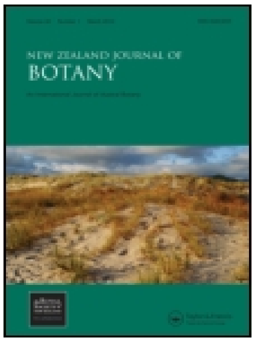

New Zealand Journal of Botany

ISSN: 0028-825X (Print) 1175-8643 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzb20

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To cite this article: Jane M. Soons (1994) Changes in geomorphic environments in Canterbury during the Aranuian, New Zealand Journal of Botany, 32:3, 365-372, DOI: 10.1080/0028825X.1994.10410479

To link to this article: https://doi.org/10.1080/0028825X.1994.10410479

Published online: 31 Jan 2012.

New Zealand Journal of Botany, 1994, Vol. 32: 365–372
0028–825X/94/3203–0365 $2.50/0

Changes in geomorphic environments in Canterbury during the Aranuian

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Abstract Changes in landforms in Canterbury consequent on the change from glacial to non-glacial conditions during the Aranuian are examined. Landform evidence may supplement that provided in the vegetation record and suggest that the montane environments of Canterbury were more sensitive to climate change than the lower, including coastal, environments. On the whole, however, it appears that landforms record only the broad change from glacial environments to those of the present. Alternations of erosion and deposition in any given valley may reflect a variety of causes, including seismic events, fire, and intense local storms, as well as longer term and regional climate change. It is concluded that the vegetation record will provide a more sensitive and detailed record of climatic variation than will the geomorphological record.

Keywords Aranuian; geomorphology; landform sensitivity; Canterbury mountains; coastal regions; Banks Peninsula

INTRODUCTION

The Aranuian was a time of environmental change during which conditions shifted from almost fully glacial to those of the present day. The period began c. 14 000 years ago, when the glaciers of the peak of the late Otiran had receded significantly, but when most of the valleys of the Southern Alps were still partly occupied by ice (Suggate 1965). The change in climatic conditions, with associated changes in vegetation cover, has been the subject of interest to botanists who have identified fluctuations in the generally warming trend of the Aranuian. In very recent years, this period of warming has become of wider interest as a possible analogue of global warming. McGlone (1988) has demonstrated, however, that climate change alone does not provide a comprehensive explanation for the known vegetation changes.

Sea level at the beginning of the Aranuian was low—probably some 60–70 m below that of today (Carter et al. 1986), giving a somewhat higher effective altitude to the land mass. Inland parts of the country would have been more continental than they are today; the Canterbury coast lay some 40 km east of its present position (Herzer 1983), and the North and South Islands were joined somewhere along the line of Farewell Spit (Stevens 1980). Nevertheless, even during glacial periods, New Zealand was open to air masses from a relatively warm Pacific Ocean, and to high insolation values. Thus, recession of glaciers and recovery of vegetation at a somewhat earlier date than the internationally defined Holocene boundary (10 000 yr B.P.) is not surprising. This paper examines geomorphic change during the Aranuian, both for its intrinsic interest and to assess whether it can be related to, and perhaps supplement, the botanic record.

EXTENT OF GLACIERS

One component of the geomorphic record during the Aranuian is information provided by glaciers, but fluvial erosion and deposition, and mass movement forms, often closely associated with the glacial history, also provide evidence for environmental change, and are part of it. The rapidity of change during the early Aranuian in Canterbury is demonstrated by changes in the extent of ice. Dating of glacier terminal positions is poor and has led to a number of assumptions and extensions of information from one valley to others that may or may

B93079
Received 7 December 1993; accepted 4 May 1994

not have similar controls. There is, however, little doubt that at the beginning of the Aranuian ice still extended well down the major Canterbury valleys. In the Rakaia Valley, the glacier terminus may have been close to the upstream end of the gorge, which was probably barely in existence (Soons & Gullentops 1973). In the Waimakariri Valley, the Cass Basin was partially ice filled (Gage 1958), and Lake Speight had not yet come into existence. Ice occupied most of the Ashburton and Rangitata Valleys above their respective gorges (Mabin 1984). In North Canterbury, the Hurunui and Waiau Valleys still held major glaciers (Powers 1962; Clayton 1968), while in the Mackenzie Basin, ice occupied much of the trenches now filled by Lakes Pukaki and Tekapo (Speight, J. 1963; Fitzharris et al. 1992).

Meltwater from the glaciers spread out as braided streams, probably wider and more vigorous even than their counterparts today, pushing their load of gravel out beyond the present coast to the lowered shore. Rising sea level to some extent countered the effect of this, reworking the gravels into barrier structures, which were backed by lagoons and topped by sand dunes, much like the coast of today (Herzer 1983).

Warming climate and receding ice

Figure 1 shows the probable extent of ice in the Rakaia Valley at three not very widely separated periods. In the Lake Lyndon / Acheron River valley, the last phase of the major late Otiran Advance, Bayfield 3, is dated at some time after 19 200 yr B.P. (Soons & Burrows 1978). By comparison with dates from the West Coast (Burrows 1988), this can be refined to c. 18 000–17 000 yr B.P. At this time, the Rakaia and its tributary valleys were occupied by a large glacier system, as were the adjacent Ashburton, Rangitata, and Waimakariri Valleys. By c. 11 000 years ago the Rakaia Glacier had shrunk until its snout lay somewhere near the entrance to the Lake Stream Valley (Burrows & Russell 1990). This recession of c. 45 km in some 6000 years must reflect a significant change in global atmospheric and oceanic circulation. The rate of recession cannot, however, be estimated by simple division. In the time between these two ice limits, a substantial readvance, the triple Acheron Advance, took place. This was paralleled by the Poulter Advances in the Waimakariri Valley, and by comparable events elsewhere. Its peak was probably reached c. 14 000 years ago but cannot be dated with confidence.

This rapid recession exposed extensive and varied new surfaces for colonisation by plants and animals. Thereafter, glaciers were confined to the narrow, upper reaches of the valleys, and receded steadily, with some interruption by relatively minor readvances (Burrows 1989; Burrows et al. 1990). For the most part, the newly exposed surfaces in these headwater valleys were steep and limited, or were valley bottom sites constantly subject to inundation and/or burial by gravel.

In parts of the Northern Hemisphere, there is evidence that the beginning of the Holocene was accompanied by a spectacular collapse of glaciers, which may have lost their sources of snow in a rapid rise of regional snowlines. This does not seem to have been the case in New Zealand. Glacier mass balance is a function of both precipitation and temperature, and the elevation of most of the catchment areas, on or close to the Main Divide, would have ensured a constant replenishment of the névé fields to maintain glacier flow.

Considerable effort has been put into identifying Aranuian fluctuations of glaciers, especially in the Mount Cook region. Burrows and others have identified fluctuations of glaciers within the Rakaia catchment, with the Cameron Valley providing a particularly useful contribution, while Chinn has produced a similar record for the Waimakariri glaciers. (For a useful summary see Gellatly et al. 1988.) A significant part of the exercise has been to try to relate such fluctuations to those of neighbouring glaciers, and in the case of Gellatly et al. (1985) to variations over greater distances. By doing so, it is hoped to demonstrate synchroneity, and therefore control by large scale regional and global influences.

Major glacier fluctuations, such as occurred during the Pleistocene, were the result of global atmospheric circulation changes. Consequently it can be argued that major glacier fluctuations should be synchronous in both hemispheres, even though when detailed and reliable dates are available there are frequently discrepancies (Salinger 1984). However, as we move closer to the present day, the evidence for synchroneity is less compelling. The uncertainty in dating becomes a more important proportion of the age of a dated feature as the present is approached. Differences in regional and local topography and the geometry of névé fields and mountain valley systems become increasingly important as glaciers diminish in size. Increasingly, adjacent glaciers behave in very different ways, and confidence in their ability to reflect other than local fluctuations of climate must diminish in proportion. The contrasts in behaviour between the Canterbury glaciers and the Fox and Franz Josef Glaciers on the

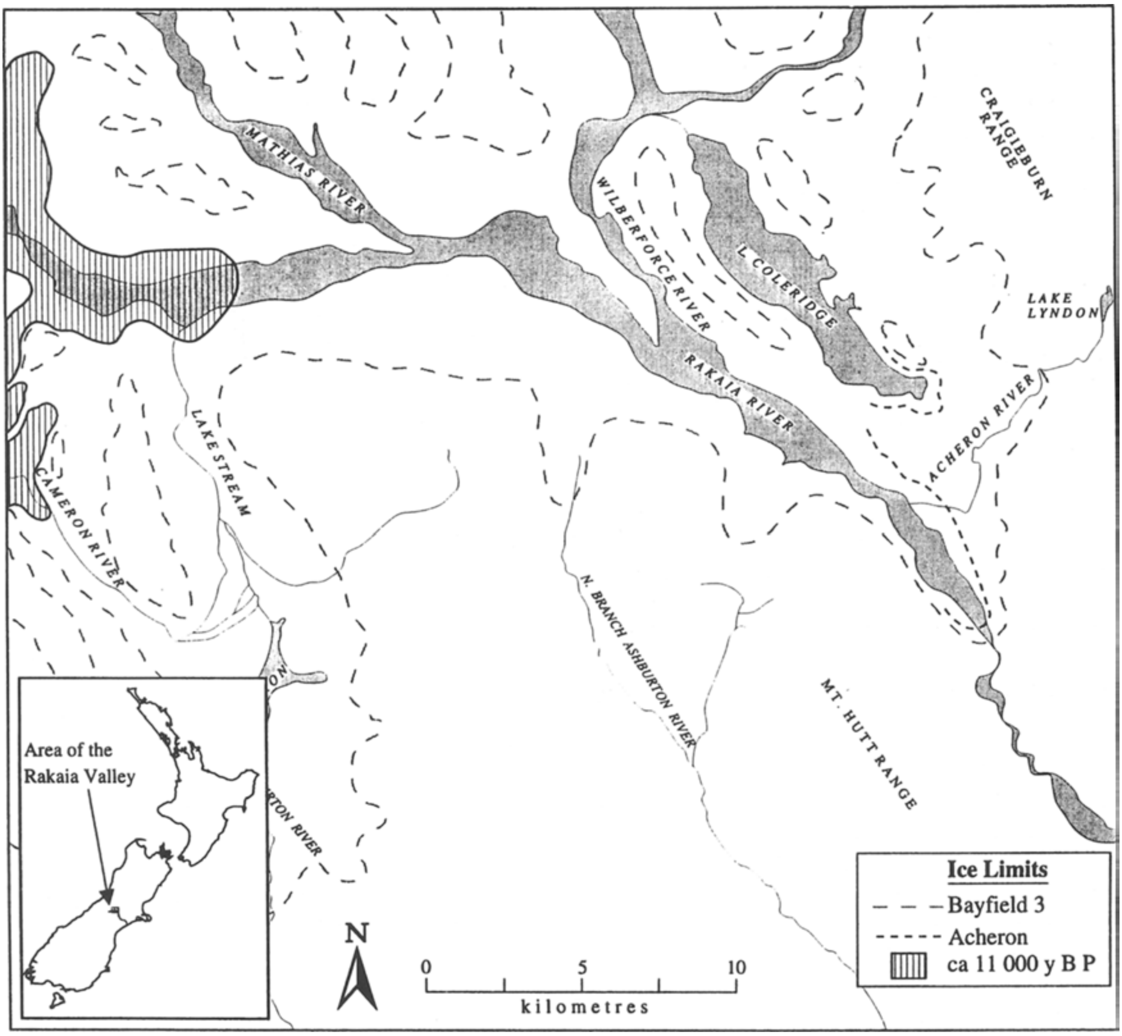

Fig. 1 Successive late-glacial and Aranuian ice marginal positions in the Rakaia Valley.

West Coast have demonstrated this on several occasions this century.

Thus, while the record of glacier behaviour is important in recording a sequence of change from full glacial to present day during the Aranuian, and is provided essentially by the landforms produced by the glaciers themselves, the interpretation of that record has its problems. Glaciers respond to two controls—temperature and precipitation—and there is no incontrovertible geomorphological evidence as to which of these changed in order to produce a given advance or retreat. Clarification must depend on other indicators, one of which may well be vegetation change.

Non-glacial geomorphic changes in the montane regions

The early Aranuian recession of glaciers was one of significant landscape disequilibrium. Major readjustments of stream channels and slopes took place. Ice-marginal drainage systems were entirely or in part abandoned, leaving sometimes spectacular channels. Streams which had previously flowed into proglacial lakes incised their channels into former deltas and across former lake shore terraces as they adjusted to new base levels. Incision frequently continued into the rock floors of valleys, and the detritus formed alluvial fans where the streams emerged onto the floors of formerly glacier-filled basins. Some changes of course were inevitable as casual accidents of erosion and deposition switched streams from one side to another of alluvial fans, or as mass movement more or less permanently blocked drainage lines. Cutting of the Rakaia Gorge is shown by the continuity of late Otiran outwash surfaces to have begun only after the recession of the glacier from the Bayfield 3 position—that is, after c. 17 000 years ago. It may have been at least partially infilled and then re-excavated during the Acheron Advances (Soons & Gullentops 1973). Some of the incision may be attributable to water released as ice-marginal lakes drained, possibly dramatically. Other smaller rivers have gorges which can only have been cut after the ice retreated, such as that of the Cass immediately upstream of its junction with the Waimakariri.

This period of landform disequilibrium and rapid readjustment to the changing conditions would have been time transgressive, the zone of adjustment following the receding ice margins. Its duration probably varied depending on the severity of the readjustment that was necessary. In some locations it is still continuing—there are many streams whose valleys can hardly be said to have achieved equilibrium with today's conditions. Nevertheless, the most vigorous period of adjustment probably ended in three or four thousand years. It ended, not because of any abrupt climate change, but because a state of near-equilibrium with the ice-free environment had been achieved. Downcutting diminished, load reduced, and the building of alluvial fans slowed down. Surface stability increased and soil development was able to proceed.

Accidents and extreme events

A geomorphic change requires a change in energy conditions. For example, lowered local base levels and removal of support for slopes consequent on the disappearance of ice provide an increase in energy for stream incision and mass movement. In contrast, variations in frost frequency, precipitation, or sunshine that are large enough to result in a change in vegetation type do not necessarily result in geomorphic changes. The extent to which soils are exposed to agents such as wind, frost, and gully erosion is critical. A shift from one vegetation type to another with little or no exposure of bare soil or loss of roots is unlikely to have much geomorphic impact. Thus, it is likely that only relatively large changes in climatic conditions will be reflected in changes in the geomorphic character of a region. Such changes may be associated with variations in the frequency of high magnitude events, or with more subtle but persistent shifts of climatic parameters.

The Canterbury high country is subject to highly variable weather and to seismic events, and although a measure of landform stability developed as climatic conditions improved during the Aranuian, there is abundant evidence that local and intermittent events occurred which disrupted that stability. Intense storms, some localised and others affecting wide areas, are characteristic, and cause damage which is not easily or rapidly healed. Such damage includes slips and gullying, as well as more or less dramatic changes of stream course on alluvial fans. Even wind may cause lasting damage to the land surface. Visible evidence of soil loss is widespread throughout the montane area and beyond, both in the dust clouds which are common in the "Nor'wester" and in the wind scalds and the complementary accumulations of fine sediments around tussocks and shrubs. More severe wind storms can result in overthrow of forest trees and consequent soil and slope modification (Burns & Tonkin 1987).

Larger scale damage may result from seismic events, and in particular from earthquake-induced slope collapse. The identity of a number of late-glacial moraines has been confused by their coincidence with the debris of massive rock avalanches. Examples are found throughout the high country—in the Macaulay Valley (McSaveney & Whitehouse 1989a), the Cass Basin, and in the Rakaia Valley between the Power Station and the mouth of the Acheron River. These and other massive rock avalanches probably testify to a major seismic event of the kind suggested by Whitehouse (1983) and Whitehouse & Griffiths (1983). Smaller landslides of indeterminate origin in the Cameron Valley have been inferred by Burrows et al. (1993) as probably occurring at a rather later date than those that descended onto moraines in the larger valleys. Canterbury in the Aranuian experienced seismic events that have had significant if localised effects on landforms, and it is probable that more evidence remains to be interpreted from the record. The geomorphic impact of such events can be responsible for substantial changes of style of erosion and deposition, and hence any such changes should be used to reconstruct climatic events only with considerable care.

The rigorous mountain climate and ongoing tectonic instability contribute to the creation of a harsh environment, in which local erosion and its associated deposition can be frequently triggered. Superimposed on the climatic and tectonic elements is the evidence of a fire history, demonstrated by a number of workers (see McSaveney & Whitehouse 1989b for a useful summary), most recently by Burrows et al. (1993). McGlone (1988) has pointed to the significance of this in reconstructing past climate conditions. McSaveney & Whitehouse (1989b) note that fire has been an element in the high country for at least 40 000 years, and that at least in the last millenium deforestation associated with burning has been responsible for erosion of steepland soils as root strength has diminished. Burning is probably one of the most effective ways of triggering rapid, substantial, and persistent geomorphic changes in the montane environment.

Paleosols, vegetation change, and geomorphology

Paleosols such as those described by Burrows et al. (1993) offer evidence of more than one phase of landscape disequilibrium. Soil formation and burial permit identification of an associated vegetation cover, and successive paleosols tend to show different vegetation assemblages. Unfortunately, paleosols are not so widespread that they can be readily used in reconstructing the history of an area, as Tonkin & Basher (1990) have pointed out. Their absence, however, may in itself provide useful information as to the stability or relative youth of a surface (Tonkin & Basher 1990). Palynological evidence, including that relating to pollen dispersal, even from spot locations, can provide valuable evidence of changes in the regional character of vegetation. McGlone (1988) has used such information to infer wider atmospheric circulation changes to account in part for regional variations in vegetation through the Aranuian. Nevertheless, as he points out, the recorded vegetation changes reflect a complex of environmental changes, not all of which are climatic or climate controlled. However, climate parameters are important, and an ability to trigger geomorphic changes may provide an indication of their magnitude. An increase in avalanche activity and/or aggradation of valley floors might indicate persistent colder or wetter conditions—or some combination of both—at high altitudes. Alternatively, they might be evidence of increased storminess, as Grant (1982) has demonstrated in Hawke's Bay. Part of the problem in using such information is to establish the areal extent of evidence of change. Another part is to translate evidence of a widespread change in soil type, vegetation cover, and landforms into a quantitative measure of the magnitude of climate change.

Because of the lack of detailed chronological information, it is difficult to determine how widespread were the phases of aggradation and erosion identified in individual valleys. While it seems logical to assume that a significant change in climate would affect a wide area, there is considerable variation in mountain meso- and micro-climates, and not all locations may be affected to the same extent. A change restricted to a single valley may indicate little, but a change that can be demonstrated to be widespread may record an environmental change of some importance.

In reviewing the geomorphic evidence for climate change, it is difficult to resist the impression that the montane areas of Canterbury, from which much of the evidence comes, were, and are, especially susceptible to minor variations in climatic parameters. The criteria for the selection of sites for tree-ring study are based on the assumption that such localities are likely to be those of stress for vegetation, and implies that climatic variations reflected at such sensitive locations were probably not effective and identifiable at lower elevations.

CHANGES BEYOND THE MONTANE AREAS

Beyond the mountain catchments, readjustment of the larger rivers of Canterbury involved deposition of sediments removed from the uplands at the seaward margins of the plains. This was the continuation of a transfer process that took place through successive glaciations and interglacials, and the correlation of glacial advance and fan building is reasonably well established. It affected even those rivers that had little or no ice in their catchments, such as the Ashley, where the cold phases of the Pleistocene would have resulted in a change not only in the temperature regime but also in the water balance, leading to reduction of vegetation cover and extensive frost weathering. This was reflected in heavily loaded streams and alluvial fan building within upland catchments, such as Lees Valley, and on the plains. The geomorphic impact of climate change on the downlands of North and South Canterbury is less clear. Changes between tussock/scrub associations and forest may have resulted in some increased susceptibility to mass movement, which in turn may locally have affected stream behaviour. On the whole, however, it seems likely that much of the impressive stream incision in some parts of North Canterbury in particular is a reflection of tectonic and seismic activity (Yousif 1987).

Coastal changes in the Aranuian

The coast provides no indicators of local environmental change that can be correlated with the fluctuations identified in the montane soil and vegetation record. The youngest fan sediments of the Canterbury Plains extend beyond the present coast, forming the long gentle offshore profile of the Canterbury Bight and Pegasus Bay. Fluvial deposition was countered by wave action in much the same manner as it is today. A sequence of barriers was built, reflecting the interplay of storm waves and river flow. Each of these barriers in turn was moved landward and eventually overwhelmed as sea level rose (Herzer 1983). Alluvial deposition was replaced by lagoonal and marine sedimentation along the toe of the fans, but complicated interactions took place as storm waves and river floods alternated in importance in reworking and providing the products of inland erosion to the coast. Until approximate stability was achieved at c. 6000 years ago, the rise of sea level was a dominant influence on coastal processes. This was a function of global, not local, change.

Banks Peninsula

Projecting roughly halfway along the Canterbury Plains, Banks Peninsula is responsible for the contrast between the coast of the Canterbury Bight and of Pegasus Bay. It blocks movement of sediment from the bight to the bay, and results in the formation of one of New Zealand's more notable coastal features, Kaitorete Spit—not, as various writers have pointed out, a spit, but more correctly a barrier beach, albeit on a grand scale.

During the Otira Glacial, the peninsula was not high enough to have carried glaciers, but it may have experienced severe cold climate conditions on its hill summits (Harris 1983). Many of its slopes carry a mantle of colluvium derived from the rocky crags forming those same summits. It offered refuges for a range of plants in its deep valleys, from which the sea was absent for most of the Otiran. Thick loess deposits accumulated on its slopes, and while there is some evidence that this was reworked from a general cover to accumulate on the lower slopes, most of the gullying and superficial mass movement, which is a feature of the peninsula, seems to be related to recent deforestation. The peninsula may have recovered rapidly from the effects of Pleistocene cold climates, and offered a favourable environment for vegetation recovery during the Aranuian. Unfortunately, the broad outline of the Quaternary history of the peninsula is not well known, let alone the details relating to climate change.

The Aranuian rise of sea level drowned first the broad Canterbury coastal plain and then the deep valleys of the peninsula. At the southern end of the plains and to the north of the peninsula, a barrier and lagoon coast developed. Near and to the north of the Rakaia mouth, the angle presented by the coast to the southerly swells eventually resulted in destruction of the barriers and lagoons, erosion of the toes of the alluvial fans, and the movement of gravel northwards. Several authors (Speight, R. 1930; Armon 1973; Lawrie 1992) have described the consequences in the change of direction of the coast and the gradual construction of a spit across the mouth of what was the combined estuary of the Selwyn and Waimakariri Rivers. Once the growing spit encountered the mass of the peninsula, further alongshore movement of gravel was prevented, the spit pivoted at its narrow western end and widened at its eastern end into the broad barrier of today. Lakes Ellesmere (Waihora) and Forsyth (Wairewa) resulted from the closure of the barrier, certainly within the last 5000 years, and possibly quite recently. Similar, if smaller, lagoons along the coast north of the peninsula also reflect the reworking of material brought down by the rivers, and together with a complex of beach ridges and dunes offer the possibility of further elucidating Aranuian events.

CONCLUSION

The alternation of climatic conditions indicated by the vegetation sequences of inland Canterbury is not replicated in any of the known coastal sequences, nor in the history of the plains and downlands. This leads to consideration of the implications of the concept of landscape sensitivity. The Canterbury high country probably was, and is, much more sensitive to relatively small changes in climatic parameters than are the lower hill and plains. It thus provides a better record of Aranuian climate change than lower country, and this record appears to be more clearly seen in the history of vegetation change than it does in the landforms. Overall, the landforms show only the effect of the gross change from glacierised to non-glacierised conditions, and the downstream effects (literally) that this produced in energy and supply of detritus. Where evidence of alternating stability and instability is found, it must be remembered that landforms, and particularly fluvial and mass movement forms, respond to a number of controls other than climate. Earthquakes, floods, and storms have all contributed to the alternation of erosion and deposition, and the effects of occasional fire episodes could be significant. In building up a history of environmental changes in the Aranuian, it is likely that the emphasis must continue to rest heavily on information provided by vegetation sequences.

ACKNOWLEDGMENTS

Ian Owens, Blair Fitzharris, Neville Moar, and an anonymous referee are thanked for their comments on a draft of this paper, as is Anita Pluck for drafting Fig. 1.

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