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LATE-GLACIAL AND EARLY HOLOCENE GLACIER ACTIVITY IN THE SOUTHERN ALPS, NEW ZEALAND

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In the Southern Alps of New Zealand, glaciers advanced to their last glacial maximum limits between 22.3 and 18 ka BP, and there is evidence for at least four more advances between 18 and 8 ka BP. A widespread glacier advance, possibly with two maxima, occurred between 16 and 14 ka BP, during which glaciers reached positions close to those attained at the last glacial maximum. After 14 ka BP, there was a significant and sustained retreat of glaciers that marks the beginning of the Post-glacial interval in New Zealand, locally known as the Aranui Interglacial. During the Aranui there is evidence for a much smaller glacier advance around 11 ka BP that may have been coeval with the Younger Dryas stade, but opinions on this are still controversial. Two younger ice advances may have occurred close to 10.25 and 8.6 ka BP. Although regional patterns of Late-glacial advances are reasonably well established, the Post-glacial advances are known only from single sites and require closer investigation. Copyright © 1996 INQUA/Elsevier Science Ltd

INTRODUCTION

The Southern Alps of New Zealand are young, rapidly rising mountains on the obliquely convergent margin of the Pacific and Indo-Australian crustal plates. The central part of the mountains rises above 2000 m, with several peaks over 3000 m. The interaction of the Southern Alps with a prevailing westerly air stream results in a temperate maritime climate with precipitation reaching ca. 12,000 mm per annum in the superhumid zone immediately west of the main divide (Whitehouse, 1987). At present, the regional snowline lies at 1500 m in southwestern New Zealand, at 1900 m at Arthurs Pass, and at 2440 m on Mt. Ruapehu in the central North Island (Fitzharris *et al.*, 1992). In the South Island over 3000 glaciers have been identified, and these cover 116 km^2 or 5% of the surface (Chinn, 1989). The largest is the 29 km^2 Tasman Glacier on the flanks of Mt. Cook. During the Pleistocene, a large and complex glacier system consisting of expanded valley and piedmont glaciers extended 700 km along the Southern Alps and averaged 100 km in width (New Zealand Geological Survey, 1973).

Establishment of details about Late Pleistocene and Early Holocene ice advances in New Zealand has been hampered by a lack of organic material suitable for radiocarbon dating, particularly in the drier eastern areas of the South Island. Most radiocarbon dates are for aggradational surfaces associated with the principal ice advances, although some organic deposits have been found in tills, including forest remnants overwhelmed by glacier ice. More recently, calibrated weathering rind data for absolute dating has become important (Whitehouse *et al.*, 1986), although the wide error bands associated with this technique mean that radiocarbon dating remains the more important dating tool.

This review outlines Late Quaternary stratigraphic nomenclature used in New Zealand and examines evidence for glacier advances between 18 and 8 ka BP in Westland, Canterbury, Nelson-Marlborough and Otago-Southland (Fig. 1). This is followed by a discussion of the major glacial events and a regional synthesis. All of the dates quoted are in uncorrected radiocarbon years BP.

LATE QUATERNARY STRATIGRAPHIC NOMENCLATURE IN NEW ZEALAND

The stratigraphic nomenclature for Late Quaternary deposits in New Zealand is summarised in Table 1. The boundary between the Otira (last) Glaciation and the Postglacial Aranuian Stage is placed at 14 ka BP, marking a period of significant and sustained glacier retreat.

Stratigraphic practices of the former New Zealand Geological Survey and its successor have involved distinguishing map units (formations) from glacier advances, naming them separately (Suggate, 1965). Most authorities have named glacier advances and formations typically after local geographic features. Only the names of the glacier advances are cited in this review. Most mapping has attempted to first define glacial sequences for the main valley systems, and then to establish correlations with other glacial sequences.

Westland

The best preserved evidence for the expansion of Late Quaternary glaciers comes from North Westland (Fig. 1) which is the type area for glaciation in New Zealand. Three Otiran glacier advances have been identified there (Fig. 2). The oldest, the Kumara 2_1 advance, overlies marine deposits of the Kaihinu Interglacial (the last interglaciation). At Sunday Creek, exposures of the

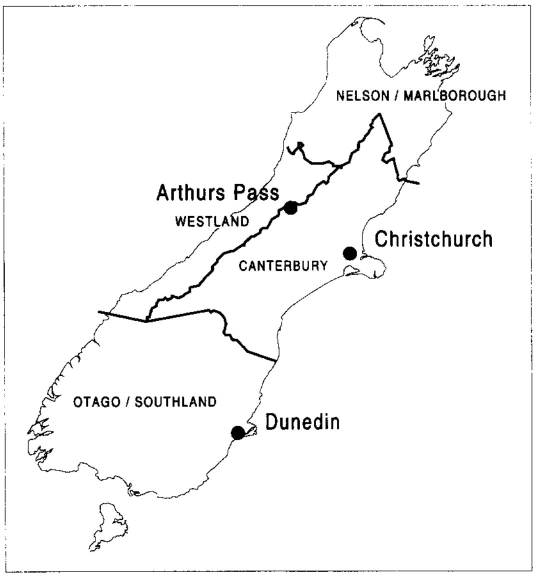

FIG. 1. Location map.

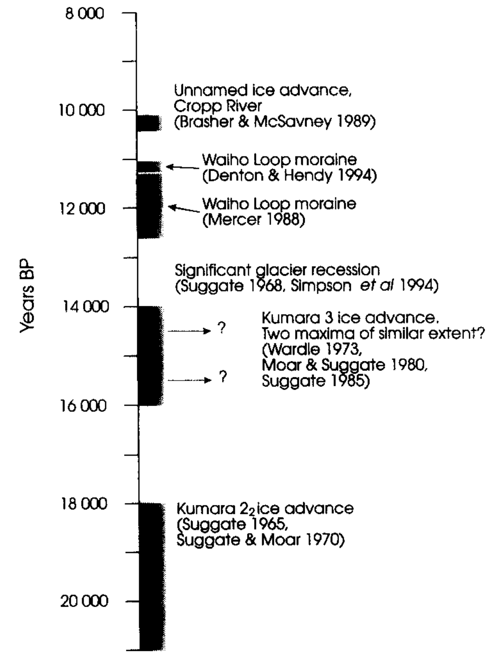

FIG. 2. Late-glacial and early Holocene ice advances in Westland.

contact show interglacial beach sands and gravels overlain by a sequence of peaty silt and outwash gravel deposited during the glacier advance. Pollen analysis of the peaty silt shows a temperate rain forest flora at the base of this deposit, followed by cooling through the silt up to the outwash gravel (Suggate, 1965; Dickson, 1972). Dates suggest the silt is older than 40 ka, and the Kumara 2_1 advance is believed to have occurred during Oxygen Isotope Stage 4 (Suggate, 1990).

The next youngest element of the Otira Glaciation is the Kumara 2_2 advance, which deposited a moraine and outwash surface that extends to the coast, where it is truncated by a post-glacial cliff. The age of the Kumara 2_2 advance is based on three radiocarbon dates. One is from carbonaceous silt deposited in a pond in the Grey Valley as an adjacent valley aggraded (23,300±300 BP, Suggate, 1965) and two from a lens of silt within the outwash gravel (18,600±290 BP: NZ 891, and 18,750±180 BP: NZ 737, Suggate and Moar, 1970, 1974). The Kumara 2_2 advance is believed to have taken place between 22.3 and 18 ka BP (Fig. 2).

The Kumara 3 advance, which post-dates the Kumara 2_2 advance, comprises two moraine loops separated by an outwash channel (Suggate, 1985). Although the Kumara 3 advance has not been dated at its type site, at another site about 100 km farther south, near Whataroa and Franz Josef, till correlated with the Kumara 3 advance rests on organic silt dated by Suggate and Moar (1970) at 16,450±200 BP, and by Wardle (1973) and Nathan (reported by Suggate, 1985) at 13,950±450 and 15,300±120 BP. Farther south at Paringa, the valley glacier had retreated into the mountains by 13,400±150 BP (Suggate, 1968; Simpson *et al.*, 1994). Thus, till associated with the Kumara 3 advance appears to have been deposited by two glacier advances of similar extent and age between 16 and 14 ka BP. These two advances were followed by rapid and sustained retreat marking the close of the Otira Glaciation.

In south Westland, the best evidence for an ice advance after the Otira Glaciation is provided by the Waiho Loop moraine on the coastal plain 11 km outside the present terminus of Franz Josef Glacier (Fig. 3). Dating this feature has proven difficult and controversial. The first radiocarbon date, reported by Wardle (1978), came from tree roots under 1.5 m of till on the side of a roche moutonneé (Canavans Knob) 1.5 km in from the moraine (11,450±200 BP: NZ 2434A). Based on the error band for this date, Wardle suggested the advance had occurred between 11,650 and 10,750 BP. Mercer (1988) reexamined the site and sampled forest material preserved beneath 2.5 m of till. Four of his radiocarbon dates were from the same log, and samples processed in the U.S.A. were washed in hot alkali and hot acid whereas those

TABLE 1. New Zealand Late Quaternary stratigraphic nomenclature

Glaciation/Interglaciation	Age
Aranui Interglacial (post glacial)	14–0 ka
Otira Glaciation	ca. 80–14 ka
Kaihinu Interglacial	ca. 128–ca. 80 ka
Waimea Glaciation	ca. 300–ca. 128 ka

FIG. 3. Oblique aerial photograph of the Waiho loop moraine.

TABLE 2. Radiocarbon dates from Canavans Knob about 1.5 km inside the Waiho Loop moraine

Date	Lab. No.	Comment	Reference
11,450±200	NZ 4234A		Wardle (1973)
11,500±200	NZ 6573A[1]		Mercer (1988)
11,700±200	NZ 6923A[1]		Mercer (1988)
12,100±275	GX 10053[1]		Mercer (1988)
12,510±120	Beta 12607[1]		Mercer (1988)
12,120±900	GX 9981		Mercer (1988)
11,740±70	A 6589	Basal organic silt	Denton and Hendy (1994)
11,140±200	average of 36 dates	woody diamict	Denton and Hendy (1994)

[1]Dates from the same log.

dated in New Zealand were washed in distilled water (Table 2). Taking into account the possible ages of the trees that were dated, Mercer concluded that the moraine had been deposited prior to the Younger Dryas Chron.

Farther north, at Cropp River, Basher and McSaveney (1989) dated wood from the base of a compact unstratified diamict at 10,250±150 BP (NZ 6576). That date and interpretation of the landforms and sediments suggested an ice advance between 11 and 10 ka BP.

Subsequently, the Canavans Knob site was re-examined by Denton and Hendy (1994). By then the section described by Mercer (1988) had been destroyed, but Denton and Hendy investigated a section which consists of 3 m of till underlain by 0.08 m of grey laminated silt, 0.03 m of laminated and organic silt, 0.5 m of wood-bearing diamict, 0.15 m of bedded silt and organic silt, and 0.05 m of organic silt resting on bedrock. They dated 36 samples from the wood-beating diamict, one from the basal organic silt and eight from surface wood on the nearby Franz Josef and Fox glaciers. The average of the 36 dates is 11,140±200 BP (Table 2). Using an approximate age of 100 years for the wood to have been transported by the glacier, Denton and Hendy suggested the glacier advance took place at 11,050±140 BP and coincided with the Younger Dryas Chron. All interpretations of the Canavans Knob site assume that the organic remains date the same event that produced the Waiho Loop moraine lying 1.5 km to the north.

The next youngest moraines in Westland occur within 4 km of the Franz Josef Glacier and are believed to date to about 5 ka BP (Sara, 1979).

Canterbury

In Canterbury, there are well preserved Late Pleistocene glacial sequences in many of the major valleys, although most attention has focused on those of the Waimakariri Valley (Gage, 1958; Chinn, 1981; Ricker *et al.*, 1992), the Rakaia Valley (Soons, 1963; Burrows and Maunder, 1975; Burrows and Russell, 1975; Soons and Burrows, 1978), and the Mt. Cook area (Burrows, 1980; Burrows and Gellatly, 1982; Gellatly *et al.*, 1988). One of the most complete Late Pleistocene to Early Holocene sequences comes from the Rakaia Valley where six glacier advances are believed to have occurred between 25 and 9 ka BP (Table 3, Fig. 4).

The Bayfield 2 advance is recorded by three moraine loops. Plant fragments resting on the brownish-grey till have a radiocarbon age of 22,800±800 BP (NZ 3140, Soons and Burrows, 1978). The next youngest ice advance is the Bayfield 3 which is believed to have occurred after 19,750 BP on the basis of a radiocarbon date from sediments lying above Bayfield 2 sediments. The Bayfield advances were followed by glacier recession.

Subsequent ice advances were considerably smaller. The next youngest glacier oscillation was the Lake Stream advance, which formed a double-crested moraine and ice-dammed lakes. A minimum age for this event is indirectly established by a bog-bottom date of 11,900±200 BP (NZ 1652, Burrows and Russell, 1975), and a date of 11,650±200 BP (NZ 1290) for organic material in the silts of a proglacial lake (Burrows, 1980). A further ice advance to within 5 km of the limits of the Lake Stream advance is the Jagged Stream advance, which is believed to have occurred between 11.9 and 10 ka BP. The next youngest ice advance lies 15 km inside the Jagged Stream advance and dates to 4.5 ka BP (Burrows and Russell, 1975).

Near Mt. Cook two widely recognised Otiran glacier advances are the Mt. John and Tekapo advances, which

TABLE 3. Late Pleistocene and early Holocene ice advances in the Rakaia Valley

Advance	Age	Reference
Bayfield 2	>22,800±800 BP (NZ 3140)	Soons and Burrows (1978)
Bayfield 3	<19,750±600 BP (NZ 4298)	Soons and Burrows (1978)
Acheron	not dated	
Lake Stream	<11,900±200 BP (NZ 1652)	Burrows and Russell (1975)
Reischek	not dated	
Jagged Stream	>9520±95 BP (NZ 688)	Burrows (1975)
Meins Knob	4540 BP (NZ 1287)	Burrows and Russell (1975)

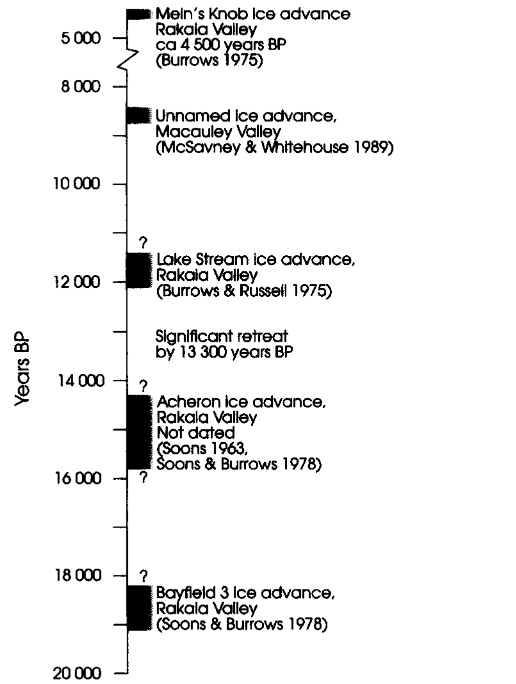

FIG. 4. Late-glacial and early Holocene ice advances in Canterbury.

are represented by end moraines enclosing lakes Pukaki and Tekapo. Their ages have been estimated by Mansergh (1973) and Wellman (1979) who compared terrace gradient data for tilted and non-tilted surfaces in the Ohau River area. The age estimates range from 18 to 16 ka BP for the Mt. John advance and 15 to 14 ka BP for the Tekapo advance. Wood in lake sediments overlying the Mt. John moraine records ice recession and early stages in the development of a proglacial lake at 11,950±200 BP (Porter, 1975).

Moraines about 18 km down valley from the present Tasman Glacier provide evidence of the Birch Hill advance. Although there has been speculation about the age of the Birch Hill moraines (Maizels, 1989), there are only two radiocarbon dates from peats, overlying the sediments (5370±30 and 5590±30 BP: QL 59, Porter, 1975), and these provide only minimum limiting ages.

Burrows (1980) argued that wood dated to >940±90 BP (NZ 4508), and embedded in a diamict at Black Birch Stream, provided an age for the Birch Hill advance, but both Gellatly *et al.* (1988) and McSaveney and Whitehouse (1989) have argued that the diamict is a rock avalanche deposit. Thus, the age of the Birch Hill advance has yet to be determined, although Birkeland (1982) suggested that the event occurred at 9000 BP ±20%, on the basis of soil development and weathering rind thickness. The Birch Hill moraines are generally regarded as being at least 8000 years old, possibly several thousands of years older (Porter, 1975; Burrows and Gellatly, 1982).

In the Macauley Valley area, wood in a diamict interpreted as till gave an age of 8460±120 BP (NZ 548; Grant-Taylor and Rafter, 1971), although Burrows (1972) believed the deposit is landslide debris. Subsequently, McSaveney and Whitehouse (1989) re-examined the site and provided a further radiocarbon date of 8690±120 BP (NZ 6473A). They supported the original interpretation and suggested that the evidence documents a 10 km-long glacier in the valley where none exists today.

In the Waimakariri Valley, the glacial sequence was originally defined by Gage (1958) who first described evidence for multiple glaciation in New Zealand. Three ice advances during the Otira Glaciation are recognised: the Otarama, Blackwater and Poulter advances. None of the deposits are well dated, although kettle-bottom sediments on a Poulter moraine yielded a minimum age of 13,750±200 BP (Burrows, 1983). For the Craigieburn area, in a tributary of the Waimakiriri, Chinn (1981) defined two early Aranuian ice advances which he named the McGrath 1 and McGrath 2. Recent study of the area by Ricker *et al.* (1992) gave ages for the ice advances based on a calibrated weathering rind growth curve (Table 4). The suggested ages are 18,400±1800 BP for the Blackwater 3 advance, 12,000±1100 to 9700±900 BP for the Poulter advance, which was followed by major retreat of the ice before a smaller advance took place between 9700±900 and 5900±650 BP (the McGrath advances).

Nelson and Marlborough

In the upper Wairau and Buller valleys the glacial sequence (Fig. 5) has been defined by Suggate (1965, 1988) and Suggate *et al.* (1973). For the Black Hill advance, which is recorded by a belt of moraines enclosing the northern end of Lake Rotoiti, radiocarbon dates for organic material in the associated aggradation surface suggest sedimentation was underway by 19,800±550 BP (NZ 4830; Moar and Suggate, 1980),

TABLE 4. Ages of glacial events in the Waimakariri River basin, from Ricker *et al.* (1992)

Glacial event	Modal weathering rind value	Calendar age (ka BP)
Barker	0–0.8	0–0.53±0.1
O'Malley	1–2.8	0.66±0.17–2.5±0.3
Arthurs Pass	3–3.8	2.8±0.17–4.2±0.47
McGrath	4.4–5.5	5.9±0.65–9.7±0.9
Poulter	5.5–6.0	9.7±0.9–12.0±1.1
Blackwater III	7	18.4±1.8
Blackwater II	7.2–7.5	21–23.3
Blackwater I	7.6–7.7	29±8.9
Otarama	8.2±0.1	56–70

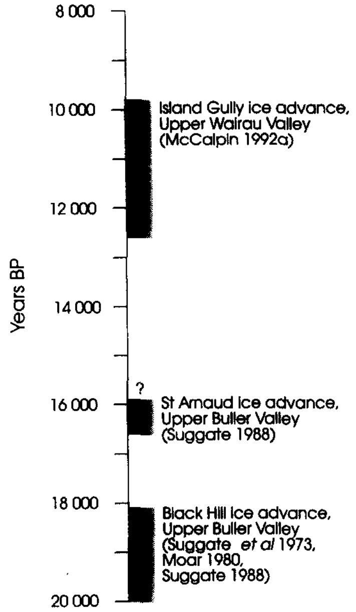

FIG. 5. Late-glacial and early Holocene ice advances in Nelson-Marlborough.

and had almost ended by 18,100±370 BP (NZ 1254: Suggate *et al.*, 1973).

Evidence for a subsequent glacier advance, the St. Arnaud, comes from a moraine belt that lies against and inside the Black Hill moraine as well as from remnants of an aggradation surface in the upper Buller Valley. A date of 16,600±390 BP (NZ 444) records initial development of the aggradation surface associated with this advance. A ledge at the bottom of Lake Rotoiti may record a minor advance after the St. Arnaud event, but the end of the Otira Glaciation is not well recorded in this area (Suggate, 1988).

In the headwaters of the Wairau Valley, a recent study by McCalpin (1992a) suggested a more complex glacial history than recognised by Suggate (1965). McCalpin identified a mid-Otiran moraine in the Tarndale Valley which he believed to date to about 20 ka BP. Although he was unable to recognise any late Otiran moraines with certainty, he suggested that a series of small moraine loops in tributary valleys may record late Otiran advances, while a moraine and outwash surface at the confluence of the Wairau River and Island Gully indicate an early Aranuian ice advance. Peat lying beneath till in that moraine gave an age of 12,600±160 BP (Beta 30056), organic clay above the till gave an age of 9460±110 BP (Beta 30057), and a buried soil on a kame gave an age of 9800±86 BP (NZ 7660). It appears likely that these dates indicate a glacier advance between ca. 12.6 and 9.8 ka BP.

Adjacent to the upper Wairau, in the Clarence Valley, McCalpin (1992b) described a moraine enclosing Lake Tennyson. Although the moraine has not been dated directly, alluvial sedimentation in the Serpentine Valley indicates aggradation between 11,310±130 (Beta 30062) and 9160±120 BP (Beta 30061). McCalpin suggested this may be related to the Lake Tennyson ice advance, although the deposits could represent aggradation unrelated to glacier activity.

Otago/Southland

In central and western Otago, the Clutha Valley contains an impressive suite of Late Quaternary moraines and extensive outwash surfaces. McKellar (1960) recognised two Otiran ice advances: the Albert Town (older) and the Hawea. The Hawea advance is represented by a triple crested moraine enclosing the southern margin of Lake Hawea, a 350 m deep ice-carved lake basin. At the outlet of the lake the Hawea River has cut a gorge 20 m deep through the moraine. Peat in an abandoned channel near the outlet gave an age of 15,100±200 BP, which is a minimum for the Hawea advance. A younger advance is recorded by moraines on the western side of Lake Hawea 5 km inside the Hawea moraine, but these have not been dated.

In the Te Anau basin of western Southland, the glacial sequence has been mapped and defined by McKellar (1973) who recognised four Otiran advances on the basis of the preservation of surface moraine morphology and weathering characteristics. Although no datable material associated with the moraines has been found, recent studies of cave sediments adjacent to lake Te Anau (P. Williams, *unpublished data*) and re-examination of the glacial sequence (S.J. Fitzsimons, *unpublished data*) will improve the chronology of Late Quaternary events in the Te Anau basin. To the west of the mountains, in Fiordland, Brunn *et al.* (1955) recorded four glacial deepening episodes of Milford Sound, and Suggate (1990) suggested the floor of the fiord was cut during the Otira Glaciation. Farther south, in Preservation Inlet, high resolution seismic profiling and piston cores inside the fiord show that the outer part of the fiord was an ice-free freshwater lake at 18,540±1,650 BP (NZ 7375), although finely laminated clays suggest the catchment was still glaciated (Pickrill *et al.*, 1992). Three radiocarbon dates give a maximum age of 9510±290 BP (NZ 5350) for the transition from a freshwater to a marine environment during the post-glacial marine transgression.

REGIONAL SYNTHESIS

Early and Middle Otiran Ice Advances (80–35 ka BP)

Glacier advances assigned to Oxygen Isotope Stage 4 are the most extensive of the last glacial cycle in New Zealand, and are well preserved throughout the South Island, although they are not well dated.

Late Otiran Ice Advances (35–14 ka BP)

Two principal glacier advances are known to have occurred in the Late Otiran Glaciation. The first is thought to have been underway by 22 ka BP in Westland (the Kumara 2_2 advance) and by 20 ka BP in Nelson (the Black Hill advance). Radiocarbon dates from outwash sediments in Westland and Nelson indicate that aggradation was still occurring at 18.6 ka BP, and had virtually ended by 18.1 ka BP. Deposits correlated with this advance are widespread in the South Island although the age of many features remains poorly known. The next ice advance appears to have been of similar extent, with end moraines preserved within 3 km of the earlier glacier limits in Westland, Nelson-Marlborough and Canterbury. Although multiple moraine belts are recognised in several locations (e.g. two in Westland and three in the Rakaia Valley) no evidence to suggest significant differences in the ages of the deposits has been found. Radiocarbon dates associated with tills and outwash gravels suggest that the younger of the Late Otiran advances took place between 16 and 14 ka BP. There is evidence for widespread and sustained retreat of glaciers after 14 ka BP (Suggate, 1968; Burrows, 1988; Simpson *et al.*, 1994). Recognition of the boundary between the Otira Glaciation and the Aranui Interglaciation (Post-glacial) is based on this widespread pattern.

Early Aranuian Ice Advances (14–8 ka BP)

The early Aranuian (14–12.5 ka BP) is characterised by a lack of glacier advances and by sustained retreat of glaciers from their advanced positions at 16–14 ka BP. The most significant advance during the Aranuian interval is recorded by the Waiho Loop moraine which lies on the coastal plain in south Westland (Fig. 3). Although Mercer (1988) believed the moraine had been formed by an advance of Franz Josef Glacier between 12 and 11.5 ka BP, recent study by Denton and Hendy (1994) suggests an age of 11 ka BP for the moraine. Whereas Mercer argued that the Waiho Loop moraine was formed before the Younger Dryas Chron (11 and 10 ka BP), the more recent study interpreted the moraine as the limit of an advance of Franz Josef Glacier that had occurred coevally with the Younger Dryas Chron. Although Denton and Hendy produced a strong argument based on 45 radiocarbon dates, unanswered questions remain concerning the construction of the moraine. The key issues are how the dates relate to the actual formation of the moraine and how long the moraine took to form. Both studies associate evidence for an ice advance at the dated site with the construction of the moraine which actually lies 1.5 km beyond the dated organic debris buried in the till. Denton and Hendy argued that it is highly unlikely that the site represents a younger ice advance because there is no evidence of a younger terminal moraine. However, a large moraine such as the Waiho Loop represents a sustained ice advance, whereas short-lived advances are likely to have produced small moraines which are easily destroyed. It is quite possible that the Canavans Knob site stratigraphy records an advance younger than that of the Waiho Loop moraine. It is also important to consider local depositional conditions during early Aranuian glacier advances in Westland. Suggate (1968) and Simpson *et al.* (1994) showed that the early Aranuian interval on the Westland coastal plain was characterised by rapid retreat of glaciers followed immediately by (or concurrent with) marine transgression. Early Aranuian glacier advances are likely to have built moraines in shallow marine environments that were being rapidly infilled with sediments. Thus, the large Waiho Loop moraine may only represent the surface of the deposit, the bulk of which is buried. The large size of the Waio Loop moraine clearly suggests that it was deposited by a sustained ice advance that had a long-lived terminal position (T.J. Chinn, *pers. commun.*, 1995). If this moraine does represent an early Aranuian ice advance, one has to wonder why no equivalent moraines are known elsewhere in Westland. The regional pattern for this important advance has yet to be established.

Other evidence of early Aranuian ice advances comes from wood embedded in a lateral moraine in the Cropp River and dated to 10.25 ka BP (Basher and McSaveney, 1989), wood in a till in the Macauley Valley dated to 8.7 ka BP (McSaveney and Whitehouse, 1989) and a moraine in the upper Wairau Valley which appears to date between 11.3 and 9.1 ka BP (McCalpin, 1992a). Regardless of the interpretation of the Waiho Loop moraine, there is growing evidence from a number of areas in the Southern Alps that one glacier advance, and possibly several, occurred between 12.5 and 10 ka BP. However, it remains to be determined with precision whether or not they occurred during the Younger Dryas interval.

LATE PLEISTOCENE ICE ADVANCES IN NORTH ISLAND (NZ), SE AUSTRALIA, AND TASMANIA

Although there is evidence of Late Pleistocene glaciation in the North Island of New Zealand, the advances are not well dated, and there is no evidence of glacier activity after the last glacial maximum (Shepherd, 1987). In southeast Australia, the Mt. Kosciusho area was covered by a small (19–32 km^2) ice mass in the Late Pleistocene (Colhoun and Petersen, 1986). Timing for the latest ice cover is not well known, but is believed to have occurred between 35 and 15 ka BP. Tasmania was more extensively glaciated than the Australian Alps and its Late Pleistocene ice cover was greater than 2000 km^2. In western Tasmania, during the last glaciation (Margaret), small ice caps formed on the central plateau and in the central West Coast Range (Colhoun and Fitzsimons, 1990; Fitzsimons and Colhoun, 1991). In the King Valley, there is evidence for two Late Pleistocene ice advances, one predating 48 ka BP, and the other occurring between 26 and 18.8 ka BP (Fitzsimons *et al.*, 1993). No younger glacial deposits are known in the area and it appears that the climatic threshold for the maintenance of permanent snow and ice was crossed soon after 18 ka BP (Fitzsimons and Colhoun, 1991).

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