*J. K. CAMPBELL

THE SURFACE EXPRESSION OF SLOW EARTHQUAKES?

CONTENTS

ABSTRACT

Two sites are described on transpressive faults in the eastern foothills of New Zealand's Southern Alps, where a precursor period of about 200 years of accelerated downcutting and warping preceded the most recent fault ruptures. Both offsets were predominantly strike-slip and include a throw of about 1 metre, but base-level drop is an order of magnitude larger and extends over kilometre scale reaches. Cycles of downcutting may have been initiated by earlier events, but deformation is concentrated in the younger terraces. At the Red Lakes site stream degradation began over 700 years ago, the top three terraces converging conventionally downstream across the Porters Pass Fault. Backtilting during incision to the fourth and fifth terraces lead to divergence on the hanging wall only and all the terraces were displaced by the subsequent rupture 500 to 600 years ago. In the Waipara River downcutting curves distinguish over 20 m of localised accelerated downcutting, from about 600 years until 250 to 300 years ago, culminating in rupture of the Bobys Creek Fault. Conventional slow earthquakes are recorded geodetically over periods of only days to months and probably differ in underlying processes from these cases. Possibly subduction generated strain is partitioned upward through the fault network by crustal thickening, fold growth and fluid migration over a long period, before stress builds to elastic limits at seismogenic depths.

KEY WORDS: Earthquake precursor, active tectonics, fluvial geomorphology, New Zealand

1. INTRODUCTION

Aseismic ground deformation has been widely documented using a variety of surface measurement methods, but generally records are of short duration relative to geological time frames. It is therefore difficult to distinguish patterns in long term changes in rate over the usual interseismic intervals associated with faults and fault related folding. Rivers crossing these structures are sensitive to ground deformation and if methods of dating fluvial landforms with adequate resolution can be found, then base-level and bedform changes provide a record of intervals between ruptures across the catchment.

Two sites are described from the eastern foothills of the Southern Alps in New Zealand on separate faults, but both part of the same general range front system (Fig.1). This system is thought to be linked to deep-seated northwest dipping backthrusts off the Alpine Fault and therefore are likely to be interconnected, sharing common processes at deeper levels. Both faults, The Porters Pass and Bobys Creek Faults are predominantly strike-slip, right-lateral, transpressive structures with paleoseismic records characterised by irregular return periods of the order of 1,000 years and capable of attaining single event displacements of at least 5 m. Both sites are more fully discussed in CAMPBELL et al (2003).

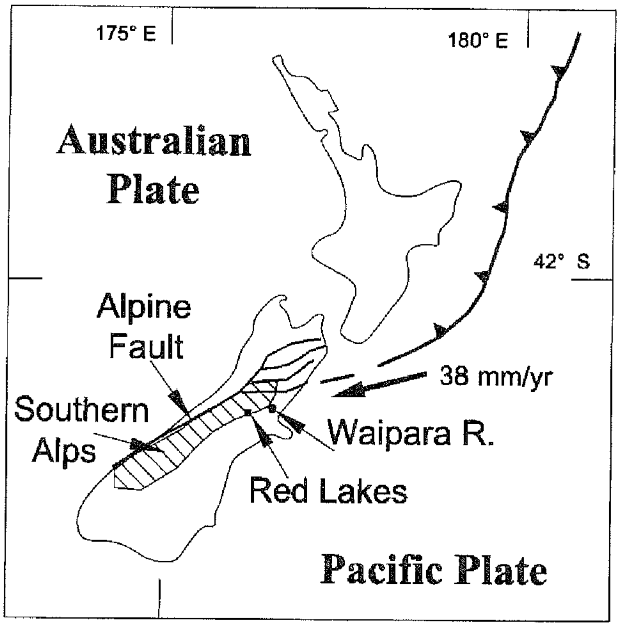

Fig. 1 - New Zealand locality map showing location of sites described.

2. SITE DESCRIPTIONS

2.1 *Red Lakes - Porters Pass Fault*

The Porters Pass Fault extends east-northeast from the Rakaia River to cut obliquely out onto the range front at the western margin of the Canterbury Plains at Porters Pass; the fault details and paleoseismic data are described in HOWARD (2001); NICOL *et alii* (2001) and HOWARD *et alii*, (in press). 10 km southwest of Porters Pass, a stream drains the Red Lakes half way between the larger lakes Coleridge and Lyndon. This stream crosses the fault, incised into a late glacial outwash surface, leaving five degradation terraces. A metre high fault scarp crosses all five terraces, changing from a sharp scarp on the youngest surface to a monoclinal warp as the fault propagated into the thick proglacial deposits. Surface offsets and trenching to the south-

* Department of Geological Sciences, University of Canterbury, New Zealand. E-mail: jocelyn.campbell@canterbury.ac.nz

west suggests that no more than one post-glacial displacement is involved. In contrast trenching at Porters Pass shows a well constrained record of multiple events and indications are that a segment boundary occurs at the intersection of several faults northeast of Red Lakes. A bracketed colluvial wedge (410 ±100 and 870±76 years BP) in that trench, plus a recent trench at the site of the Acheron Landslide 4km northeast of Red Lakes (SMITH, 2003) showing offset of soils containing 600 year old charcoal, has shown that these dates are compatible with surface rejuvenation of the landslide dated by weathering rind and lichenometry ages of 490 ±55 years BP (HOWARD, 2001) and 460 ±10 years BP (BULL, 1996) respectively. Therefore the data point to the last rupture event taking place between 500 to 600 years ago and constrains the age of the youngest displaced terrace.

A weathering rind date based on the method of MCSAVANEY (1992) of 690 ± 50 years BP (HOWARD, 2001) dates the first of the degradation terraces. The top three (T_I - T_{III}) grade downstream converging at a uniform rate towards the junction of this stream with a larger river draining to Lake Coleridge, reflecting a normal response to a general lowering of base-level and unaffected at that time by the fault (Fig. 2). T_{IV} diverges downstream relative to the top three surfaces as far as the fault and tends to breakup into several minor terraces close to the present scarp, which are unmatched across the fault. T_V is very close to present stream level, terminating abruptly at the fault scarp and is now back tilted upstream. If only one faulting event is involved in this sequence, then the terrace gradients appear to require the initiation of downcutting, followed by continued incision during the onset of backtilting and warping of the hanging wall prior to final rupture. The weathering rind dating may not reliably bracket these events into a period of approximately 200 years, but the general field relationships appear to require that a period of precursor deformation immediately preceded the faulting event.

2.2 *Waipara River - Bobys Creek Fault*

The second site involves tributaries of the Waipara River immediately north of the Canterbury Plains, crossing two opposing northeast striking thrusts the Mt Grey and Karetu Faults and two east- west striking faults with a dextral transpressive slip vectors, the Bobys Creek and Birch Faults. These are interconnected and involved in the growth of two associated anticlines, the Doctors and Onepunga Anticlines. All four faults appear to have ruptured quasi-synchronously. The fault which can be most clearly tied to the river history during this most recent period of activity on these faults (NICOL & CAMPBELL, 2001) is the east-west striking Bobys Creek Fault which is crossed by the river system leaving a series of terraces displaced by the fault, other than the youngest. A broad aggradation surface once representing a period of mid-Holocene base-level stability has been incised by up to 50 m over the last 2 kyr. Weathering rind dating of degradation terraces, with some internally consistent radiocarbon dates, allows for downcutting curves to be generated for the various tributaries and the pattern of downcutting falls into two groups. In tributaries not involved with the structures, the downcutting has proceeded relatively uniformly, while those crossing the faults and folds show a steep acceleration of downcutting rate beginning about 800 years ago (Fig. 3a). Subtracting the regional downcutting from the latter curves (Fig. 3b) suggests that approximately 20 to 25 m of downcutting can be attributed to differential regional uplift, possibly associated with growth on the Doctors Anticline. Rupture of the Bobys Creek Fault occurred when the river was 8 m above present level, towards the end of the period of accelerated degradation, based on the elevation of the youngest terraces to be offset and widespread landslide deposits on these surfaces, but no lower. Interpolation into the downcutting curve (Fig 3b) and weathering rind peaks on exposed fault scarps, places this event most probably at the younger end of a period between 250 to 400 years ago.

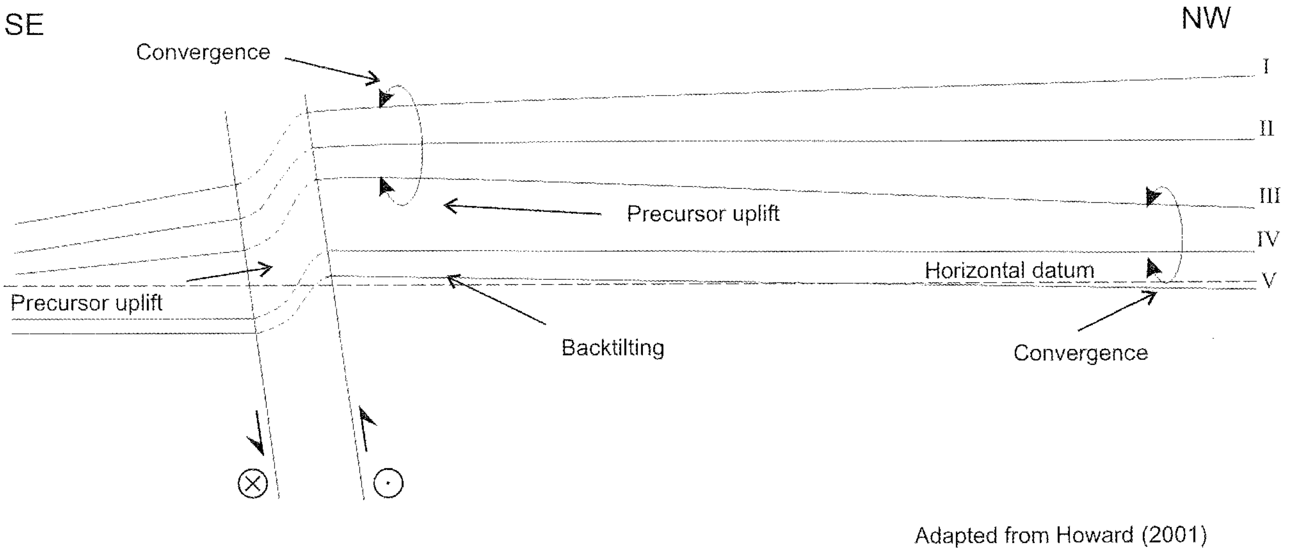

Fig. 2 - Terrace profiles over the scarp of the Porters Pass Fault at Red Lakes. Note uniform convergence of top three terraces downstream (right to left) across future fault break during initial degradation. T_{IV} diverges downstream as far as the fault indicating onset of folding over fault zone and also reversed gradient of lowest terrace T_V. All five terraces are displaced by a single post T_V event.

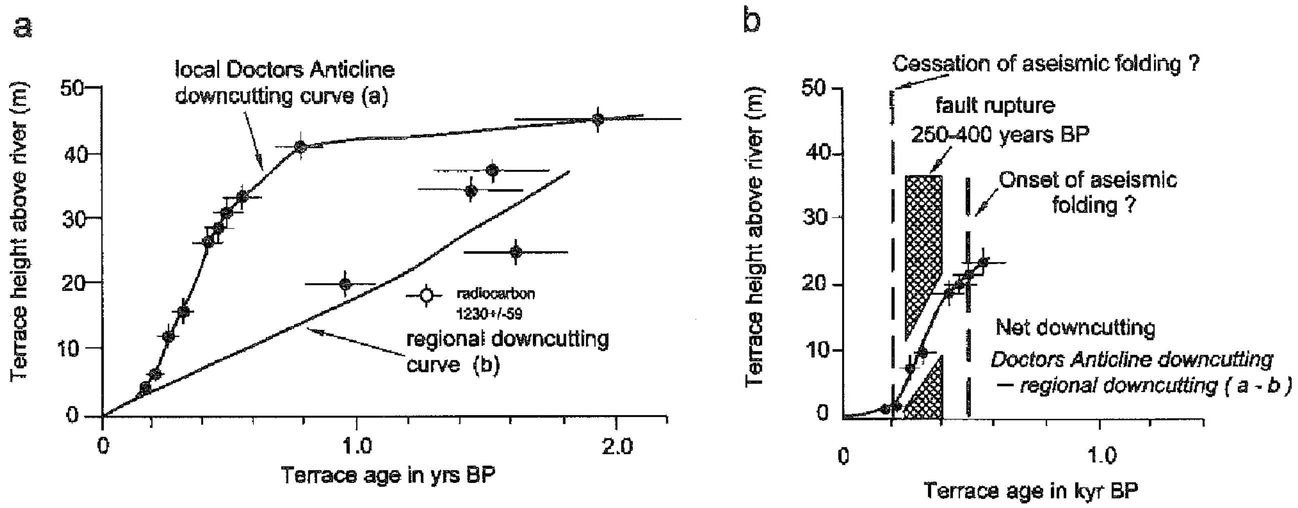

Fig. 3 - a. Downcutting rates in the Waipara River catchment derived from elevation and weathering rind dating of degradation terrace surfaces. Curve (a) relates to reaches affected by the Doctors Anticline and curve (b) to tributaries outside the affected area. b. Differential incision relating to activity on the Doctors Dome Anticline. The age range of faulting is derived from weathering rind data on exposed scarps in gravel from all four faults, but stratigraphic evidence suggests the youngest faulting is close to 250 years BP.

3. DISCUSSION AND CONCLUSIONS

Both cases suggest a common pattern of general uplift leading to a base-level drop preceding the surface rupture involving downcuttting significantly greater than the surface expression of differential uplift at the fault. Better methods of dating the fluvial terraces would greatly refine the case for accelerated and progressively more concentrated deformation close to the fault, but the estimated rates should be detectable in river records and readily measured if they were to recur at the present time. If these events are not unique to this fault system, and there is some evidence that they have occurred elsewhere in the New Zealand tectonic setting at least, then there may be potential to target faults approaching the end of the seismic cycle for close monitoring by appropriate instrumentation. The mechanism of this style of deformation is speculative, but it is likely to involve the upward transfer of strains generated at the deep plate boundary interface through shortening, high pressure fluid flow and off plane strain propagation through a network of faults damped by mid-crustal rheidity contrasts.

ACKNOWLEDGEMENTS

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