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A mid Otira Glaciation palaeosol and flora from the Castle Hill Basin, Canterbury, New Zealand

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Abstract A section exposed at the Broken River road cutting in Castle Hill Basin revealed a palaeosol resting on reddish, rusty gravel and beneath 30 m of fresh-looking, grey, glacio-fluvial outwash gravel deposited by a meltwater stream during the Blackwater advances of the Waimakariri Glacier. A radiocarbon date >37 000 ± 200 yr B.P. (NZ 7518) was obtained for the palaeosol. Pollen spectra from it are dominated by a herbaceous plant assemblage indicating cold climatic conditions. Redeposited pollen from adjacent Tertiary rocks is also present. The soil appears to have been formed in a marshy habitat soon after the onset of the Blackwater 1 glacial episode (the first cold phase of the middle part of the Otira Glaciation).

Keywords glacial advance; glacio-fluvial outwash; radiocarbon date; herbaceous pollen flora; cold climate

INTRODUCTION

In 1987 a buried soil with an organic A horizon was exposed at the road cutting on Highway 73, near the north side of the bridge across the Broken River, Castle Hill Basin, Canterbury (grid reference NZMS 260 K34/072784), at 670 m a.s.l. (Fig. 1). The site was examined several times in subsequent years but was destroyed during road works connected with the building of a new bridge across the Broken River in 1992–93.

Organic material interbedded with glacial or glacio-fluvial deposits is rare in Canterbury. The stratigraphic position of the site, beneath thick glacio-fluvial outwash gravel of mid-Otira Glaciation age (Gage 1958, 1977), suggested that it would be worthwhile to obtain a radiocarbon date and pollen analysis for the soil. This paper reports and interprets the stratigraphy of the site, a radiocarbon date for the palaeosol, and the results of a pollen analysis of two samples taken from it.

General geography and stratigraphy of the region

The Castle Hill Basin is a depression in the Waimakariri catchment of the Southern Alps, between the Waimakariri River and the Triassic sandstone and argillite (Torlesse Group) massifs of the Torlesse (1989 m), Craigieburn (2194 m), and Broken Hill (1573 m) ranges. It is drained by the Broken River, with several large tributaries rising in the Craigieburn Range (Fig. 1). At the north end of the basin, Cave Stream, the head of the Broken River (with several tributaries), and the Thomas River are incised deeply into Pleistocene gravels and, in places, into the downfaulted and folded Tertiary and Cretaceous rocks which occupy the floor of the basin (Gage 1970). Prominent terraces, cut into the gravels and the limestone and other Tertiary and Cretaceous rocks, line the stream courses (Gage 1958, 1977; Breed 1960) (Fig. 2).

METHODS

The positions of adjacent terrace tread surfaces relative to the palaeosol site were checked with an abney level, which was also used to measure slope angles. Some distances and heights on steep terrace risers

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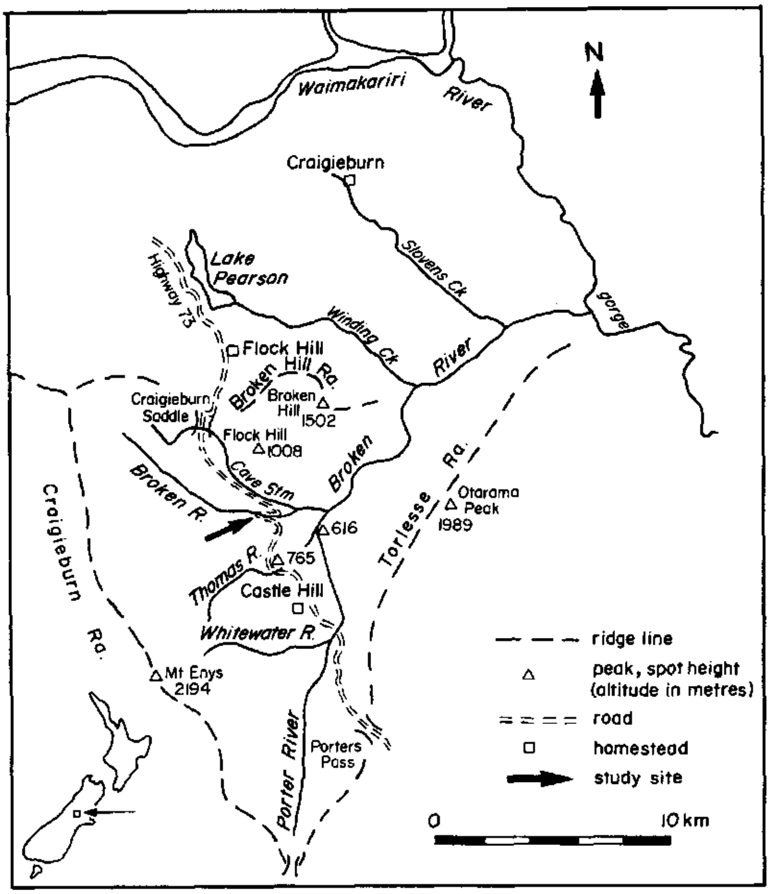

Fig. 1 Location map.

were measured with a long metric tape. Data were plotted on a photo-enlargement of NZMS 260, sheet K34. This enlargement was used in conjunction with aerial photographs to prepare Fig. 2.

The section represented in Fig. 3 was exposed at the Broken River cutting in 1987–1992. Samples for radiocarbon dating and for pollen and macrofossil studies were taken after cutting the deposit back to avoid the possibility of contamination with modern material. Pollen samples were prepared by the methods recommended for siliceous material by Faegri & Iversen (1964). Macrofossil samples were examined after washing and sieving. Plant nomenclature follows Allan (1961) and Connor & Edgar (1987).

RESULTS AND INTERPRETATION

Late Pleistocene stratigraphy

Gage (1958, 1977) recognised three main advance episodes of the Otira Glaciation (the last Pleistocene glaciation in New Zealand) in the Waimakariri catchment, each separated by intervals of major ice retreat or deglaciation. They are the Otarama (early), Blackwater (middle), and Poulter (late) advances. Each is recognised by distinctive end moraines and down-valley trains of outwash gravel, forming gently sloping surfaces which have been cut into and partly removed by subsequent stream erosion.

Only one Otarama-age stadial is recorded by Gage (1958, 1977), but there were two (possibly three) Blackwater stadials and two Poulter stadials. Each gave rise to separate moraines and outwash sheets. In the Castle Hill Basin there are no Otiran moraines except those beneath cirques in the Craigieburn Range (Ricker et al. 1993), so most of the stratigraphic evidence for events of the Otira Glaciation is deduced from glacio-fluvial outwash deposits. The two sources for the outwash were cirque glaciers in the Craigieburn Range and a meltwater stream flowing from a distributary lobe of ice from the main Waimakariri Glacier which several times reached the Craigieburn Saddle (Fig. 1).

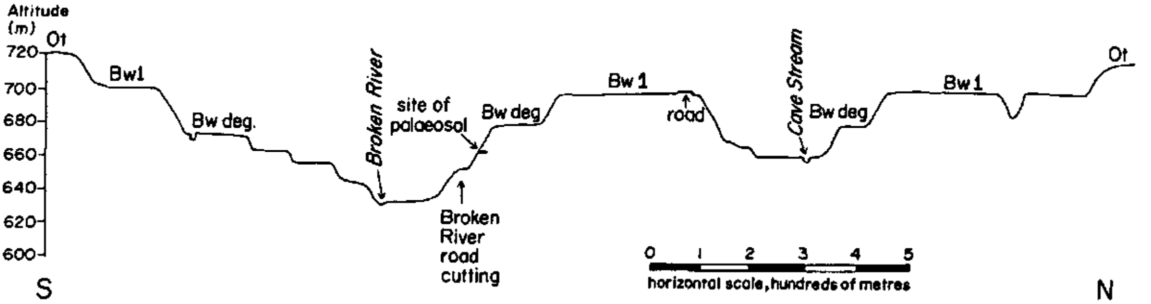

Fig. 2 Profile on a line S-N through the palaeosol site, to show its relationship to adjacent glacio-fluvial and fluvial landforms. Assumed ages of surfaces: Ot Otarama (oldest); Bw1 Blackwater 1; Bw deg. degradation surface formed towards end of Blackwater glacial episode.

Gage's (1958, 1977) maps show no outwash of Otarama age close to the present study site. However, Breed (1960) described deposits of this age (which he called the Enys surface) on the interfluve between the Thomas and Broken Rivers, along the east side of Cave Stream (Ot in Fig. 2), and lower in the basin near a tributary entering the Broken River from east of Flock Hill. One small exposure of Otarama age outwash gravel was seen during the study at a road cutting 650 m south of the Broken River, on Highway 73. The gravel is only very weakly weathered and faintly brown in colour.

The main outwash surfaces (Bw, Fig. 2) near the study site were mapped by Gage (1958) as being of Blackwater age. He stated that the Winding Creek distributary lobe of the Waimakariri Glacier deposited a moraine at the Craigieburn Saddle in Blackwater 1 time, and that a vigorous meltwater stream discharged from this position into the Castle Hill Basin. He did not clearly indicate that this also happened in Blackwater 2 time, but Breed (1960) did. Breed plotted profiles showing that distinct surfaces (which he called the Cheeseman surfaces) were formed and that the Blackwater 1 age surface is the most extensive in the Castle Hill Basin. Breed's presumed Blackwater 2 age surface is less extensive and lower than the Blackwater 1 but, like the latter, in Cave Stream it can be traced upstream to Craigieburn Saddle. As Gage (1958) indicated, the Blackwater surfaces are underlain by fresh-looking, unweathered grey gravels. As no break has been identified in the Blackwater age gravels at the site, or elsewhere in the Castle Hill Basin (cf. Breed 1960), it seems possible that only one glacial episode is represented among the gravels in the floor of the basin. In this case it must be Blackwater 1, and the "lower Blackwater" surface in Cave Stream, recognised by Breed, appears to be merely a degradational terrace formed when the ice-level fell at the Craigieburn Saddle as the glacier began to recede, the gravel supply declined, and the meltwater stream cut down into the unconsolidated gravels. Hereafter it is recognised as such (Fig. 2). Terraces also occur at similar heights in the Broken River Valley. Moraines and outwash surfaces of Blackwater 2 age are, however, present in the valley systems 12–15 km north of the Broken River road cutting site (Gage 1958, 1977). Also, Ricker et al. (1993) identify moraines and outwash of Blackwater 2 age in tributaries of the Broken River at the foot of the Craigieburn Range.

The Blackwater age surfaces are little affected by secondary dissection (which occurred after the main episodes of down-cutting by the rivers into unconsolidated gravels, at the end of each period of glacial advance). Consequently the terraces are sharply defined, with angular transitions between risers and treads. The Otarama age surfaces, by contrast, have undergone substantial erosion and secondary dissection. Small side streams have cut many minor channels across the terrace edges and the riser-tread transitions are rounded. The conclusion is that erosive processes were very active in the time between formation of the Ot-age and Bw-age terraces and relatively less active since the Bw down-cutting.

Detailed site stratigraphy

Before the deposition of late Pleistocene gravels, a minor terrace appears to have been cut in the Miocene estuarine sands at the base of the section where the palaeosol was exposed (Fig. 3). The shallow layer of rusty reddish alluvium above the estuarine sand lay against this terrace. It was probably a remnant of a thicker deposit of gravel deposited, but then largely removed, at some time prior to the Blackwater glacial events. It might have been of

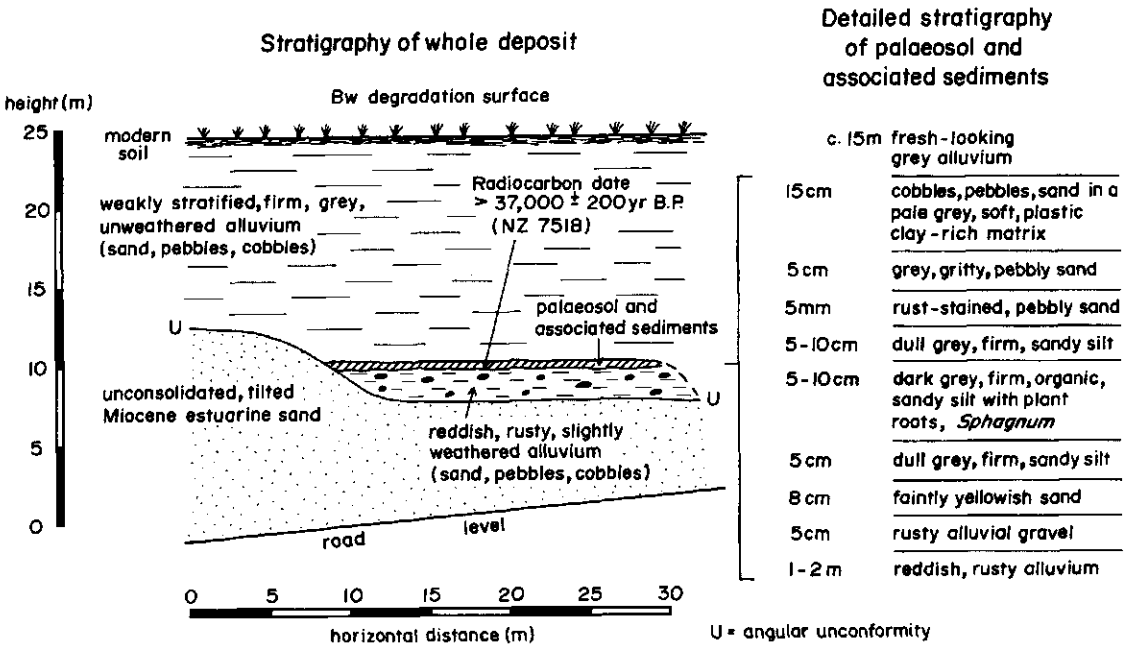

Fig. 3 Stratigraphic section of the deposits associated with the palaeosol, Broken River road cutting.

Otarama age but it could have been deposited in the non-glacial interval after that event. The reddish colour may not reflect very great age; the larger individual clasts (pebbles and cobbles) were hard and did not appear to be strongly weathered; the reddish colour seemed to be a surface coating. Groundwater seepage and accumulated ferric sesquioxide could account for the colour.

Above this reddish gravel lay a series of thin layers which developed in chronologic sequence as follows: deposition of sand and sandy silt on the gravel, marginal to a stream; formation of an impervious (ferric sesquioxide-rich) layer between the sand and gravel, waterlogging, and soil formation, with organic enrichment of the sandy silt through growth of plants which included *Schoenus pauciflorus* and *Sphagnum cristatum*; burial of the soil by sandy silt, then sand; deposition of a very plastic, clay-rich layer; deposition of about 30 m of weakly stratified alluvium (cobbles, pebbles, and sand) over the whole deposit. Abundant pebbles and cobbles in the plastic clay may have been mixed with it when the alluvium was first deposited. Subsequent downcutting by the Broken River formed a degradation terrace in the alluvium about 12 m above the site of the palaeosol, before further downcutting and erosion of gravel and the Tertiary beds down to the present level of the river floodplain. The sequence described above was exposed during road-widening at the Broken River road cutting in the 1980s; the palaeosol and underlying reddish gravel cropped out over 20 m of exposure. Both the reddish gravel and the palaeosol extended laterally (to the north) for a short distance only, however, for they were completely removed during further road-widening in 1992–93, when about 10 m thickness of material was scraped from the side of the cutting. This also removed the glacio-fluvial gravel which lay over the deposit and exposed much more of the Miocene sands which had been masked by this gravel.

Radiocarbon date and pollen analysis

A date of >37 000 ± 200 radiocarbon years B.P. (NZ 7518) was obtained for organic silt from the palaeosol (based on the half-life 5568 yr for radiocarbon and with a radon correction). This means that the sample age was beyond the limits of radiocarbon dating. The indeterminate age of the palaeosol prevents pin-pointing of the ages of related events. However, it is important to know that the glacial episode (here assumed to be Blackwater 1) which gave rise to the gravels above the palaeosol, occurred prior to 37 000 radiocarbon years ago.

Pollen and spore spectra from the top and base of the palaeosol (Table 1) contain three main elements:

(a) Taxa which occur in herbaceous vegetation today (the most prominent).
(b) Taxa present in scrub or forest today (sparsely represented).
(c) Taxa which have been long extinct; these were redeposited from adjacent Tertiary rocks further up-valley (sparsely represented).

The herbaceous taxa, except the fern *Gleichenia*, all occur to this day in the mainly grassland plant communities of the Castle Hill Basin. Species of wet environments are well represented. The prominence of herbs in the palynoflora and the sparsity of woody plant taxa (which are now relatively abundant in the Castle Hill Basin) indicate that climate was severe at the time. Sources of woody plant taxa were probably distant; exceptions may be Asteraceae (some of which may have been herbaceous), *Coprosma*, and *Phyllocladus*. Among the battered, apparently redeposited pollen grains, *Casuarina*-type and *Eucalyptus*-type could have originated in Australia or New Zealand. It should be noted that the present indigenous vegetation of the area is predominantly herbaceous (as a result of burning of the once dominant beech forest a few hundred years ago (Molloy 1977)), with scattered patches of *Nothofagus solandri* var. *cliffortioides* forest and extensive scrub containing *Discaria toumatou*, *Leptospermum scoparium*, *Coprosma* spp., *Hebe* spp., and several other taxa.

DISCUSSION

How does the Broken River road cutting palaeosol relate to other Otiran deposits in glaciated parts of the South Island, in terms of age and environment? Among the relatively few radiocarbon dates from central South Island localities for events in the mid Otira Glaciation (cf. Suggate & Moar 1970; Soons & Burrows 1978; Suggate 1985; Burrows 1988; Lowell et al. 1995), only that being described in this paper and one or two others appear to be related to minor halts in glacial deposition earlier than 35 000 years ago. One is a date (>36 400 years B.P.) for plant material in a palaeosol buried by till in the Balmoral 1 moraine at the Mary Range, near Lake Pukaki, Mackenzie Basin, South Canterbury (Mansergh 1973). In an ancient fan composed of angular gravel at Going's Creek, near Lewis Pass, North Canterbury, a thin organic layer (presumed to be a palaeosol) is dated 41 200 ± 2400 years B.P. Pollen spectra from this layer are dominated by grasses, other herbs, and the shrub *Phyllocladus* cf.

Table 1 Pollen and spore spectra from base and top of the palaeosol. Data presented as percentage of total pollen counted (excluding spores and redeposited types). Subheadings indicate vegetation in which taxa often occur now. w = plants mainly of wetland sites; * = noted during scan following count; tr = <1% of pollen sum; h = some could be included in herb/dwarf shrub category.

	Base of soil	Top of soil
Herbaceous (including ferns and dwarf shrubs)		
Acaena	tr	*
Anisotome	2	1
Apiaceae	tr	2
Brassicaceae	*	1
Chenopodiaceae	*	*
Neopaxia (= *Claytonia*)w	tr	*
Colobanthus	1	*
Cyperaceae w	42	68
Epilobium	–	*
Gaultheria	*	–
Gentiana	tr	tr
Geranium	–	*
Gonocarpus	–	*
Gunnera	tr	*
Hydrocotyle	tr	*
Kirkianella	2	1
Lilaeopsis w	tr	1
Myosotis australis-type	–	1
Nertera	–	*
Plantago	*	tr
Poaceae <40 μm	37	19
Poaceae >40 μm	tr	1
Ranunculus	–	*
Raoulia	tr	1
Rumex	–	*
Stellaria	–	*
Thymelaeaceae	–	*
Wahlenbergia	*	–
Blechnum	tr	tr
Gleichenia w	–	*
cf. *Ophioglossum*	–	*
Scrub/forest (including ferns)		
Asteraceae h	4	2
Coprosma h	tr	2
Dacrycarpus	*	*
Halocarpus	*	*
Metrosideros	tr	–
Nothofagus fusca-type	–	tr
N. menziesii	–	tr
Phyllocladus	1	tr
Podocarpus undifferentiated	–	*
Phymatosorus	*	–
Extinct taxa redeposited from Tertiary rocks		
Casuarina-type	–	*
Eucalyptus-type	–	*
Lagarostrobos franklinii-type	*	2
Nothofagus fusca-type	*	–

alpinus (N. T. Moar in Anon. 1973; R. P. Suggate pers. comm.)

Judged by the plant fossils recovered from all of these palaeosols, severe climatic conditions prevailed in the Canterbury mountains at the time(s) of their burial. Plant remains in the Balmoral moraine palaeosol included *Phyllachne colensoi* (a cushion plant) and *Dracophyllum pronum* (a prostrate shrublet) (C. J. Burrows unpubl. data). At present these two species grow at altitudes of 1230 m or more, on windswept, cold, ridge-top sites on mountains north and west of Lake Pukaki. The Balmoral palaeosol site, at about 500 m, is 730 m lower than this. Occurrence of alpine vegetation at relatively much lower levels than now accords well with the values calculated by Porter (1975) for lowered snowline during the Balmoral glacial event.

These dates from Broken River and the Mary Range **may** record the same glacial episode. Other criteria are needed to decide with certainty whether Blackwater 1 and Balmoral 1 moraines are correlatives, although this is a reasonable assumption.

A dated deposit beside the Acheron River, Rakaia Valley, 16 km to the south of the Broken River road cutting site, helps to define the regional chronology for the later part of the mid Otira Glaciation. A radiocarbon date of 22 200±750 yr B.P. (NZ 3940) was obtained for plant fossils from lake silts deposited in a channel cut in till and outwash gravel of Bayfield 2 age and before a renewed (Bayfield 3) advance of the Rakaia Glacier. Thus it is younger than the Bayfield 2, which is believed to be a correlative of the Blackwater 2 glacial episode in the adjacent Waimakariri Valley (Soons & Burrows 1978).

Scant though the dateable material for the period is in the eastern South Island, it now appears that several episodes of the Otira Glaciation there can be correlated with those in the western South Island (Suggate & Moar 1970; Suggate 1985; Burrows 1988). In turn, the New Zealand chronology for the last Pleistocene glaciation matches those for South America and the Northern Hemisphere quite well (Lowell et al. 1995).

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