50th Kaikoura05

The Organising Committee extends a warm welcome to all delegates and visitors to Kaikoura, where it all began 50 years ago.

Please note that all information in this publication was correct at the time of going to print. However, due to factors beyond our immediate control, such as weather, road conditions and permission for land access, some unexpected late changes in field trip routes and itineraries may be required.

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50th Annual Conference

28 November to 1 December 2005
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Kaikoura

Field Trip Guides

J. R. Pettinga and A. M. Wandres (Editors)

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MT FYFFE AND KAIKOURA PLAINS: ACTIVE TECTONICS, FAN MORPHOLOGY AND HAZARDS

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INTRODUCTION

The Kaikoura area has many fascinations for those interested in the way Planet Earth, and human society occupying it, function and interact. Here, in a small district, are tectonics, seismicity, fluvial processes, hillslope processes, base-level change and coastal erosion and accretion; in which active environment are human settlements, primary and other industries, transport corridors and recreation.

The aim of this brief field trip is to give a broad introduction to the interaction of the mountains, rivers and alluvial fans, using the tectonic/geomorphic evidence these interactions have produced; to pose some questions that require answers; and to consider briefly the implications for sustainable human use of the area.

ITINERARY

Depart Kaikoura	08.20
Arrive Mt Furneaux site (Stop 1)	09.00
Depart Mt Furneaux site	09.30
Arrive Waimangarara fan (Stop 2)	10.00
Depart Waimangarara fan	11.00
Arrive Hapuku fanhead (Stop 3)	11.30
Depart Hapuka fan toe (Stop 4)	12.15
Arrive Kaikoura	12.20

Figure 1: Kaikoura locality map showing stops. Broken line is approximate Hope Fault location.

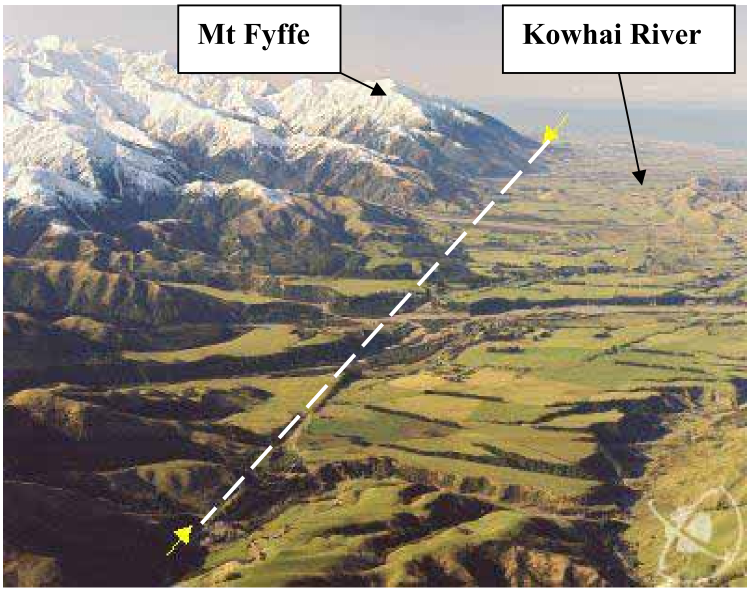

Figure 2: Hope Fault: Mt Fyffe top centre *http://data.gns.cri.nz/af/faultImage.jsp?id=113*

GEOMORPHIC BACKGROUND

The Seaward Kaikoura Range is highly active, both tectonically and geomorphically. Oblique convergence between the Pacific and Australian crustal plates results in a high angle reverse slip component of faulting that increases to the northeast where the Seaward Kaikoura Range rises to 2600 m. Right steps in the Hope fault mark changes in topography and style of faulting (Van Dissen and Yeats, 1991). Uplift rates are estimated to be about 4 to 6 m/ky. The southwestern end of the Hikurangi trench lies just offshore, and ocean depths exceed 1500 m within 10 km of Kaikoura Peninsula.

Mean annual precipitation is about 2 m. Daily rainfall amounts can be as much as 0.5 to 2.0 m. These rugged mountains are underlain by highly fractured greywacke sandstone with some argillite and tuffaceous sandstone. Erosional increase of relief causes these slopes to crumble instead of forming high, massive cliffs such as one might expect to form in massive plutonic rocks. Hillslopes in the Kowhai drainage basin yield sediment in excess of 5,000 tonnes/km^2/yr (O'Loughlin & Pearce, 1982, Mackay, 1984), which is equal to a denudation rate of approximately 1.8 m/ky. This is >100 times greater than undisturbed forested basins of tectonically inactive watersheds (Costa, 1994), but only 17 percent of the sediment yield measured in wetter parts of the Southern Alps (Griffiths and McSaveney, 1983) that receive five times the mean annual precipitation of the Seaward Kaikoura Range.

<u>*Extract from Eusden, Pettinga, and Campbell (2005)*</u>
"The Hope Fault defines a fundamental strain partitioning boundary in the northern part of the South Island, separating predominantly oblique strike-slip from predominantly thrust-dominated structures (Pettinga et al. 1998, 2001; Pettinga 2002). The Hope Fault has the highest slip rates of the faults that comprise the Marlborough Fault System and is the second fastest slipping onland fault in New Zealand, the fastest being the Alpine Fault (Knuepfer 1984, 1992; Van Dissen 1989; Bull 1991; McMorran 1991; Van Dissen & Yeats 1991; Berryman et al. 1992; Pettinga et al. 1998; Norris & Cooper 2001; Langridge et al. 2003). It extends c. 220 km to the northeast from its diffuse junction with the Alpine Fault east of Hokitika, towards the coast north of Kaikoura... The Hope Fault has been divided into three principal segments based upon changes in structural style, slip rate, and

geomorphic expression. From southwest to northeast the segments are: (1) the Taramakau-Hope River segment; (2) the Conway segment; and (3) the Mt Fyffe segment (adapted from Cowan 1989; Cowan & McGlone 1991). The fault has also been identified offshore in the Kaikoura region by Barnes & Audru (1999). Slip rates along the Hope Fault increase from 10 to14 mm/yr in the Taramakau-Hope River segment to 11–35 mm/yr in the Conway segment, and then decrease to 5 mm/yr in the Mt Fyffe segment, where motion is transferred to the Jordan Thrust (Van Dissen 1989).”

Mt Furneaux (stop 1)

Late Quaternary right-lateral displacements by the Hope fault play a key role in local tectonics and topography. The watershed of the Kowhai River has not remained in the same place, relative to its piedmont reach, because each surface rupture on the Hope fault shifted the watershed farther northeast. Several workers have estimated rates of lateral shift to be between 25 and 33 m/1,000 years. The Hope fault is truly one of the world’s most active fault zones. In just 200,000 years floods from the Kowhai watershed were discharged directly down the Kahutara River at location A on Fig. 3, then Humbug Stream, Bellbird Stream, and now the present course at B. A prominent stream terrace at C was created by the Kowhai River, but now is being removed by encroaching Cribb Creek whose large watershed is also moving northeast.

The Kowhai River has flowed down its present course for only a short time. Stream-channel entrenchment kept the river in a circuitous route to the sea down the present anomalously broad valley of Bellbird Creek to join the Kahutara River. Then a recent aggradation event (presumably the result of earthquake-induced landslides in the watershed) backfilled the gorge and the Kowhai River was free to take a much more direct route to the sea. An exceptionally active stream quickly laid down a blanket of Our drive to Dairy Farm Road is past the present fanhead of the Kowhai River and then down the broad and undissected surface of the recent aggradation event. Rapid backfilling dammed tributary valleys. The trip stop is at a small example, and more impressive dams ponded Lake Rotorua and Lake Rotoiti further south in the ‘Lake Hills’.

The intensity of soil-profile development on the aggradation event surface, although a rough approximation is one way to estimate how long the Kowhai River has been in its present course. Phil Tonkin and Peter Almond have dug and augered soils at the Dairy Farm Road stop and at the Lake Rotorua dam. These incipient soil profiles appear to be only 2,000 to 4,000 years old. This brief time span has been far too short for tectonic and climatic perturbations to create a flight of stream terraces such as we will see along the Hapuku River.

The new route of the Kowhai River continues to threaten the ‘West End’ business district of Kaikoura, which was built in a floodplain. In just 140 years, floods have surged through town 15 times, despite expensive engineering works. Why can’t this river be tamed?

The present steep course of the Kowhai River is unstable because insufficient time has passed to establish the more systematic behavior we associate with flow in single thread channels. Geomorphologists make logarithmic plots of ‘bankfull’ discharge and channel slope to identify domains of meandering and braided streams. Leopold and Wolman (1957) pointed out that some streams (such as the Wairau River upstream from Blenheim) are close to the threshold between stream-channel-pattern domains. This means that humans can install structures to encourage the stream to flow in a slightly sinuous single channel instead of the

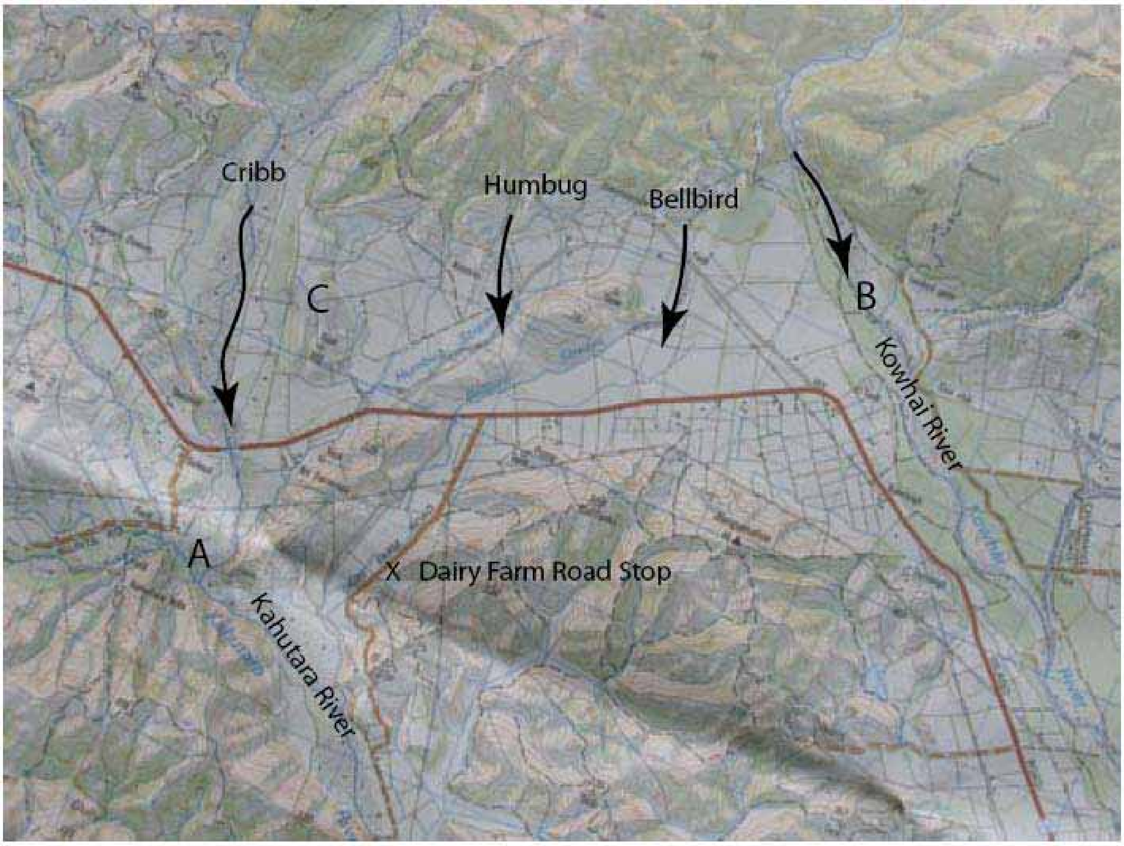

Figure 3: Kowhai River fanheadalluvial-fan and fan-delta deposits 6 km wide on both sides of Kaikoura Peninsula, from the 'Lakes Hills' to Middle Creek.

less stable anastomosing braided channel pattern. The Kowhai River, however, appears to be distant from potential equilibrium as a single-thread river. So it is no surprise that all engineering attempts to modify the behavior of the Kowhai River failed because flood discharges are much too large for such a steep gradient imposed on the stream by recent Hope fault tectonic activity. Excess stream power (largely a matter of slope and magnitude of streamflow) associated with exceptionally large discharges of the Kowhai River have defeated flood-control measures in the past and can be expected to do so in the future. The problem is compounded by the exceptionally large sediment yield of the drainage basin. Times of insufficient bedload transport rate produce episodes when the streambed is raised quickly by deposition of cobbles and boulders. Stop banks are quickly overtopped. This problem will be even worse after the next Hope fault earthquake greatly increases landsliding and the sediment yield in the Kowhai River drainage basin.

Tectonics and Topography of a Thrust-Faulted Mountain Front, Hope Fault at the Waimangarara River, New Zealand[1] (stop 2)

Tilted stream terraces are sure to catch the attention of the tectonic geologists, especially when alluvium deposited with a 3° downvalley dip now tilts 2° to 5° upvalley (Fig. 4). The

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[1] This section is from Chapter 1 of Bull, in press.

Waimangarara River stream terraces were ruptured by a splay of the Hope fault that bounds the Seaward Kaikoura Range of New Zealand. The two oldest, late-Holocene, stream terraces, T1 and T2, have the same backtilt, so the tectonic deformation is younger than the T2 terrace-tread age. Terrace T1 is 5 m above T2. Terrace tread ages was estimated with weathering rind analyses, a surface-exposure dating method (Whitehouse and McSaveney, 1983; Whitehouse, et. al., 1986; Knuepfer, 1988). Analysis of boulders on the T2 tread (Fig. 5) implies a late Holocene age. This greywacke sandstone does not have nice, sharp weathering rinds, and rind thickness ranges from 1 to 4 mm.

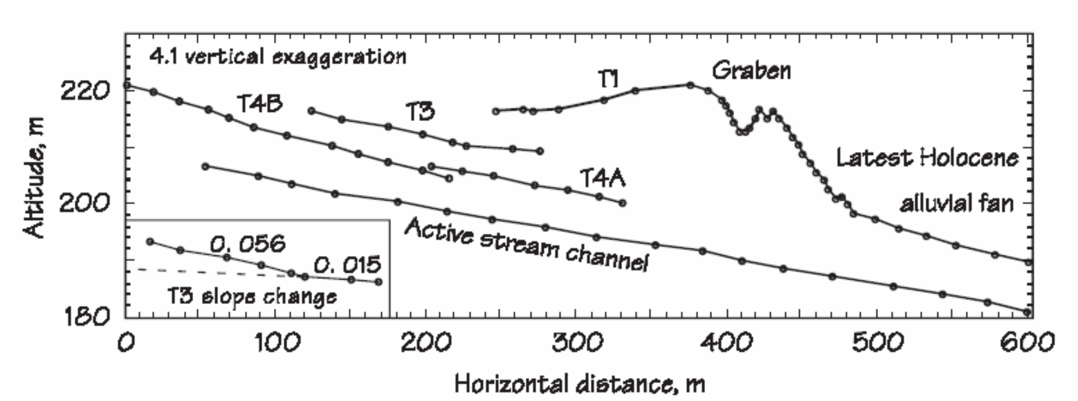


Figure 4: Stream terraces of the Waimangarara River that have been deformed by recent surface ruptures of the range-bounding Hope thrust fault, Seaward Kaikoura Range, New Zealand. A young stream terrace is strongly backtilted, and is much higher than one might expect from late Quaternary uplift rates.

We used the McSaveney (1992) procedure. A peak at ~2.5 mm dates as 2,200 ±300 years before present. Even a 4 mm peak would date to only ~4,700 yr BP.

Terrace T3 is not back tilted but has a fourfold decrease in slope as it approaches the deformed older stream terraces (Fig. 4). So it appears that the range-bounding fault ruptured between T2 and T3 time, and again since T3 time. Scarp height is an impressive 18 m. Vertical offset of 7 m is a minimum value because T1 and T2 have been buried by an alluvial fan downstream from the fault scarp. The prominent graben at the folded scarp crest (Fig. 6) can be used to postulate locations of antithetic and synthetic faults above the master thrust fault, which is presumed to dip less than 50° (Van Dissen, 1989). We suspect that neither the large scarp height nor upvalley stream-terrace tilt is indicative of slip rates on this segment of the Hope fault. The T1 fault scarp on the other side of the river is only about 4 m high, which is a more reasonable offset for two surface-rupture events. Adjacent segments of this mountain front lack high fault scarps that date to the most recent event. Dip and style of faulting may change within short distances, and subsurface exploration techniques are needed here to fully appraise two possible scenarios. The geologic map (Fig. 6) portrays a zone of deformation that tapers towards the southwest and seems to be diffuse on the north side, and abruptly terminated by the rangebounding thrust fault on the south side. A model of imbricate thrust faulting (Fig. 7) can account for the width of the deformation zone, and synthetic and antithetic faults could produce grabens. If one uses the critically tapered wedge model of Davis et. al., (1983), the scrunching shown in Figure 8 reflects a fault-kinematic equilibrium. Wedge shape would influence dip of the basal detachment surface, synthetic and antithetic fault movements, and thickness of scrunched rock and alluvium.

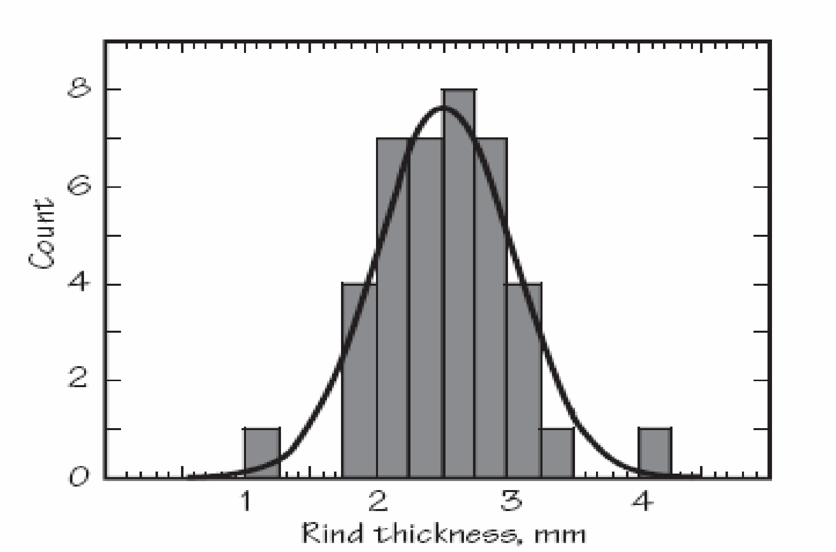


Figure 5: T2 stream terrace tread weathering rinds in fractured greywacke sandstone predate the older of two recent surface-rupture events. Normal distribution curve has been added. 0.25 mm class interval. n= 40.

So, much of the rock uplift here may be the result of tectonically induced scrunching processes of folding and bulldozing. Brittle fractured greywacke sandstone under low confining pressures may behave like loose boulders. More coherent bedrock slabs may fail by rupture along secondary faults. The systematic deformation shown in Figures 6 and 8 could result from folding instead of haphazard bulldozing processes.

Scarp-crest grabens would result from tensional stresses at the crest of an anticline in a folding-dominant model. The Waimangarara River has frequent large flow events that deposit bouldery alluvium on the adjacent piedmont. Erosional widening of the bedrock valley floor in the mountain-front reach may have thinned the slab above the range-bounding thrust fault prior to the recent surface rupture events. Reduction of rock mass strength below a critical-tapered-wedge threshold would have favored tectonic scrunching processes in the broad valley floor upstream from the fault trace, but not along the adjacent parts of this mountain front.

Rock uplift, r_u, at location 1 in Figure 8 is mainly a function of magnitude of slip along the fault plane, D, and dip of the thrust fault,

$$r_u = \sin\alpha D \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Rock uplift at location 2 in Figure 8 could be largely bulldozed materials above the plane of the thrust fault where scrunch rock uplift, sr_u, has occurred at several fault splays.

$$r_u = \sin\alpha D + sru\ \Sigma(1, 2, 3, 4)\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

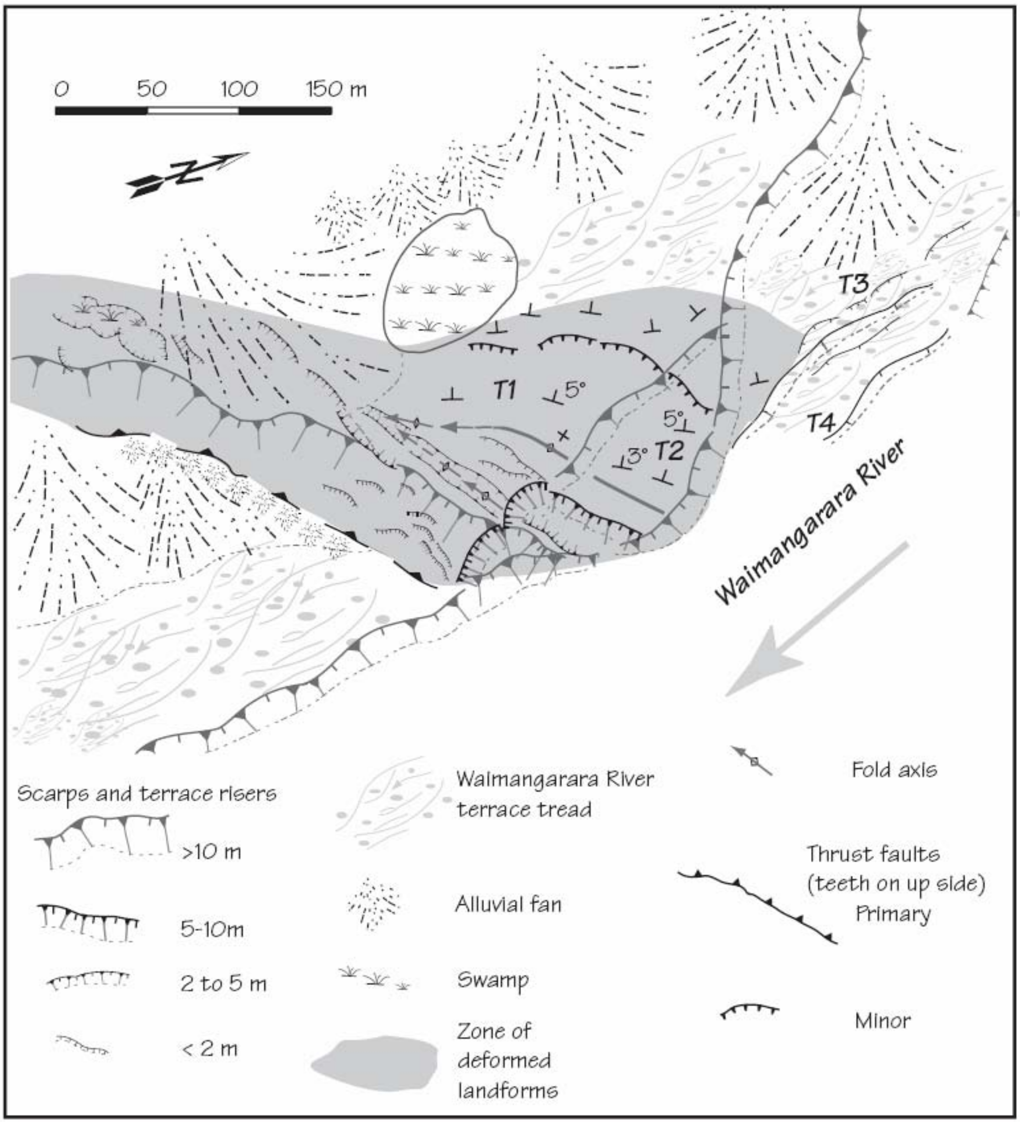


Figure 6: Geologic structures, landforms, and tectonically deformed stream terraces of the Waimangarara River. Mapped by Jarg Pettinga, University of Canterbury.

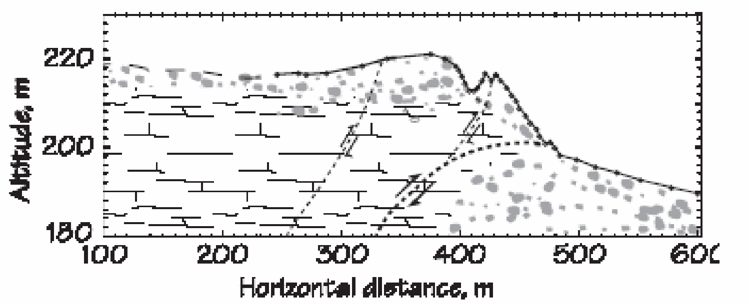


Figure 7: Model in which fault steepening towards the surface rotates the stream terraces, creating the backtilting of T1 and T2. Grabens at scarp crest record antithetic and synthetic faulting.

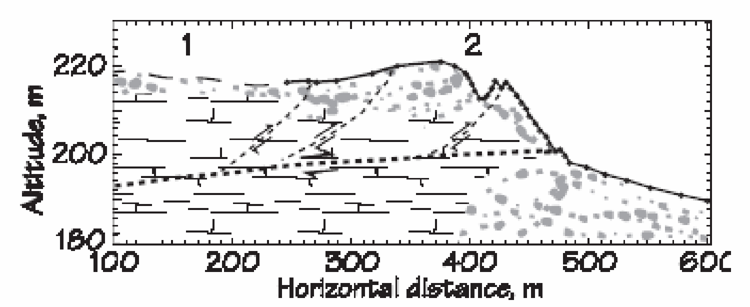


Figure 8: Critical wedge model in which movement along gently dipping thrust fault has bulldozed and/or folded the fractured greywacke sandstone.

The longitudinal profile of the Waimangarara River reflects several possible tectonic inputs. The stream changes its vertical position in the landscape in response to bedrock uplift. However, fluvial adjustments to rock uplift in the longitudinal profile do not distinguish between regional isostatic uplift, slip on thrust faults, folding, and local scrunching of fractured greywacke sandstone. We conclude that the Waimangarara River stream terraces are not ideal time lines passing through a tectonically deforming landscape. The deformed stream terrace treads are good reference surfaces for describing the complicated total bedrock uplift, but should not be used for estimating fault slip rates. Thrust-fault displacement has a vertical component, but secondary folding and crushing is largely a function of horizontal displacement. Both contribute to rock uplift. This local increase in crustal loading due to scrunching is too small to overcome lithospheric rigidity, so should have minimal isostatic effects on rock uplift.

Kowhai and Hapuku Rivers: contrasting fan morphologies (stops 3 and 4).

The two major rivers of the Kaikoura outwash-fan system are the Kowhai, draining the southern Seaward Kaikoura range, and the Hapuku, draining the central-northern part of the same range. As Fig. 9 shows, both catchments are similar in size and topography. They are also presumably similar in precipitation and lithology, being closely adjacent. It is therefore remarkable that their fanhead morphologies contrast dramatically.

While the Kowhai fanhead is completely devoid of well-defined terraces, the fanhead of the Hapuku has at least three terraces, extending all the way to the sea, with maximum heights of 5-10 m (Fig. 10). Given the similar settings noted above, and presumably similar postglacial tectonic, seismic and base-level histories, this contrast is notable.

Some possible causes are:

1. Large-scale mass movements. The Hapuku terraces reflect the occurrence in that catchment of one, or a series, of large landslide events. The 10^7 m^3 Mt Adams landslide of 1999 in the Poerua catchment, south Westland (Hancox *et al*, 2005), has aggraded its fan head, indicating that similar (but probably larger) event(s) may have caused the Hapuku terraces. The inference would be that no such landslides have occurred in the Kowhai catchment.

2. Glacial base-levels. The bathymetry offshore of the Kowhai and Kahutara Rivers is in close proximity (~3 km) to the Kaikoura canyon, a deep trench close inshore (Lewis &

Barnes, 1999); while the Hapuku offshore bathymetry meets the shelf edge (200 m depth) at least 10 km offshore (Fig. 11). During low postglacial sea levels, the Kowhai may have cut a deep valley through the shelf to a base-level at the canyon edge, with correspondingly lower bed levels at the rangefront, and be still aggrading its bed. Thus any old (> 1-2 ka) terraces may have been buried by subsequent aggradation. The Hapuku, on the other hand, may have built its terraces during low sea levels when its course was very much longer than at present.

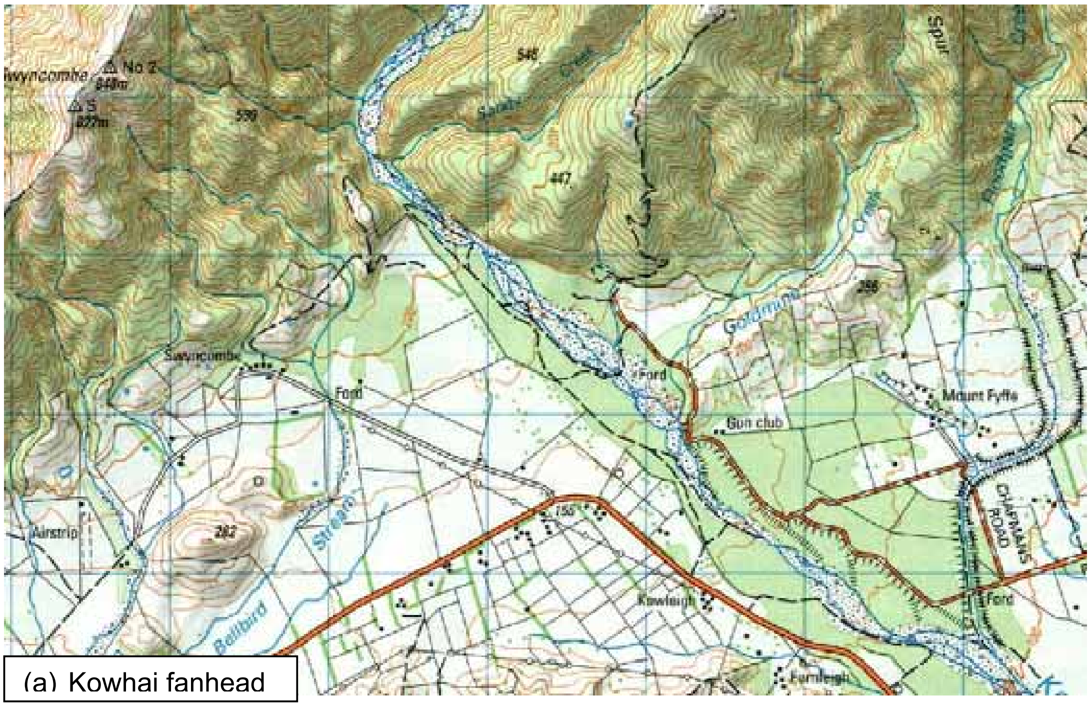
3. Aggradation of ~ Stone Jug & Flax Hills age (14-40 ka); the corresponding Kowhai terraces could then have been buried by later aggradation, though this is difficult to reconcile with the corresponding stream gradients (Fig. 12).

Figure 9: Kowhai (left) and Hapuku (right) catchments and fans outlined.

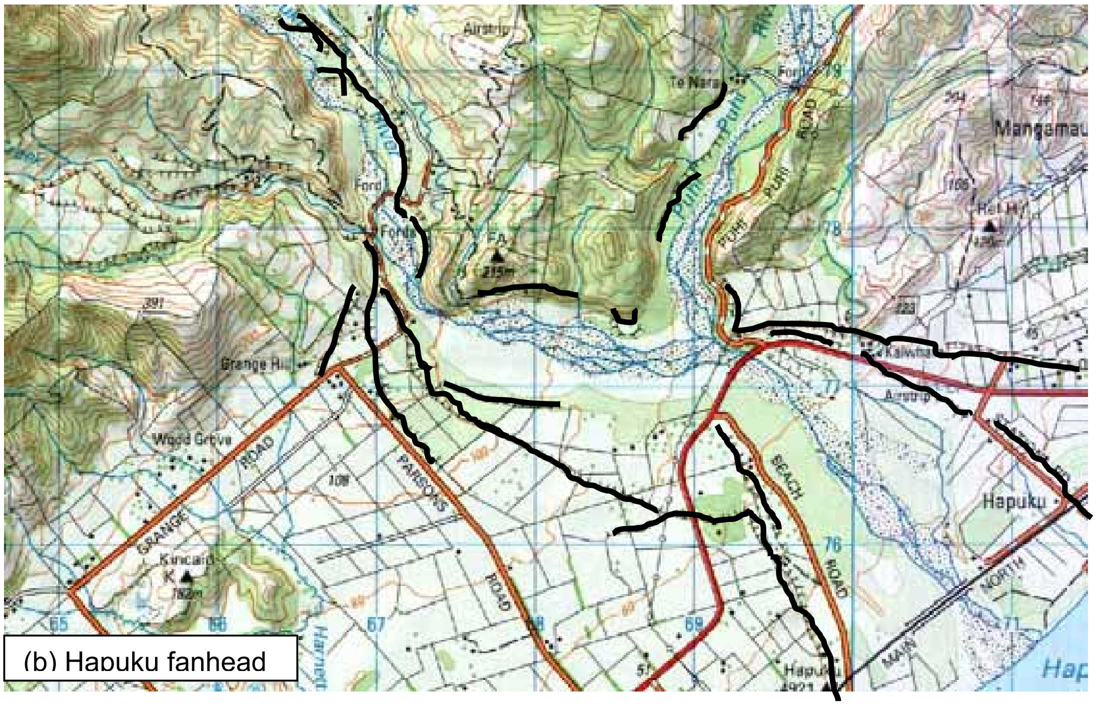
The longitudinal profiles of the two rivers also present a curious contrast (Fig. 12). The Kowhai and its fan have a gradient of about 2% onshore, while the offshore gradient is significantly steeper at 3%. The onshore gradient of the Hapuku is 2.5%, while offshore its fan slopes at 0.8%

Information on the ages of the Hapuku terraces may be of value in this investigation. It is interesting, however, that the terraces extrapolate to present-day sea-level only a few hundred metres offshore from the present coast, perhaps indicating that they were emplaced when the sea was at its present level and the coast a few hundred metres farther seaward.

These contrasts no doubt result from the recent geomorphic history of the range and its range-front fan systems. Unravelling that history is a fascinating investigation in itself, and in addition has implications for the future geomorphic development of the system, which in turn has potential implications for the sustainability of facilities sited on it.



(a) Kowhai fanhead



(b) Hapuku fanhead

Figure 10: Kowhai (a) and Hapuku (b) fanheads. Note the complete absence of natural terraces in the former, and the well-defined terraces (black lines) of the latter.

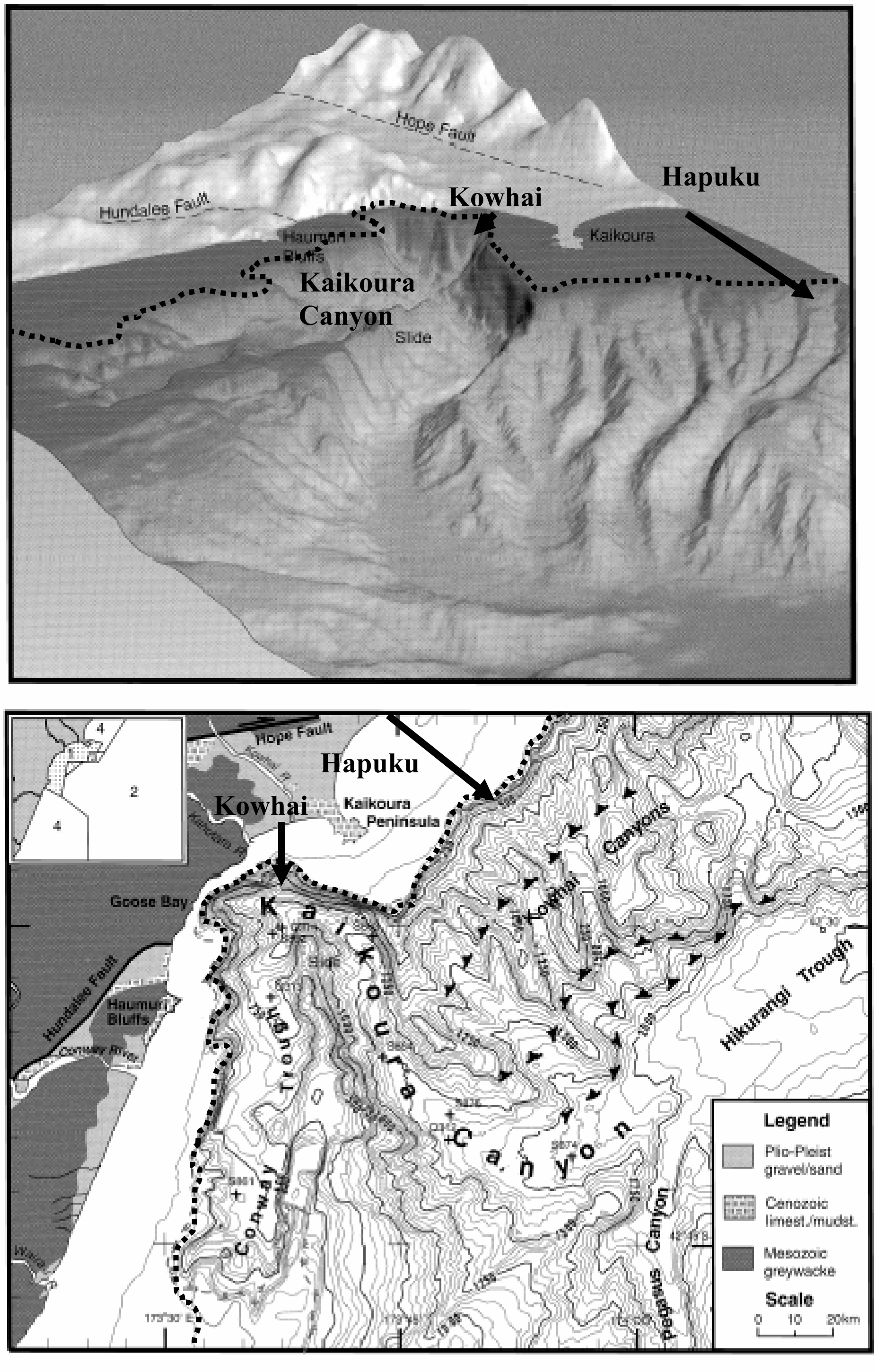


Figure 11: Low-sea-level courses of the Kowhai and Hapuku (after Lewis & Barnes, 1999) Approximate position of -130 m contour shown dotted.

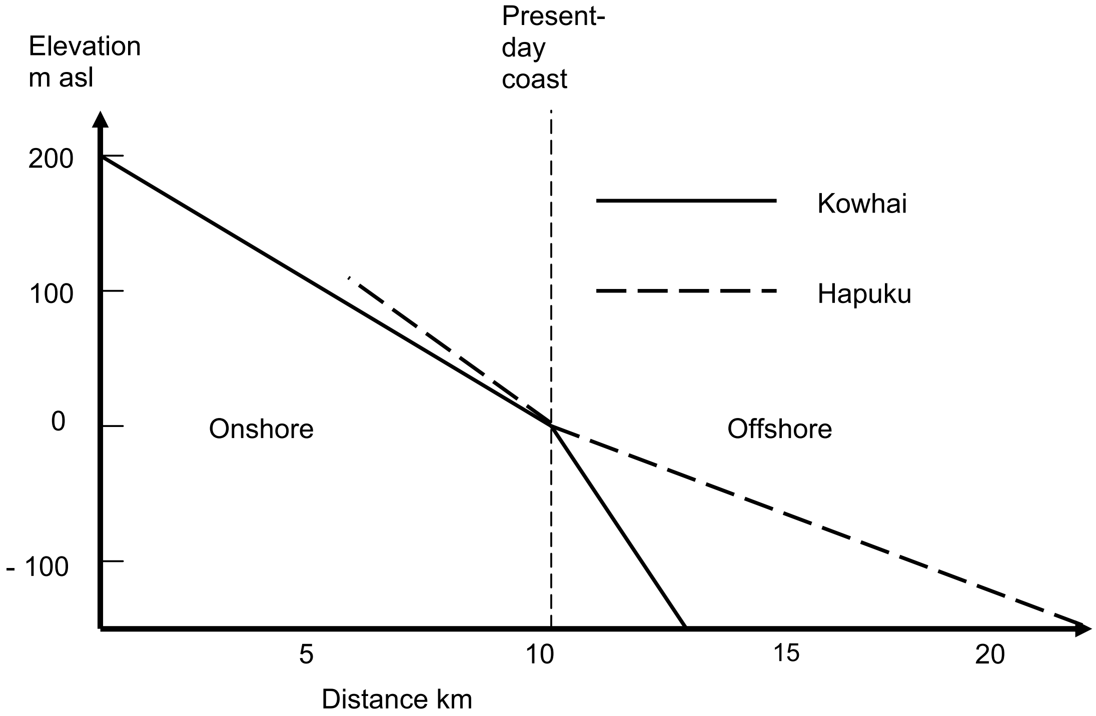


Figure 12: Approximate longitudinal profiles of the Kowhai and Hapuku rivers from their gorges to the glacial coastline at ~ -130 m asl.

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