were free from flooding for periods long enough to permit establishment of forests.

DILLONS POINT FORMATION (new name)

Dillons Point Formation is the stratigraphic unit proposed for the postglacial marine, estuarine, lagoonal, and eolian deposits of the coastal Wairau Plain.

It is named from the Dillons Point locality about 6 km east of Blenheim on the southern bank of the Wairau River, just upstream from the river mouth.

The Cloudy Bay coast was several kilometres to the east during the Otira Glaciation. The climatic warming that marked the end of the Otira Glaciation melted large volumes of ice to produce a rapid rise in sealevel, and the sea transgressed over the coastal alluvial plains. Cotton (1913) noted sea cliffs on the northern side of the Wairau Plain as far inland as Tuamarina, and Jobberns (1928) noted cliffed spur ends at the base of the Vernon Hills on the southern side of the plain. Sand dune remnants, assumed to mark a temporarilly stable coastline about 6000 years ago, form an arc from Spring Creek to Vernon. Drill logs show that postglacial marine deposition extended further inland than the sand dune arc (Fig. 2), and radiocarbon dates suggest the maximum westward transgression occurred about 7000 years ago.

Pickrill (1976) suggested that the Boulder Bank was formed about 6000–7000 years ago when the postglacial rise in sealevel had become relatively stable at a level close to that of the present day. Erosion of the Marlborough coast south of the Wairau River provided material which was transported and sorted by the north-flowing coastal current to build the Boulder Bank part of the way across Cloudy Bay. Once formed, Boulder Bank acted at a littoral conveyor, so that progradation of the coast occurred in the north with the formation of a series of gravel beach ridges and swales. Floods in the Wairau River broke through the bars that were successively built across its mouth and have maintained an outlet to the sea; this process continues to the present day. South of the present-day Wairau River mouth several small clumps of seaweed (*Macrocystis*) grow just below low-tide level where boulders have accumulated on the seabed offshore from the Boulder Bank. Aerial photographs taken at irregular intervals, and observations over the last 30 years, show that some of the seaweed clumps are relatively permanent, suggesting that boulder-size material is now rarely transported by the littoral movement along the Boulder Bank. No obvious movement of boulder-size material occurred during the storms of 11 March 1975 (Cyclone Alison) and 1 August 1975.

In the southern part of the coastal Wairau Plain, fine-grained sediments gradually accumulated in the estuary and lagoons behind the Boulder Bank. The rate of silt deposition may have increased since the completion in about A.D. 1800 of the "Maori Channels" (Elvy 1957) dug by the Maoris as an aid to catch fish and birds, and since the development following European settlement of an extensive system of drains into the lagoons. Subsidence associated with the 1848 and 1855 earthquakes (Buick 1900; Cotton 1954; Eiby 1973) probably deepened the lagoons and extended their area.

Type section

The Dillons Point Formation type section consists of the strata overlying Rapaura and Speargrass Formations in well P28/w44 located about 2 km east of Tuamarina (grid reference P28/924744 [S22/272084]). The wellhead is 3 m above mean sealevel.

Well No. P28/w44, Tuamarina — Log

Depth from ground surface (metres)	*Lithology and other data*
0–0.3	Top soil
0.3–3.1	Grey clay
3.1–6.1	Grey sand
6.1–8.5	Grey sand and shells with some wood (P28/f7508, depth 7 m, NZ4011A, 4250 ± 60 years B.P.)
8.5–12.5	Grey gravel, sand and shells (P28/f7509, depth 9 m, NZ4018A, 5040 ± 130 years B.P.)
12.5–19.5	Grey fine sand with shells (P28/f7510, depth 16 m, NZ4019A, 5740 ± 130 years B.P.) (P28/f7511, depth 18 m, NZ4020A, 7750 ± 160 years B.P.)
19.5	Clay and shells
19.5–22.6	Grey gravel, sand and shells (P28/f7512, depth 20 m, NZ4021A, 7300 ± 160 years B.P.)
22.6–24.4	Grey sandy clay
24.4–26.8	Sandy clay with wood—Rapaura Formation
26.8–28.7	Grey gravel and sand—Speargrass Formation
28.7–30.2	Clay bound gravel—Speargrass Formation

Distribution and variation

Dillons Point Formation underlies the Wairau Plain from Rarangi to White Bluffs at the Cloudy Bay coast to about 7 km inland to Spring Creek and Blenheim (Fig. 4) where it interfingers with the westward-derived fluviatile deposits of Rapaura Formation. The maximum thickness measured is 60 m in a bore (P28/w982) at Rarangi on the northern extremity of the coastal Wairau Plain.

Well P28/w44 is located on the northern coastal Wairau Plain north of the Wairau River diversion channel and offshore from the Boulder Bank (see Pickrill 1976). An examination of the lithologies and fauna encountered by wells shows the influence of the Boulder Bank on the depositional environment. Beach gravels and sand occur in the north while sand, silt, and clay sediments dominate in the south. Table 2 in Appendix 1 lists faunal environments. Estuarine and lagoonal species occur in all collections, but only those from the northern part of the Wairau Plain contain a significant number of open ocean, sandy beach, or rock dwelling species. Faunas younger than 5000 years in the south suggest a lower than oceanic salinity, while those from the north have a consistent open beach and rock dwelling species content.

The grey sandy clay and grey gravel, sand, and shells overlying Rapaura and Speargrass Formations in well P28/w44 are interpreted as representing a transition from terrestrial (Rapaura Formation at 24.4–26.8 m) through estuarine to marine embayment environment as the sealevel rose and transgressed over the land surface. The transgression extended inland in this area to about 4 km west of the well, about 6600 years ago (NZ3125A). The faunas of P28/f7511 and f7512 encountered in well P28/w44 indicate an estuarine influence (Appendix 1, Table 2) at Tuamarina in advance of the marine transgression and prior to the formation of the Boulder Bank. The apparent age reversal with depth for these 2 samples (NZ4021A and 4020A) may be accounted for by discrepancies introduced by the need to dilute the counting gas during the radiocarbon dating process. The probability is that the younger age (NZ4021A, 7300 ± 160 years B.P.) for the deeper sample may be too young, and that there is no great difference in age between these 2 samples (T. L. Grant-Taylor pers. comm.). Once the Boulder Bank was established, coastal progradation resulted in the infilling of the bay at the northern end of the Boulder Bank from 5000 to 4000 years ago. This is represented by deposits showing estuarine with open ocean influence (see Table 2) from 19.0 to 6.0 m below ground surface in well P28/w44. Some subsidence must have occurred (see below: Tectonic activity). The overlying 6 m of soil, clay, and sand are interpreted as representing gradual infilling of a lagoon formed adjacent to the

Pukaka River outlet onto the Wairau Plain, behind the beach ridges and swales of a prograding coast. A transition from lagoonal to swamp environment with the growth of a forest adjacent to the Pukaka Swamp, followed by flooding to drown and bury the trees (in 1–2 m of alluvial silt) occurred prior to European occupation of the Wairau Plain.

Present-day surface

The most obvious surface feature of Dillons Point Formation is an arc of sand dunes from Spring Creek to Vernon. The dunes lie on the western edge of the outcrop of Dillons Point Formation in the south and are surrounded and partly buried by younger deposits of the Rapaura Formation in the north.

A dune at Riverlands rises 15 m above the plain surface (18 m above present-day sealevel) (Fig. 9). In the northern part of the coastal Wairau Plain, beach ridges and swales formed by the prograding coast extend from east of the Wairau River through to the present-day coast. The beach ridges consist of sand, grit, and beach gravel while the swales contain swamps and when drained form soils derived from silt and sand. In the southern coastal Wairau Plain, inland from the Wairau Lagoons, a meagre soil layer has developed on drained lagoonal sediments. Soils developed on Dillons Point Formation are saline with the salinity decreasing inland.

TECTONIC ACTIVITY

The Wairau Fault has probably been active in the last 1000 years (Lensen 1976) and surface fault traces occur as far east as Renwick. Earthquakes have affected the postglacial deposits of the Wairau Plain in historical time. An earthquake in 1848 produced about 1.5 m of subsidence on the Cloudy Bay coastline (Roberts 1855; Cotton 1954; Eiby 1973) enlarging the Wairau Lagoons and deepening the Opawa River. The increase in depth of Opawa River influenced the selection of the site for Blenheim at the furthest upstream navigable limit. Further subsidence (about 45 cm) of Wairau Lagoons occurred in another earthquake ("Wairarapa Earthquake") in 1855 (Buick 1900). It is possible that the subsidence was caused by earthquake compaction of the water-saturated sand, silt, and clay sediments of Dillons Point Formation (G. J. Lensen pers. comm.).

To judge whether tectonically induced subsidence has affected the Dillons Point Formation deposits it is necessary to compare the heights of radiocarbon-dated samples (Table 1) with the heights of the postglacial rise of sealevel where unaffected by tectonic activity. This is done in Fig. 10 using the curve of Gibb (1979) who interpreted data from sites round the New Zealand coast, made allowance for local tectonic affects, and concluded that sealevel reached that of the present day about 6500 years ago and has since fluctuated only slightly. Note that Fig.

Fig. 9 Sand dune at Riverlands, Dillons Point Formation (grid ref. P28/928643).

10 is a composite curve and as such is not entirely applicable to individual localities in different areas. For example, at the Firth of Thames, Schofield (1960) has described beaches formed by a postglacial eustatic sealevel higher than present. Figure 10 shows that all Wairau Plain radiocarbon samples fall below Gibb's curve and the simple inference is general subsidence. No pattern of differential subsidence can be discerned.

Figure 10 shows at least 3 samples (NZ4019A, 4411A, and 4412A) which appear anomalous in that they indicate subsidence exceeding the 5 m or less suggested by the rest of the radiocarbon-dated samples. NZ4019A has an estuarine fauna with an open beach content (see Table 2 in Appendix 1) and may have been deposited offshore near the mouth of an estuary to account for the deep burial depth. NZ4411A and 4412A could have been deposited in a deep hole in the lagoons behind the Boulder Bank at an early stage (4500–5200 years ago) of infilling of the lagoons. The precise heights of deposition of the other samples are also subject to a degree of uncertainty. The shells (dominantly estuarine) may have been carried into deeper water to give an exaggerated depth for sealevel. Gibb (1979) rejected Wairau Plain radiocarbon dates when constructing his curve because he considered that the method of sampling was unrealiable and that there had been contamination of the shells. Subsidence since deposition would seem to be a more valid reason for not using the Wairau Plain radiocarbon dates.

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Table 1 Fossil and radiocarbon samples.

NZ ^{14}C No.	Age (years B.P.)*	N.Z. Fossil Record File No. P28/f	Sample	Locality	Grid ref. sheet P28/	Depth from surface (m)	Altitude with ref. to m.s.l. (m)
1619A	1580 ± 65	9664	Wood	Riverlands	917644	6	-3
1620A	6950 ± 110	9665	Shells	Riverlands	917644	18	-14
1934A	240 ± 60	8584	Wood	Fairhall	856647	9	+2
1955A	4640 ± 90	9666	Shells	Vernon	976616	6	-5
1956A	4500 ± 90	9667	Shells	Vernon	975611	3	-2
3125A	6600 ± 80	6504	Shells	Spring Creek	889733	11	-4
3140A	6240 ± 140	7506	Shells	Grovetown	908680	15	-11
3141A	6630 ± 80	7507	Shells	Grovetown	908680	16	-12
3156A	< 200	6505	Wood	Rapaura	873709	10.5	0
4011A	4250 ± 60	7508	Shells	Tuamarina	924744	7	-4
4018A	5040 ± 130	7509	Shells	Tuamarina	924744	9	-6
4019A	5740 ± 130	7510	Shells	Tuamarina	924744	16	-13
4020A	7750 ± 160	7511	Shells	Tuamarina	924744	18	-15
4021A	7300 ± 160	7512	Shells	Tuamarina	924744	20	-17
4320A	4420 ± 120	1	Shells	Spring Creek	906714	7	-2
4321A	6080 ± 100	2	Shells	Spring Creek	906714	10	-5
4322A	5620 ± 100	3	Shells	Spring Creek	920720	11	-8
4323A	6720 ± 150	4	Shells	Spring Creek	906724	12	-7
4410A	3240 ± 110	8	Shells	Vernon	976622	6	-4
4411A	4600 ± 120	9	Shells	Vernon	976622	12	-10
4412A	5110 ± 130	10	Shells	Vernon	976622	18	-16
		11	Shells	Vernon	976622	24	-22
		12	Shells	Vernon	976622	49	-47
		14	Wood	Marshlands	941759	1	+2
4551A	1080 ± 70	15	Shells	Wairau Pa	918712	2	+1

* Old half life uncorrected for secular effects.

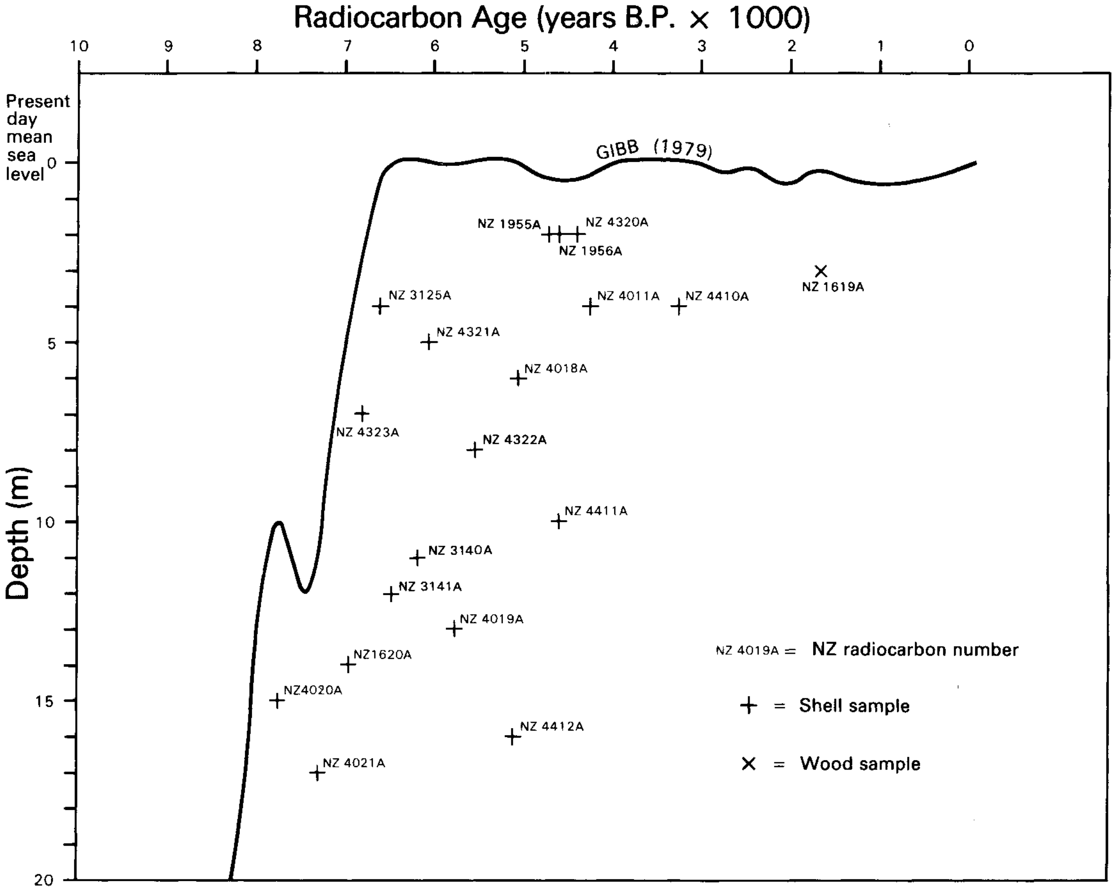

Fig. 10 Comparison of radiocarbon-dated samples (Table 1) with postglacial rise of sealevel (composite curve from Gibb 1979).

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APPENDIX 1

Faunas and paleoecology of Dillons Point Formation

A. G. BEU

INTRODUCTION

The accompanying Table 2 lists macrofaunas of Dillons Point Formation collected from sites (mainly water wells) on the Wairau Plain. The collections are identified by the fossil record numbers along the top of the table and NZ^{14}C numbers and age at the bottom (if dated); localities are given in Table 1, in Brown (above). In Table 2 macrofaunas have been arranged from left to right in order of decreasing age, within 2 quite widely separated areas: the northern coastal area of Wairau Plain, and the southern coastal area of Wairau Plain near the present Wairau Lagoons. The faunas were compared to determine their environments of deposition.

METHOD

In Table 2, the taxa in each fauna have been classified into 6 classes, according to the environments inhabited by present-day specimens of the same species. Present environments were determined from Powell (1977) and from the author's experience.

The first class includes 9 species of bivalves that are restricted to water a few metres deep off oceanic sand beaches. Members of this class are found in a small number of samples, all from the northern coastal area. The second class contains 28 molluscs, 2 polychaetes, and a crab that are all euryhaline, or are not identifiable closely enough for their salinity preferences to be clear. Most of the taxa are known to occur both on oceanic sand beaches and in the outer parts of large estuaries and enclosed embayments. The third class includes 5 molluscs, a polychaete and a barnacle that live only in the intertidal and shallow subtidal zones of rocky shores. They are all found both in large embayments and on open rocky coasts, and so are more useful as indicators of the proximity of rocky shores than as salinity indicators; most occur in samples from the Wairau Lagoons area. The fourth class includes only 3 gastropods restricted to large, very shallow sandy bays or the outer parts of large, sandy estuaries. Examples of similar modern environments are Doubtless Bay, Northland, and Blueskin Bay, Waikouaiti, north of Dunedin. The fifth class includes 6 bivalves and 6 gastropods that are restricted to the lowered salinity of estuarine sand and mud flats. Two species, *Austrovenus stutchburyi* (the most common fossil in Wairau Plain faunas) and *Paphies australis*, can occur in the brackish mudflats of the estuarine high-tidal zone, where they reach only a small size. *Amphibola* is restricted to the estuarine high-tidal zone. The final class includes only 2 molluscs restricted to freshwater streams and ponds; *Potamopyrgus* is small and easily washed into estuaries from streams, and so is not uncommon in shallow-water marine deposits, whereas *Hyridella* is found only in freshwater deposits.

RESULTS

Comparison of the proportions of the 6 classes in the faunas allows the deduction of 7 depositional environments. The environment inferred for each sample is indicated by letters in the bottom row of symbols in Table 2. The environments inferred are: A, freshwater stream or pond; B, the high-tidal zone of an estuary or lagoon; C, the outer area of a large estuary or lagoon, with markedly higher salinity than in (B); D, near the mouth of a large estuary, lagoon, or enclosed embayment, with salinity higher than in (C); E, mixed estuarine and ocean beach faunas, possibly deposited in a bay-bar; F, near the head of a large, sandy, open bay with almost oceanic salinity; G, an open ocean sand beach. Figure 10 (above) shows that tectonically induced subsidence affected the Dillons Point Formation macrofaunas subsequent to deposition. In view of the complex relationship between age of the samples (see Table 1) and their stratigraphic position, shown particularly in Fig. 4 (above), it is not possible to determine the sequence of environmental changes that occurred in the northern coastal Wairau Plain. However, some conclusions can be drawn.

The southern coastal Wairau Plain, near the present Wairau Lagoons and behind the Boulder Bank, has remained in a situation similar to its present strongly estuarine one (fauna greatly dominated by *Austrovenus stutchburyi*) for at least the last 6000 years. By contrast, faunas beneath the northern coastal Wairau Plain demonstrate that a complex series of environmental changes has been superimposed on the simple postglacial marine transgression and subsequent progradation that occurred in tectonically stable areas of New Zealand. This difference in environmental history reflects the exposure of the northern Wairau Plain (outside the Boulder Bank) to rapid depositional changes related to tectonics and changes in the course of the Wairau River. The southern coastal Wairau Plain (behind the Boulder Bank) was buffered from environment change.