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EROSIONAL AND DEPOSITIONAL TRENDS IN RIVERS OF THE CANTERBURY PLAINS, NEW ZEALAND

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ABSTRACT

The major rivers of the Canterbury Plains — the Waimakariri, the Rakaia, the Rangitata and the Ashburton, on emerging from the Southern Alps and foothills have built out fluvioglacial fans, and with progressive downstream aggradation formed a series of surfaces over 50 km wide and 160 km long. Each river has aggraded across the entire width of the plain during glacial maxima, and is inferred to have incised a seaward-developing trench, typically 2 km wide, during each interglacial period. Flow regimes and gradients throughout the late Quaternary were controlled by sediment load, sea level, and coastline position. Waimakariri River terrace sequences indicate that the dominant control of river gradient during glacial periods was sediment load; but during interglacials, sea level and sediment load were of equal importance.

Bed-level measurements for the Waimakariri River show a change from river entrenchment upstream and fan building downstream at about 18 km to 19 km from the coast, and a downstream migration of the intersection point. Relatively recent coastal erosion of the Canterbury coast to the south of the Rakaia River mouth, has caused the development of trenches extending inland from the coast.

Keywords: Canterbury Plains; NZMS262 380; Waimakariri River; Rakaia River; Ashburton River; Rangitata River; braided rivers; Quaternary; glacial maxima; gravel plains; river flow; river profile; tectonic influences; coastal processes.

PHYSICAL SETTING

The Canterbury Plains (Fig. 1) are a series of coalescing glacial outwash and alluvial fans progressively built during the later part of the Quaternary by eastward-flowing rivers emerging from the foothills of the Southern Alps. The catchments are composed dominantly of highly indurated greywacke and argillite of the Torlesse Supergroup that has been intensely folded and faulted during two major orogenies. Fracturing and jointing in these rocks has facilitated mechanical weathering during the rigorous fluctuating climates of the Quaternary. The durability of the derived clasts has enabled them to survive several episodes of transport and deposition.

The plains extend eastward to Banks Peninsula, a volcanic complex erupted during the Late Miocene, which was probably an offshore island until the later Quaternary. Diversion of northward-flowing ocean currents by the peninsula allowed coastal progradation to the north in its lee, in contrast to the coastal erosion that persists to the south (see Fig. 1). Measurements from petroleum exploration bores (e.g. J.D. George I — Seafield) indicate that gravels forming the plains are over 500 m thick, and are probably considerably thicker in subsurface tectonic depressions. At their inner margins the plains reach an altitude of about 350 m. In places the boundary between the plains and adjoining steepland is marked by intervening surfaces of dissected moraine or tectonically disturbed upper Cenozoic gravels. Thus the boundary is not everywhere clear-cut physiographically, and the constituent surfaces are of different ages in different parts of the plains.

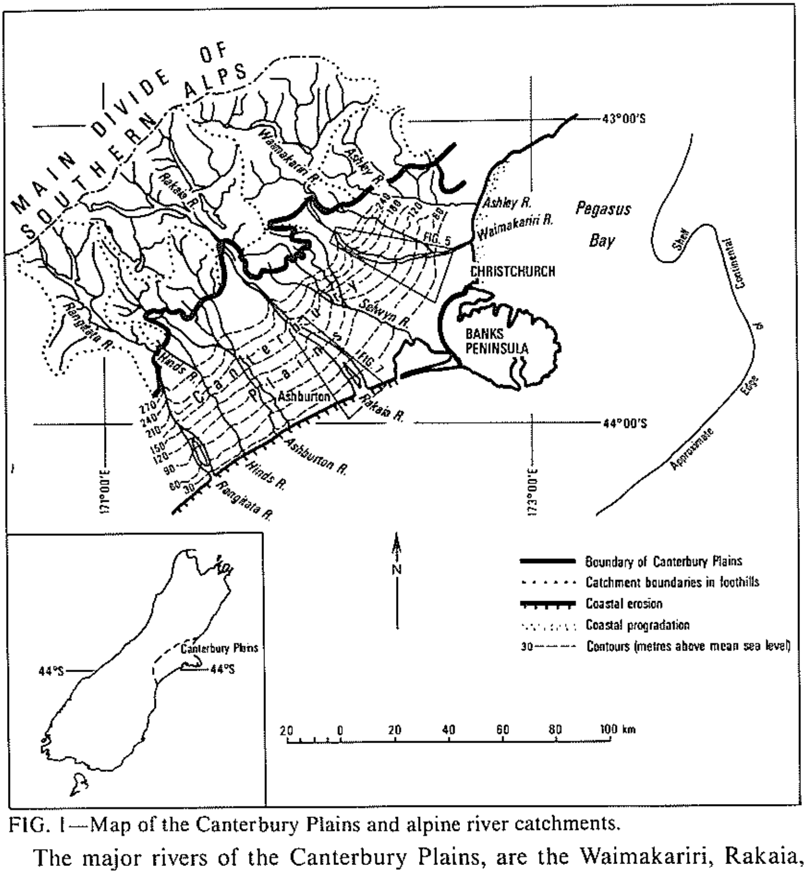

FIG. 1—Map of the Canterbury Plains and alpine river catchments.

The major rivers of the Canterbury Plains, are the Waimakariri, Rakaia, Ashburton, and Rangitata (Fig. 1). Between the conical segments of fans of these major rivers, minor rivers drain the consequent troughs. It is difficult to define "watersheds" across the plains, for although the major rivers have built by far the largest sectors of the plains, these sectors are convex in transverse section, with surface streams flowing away from the high terrace edges above the incised rivers and towards inter-fan rivers. The only direct catchments of the major rivers in their plain reaches are their flood plains, typically about 120-150 km² for each. Each river's discharge, sediment transport, aggradation, and degradation is controlled almost entirely by its area of high country catchment, although shoreline degradation and progradation may also play a part in determing near-coastal aggradation or downcutting. Approximate areas of mountain catchments for selected rivers, listed from north to south are: Ashley — 1000 km², Waimakariri — 2400 km², Selwyn — 680 km², Rakaia — 2600 km², Ashburton — 950 km², Hinds — 160 km² and Rangitata — 1600 km².

Only the Waimakariri, Rakaia, and Rangitata rivers have catchments that extend to the divide of the Southern Alps, where precipitation is greatest. The Rakaia has the longest alpine boundary, and as a consequence has a mean flow almost double that of its northern neighbour, the Waimakariri, even though the latter has a catchment of comparable size (Fig. 1).

The major rivers occupy glacially moulded bedrock valleys with high-gradient gravel-filled beds in the upper catchment, and cross the Canterbury Plains in braided channels on wide gravel flood plains. Where the rivers emerge from the alpine foothills the flood plain of each river is entrenched more than 100 m below the plains surface, but this entrenchment decreases seaward. The flood plain is normally more than 2 km wide, and at normal flow is crossed by numerous braided channels separated by lozenge-shaped gravel bars with drapes of sand. The bars are typically 1 m high and 0.1 km² in area, and in places are temporarily stabilised by vegetation.

Average annual precipitation is about 650 mm near the coast, 1000 mm at the inner margin of the plains, and 5000 mm at the main divide, where rainfall intensity is commonly over 300 mm in 24 hours (New Zealand Meteorological Service, 1979). The dominant flood-producing rainfall is carried by northwest winds which bring rain to the alps, and hot dry conditions to the Canterbury Plains. Floods of 100 year recurrence interval exceed 4000 m³/s for the major rivers. The provincial capital Christchurch is at threat from flooding by the Waimakariri River, although the construction of artificial embankments and straightening of the river's course below a point about 19 km from the sea has prevented major flooding since 1868.

RIVER TRENDS THROUGH THE QUATERNARY

Present-day hydrological and sedimentation patterns were initiated in the early Quaternary after the Southern Alps and alpine foothills were uplifted durng the Kaikoura Orogeny. The hard greywacke and argillite of the Torlesse Supergroup basement rocks responded to tectonism by brittle fracture that produced shearing, major faults, and a variety of associated joints. Mesozoic and Tertiary sediments were folded over deeper faults and fault blocks. The younger sediments were quickly eroded from structural highs, leaving the alpine region dominate by exposures of complexly folded and faulted, indurated Torlesse rocks.

Intense erosion followed the late Tertiary tectonism, producing durable clasts which survived as coarse gravels for distances greater than 60 km from their source, judged by the existence of gravel at depths of at least 500 m near the present-day coast. Erosion also almost certainly quickened during the onset of cyclic climatic fluctuations of the late Quaternary. Suggate (1965) recognised a succession of five glaciations, each marked by morainic deposits which could be traced downstream to fluvioglacial outwash surfaces. Each glacial maximum was associated with a sea level some 120 m lower than the present, so that

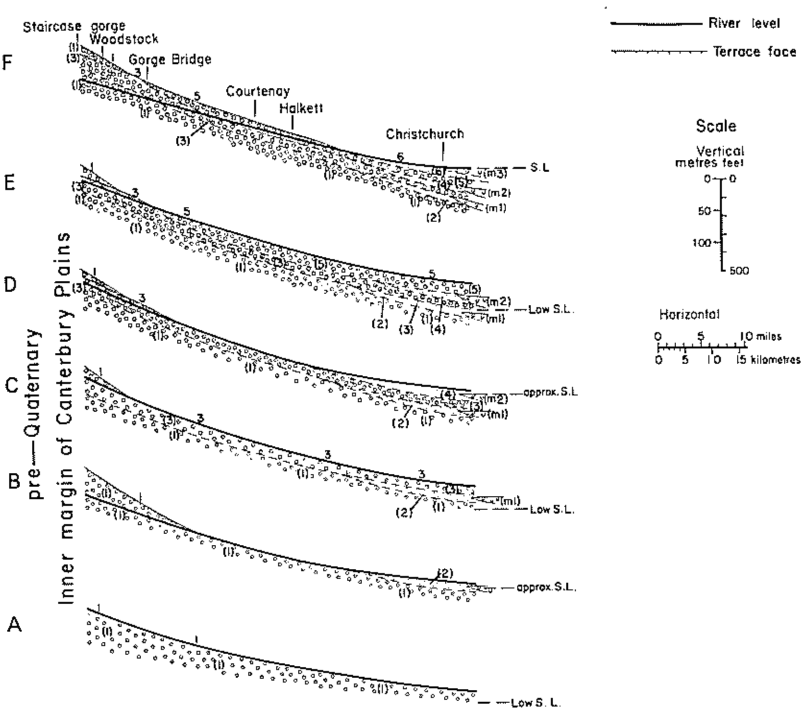

FIG.2—Section through the Quaternary sequence in the Waimakariri sector, Canterbury Plains.

(A) Early Glaciation. Sheetflood deposition of poorly-sorted greywacke gravel (1) to aggradational surface 1, now preserved only near the inner margin of the plain, gradient 11.7 m/km.

(B) Penultimate Interglacial. Dissection of preceding glacial outwash (1) in upper reaches. This was transported and deposited downstream as alluvium (2). Marine transgression caused estuarine and marine deposition (ml) in the Christchurch area, now encountered in groundwater wells.

(C) Penultimate Glaciation. Renewed deposition of outwash (3) to surface 3, now preserved in the inner and central plains. The surface gradient at the inner margin of the plains is 9.5 m/km.

(D) Last Interglacial. Entrenchment of the river into preceding outwash with transport of the derived material downstream and consequent deposition of alluvium (4). Marine transgression led to the deposition of the estuarine and marine wedge (m2) in the Christchurch area.

(E) Last Glaciation. Renewed sheetflood deposition of outwash (5) to aggradational surface 5, preserved in the central plains with a surface gradient of 8.4 m/km.

(F) Scale section along the Waimakariri River. The river entrenched itself during the postglacial period into the preceding glacial outwash, spreading the derived material further downstream (6). The boundary between degradation and aggradation (the intersection point) moved progressively downstream with time. Marine transgression led to the deposition of marine and estuarine sediments (m3) = Christchurch Formation of Suggate (1958) beneath Christchurch.

the shoreline was about 90 km offshore at the edge of the present continental shelf (see Fig. 1). The peak of aggradation for each glacial episode was essentially contemporaneous with the peak of ice advance. Glacial deposits can be distinguished by slight variations in degree of weathering, matrix texture and colour (though only with certainty where they are in contact), and by the relationships of aggradation surface remnants. Proglacial deposits form surfaces that can be correlated across subsequently dissected valleys with no significant vertical break in the component material. This contrasts with interglacial deposits which typically form distinct veneers on older gravels. The terrace surfaces associated with the veneers are unmatched.

During each glacial advance there was an accelerated sediment yield partly caused by lack of vegetation cover in the mountains and foothills, and partly by the increase in mechanical weathering that accompanied temperature decline. The Canterbury rivers, choked by debris, deposited their loads to form sheet deposits as they emerged from the foothills. These sheets consisted of coalescing fans, constructed by laterally migrating rivers, which progressively extended aggradation downstream to form convex fans with contours concentric about the interesection point, the point of change from degradation to aggradation (Hooke, 1967). The later outwash of the Waimakariri was deposited in a trench carved into earlier outwash, and it is inferred that this was the general relationship through the Quaternary. Although the point of emergence of rivers from the foothills remained fixed throughout successive ice advances, there is no reason to suppose that the sphere of influence of each river across the plains remained constant.

During interglacials, rivers became entrenched in earlier outwash. Evidence for this is best seen in channels that have been carved during the postglacial period.

The main features of river activity during interglacials were the formation of:

1 Trenches that extended from the foothills downstream, deepening and lengthening progressively with time.
2 A series of degradational terraces which mark stages of lateral as well as vertical degradation of the river trenches.
3 A veneer of floodplain deposits capping each terrace.
4 An alluvial fan deposited downstream from the intersection point and derived in large part from the trench development above that point (Fig. 2, 3).

Figure 4 depicts trends throughout the late Quaternary. It is based largely upon demonstrable relationships between older and younger sets of glacial outwash gravel exposed in the inner plains, and upon terrace relationships in the central and lower plains.

The lateral expansion of the smaller consequent rivers across the plains has always been constrained by the major outwash fans of their larger neighbours. The regimes of the smaller consequent rivers have been dominated by short-term local climatic fluctuations rather than by long-term effects of glacial-interglacial cycles.

The Ashley River exhibits a similar pattern to that of its larger neighbour the Waimakariri. A wide aggradational surface of periglacial material was constructed during the Otira Glaciation and later deeply incised during

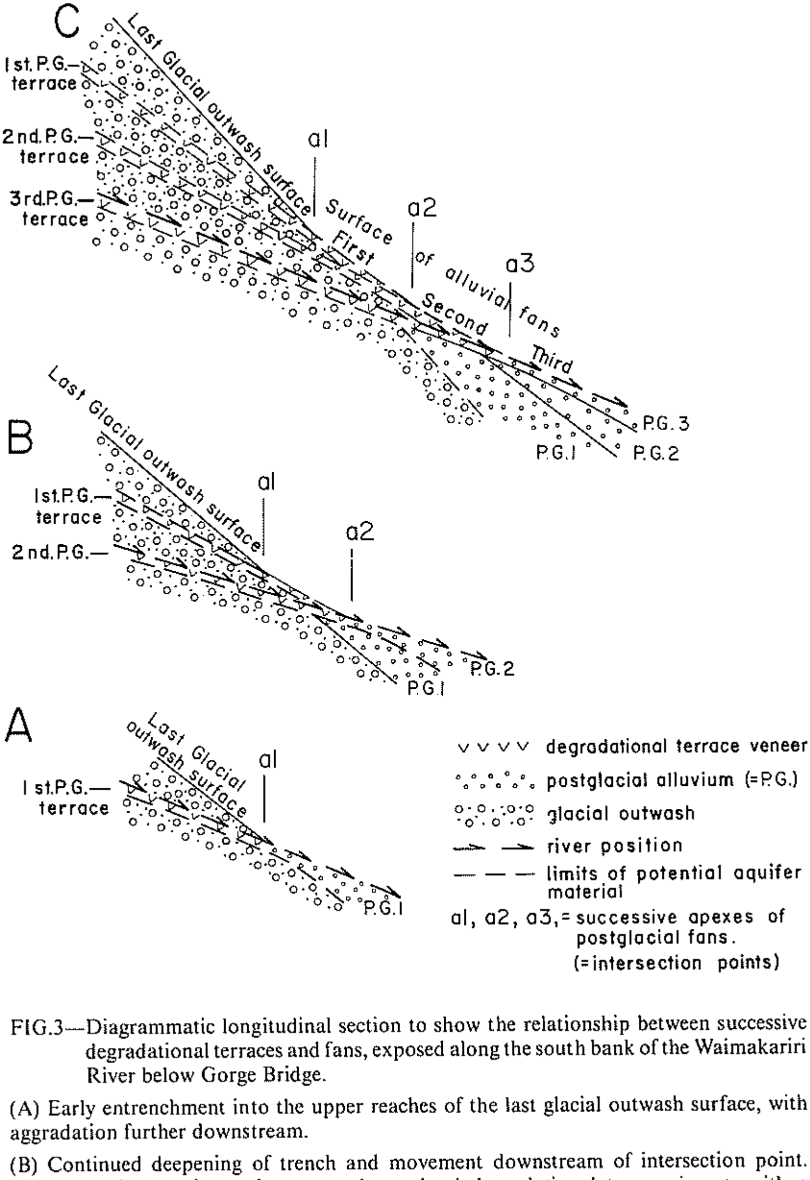

FIG.3—Diagrammatic longitudinal section to show the relationship between successive degradational terraces and fans, exposed along the south bank of the Waimakariri River below Gorge Bridge.

(A) Early entrenchment into the upper reaches of the last glacial outwash surface, with aggradation further downstream.

(B) Continued deepening of trench and movement downstream of intersection point. Above the intersection point a new lower level degradational terrace is cut, with a veneer of young gravels at the top; below the intersection point, a contemporary fan of young gravels is deposited over immediately older fans to form a continuous succession.

(C) Further deepening. Additional entrenchment and movement downstream of the intersection point. New degradational terraces above the intersection point; continuous fan building below the intersection point.

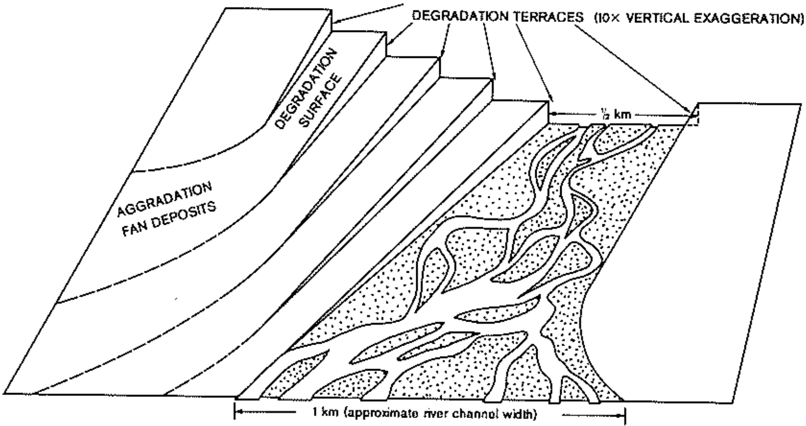

FIG.4—Diagram showing relationship between degradation surfaces and aggradation fans along the south bank of the Waimakariri River downstream of Gorge Bridge.

postglacial time. The Ashley River is on the northern fringe of the plains, and its relationship to structural trends can be examined in neighbouring older deposits (Mairaki Downs — lower Quaternary), where it crosses a series of folds that have been active during the late Quaternary, between 24 km and 18 km from the river mouth. At present the Ashley River is aggrading below a point about 8 km upstream from its mouth.

The Selwyn River, with its small foothills catchment, has probably always depended for its load on outwash material supplied by its larger neighbours which also restricted its lateral development. It has re-sorted this material repeatedly during the localised episodes of aggradation and degradation initiated by minor climatic events, dominantly fluctuating rainfall intensity. The river is currently incised within an aggradational surface judged to be coeval with a late advance of the Otira Glaciation, except in the lowest part of its course where controlling stopbanks prevent aggradation on the alluvial fan.

The trench of the Ashburton River is less pronounced than that of the Rangitata, which is of comparable catchment size, but this probably relates to the Rangitata's high-alpine, and hence high-rainfall catchment. The Ashburton River, composed of two main branches, has several nearby parallel streams, and it seems likely that its activity during glacial maxima has been the construction of a narrow (approximately 6-10 km) sector of plain within the lateral constriction of neighbouring outwash fans. This would account for the presence of numerous lenses of river-deposited silt within the upper gravels in the Ashburton sector, which probably resulted from backfill deposition following local ponding. Coastal entrenchment due to headward erosion from retreating cliffs is prominent in the lower Ashburton, and its effects extend 20-25 km inland up to an altitude of about 120 m.

The Hinds River is not deeply entrenched and has contributed to a zone of swampy flats, most now drained, in its lower reach. Headward erosion from a regressing coastline has led to the formation of a trench extending about 4 km inland.

The central flood plain of the Waimakariri River is situated within a trench that shallows more-or-less uniformly in a downstream direction (Fig. 5). The steepening of river gradient at about the 150 m contour that shows as an irregularity in precise bed levels (Fig. 6), and the increasing gradients with age shown by degradational terraces and outwash surfaces (Fig. 5) suggest that tectonism is still active. Whatever the reasons, there can be no doubt that during the past few thousand years the intersection point has migrated downstream by some 35-40 km from a considerably higher level (corresponding to the present 190 m contour) than the present-day intersection point. The position of the present-day interesection point can be judged from contour geometry to be somewhere between the 30 m and 60 m contours, and is assessed with more accuracy from bed-level trends of the past 50 years in a later section. The relative ages of younger fan surfaces are indicated by radiocarbon dates of surface and near-surface organic material (Fig. 5) published by Cox & Mead (1963), Grant-Taylor & Rafter (1971), and Suggate (1968).

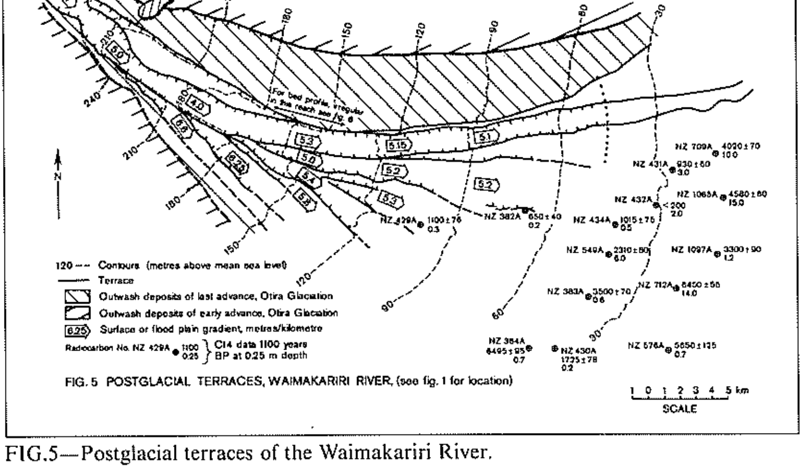

FIG.5—Postglacial terraces of the Waimakariri River.

The Waimakariri River, with some contribution from the Ashley River, has over the past 6500 years of relatively stable sea level prograded a coastal zone about 14 km wide. This zone, measured from the furtherest inland coastline to the present coastline (Wilson, 1976), has a total area of about 200 km^2, an average thickness of perhaps 15 m, and a volume of about 3 km^3. Coastal progradation in Pegasus Bay, in contrast to the coastal erosion in the south of the peninsula, is a result of the protection of the Waimakariri and Ashley river mouths by Banks Peninsula from the effects of the northward-flowing coastal current.

The total amount of postglacial trench erosion by the Waimakariri River provides a lower limit to the total amount of progradation. A high proportion of the river's load can be ascribed to reworking of older gravels, with an

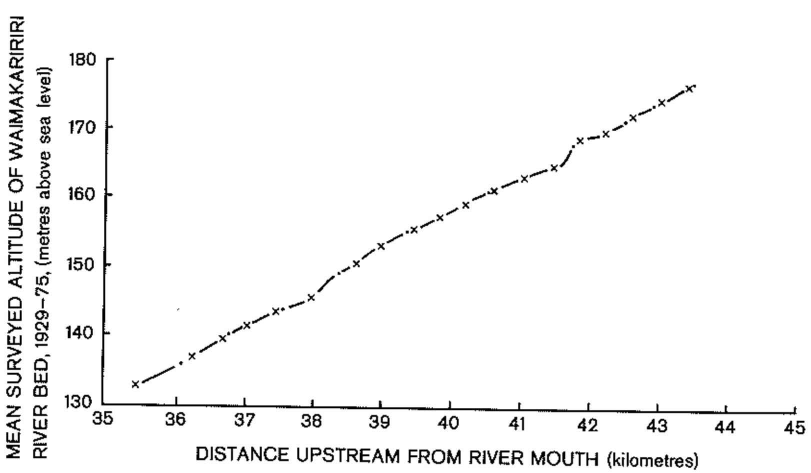

FIG.6—Bedform of Waimakariri River as measured by successive surveys 1929-1975. Note irregularity in the 37-42 km reach (cf. Fig. 8).

unknown amount of debris being contributed by postglacial erosion from the alpine region. A minimum value for the total amount of material deposited can be roughly assessed by estimating the volume of its trench below the last major aggradational surface of glacial outwash. This volume, calculated for a river length of 70 km (from the lower end of the Staircase gorge, where the river emerges from the foothills) is about 2.5 km^3. If this has been removed by trenching initiated at the beginning of the postglacial, about 14 000 years ago, the average annual amount of material removed is about 180 000 m^3. If river entrenchment began only after sea level approached its present position some 6500 years ago, the annual average increases to about 420 000 m^3.

The postglacial trench of the Rakaia River has involved the erosion of about 8 km^3 of gravels; over three times the volume of the Waimakariri trench. The Rakaia sector of the Canterbury Plains coastline is being eroded at a rate of 2 m per year. Contours across the coastal reach (Fig. 7) show that the Rakaia trench decreases in depth seaward to about the 60 m contour, at about 14 km upstream from the sea, then increases again towards the coast. The implication is that the seaward-advancing river entrenchment, a consequence of reducing river load during the postglacial, has extended the river profile down to 60 m, and that landward-advancing entrenchment, a consequence of lowered coastal base-level due to eroding cliffs, has produced the profile below 60 m.

The volume of the Rangitata trench across the plains is about 2.7 km^3, a similar figure to that of the Waimakariri River, despite the Rangitata's smaller catchment. Cliffs near the Rangitata River mouth are considerably lower than those near the Rakaia River. Since the gradient of the outwash surface deposited during the Otira Glaciation is similar in each locality, the lower cliffs at the Rangitata mouth suggest that coastal erosion has been slower. This would explain the lack of evidence of landward trench development from the coast, so that the incision of the flood plain becomes progressively shallower in a seaward direction right to the coast.

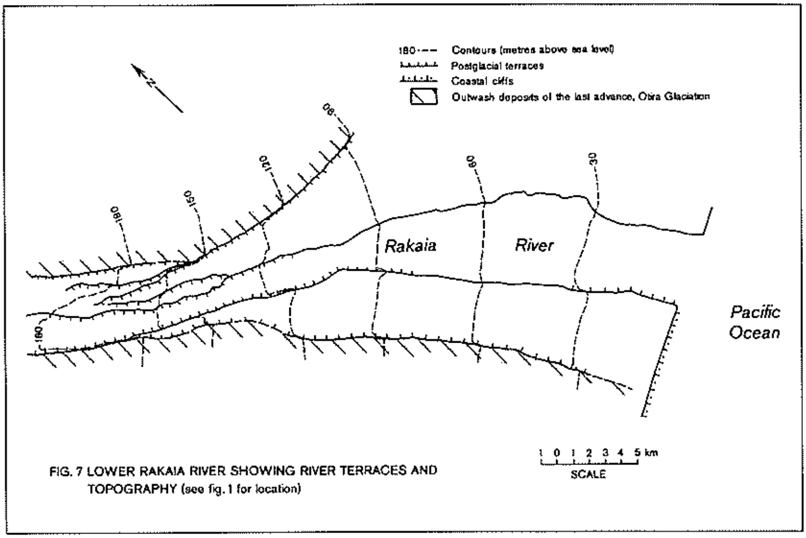

FIG.7—Lower Rakaia River showing river terraces and topography.

The near-coastal reaches of the Waimakariri and Rakaia rivers are presently shifting away from Banks Peninsula which separates them (see Fig. 1), a trend that has been evident for a thousand years or more. It is marked in both rivers by the presence of a single entrenched river bank on the side furthest from the peninsula, and a succession of small steps on the near bank (south bank/Waimakariri River, north bank/Rakaia River). In the Waimakariri River the south bank terraces decrease in age and swing progressively northward (Fig. 5). Relative subsidence in the plains north and south of the rivers may have influenced the development of the rivers' courses.

TRENDS DURING THE LAST FIFTY YEARS

Flooding of the Waimakariri River is a threat to Christchurch, and a great deal of engineering and scientific effort has been devoted to measuring and predicting the river's fluctuations, controlling its lateral limits, and determining trends of aggradation and degradation. Bed-level measurements carried out for the Waimakariri River (Fig. 8) illustrate measured changes over almost 50 years (see Griffiths (1979) for details). A change from degradation to aggradation occurs at about 18 km to 19 km from the coast, supplementing the longer-term evidence of the advancing intersection point. There is no definite evidence of historic short-term trends in Pegasus Bay coastal progradation, but the average amount of coastward progradation during the past 6500 years has amounted to over 2 m/year (Wilson 1976, p. 107, 108). Bed changes in other rivers of the plains are less of a threat to life and property than those in the Waimakariri River, and consequently regular measurements of change have not been carried out.

It can be forecast from evidence of long-term changes that coastal erosion will produce deepening or entrenchment of rivers into their beds at the coast,

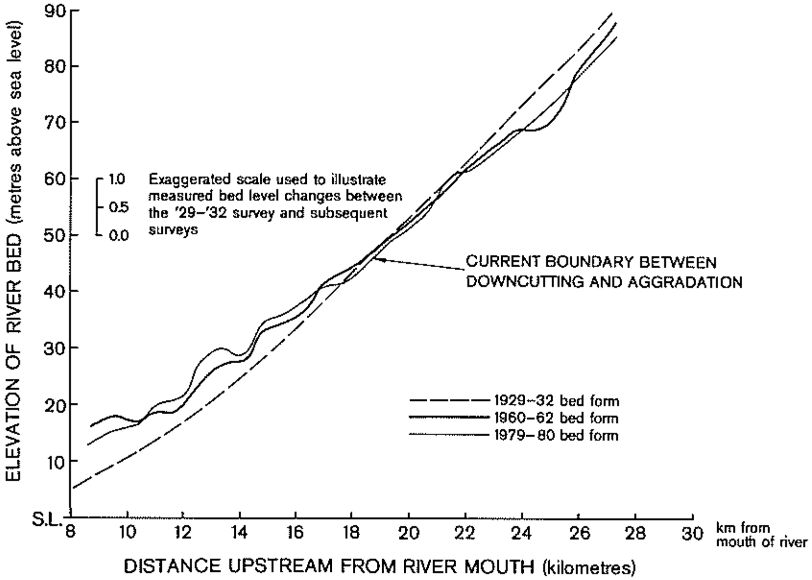

FIG.8—Waimakariri bed level changes from 1929 to 1980.

and this entrenchment will shallow progressively inland. "Load erosion", i.e., trenching during progressive reduction of river load at the inner margin of the plains, might be expected to deepen existing trenches. On this basis it can be predicted that the intersection point of the Waimakariri River will move downstream from its present position about 19 km from the coast. The intersection point of the Rakaia River, some 14 km from the mouth, should also move downstream, though the effect might be reduced or cancelled by trenching caused by coastal erosion. The Ashley River might be expected to incise its present trench in the reach where uplift has taken place in response to relatively recent (late Quaternary) movement, and to continue to aggrade (or to attempt to do so against the constraints of flood protection work) below about 8 km from the coast. The Selwyn River, controlled by stopbanks in its lowest 6 km, will continue to develop a delta into Lake Ellesmere, its coastal "estuary", while the Ashburton and Hinds rivers should extend the depth and length of their present trenches.

FACTORS CONTROLLING RIVER ACTIVITY

The balance between aggradation and degradation in Canterbury rivers has been dictated by river loading, eustatic sea level fluctuation, coastal erosion and progradation (in turn dictated by coastal currents), and tectonism. Deep, seaward-shallowing trenches through the inland Canterbury Plains could be a consequence of alpine uplift and coastal subsidence or of contrasting glacial river loads (high) and interglacial (low) river loads due to climatically controlled catchment vegetation as well as direct glacial fluctuations. Seaward-deepening trenches are a consequence of falling base-level due to coastal erosion or to coastal uplift. The greater length and depth of inland trenches (progressively shallowing downstream) compared with that of coastal trenches (progressively shallowing upstream) strongly suggest that the effects of river loading in response to climate and/or tectonism have been more significant than those in response to coastal erosion. It is difficult to separate the effects of each, but the following lines of evidence are pertinent.

1 Successively younger glacial aggradational surfaces have successively lower gradients in the Waimakariri sector of the plains (see Wilson — Quaternary geology of the northern part of the Canterbury Plains, 1:100 000. New Zealand Geological Survey miscellaneous series map 14 (1 sheet) and notes in prep.). Thus there is a 2.2 m/km difference in gradient between a Waimea glacial outwash surface (Woodlands Formation — Brown & Wilson — A review of the late Quaternary stratigraphy of the Canterbury Plains, New Zealand; in prep.) and an early last (Otira) glacial surface (Windwhistle Formation — Brown & Wilson, in prep.) near the inner margin of the plains at a distance of about 50 km from the crest of the Southern Alps. The age difference of the surfaces is about 100 000 years. In the central area of the plains, about 70 km from the alpine divide, the difference in gradients between an early last glacial (Windwhistle Formation) and a late last glacial surface (Burnham Formation — Suggate 1963) (age difference about 35 000 years) is about 1 m/km. The trend for progressive shallowing of gradient with time has continued through postglacial degradational surfaces (see Fig. 5). Gradient changes are not entirely systematic, but surface gradient reductions with time of about 0.1 m/km in about 500 years at a distance of about 80 km from the alpine divide seems a reasonable average.

2 Postglacial sea level rise in coastal Christchurch inundated a fringing estuarine peat (Suggate, 1958 and 1968; Wilson, 1976). A peat at 34 m depth at the coast gave a radiocarbon age (NZ5158A)* of 9850 +/- 140 years B.P. (Brown & Wilson, in prep.) and this indicates the order of sea level changes during the postglacial period. Without coastal subsidence, peat formed during interglacial transgression might be expected to occur down to depths commensurate with eustatically low sea level (to 120 m depth). In fact peats at the base of marine sequences in water wells occur at the limits of explored depths, at about 200 m, which indicates that considerable subsidence of the coastal region has taken place.

3 Orogenic-type folding and faulting is more common in New Zealand than simple epeirogenic tilting. If tectonism has played a part in dictating regimes, it is more likely to have done so by gentle uplift at anticlinal folds through which the river has maintained a superposed trench. This type of superpostion appears to be common in northern Canterbury rivers, from the Ashley River northwards (e.g., lower Waipara gorge, upper and lower Ashley gorges).

4 During interglacial times the mountain catchment of Canterbury rivers must have been more densely vegetated than in glacial times. Reduced vegetation cover, together with the increased crossing of the freeze-thaw temperature line during the glacial periods, must have increased mechanical

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

weathering in periods of prolonged cold conditions. This climatic effect alone probably ensured that glacial rivers emerging from the foothills were laden with rock debris to build out the unsorted sheet deposits. Climatic effect alone would also ensure that glacial retreats following temperature rises produced reduced river loads at the inner margin of the plains. Load reduction would immediatley instigate trench-cutting in the inner plains and this, once started, would concentrate the drainage system into a single channel entrenched through unconsolidated material, and facilitate degradation.

It is concluded that the principal factor influencing Canterbury river regimes is sediment loading, as determined by climate. In a tectonically active country like New Zealand, folding and uplift may also have played a significant part. Eustatic changes during the climatic alternations of the Pleistocene did not appreciably change river gradients or river regime as they affected river length as well as sea-level. Relatively recent coastal erosion (which would be interrupted by any episode of coastal subsidence) has played a minor partin river activity by causing the development of trenches extending inland from the coast.

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