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.

Bibliographic References:

Programme & Abstracts Volume

A.N. Author (2005) What I did in my holidays. *In:* Pettinga, J.R. and Wandres, A.M. (eds.) Programme and Abstracts, Geological Society of New Zealand 50th Annual Conference, Kaikoura, New Zealand. Geological Society of New Zealand Misc. Publ. 119A, x-y p.

Field Trip Guide Volume

A.F.T. Leader (2005) A tour of my field area. *In:* Pettinga, J.R. and Wandres, A.M. (eds.) Field Trip Guides, Geological Society of New Zealand 50th Annual Conference, Kaikoura, New Zealand. Geological Society of New Zealand Misc. Publ. 119B, xx-yy p.

Geological Society of New Zealand

50th Annual Conference

28 November to 1 December 2005
Kaikoura Memorial Hall and Takahanga Marae
Kaikoura

Field Trip Guides

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

Organising Committee

Jarg Pettinga and Keith Lewis (Co - Conveners)
Anekant Wandres
Tim Davies
Kari Bassett
Jocelyn Campbell
Malcolm Laird
Margaret Bradshaw
Student Helpers

with administrative assistance from:

Janet Simes (Absolutely Organised Ltd)
Janet Warburton

Geological Society of New Zealand Miscellaneous Publication 119B
ISBN 0-908678-02-9

Field Trip Guides – Contents

Field Trips 3A/3B & 10

STRUCTURE, STRATIGRAPHY AND ACTIVE TECTONICS OF INLAND NORTH CANTERBURY

Jocelyn Campbell, John Bradshaw and Jarg Pettinga

Dept of Geological Sciences, University of Canterbury,
Private Bag 4800, Christchurch

Jocelyn.camplbell*canterbury.ac.nz

john.bradshaw*canterbury.ac.nz

jarg.pettinga*canterbury.ac.nz

INLAND ROUTE CHRISTCHURCH - KAIKOURA

CHRISTCHURCH TO KAIKOURA: STRUCTURE, STRATIGRAPHY AND ACTIVE TECTONICS OF INLAND NORTH CANTERBURY

Introduction

From Canterbury to Kaikoura a geological transect passes from the very margins of the modern plate boundary deformation zone to the Hope Fault, where the fastest slip-rates are now concentrated. It also crosses more ancient boundaries, including the transition into the Pahau terrane of the Torlesse Group basement, it follows the passage from the northern Canterbury Cretaceous - Tertiary basin and sub-basins into the boundary with the Marlborough basin at Kaikoura and it crosses the transition into the southern end of the Hikurangi subduction margin. Young deformation makes its mark everywhere, uplifting and exposing the older rocks in ranges and basins. Imprinted across this landscape are erosion surfaces and gravel sheets punctuating the evolving topography with the overprint of Quaternary climatic events, exaggerated here by the great volumes of water and sediment driven by the dynamic glacier systems emanating from the Southern Alps. This introduction briefly reviews the principal features of the stratigraphy, the present tectonic setting and draws attention to the importance of the Quaternary surfaces and soils that are essential to providing datum surfaces, the key to the rates of modern deformation.

Christchurch to Kaikoura transect – a stratigraphic framework. – J.D. Bradshaw

Basement

Torlesse rocks form the basement throughout the region and are divisible into the Rakaia sub-terrane, the Esk Head Melange and the Pahau subterrane. West of Christchurch, Permian-Triassic Rakaia sub-terrane rocks form the Torlesse Range and other high peaks visible from the Waimakariri Bridge. To the north the Esk Head Melange reaches the edge of the Plains in the area south of Mt Grey, a prominent landmark visible during the first hour or more of the journey. It is exposed in the head of the Ashley River and its right-bank tributaries and comprises Triassic and Early Jurassic pillow basalt, chert and carbonate blocks in a highly disrupted matrix of Pahau sediments. The Pahua sub-terrane forms the basement for the remainer of the area to the north. The Pahau rocks are in part derived from the Rakaia rocks and a genetic connection can be demonstrated (Wandres et al. 2004). The unit takes its name from the Pahau River which is crossed just south of Culverden.

Much of the Pahau material was deposited as turbidites in a submarine fan setting. Pro-delta and delta facies have, however, been identified in the Pahau River (Bassett & Orlovski 2004). These two interpretations are not necessarily incompatible: the subduction-accretion process may well have produced large outer-arc islands on which fluvial systems would have developed. The provenance of the Pahau rocks includes both older Torlesse rocks and material from a major source similar to the Late Jurassic to Early Cretaceous rocks of the Median Batholith or MTZ (Wandres et al. 2003). The Pahau rocks range from relatively well-stratified, (apparently) simple packets to highly deformed rocks and broken formation.

West of Culverden, deformed Pahau rocks are cut by mid-Cretaceous (98 Ma) syenite and gabbro intrusions. There are also related dikes that cut the Esk Head Melange and sub-aerial trachytes. Magmatism occurred during the post-subduction – pre break-up interval.

Cretaceous-Cenozoic cover

In the broadest sense the Late Cretaceous-Cenozoic rocks represent the deposits of a major transgressive regressive cycle, starting with Cretaceous marginal marine rocks, changing up section through marine clastics to carbonates in the Oligocene and then reverting to marine clastics and eventually non-marine gravels in the Miocene to Holocene. The transgressive change to carbonates occurs earlier and the deposits are thicker in the north (Kaikoura area) than to the south.

Within this broad picture there is enormous variation that has resulted in a large number of described formations and members, rapid changes in thickness, and local unconformities. In the south the thickness of the transgressive succession is small and subsidence rates were generally low: the succession varies from around 100 m to a little over 400 m. The Waipara section (Fig. 1) is typical and starts with Broken River Formation (coal measures) unconformable on Torlesse followed by marine Cretaceous muddy sandstones of the Conway Formation and a mudstone (Loburn Mudstone) that has the K/T boundary near its base. Widespread Early Paleocene glauconitic sandstone (Waipara Greensand) is followed by mudstone of Late Pleocene-Eocene age. The white fine-grained, locally chalky, Amuri Limestone of Late Eocene-Early Oligocene age represents the peak of the transgression.

Local tectonic control is seen and/or suggested by a number of features. In the Waipara valley Nicol (1993) has mapped Cretaceous rocks clearly controlled by syn-sedimentary faulting (Fig. 2 attached) and sections presented by Field & Brown (1989) carry the same implications (Fig.1). Lewis (1992) studied all available sections in the Amuri Limestone below the upper bounding unconformity and concluded that the unconformity cut across a series of gentle folds. My own view is that the variations could be explained by gently tilted blocks separated by small normal faults, but this needs further investigation. Overall, it appears that regional extension continued for a long time after continental separation and had a controlling influence on sedimentation in much of southern New Zealand. The younger Eocene and Oligocene phases are probably related to the new plate pattern that started with the opening of the SE Tasman Sea. This is marked by the formation of new ocean crust and the northward propagation of a diffuse extensional plate boundary zone through southern New Zealand.

South of a line from the Hurunui Mouth to near Waiau there was a topographic basement high where the Cretaceous to Oligocene succession is largely absent and north of this line is very thin and incomplete. North of Waiau, the Stanton Conglomerate and the paralic Lagoon Stream Formation suggest a local fault controlled basin subsequently buried by Conway Formation and a thin development of Amuri Limestone. The inland succession in this area is particularly distinguished by the development of the Cookson Volcanics "Group". Coote (1987) estimated a thickness of over 540 m and Field & Brown (1989) imply (p.72) a thickness of over 1000 m. The volcanic rocks are predominantly basaltic and comprise pillowed and massive flow rocks, volcanic breccia, volcanic conglomerate, volcanic sandstone and tuffs. Fragmental rocks predominate and Surtseyan, Strombolean and Hawaiian eruptive styles were identified by Coote. The preserved deposits are marine, generally bedded and include horizons of shelly limestone with thick shelled bivalves, other molluscs, and echinoid debris. An eroded surface suggestive of marine planation separates the volcanic rocks from overlying and overlapping Spy Glass Formation, Waima Siltstone or Mt Brown Formation.

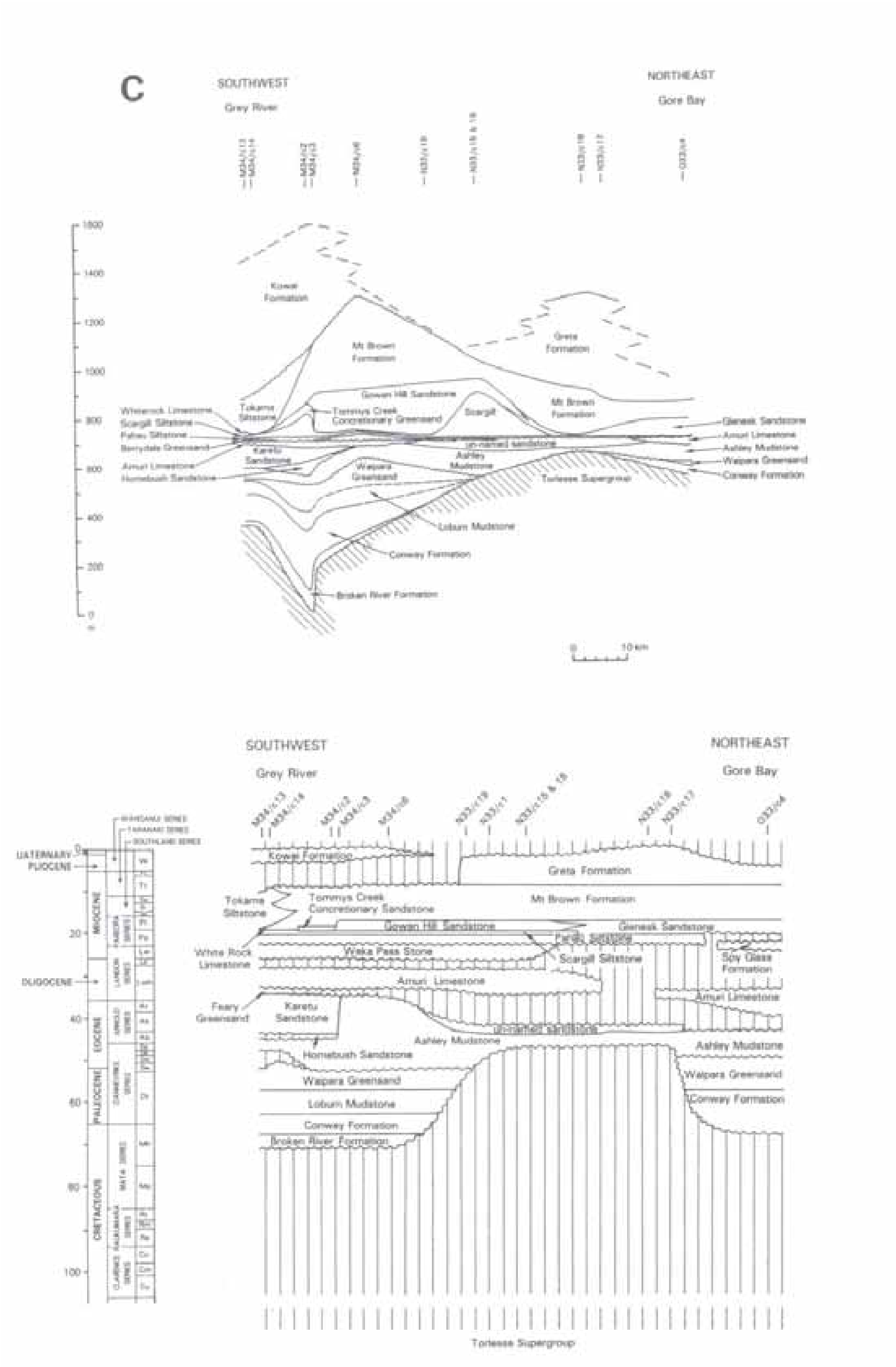


Figure 1: Facies and thickness relationships of the Cretaceous – Tertiary sequence from Canterbury to Kaikoura (from Field and Browne, 1989; King et al. 1999)

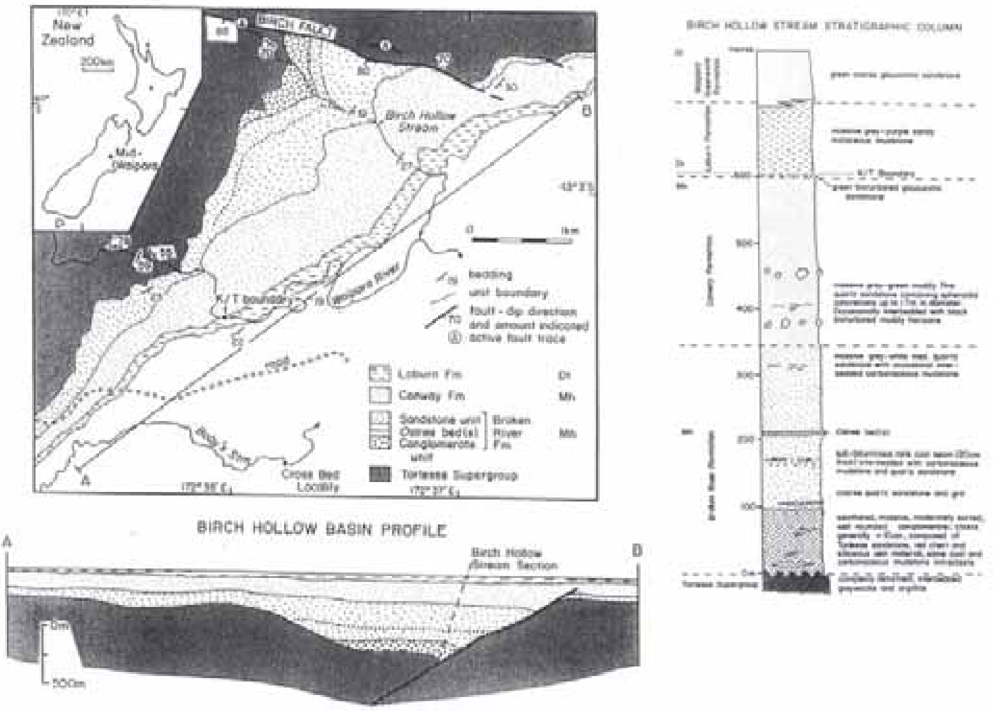


Figure 2: Half-graben associated with Cretaceous normal fault extension on the Birch Fault, now inverted by reversal of movement in the late Cenozoic. (from Nicol, 1993)

The age of the volcanism appears to be Late Oligocene (Duntroonian-early Waitakian) a time consistent with the appearance of basic volcanic material in most inland Oligocene sections. The thickness (500m +) and marine character imply an extremely high rate of subsidence during a period of 2 - 2.5 million years (between 200 and 400 m/million years depending on thicknesses and times used). During this period subsidence in the Canterbury basin was extremely low, and the Cookson Volcanics are thicker than the whole Late Cretaceous-Late Oligocene section in many parts of north Canterbury. The same time interval is absent to the northeast in the Amuri Bluff to Kaikoura area. The volcanic rocks are within-plate mantle-sourced material that seem to fill a local 'black hole'. The occurrence suggests closely linked tectonic (probably extensional) and magmatic processes.

This occurrence of Cookson Volcanics is limited to the west by the Hope Fault. Flows and minor intrusions of Cookson Volcanics occur in the Middle Clarence Valley to the east of the Clarence fault. Reay (1993) records a maximum thickness of more than 50 m. This is the only other thick occurrence of Cookson Volcanics in the area and if they are related to the same centre, would suggest around 50 km of dextral displacement on the Hope Fault.

North of a line through the Waiau River mouth to the saddle at Whale Back, pre-Haumurian Cretaceous rocks appear. In the coastal section the succession commences with the Piripauan Okarahia Sandstone and is followed by the classic succession seen north of Haumuri Bluff. Similar rocks occur as far west as the upper Leader River but not on the inland route. Further to the north the inland route passes to the west of outliers of older (Ngaterian) rocks resting unconformably on highly deformed Torlesse. The succession includes a minor development of Warder Formation (coal measures) at the base and a thick section in conglomeratic Bluff

Sandstone (up to 300 m). To the north, around Green Burn, the Bluff Sandstone is overlain unconformably by Conway Formation and Amuri Limestone and most of the Late Cretaceous is missing. The relationship of these rocks to those of the Kaikoura Peninsula is not clear. Pre-Mata rocks occur in the core of the "Racecourse Anticline" in South Bay but their affinities are open to interpretation. King et al. (1999) provide two different columns for the Kaikoura Peninsula (Fig. 3). These differences may be resolved during the coming week

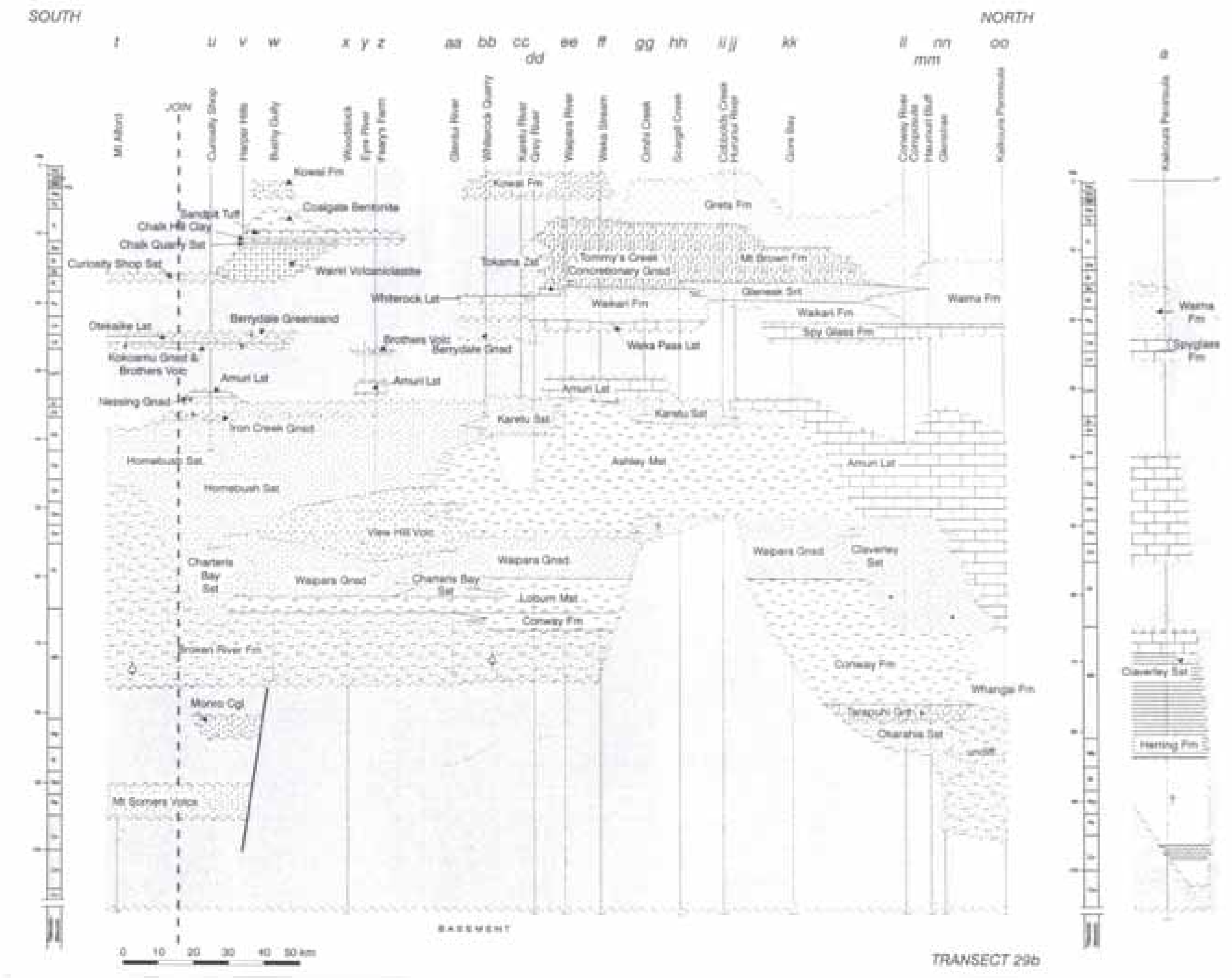


Figure 3: Local terminology and correlations between formations in the Canterbury to Kaikoura transect and comparison between columns for Kaikoura Peninsula provided in King et al. (1999)

References

Bassett, K.N., and R. Orlowski: 2004 The Pahau Terrane type locality: fan delta in an accretionary prism trench-slope basin, *New Zealand Journal of Geology and Geophysics*, *47*: 603-623.

Coote, A., 1987: Cenozoic volcanism in the Waiau area, north Canterbury. Unpublished M.Sc thesis, University of Canterbury thesis, 1987.

Field, B.D, Browne, G.H. 1989: Cretaceous and Cenozoic sedimentary basins and the geologic evolution of the Canterbury region, South Island, New Zealand, 94 pp., New Zealand Geological Survey, Wellington.

King, P.L., Naish, T.R., Browne, G. H., Field, D.B., Edbrooke, S. W. 1999: Cretaceous to Recent sedimentary patterns in New Zealand., 35p and 1 enclosure pp., Institute of Geological and Nuclear Sciences, Lower Hutt.

Lewis, D.W., 1992: Anatomy of an unconformity on mid-Oligocene Amuri Limestone, Canterbury, New Zealand. *New Zealand Journal of geology and Geophysics*, *35*: 463-475.

Nicol, A., 1993: Haumurian (c. 66-80 Ma) half-graben development and deformation, mid Waipara, North Canterbury, New Zealand. *New Zealand Journal of Geology and Geophysics*, *36*:127-130.

Reay, M.B., 1993: Geology of the Middle Clarence Valley. Map (1:50,000) and 144p. pp., Institute of Geological and Nuclear Science, Lower Hutt.

Wandres, A.M., J.D. Bradshaw, and T. Ireland, 2005: The Paleozoic-Mesozoic recycling of the Rakaia Terrane, South Island, New Zealand: sandstone clast and sandstone petrology, geochemistry, and geochronology. *New Zealand Journal of Geology and Geophysics*, *48*: 229-245.

Wandres, A.M., J.D. Bradshaw, S.D. Weaver, R. Maas, T.R. Ireland, and G.N. Eiby, 2004: Provenance analysis using conglomerate clast lithologies: a case study from the Pahau Terrane of New Zealand, *Sedimentary Geology*, *167*: 57-89.

Tectonic setting and major structural domains

J.K. Campbell and J.R. Pettinga

The southern margin of the north Canterbury basin lies on the northern side of the Chatham Rise which has always formed a basement high from the late Cretaceous onwards extending onland as the basement and thin cover exposed in the Malvern Hills. Intermittent episodes of east-west normal faulting have continued on the northern slopes of the offshore Chatham Rise from the Cretaceous to the present time down the transitional slope from continental to oceanic crust. As noted above, onshore, the Cretaceous extensional structures have now been reactivated and inverted as oblique dextral-thrust hybrids and overprinted by the dominant north to northeast grain of thrust driven anticline-syncline pairs. These form the main coastal and foothill ranges emerging across the major drainage systems coming from the Southern Alps. The thrust system reflects the convergent component generated by the whole obliquely transpressive plate boundary deformation and more particularly along the coast, by the influence of the transitional structures at the termination of the southern limit of the downgoing oceanic slab of the Hikurangi margin subduction. This extends south from the North Island until blocked by the more buoyant Chatham Rise.

The Canterbury Plains lies at the junction between the expanding margins of two elements of the plate boundary system migrating into this basin. The first element relates to the influence of the Alpine Fault. Widely held current views of the structure of the Southern Alps suggest that backthrusts off the east dipping plane of the Alpine Fault are thought to break up from a deep seated mid-crustal decollement to form the uplifted wedge of the Southern Alps. With time, the deformation zone has expanded by the footwall propagation of more such thrusts that uplift a large slab of upper crust with each step out. This upper plate becomes shortened internally by a further suite of higher level faults forming the system of basement cored ranges and intervening tectonic basins. This deformation boundary advances incrementally and in Canterbury, the range front backing the plains marks one such incremental step out from the Harper Fault, and recent work has shown that a new system has now extended beneath the plains, expressed as active folds driven by thrusts propagating to the surface.

The second element relates to the Marlborough Fault System (MFS) which is dominated by the major transpressional east-northeast strike-slip systems that provides the transfer mechanism between the east facing ocean-continent subduction system and the west facing intra-continental Alpine Fault plate boundary. Slip-rates and more general stratigraphic evidence suggests that this broad zone of shearing is also expanding and the zones of highest strain rate has migrated south with time, now focused on the Hope Fault, where slip-rates are comparable to those on the southern section of the Alpine Fault. By the late Quaternary,the southern edge of the MFS has now migrated to the northern margin of the Canterbury Plains in the form of disseminated shear as the Ashley Fault system and the Porters Pass-Amberley zone expressed as en-echelon folds and intricately linked thrust and strike-slip transfer faults.

The segmented range front system bounding the first major ranges west of the Plains typified by the Mt Hutt and the Torlesse Ranges swings more northerly in strike at the prominent, curved thrust under Mt. Grey. It continues north to form the western

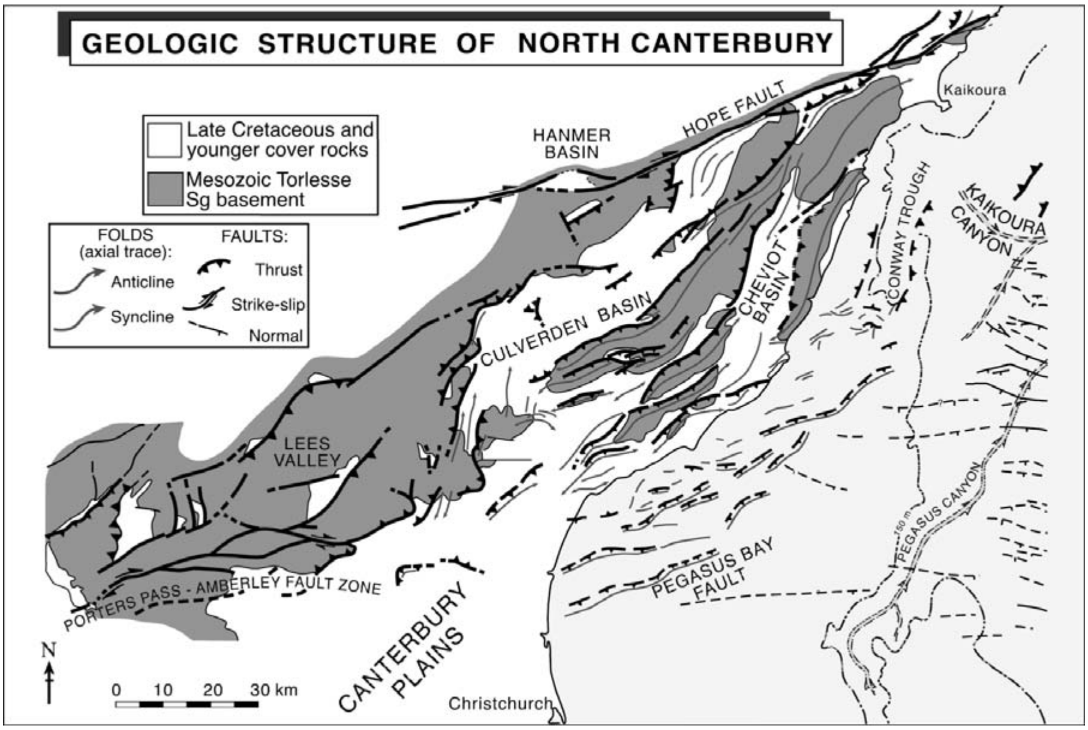


Figure 4: Major structural elements of North Canterbury

margin of the Culverden Basin as a series of thrust related anticlinal range fronts jutting obliquely into the basin. At the same time, the southern remnants of east coast convergence drives a system of west-facing thrusts, emerging from the sea, to form the coastal ranges and foothills. The two systems converge head-to-head just north of Mt Grey trapping the tight, upright McDonald syncline between the opposing thrust systems. Further north the Culverden Basin still separates the two fronts, but regional uplift and encroachment of structures into the basin are rapidly breaking up and removing the remaining cover sediment fill.

Although interrupted by cross-cutting faults, the Culverden Basin extends north of the Waiau River into the Wandle Syncline which is dragged into, and truncated against, the Hope Fault. Nearer the coast, the thrust system reverses face to the east, approximately at the termination of the subducting slab, and basins such as the Cheviot Basin onshore, and the Conway Trough offshore, illustrate the progressive stages in the evolution of these thrust basins from marine infilling, to uplift and eventual destruction, now well advanced in the Culverden example.

The history of drainage across these emerging mountain ranges is one of diversion and entrapment into antecedent gorges. Why rivers such as the Charwell and Conway draining across the Hope Fault are now cut deep into gorges across several ranges to reach the sea is anomalous. The Hope Fault occupies one side of a fault angle depression that extends to the coast at Kaikoura and clearly remnants of old gravels and high level aggradation surfaces are indicative of drainage which followed this natural course. How these major rivers came to be trapped into their present positions is unclear.

The high slip rates and transpressive character of the Hope Fault has given rise to a variety of exceptionally well expressed landscape features, not only on the fault trace itself but over a broad zone of secondary structures. The inland road approaches the fault quite closely and provides good views of many of these landscape features.

Throughout the whole area, the imprint of Quaternary climatic change provides important markers in the landscape in the form of erosion and aggradation surfaces, cycles of sea level and base level change. Datum surfaces document the location and style of active ground deformation. Providing an age for such surfaces allows for estimations of rates of uplift, folding and fault displacement. In many cases the surficial cover of loess and soils integrated into the stratigraphic geomorphology is the only practical method of correlation and estimating the likely age of surfaces. Close collaboration with soil scientists is now an integral part of active tectonic research.

This overview is based on, and acknowledges, the contributions of many post-graduate students, staff and collaboratorating scientists under the Canterbury Active Tectonics Programme. It is not practical to reference all of them comprehensively in this short text. Particularly relevant papers are referenced with individual sites

Because parties will be traveling both ways through this area and will comprise different interest groups, not all the sites described below will be visited during a single trip between Christchurch and Kaikoura while brief stops may be made at other points depending on interest. To avoid duplication a single set of descriptions is provided and a selection of stops will be made by each party.

CHRISTCHURCH TO WAIPARA

State Highway 1 north from Christchurch travels along the approximate western limit of the post-glacial marine transgression. To the west the surface of the Canterbury Plains have formed by the aggregation of coalescing fans of major braided rivers carrying large volumes of outwash gravels to the coast from the glaciated ranges of the Southern Alps during the Pleistocene. The surface is superficially uniform, but in detail is a compound of merging aggradation events, further modified by surficial processes and the effects of fluctuating sea level and tectonic deformation.

Progradation during the last 6,000 years has shifted the coastline in stepped increments eastward by up to 2 kilometres. Deposits comprise cycles of former beach ridge gravels, dune sands, estuarine deposits, and peat swamps. The western limit of transgression is marked by a seacliff which gradually increases in height northward from near Leithfield where it is close to the road. At Leithfield, and west of the cliff, glacial outwash forms the higher dissected surface, while to the east and near the highway an extensive stabilized dune system can be observed.

Approaching Amberley the highway crosses the incised meander loops of the Kowai River trapped in the tip of a southward propagating anticline and the road steps up onto this uplifted surface before the township. To the North and west of Amberley evidence for active tectonic deformation becomes clearer. The hills to the northeast are evolving in response to the growth and southward propagation of the Cass Anticline (Fig. 1) A core of Mesozoic Torlesse Supergroup "greywacke" is flanked by younger folds elevating the Cretaceous - Tertiary sequences. The lower Waipara River is deeply incised into an antecedent gorge across the Cass structure.

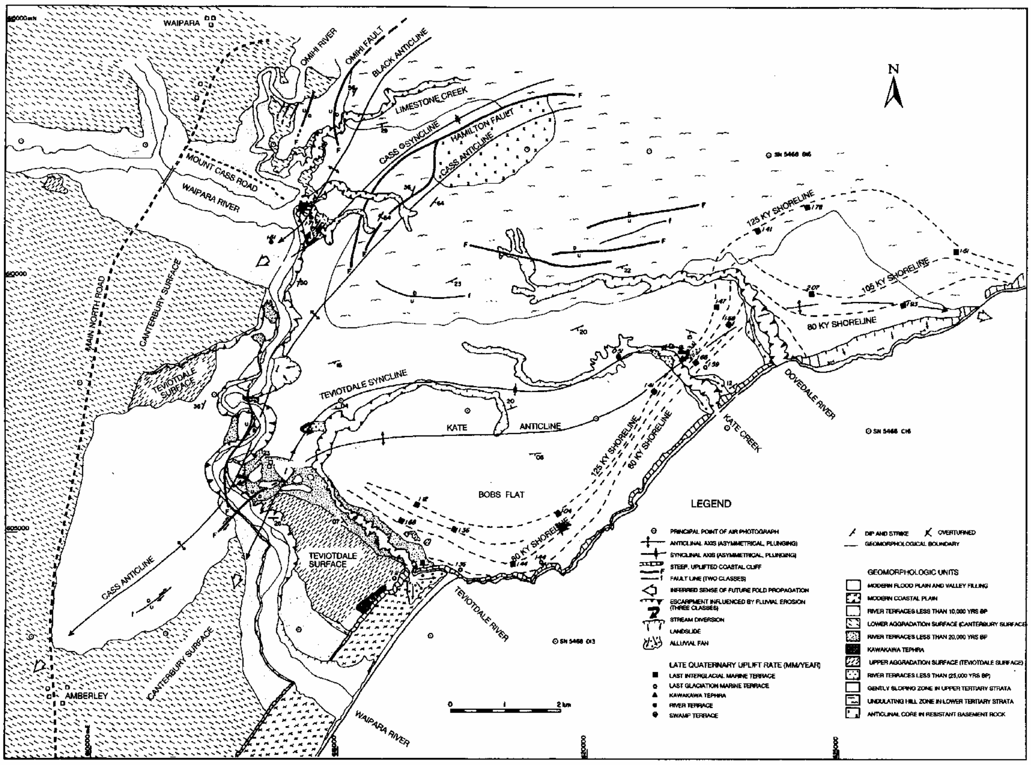


Figure 1: Map of the lower Waipara Rover Gorge through the propagating coastal folds. Remnants of the Teviotdale surface are uplifted on the flanks of the anticline, as are Pleistocene shorelines. Holocene cliffing and progradation are shown near the river mouth. *(from Al Daghastani and Campbell, 1995)*

West and southwest of Amberley Lower to Middle Pleistocene gravels and the underlying Cenozoic sequence occupy a synclinal trough extending north to Omihi and are deformed and elevated along the range front marking the northwestern limit of the Canterbury Plains. This zone of ongoing deformation has developed in response to the complex fault movements along various strands within the Porters Pass - Amberley Fault Zone, a hybrid juvenile strike-slip-thrust fault system (Cowan et al 1996).

Late Quaternary stratigraphy and geomorphic history of the Waipara - area of north Canterbury

P.J. Tonkin

Nicol et al., (1994) integrated data on bedrock structure, Quaternary stratigraphy, geomorphology and soil morphology in their analysis of the rates of deformation, uplift and landscape development associated with active folding in North Canterbury. The landforms developed on the growing anticlines form; domes, cuesta, hog backs, undulating downlands and dissected basin margins. These are underlain by a contrasting sequence of lithologies with soils and regoliths developed on greywacke, glauconitic sandstones and mudstones, hard and chalky limestones, calcareous and non- calcareous sandstones and weathered conglomerates. The sedimentology and geochemistry of these rocks is reflected in their weathering to form distinctive soils. An indicator of the relative stability of hilly land surfaces in the late Quaternary is the accumulation and retention of loess. Soil mapping, including detailed studies of soils on cuestas and downlands associated with active folds, indicates a limited retention of loess. Loess mantled terraces and fans occur both upwind and down wind of these landscapes, so loess was transported across the region throughout the late Pleistocene. It is concluded that slopes continued to erode at rates equal to or greater than the rate of loess deposition. Evidence from small fans along the western and northern side of the Waipara basin and Omihi Valley show that this is still a region of erosion from the basin margins, with areas of farmland buried by fan aggradation, as happened at Glenmark between 1941 and 1951.

A prerequisite for the documenting active fold growth is the recognition of Quaternary marker horizons of sufficient age and lateral extent to display gradients that depart from an initial orientation. In north Canterbury these include flights of terraces with definable geomorphic surfaces as well as other marker horizons such as late Pleistocene loess and fine textured basin fills which contain disseminated or thin interbedded 22.6 ka Kawakawa tephra, (Nicol, et al., 1994, Kohn, 1979). Nicol et al., (1994) describe five groups of geomorphic surfaces in Waipara region using soil morphology, elevation and available age data. Their identification is aided by an array of soils that specifically relate to fill terraces and groupings of similarly aged fill-cut terraces along the Waipara River and Omihi Stream. The oldest is the Teviotdale surface (Wilson, 1963), which is mantled by loess with interbedded Kawakawa tephra. This surface of small areal extent, occurs north, south and southeast of the Waipara River, and is underlain by the Teviotdale gravels. This formation is poorly studied and may comprise a number of identifiable gravel members separated by loess and/or silt beds with soil fabrics.

A pre-Teviotdale stratigraphy is exposed along the south side of the Waipara River adjacent to the The Mound a topographic knoll which is the surface expression of a westward overturned thrust faulted anticline.. The Canterbury surface (Wilson, 1963) and its equivalent in the Omihi Valley, the Omihi surface

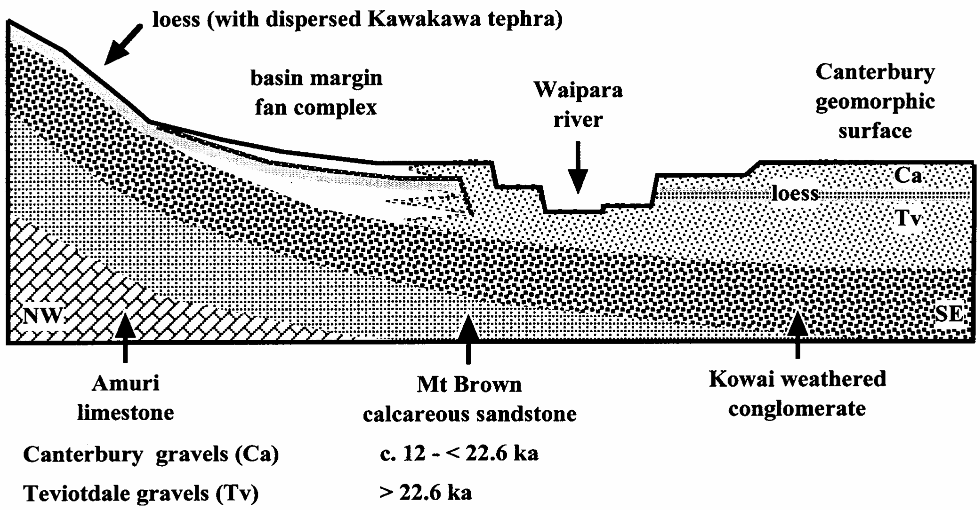


Figure 2: Shows a cross section of the Waipara River west of Waipara town.

(Nicol et al., 1994) are the most extensive. The Omihi fill terrace is underlain by c. 3m of calcareous clays, silts, sands and gravels which contain or overlie the Kawakawa tephra. Nicol et al., (1994) postulated that the Omihi surface was incised about 12±2 ky. Omihi and Canterbury surfaces merge at the same height suggesting both are of similar age. The Weka surface is stratigraphically younger and gravels and sands of the Weka fan interfinger with and bury the Canterbury and Omihi alluvium. Buried Teviotdale surface complete with loess cover, extends beneath the Weka fan and Canterbury gravels. The loess marker is also interbedded with fans deposits from small catchments along the north and western margins of the Waipara Basin and Omihi Valley. On the flanks of the dissected basin margin the loess occurs as discontinuous remnants on ridges and is underlain by the weathered conglomerate. The youngest geomorphic surface includes a flight of closely spaced fill-cut terraces that date from the late Holocene with one radiocarbon age indicating one of these terraces dates from about 1008±63 years BP. (NZ7957).

References

Al-Daghastani, H.S.Y and Campbell, J.K., 1995: The evolution of the lower Waipara River gorge in response to active folding in North Canterbury, New Zealand. *ITC Journal, 3*: 246-255

Cowan,H.A., Nicol, A, Tonkin, P., 1996: A comparison of historical and paleoseismicity in a newly formed fault zone and a mature fault zone, North Canterbury. *New Zealand Journal of Geophysical Research, 101*: 6021-6036

Nicol, A., Alloway, B., Tonkin, P. 1994: Rates of deformation, uplift and landscape development associated with active folding in the Waipara area of North Canterbury, New Zealand. *Tectonics, 13*:1327-1344.

Kohn, B.P. 1979: Identification and significance of a late Pleistocene tephra in the Canterbury District, South Island New Zealand, *Quaternary Research, 11*:78-92.

Wilson, D.D. 1963. The geology of the Waipara Subdivion (Amberley and Motunau Sheets S68 and S69) *N.Z. Geological Survey Bulletin 64*: 122pp

BOBYS STREAM FAULT AT THE DEANS, MIDDLE WAIPARA RIVER

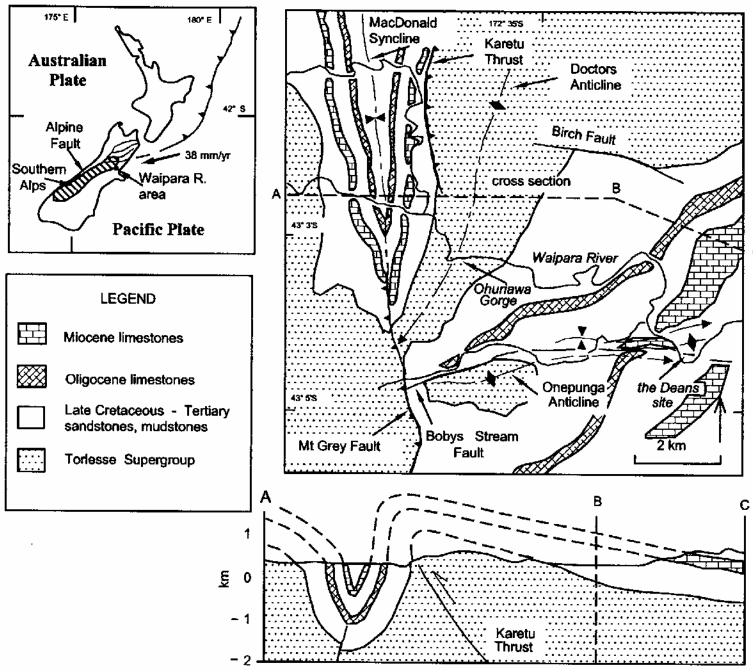


Figure 1: Middle and upper reaches of the Waipara River showing the major elements of the structure and selected geological units *(fromNicol and Campbell, 2001)*

This site is located on Ian Turnbull's family farm "the Deans" at the last major meander in the incised middle reaches of the Waipara River before it exits the foothills. Located on the terraces within the meander, the site is accessed by footbridge or shallow ford from the farmyard area.

Figure 1 shows the four major fault systems that control the regional structure of the middle and upper reaches of the Waipara Valley. The frontal ranges bordering the inner margins of the Canterbury Plains are bound by a segmented system of east facing thrusts that extend northward to form the western boundary of the Culverden Basin. In this area the Mt Grey Thrust forms the prominent scarp at the head of the valley and splays into the tightly appressed McDonald Syncline further northeast, bound by the west-facing Karetu Fault and associated Doctors Anticline (Wilson, 1963; Nicol and Campbell, 2001). Close to the junction of these opposing thrust systems, an east-west striking, anastomosing fault system, the Bobys Stream Fault is truncated against the Mt Grey Thrust. This strikes eastward across a wide, late Pleistocene valley fill and degradation terrace system, forming a recent trace across these late Quaternary surfaces. Four kilometres north, the parallel east-west Birch Fault has been shown to control a former Cretaceous half graben and has now been inverted under the present transpressional regime (Nicol, 1993).

The well-exposed classic Cretaceous-Tertiary cover sequence is exposed as a simple 30°east dipping succession in the main course of the Waipara river where it exits from the Ohuriawa Gorge incised into Torlesse Group basement across the Doctors Anticline. Associated with the Bobys Stream Fault this succession is folded into an anticline-syncline pair generated by dextral-oblique thrusting on the fault. Progressive overriding across the footwall syncline towards the western end, results in the anomalous increase from one to five kilometres of strike separation of corresponding units across the fault. The sequence is exposed in the deeply incised tributary of Bobys Stream, providing both good control on the structure, and also a temporal framework for identifying the relative timing of late Holocene ruptures along the fault in relation to downcutting and terrace formation. There appears to have been very slow degradation and valley-wide planation during the early stages of Holocene downcutting, but at some point between, 2 - 3 ka ago a sudden base level drop triggered rapid incision into the broadest upper terrace surface, the Waipara Surface (Nicol and Campbell, 2001). The fault trace forms a north-facing two metre high scarp on the Waipara Surface, observable close to the road on Randolph Downs, the property opposite the entrance gate to the Deans. Eastward the scarp dies away on this surface over the next two kilometres into the plunging termination of the hanging wall anticline.

The meander loop at the Deans site encloses a flight of degradation terraces (Fig 2) and is crossed by the fault trace, expressed as a metre high scarp, clearly associated with dextral offset of terrace risers. At this location the fault dips steeply south at 80° juxtaposing grey sandy silts of the Waikari Formation (late Oligocene - early Miocene) against uppermost yellow-brown sandy gravels and shelly limestones of the Mt Brown (late Miocene) and overlying Kowai (Pliocene - early Pleistocene) Formations. A thick footwall wedge of late Pleistocene aggradation gravels underlies the terraces to within a few metres of present river level, and the hanging wall is bevelled in bedrock and capped by late Holocene terrace gravels. These thicken from 1 to 3 metres away from the fault and reflect the tilt direction of the terrace surface. There is an abrupt drop below the lowest offset terrace at 25 m to a surface 6-8 m above present river level and this surface does not show any trace of the fault. However, on the south bank, a relic of the same surface is covered by extensive landslide deposits from large scars in the steep scarp below the strike ridge of Mt. Brown limestone forming the skyline. Other landslide deposits on the same former river level occur upstream.

The geomorphic relationships imply that the last rupture event must post-date the lowest offset terrace and pre-date the 8 metre terrace, an interpretation supported by the evidence of coeval landsliding. If the age of these terraces can be established, the timing of the last event can be bracketed. The single event displacement of the terraces should provide some measure of the likely magnitude of that event. It should be noted that there is general evidence from the catchment that penecontemporaneous rupture occurred on all the four faults contributing to this interlinked set of structures (Cowan et. al., 1996; Nicol and Campbell, 2001).

Data on dating of the terraces surfaces and fault scarps by weathering rind measurement methods (Mc Saveney, 1992) using the abundant Torlesse Group clasts of the terrace gravel capping and those which are freshly exposed by fault rupture, are presented fully in Nicol and Campbell (2001). Good radiocarbon sites were scarce, but three dates that can be related to this chronology tend to confirm the general time frame. Fig 3a, summarises the dates for the flight of terraces through this area using data derived from the whole catchment, showing a separation of curves in the histories of downcutting where tributaries are closely associated with active structures, principally the Doctors Anticline. Fig 3b, separates out the regional dowcutting and the net difference shows that approximately 20 metres of downcutting appears to have begun and accelerated from 200 to 300 years prior to the rupture event. In detail, this appears to be related to a period of growth on the anticlines associated with the fault system. Evidence, such as the tilting apparently synchronous with gravel deposition on terraces close to the future rupture zone, suggests more localised deformation immediately prior to the event. An apparently similar sequence of events has been identified elsewhere (Campbell et al., 2003).

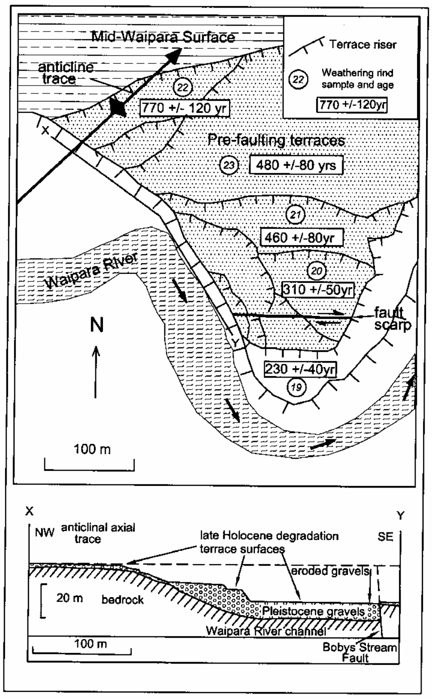


Figure 2 (caption below)

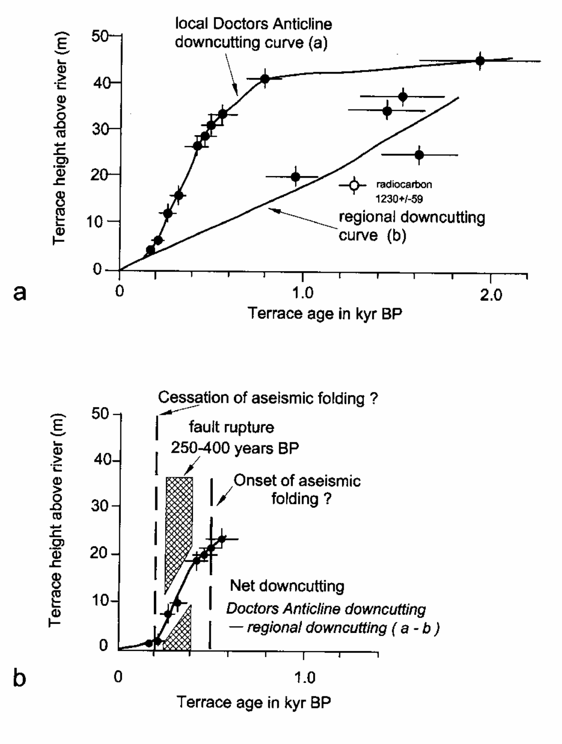


Figure 3 (caption below)

Figure 2: Detail of the terrace sequence at the Deans site showing the age of the surfaces determined from weathering of surface clasts, the location of the trace of the Bobys Stream Fault and a cross section showing the wedge of aggradation gravels truncated by ongoing uplift on thefault. Note that the age is relative to BP 1991 datum when rind thickesses were measured. *(Nicol and Campbell, 2001)*

Figure 3: a. Downcutting curves amalgamated from data on branches of the Waipara River b. Residual curve when regional downcutting is subtracted from downcutting associated with the Doctors Anticline. *(Nicol and Campbell, 2001)*

The direct weathering rind dating of exposed fault scarp gravels from all the four faults in this system lies within a band from 400 to 250 ka, but given the margin of error in the dating method, it is not known how synchronously individual faults ruptured. The landslide evidence suggests that the event on the Bobys Stream Fault was close to the end of rapid downcutting to the 8 m terrace. Elsewhere on the fault, an unpublished radiocarbon age of 159 ± 55 BP (NZA 11806) was obtained from swamp grasses recovered from a pocket of silt incorporated into disturbed gravels in a trench cut into the 2m scarp on the Waipara Surface 2.5 km further west. The calibrated secular age of 1740 ± 90 AD is consistent with weathering rind data estimate. At least two, and probably three events post-date the Waipara Surface, of which the most recent is the Deans event and is the youngest major ground rupture event identified in paleoseismic studies in the Canterbury area.

The offsetting of the three small terraces at the Deans, initially presents a paradox. Fig. 4a shows the detailed topography of the fault scarp and three risers. As will also be evident on the ground, taping or scaling off the offset of the apparent projections of the riser pairs onto the fault trace produces an offset as large as 12 m for R2, virtually nothing for the older R1 and a modest 1 to 2 metres for the youngest R3.

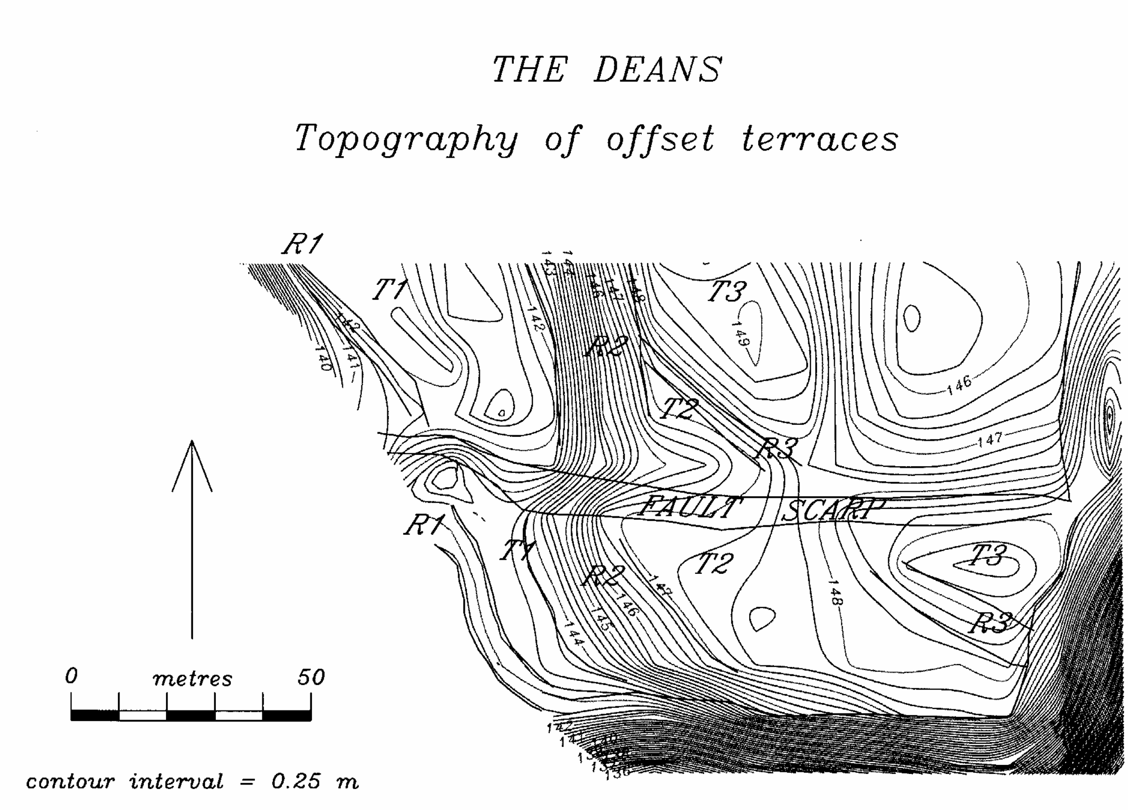


Figure 4: Contour map of the topographic detail of three offset terraces. T = terrace surface R= terrace riser.

The most rational solution to the problem seems to lie in a geometric relationship between the angle at which the riser intersects the fault, the dip of the fault plane, and the amount of material collapsed off the hanging wall during oblique-transpressive slip. The fault is exposed over the terrace edge as a clean plane dipping steeply south and breaking out close to the base of the surface scarp. Detailed topographic contouring allows structure contours on the fault plane to be reconstructed above present ground level. Collapse of the overhanging fault scarp destroys the topographic detail of the terraces close to the fault, but the riser planes can be projected onto the reconstructed fault plane by extending the topographic contour trends and the gradients of the break in slope bounding the riser. It is clear that where a terrace intersects the fault plane at an acute angle pointing in the strike slip direction, the true slip exceeds the apparent offset (as in R1) and where the terrace makes an angle pointing away from the slip direction the true displacement is decreased (as in R2). Riser 2 is further complicated, because it is clear on aerial photographs that the riser is a compound surface where an older terrace margin is scooped out by a later meander, bevelling just the corner on the south side of the fault. This means that it is not appropriate to project the majority of the contours defining R2 onto the fault on the south side and the curve of the meander needs to be reconstructed through the missing section.

Elements of subjectivity in projecting the riser contours onto the fault plane still limit the precision with which the displacement can be measured, but a value of 9+/- 2m produce a plausible reconciliation for a common offset for all three risers. For a single event displacement this is substantial and would suggest and event which could be as large as M_w 8., which is in conflict with the exposed rupture length of 8 to 9 km that would be more consistent with a value closer to M_w 6.7.

It is thought that the Bobys Stream and Birch Faults probably function as strike-slip transfer structures accommodating the interaction of the opposing thrust systems of the Mt Grey and Karetu Faults and the Doctors Anticline. As such, the Bobys Stream Fault rupture surface may extend some distance under the Mt Grey front. Furthermore, if these faults are closely connected and rupture partially or completely synchronously, the total rupture area may be substantial and totally compatible with thrust displacements of this size being taken up in the transfer system. The complexity of the fault connections at depth and the relatively juvenile state of development of this fault system suggests that conventional application of such parameters as rupture length and displacement as a measure of paleoseismic magnitudes should be used with caution.

References

Campbell, J.K., Nicol, A. and Howard, M.E. 2003. Long-term changes to river regimes pior to late Holocene coseismic faulting, Canterbury, New Zealand. *Journal of Geodynamics, 36*:147-168

Cowan, H., Nicol, A. and Tonkin, P., 1996. A comparison of historical and paleoseismicity in a newly formed fault zone and a mature fault zone, north Canterbury, *New Zealand. Journal of Geophysical Research, 101(B3)*: 6021-6036

McSaveney, M.J., 1992. A manual for weathering-rind dating of grey sandstones of the Torlesse Supergroup, New Zealand. 92/4, Institute of Geological and Nuclear Sciences.

Nicol, A., 1993. Haumurian (c. 66-80 Ma) half-graben development and deformation, mid Waipara, North Canterbury, New Zealand. *New Zealand Journal of Geology and Geophysics, 36(1)*: 127-130.

Nicol, A. and Campbell, J.K., 2001. The impact of episodic fault-related folding on late Holocene degradation terraces along Waipara River, New Zealand. *New Zealand Journal of Geology and Geophysics, 44(1)*: 145-155.

Wilson, D.D. 1963. The geology of the Waipara Subdivion (Amberley and Motunau Sheets S68 and S69) *N.Z. Geological Survey Bulletin 64*: 122pp

MIDDLE WAIPARA RIVER STRATIGRAPHIC SECTION

Figure 1: View north across the middle Waipara valley where the Cretaceous-Tertiary sequence dips east at 30°. Mt Brown limestones form the strike ridge on the right hand skyline, underlain by Waikari siltstone. The white limestone ridge in the middle ground is composed of slightly softer Amuri Limestone overlain by more resistant, massive Weka Pass Stone Floating blocks of limestone are carried by the underlying eathflow in the unstable Ashley Mudstone and Waipara Greensand. Out of view upstream the dipping beds of greensand below the terrace pass into Cretaceous Conway and Broken River Formation *(Photo J.R. Pettinga)*

<u>Laidmore Road</u> (M34 764936).

This excellent view point looking to the north, provides examples of a wide range of geological features. In the distance to the northwest, the Torlesse rocks of the Doctors Range lie in the core of a southwest plunging anticline. The core is picked out by the rough grazing land. Better soils mark the Cretaceous-Cenozoic rocks and terraces. To the left, in the gorge, Torlesse rocks are overlain by thin Broken River Formation coal measures and then by Conway Formation, here a highly bioturbated muddy sandstone with reptile bones, particularly in concretions. Downstream but still to the left is the Loburn Mudstone and the K/T boundary.

Almost directly below, where the road reaches the river, is the Waipara Greensand and to the right the Ashley Mudstone marked by the development of major earth-flows. The Amuri Limestone and Weka Pass Limestone form a single escarpment, below the much higher escarpment of the Mt Brown Formation.

In detail, the Broken River Formation thickens rapidly from the Waipara River, northeastwards towards Birch Hollow, but thins rapidly across a fault active during the Haumurian (Fig.2 in the introductory overview section).

About turn!

Looking to the south and towards the left, a second escarpment of Mt Brown Formation forms the skyline and a little to the right a line of white outcrops marks the reappearance of the Amuri Limestone beyond the line of the Bobys Stream Fault. Mt Brown is the high point seen to the right of the quarry. The main escarpment continues to the west towards Mt Grey. There is a steeply plunging syncline beyond the western end of the escarpment and the Torlesse rocks of Mt Grey are displaced to the east on a thrust.

You are standing at or near the unconformable contact of the Amuri Limestone and the Weka Pass stone. The Weka Pass Stone is overlain by the Waikari Formation within which is a lens of limestone, the Claremont Limestone forming the outcropping ridge on the west side of the road bridge. This appears to fill a channel scoured into the Waikari Formation (J.K. Campbell pers.comm). There are, however, other older interpretations.

Post-Otaian Miocene sediments are grouped in the Mt Brown Formation. The formation is predominantly very fine sands and silts with prominent beds of shelly limestone with abundant bryozoa and brachiopods.

Conformably over the top of the Mt Brown beds shallow marine sands and sandy gravels of the Kowai Formation are exposed for about another kilometre downstream before passing below the fill of late Pleistocene gravels. Elsewhere, the Kowai Formation extends through the Pliocene into the early Pleistocene, becoming progressively more estuarine and fluvial with an increasing proportion of well rounded, weathered Torlesse-derived clasts. At that time it is considered that the frontal ranges had not yet emerged and these clasts were came from much further west in the Southern Alps than the local source of modern gravels. Local unconformities become increasingly common higher in this formation, although this unit shows up in the seismic stratigraphy as a widespread, uniform package internally characterised by strong regular reflectors.

MCDONALD SYNCLINE AND THE UPPER WAIPARA RIVER

The McDonald Syncline is a tightly appressed upright fold caught between opposing thrust systems. On the west the series of range front thrusts extending north from the Mt Grey Fault ultimately continue up the west side of the Culverden Basin and uplift the foothills of the Southern Alps. On the east the Karetu Thrust bounds the boomerang shaped Doctors Anticline Dome, but is interrupted to the north by another east-west cross-cutting fault at Pyramid Valley, although active faulting and fold growth continues in the same trend, to form the Hawarden Anticline jutting into the southern end of the basin. Through the central part of the structure Torlesse Group basement rocks are carried by this fault over the east side of the syncline, progressively steepening and overturning the limb and overriding the lower units until the prominent strike ridge of Omihi Formation (Amuri and Weka Pass limestones) is seen to be truncated by the fault (Fig. 1).

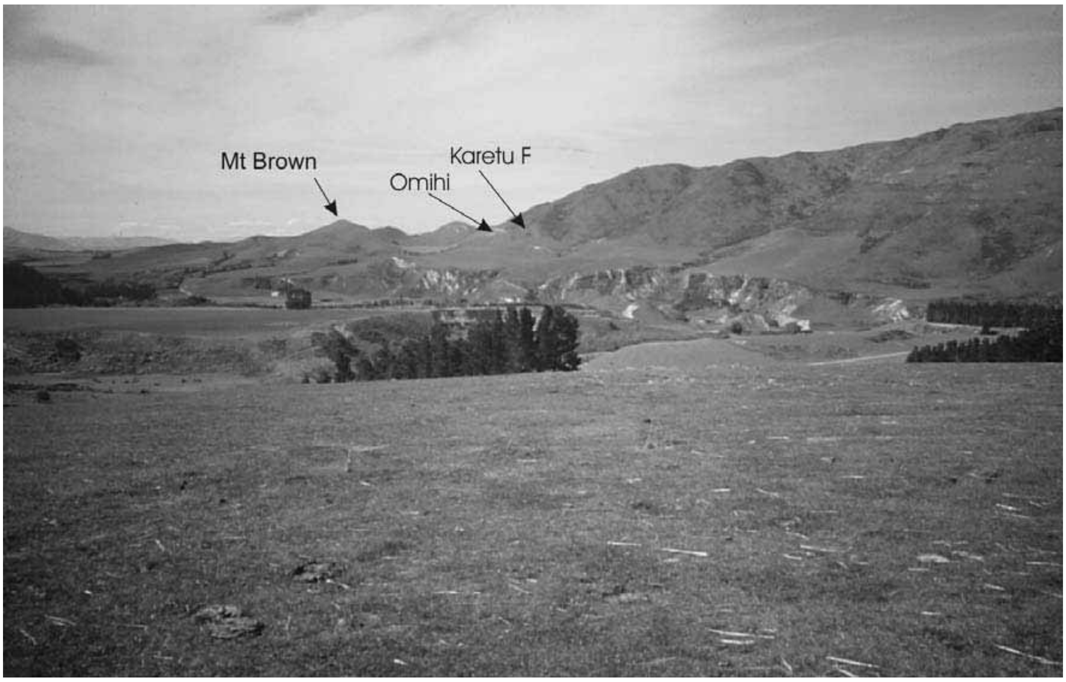


Figure 1: View to the north along the east limb of the McDonald Syncline. The axis of the McDonald syncline is on the left hand side of the picture and the Doctors Anticline Dome rises to the right. The light coloured exposures in the Waiapara River valley are of the upper Mt Brown and the stratigraphically lower Omihi Formations separated by the Waikari siltstones. The limestones form strike ridges on the skyline where the limb of the syncline is overturned in response to the overthrusting of Torlesse Group on the Karetu Thrust.

At the southern end of the structure, the Mt Grey Fault splays into the core of the syncline and steep east-facing reverse faults extend into the east limb overthrusting Cretaceous Broken River coalmeasures onto terrace gravel, where the South Branch tributary joins the the Waipara River. The Karetu Fault appears to die away within basement just north of the antecedant Ohuriawa Gorge where the river abruptly turns at right angles to cross the nose of the Doctors Anticline.

Superimposed across both the McDonald Syncline and the Doctors Anticline Dome is a system of east-west cross folds, producing steeply plunging corrugations in the limbs of the syncline and coaptation folding of the anticline (Fig. 2). While this folding is on a kilometre scale wave length, the right angle bend in the dome reflects the intersection of two major hanging wall anticlines associated with the north striking Kaertu Fault and the east-west striking system of thrust faults south of the Waikari Valley.

The evidence that the east-west structures originated in Cretaceous extension is discussed in the introductory overview. Nicol's work has shown that the present principal compression is directed northwest to southeast and generates oblique transpression on both structural trends. The essentially synchronous basin and dome cross-folding controlled by these basement faults is ubiquitous throughout Canterbury and strongly curved anticlines are a characteristic of the regional structure with complex conical geometric elements (Nicol, 1991;1993; Nicol and Wise 1992; Mould, 1992; Litchfield, 1995; Litchfield et al., 2003).

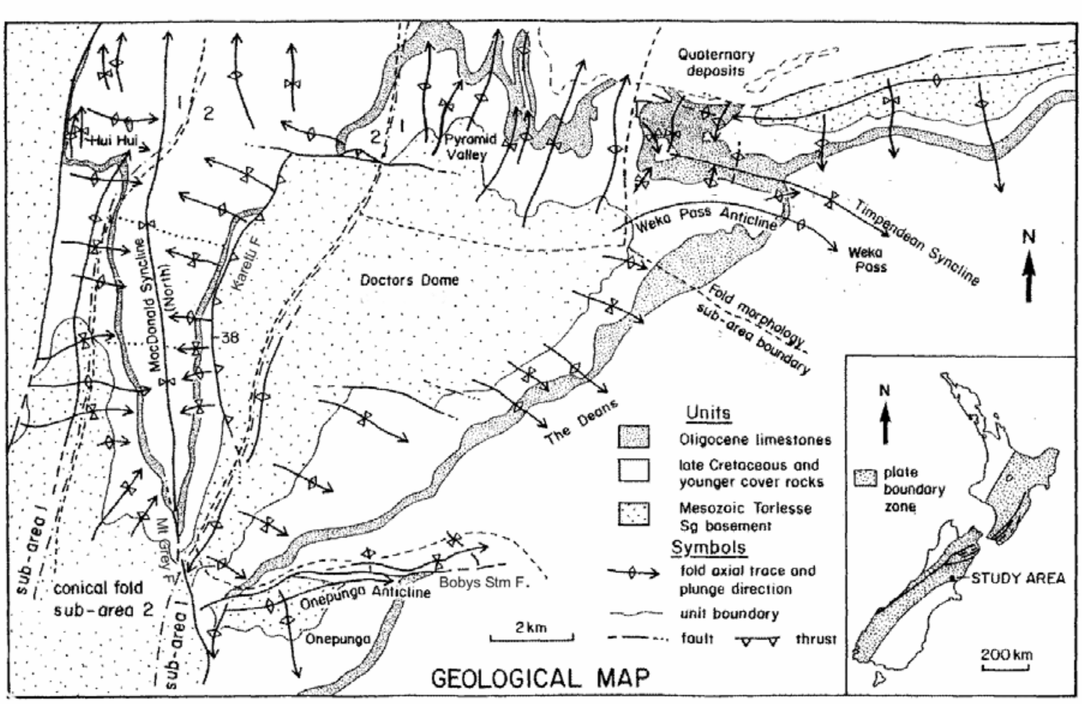


Figure 2: Structure of the Doctors Dome area. Fold details were derived by structure contouring the unconformity at the interface between Torlesse basement rocks and the cover sequence and the top of the Oligocene limestones. *(map from Nicol, 1991)*

Good sections through the full Cretaceous-Tertiary sequence in the steeply dipping limbs are exposed in the tributaries of the Waipara in the South Branch, but the lower units are lost further north because of the faulting. Pleistocene aggradation gravels form a thick accumulation in the core of the syncline although the present Waipara River course is now incised into the east side of the valley. Radiocarbon dates of ≥43,600 yr BP (NZ7933) and 30,160 ±430 yrs BP (NZ7851) have been recovered from lenses within the middle of the gravel accumulation (Nicol and Campbell, 2001). These are capped by fan deposits washed from the western range front. Loess does not accumulate on the areas underlain by the pre-Quaternary units and a single loess sheet can be found in places on the aggradation surface where it is unmodified.

The Waipara River appears to have had a chequered history. As will be seen to the north, drainage from the present headwater catchment at one time drained northeast into the southern Culverden Basin and until the late Pleistocene, clearly left channels leading to two air gaps through the growing Hawarden Anticline, discussed at another stop. At still earlier times coalescing drainage in the southern part of the Culverden basin variously found its way out through the Waikari Valley, and also across the emergent ranges in the air gap south of the Timpendean Syncline.

The upper reaches of the Waipara River were either captured or diverted into the axial drainage down the McDonald Syncline, where an earlier outlet left an air gap and relics of higher erosion surfaces across the prominent limestone strike ridge well south of the present middle Waipara Gorge. Diversion and incision into the present course through Ohuriawa Gorge seems likely to be a consequence of closure and plunge reversal of the McDonald Syncline, coupled with blockage by the advancing Mt. Grey Thrust Front. Even the lower reaches of the Waipara had to find its way to sea through the emergent coastal fold complex leaving a pattern of shifting channels and antecedent drainage history (Al-Daghestani, and Campbell, 1995).

References

Al-Daghastani, H.S.Y. and Campbell, J.K. 1995: The evolution of the lower Waipara River gorge in response to active folding in North Canterbury, New Zealand. *ITC Journal, 3*: 246-255

Litchfield, N.J. 1995: Structure and tectonic geomorphology of the Lowry Peaks Range-Waikari Valley District, North Canterbury. Unpublished M.Sc. thesis, University of Canterbury 205pp

Litchfield, N.J., Campbell, J.K., Nicol, A, 2003: Recognition of active reverse faults and folds in North Canterbury, New Zealand, using structural mapping and geomorphic analysis. *New Zealand Journal of Geology and Geophysics*, *46*: 563 - 579

Mould, R. 1992: Structure and kinematics of late Cenozoic deformation along the western margin of the Culverden Basin, North Canterbury, New Zealand. Unpublished M.Sc. thesis, University of Canterbury 174pp.

Nicol, A. 1991: Structural styles and kinematics of deformation on the edge of the New Zealan plate boundary zone, Mid-Waipara region, North Canterbury. Unpublished Ph.D.. thesis University of Canterbury 171pp

Nicol, A. 1993: Conical folds produced by dome and basin interference and their application to determining strain ; examples from North Canterbury, New Zealand. *Journal of Structural Geology 15*:785-792)

Nicol, A. and Wise D.U. 1992: Paleostress adjacent to the Alpine Fault of New Zealand: faut, vein and stylolite data from the Doctors Dome Area. Journal of Geophysical Research 97: 17,685-17,692

HAWARDEN ANTICLINE – SOUTH CULVERDEN BASIN

Figure 1: Downplunge aerial view along the crest of the active Hawarden Anticline. Two flat floored antecedent valleys grading to the Burnham (Last Glacial Maximum) surface cross the propagating tip. Note the marked asymmetry to the cross valley profiles of these channels. As the fold propagated older aggradation and erosion trimlines are preserved around the nose of the fold. Relics of these progressively tilted surfaces can be seen on the further hill, tilted around the flanks and down from the highest point on the hill top. *(Photo J.R. Pettinga)*

Active folds offer an opportunity to glimpse the initial stages of mountain development. Early stages in the structural evolution of thrust-related folds may reveal mechanisms underlying fault scaling relationships, such as what controls concurrent rates of uplift and lateral propagation. In North Canterbury, South Island, New Zealand, Late Quaternary active folding in the southern Culverden Basin may reflect the eastward propagation of a range-bounding thrust system. To characterize and quantify evolution of the Hawarden anticline, which is approximately 2km wide and 7 km long, we used detailed geomorphic mapping, shallow seismic reflection surveying, and high-precision GPS surveying of deformed fluvial terrace remnants preserved along the fold. The fold is formed in a package of gravels that have been associated with several glacial advances and filled large portions of the Culverden basin. Absolute dates on the 3-4 fluvial terrace levels are lacking, although Kawakawa tephra (22.6 ka) was identified in at least one of the units. Seismic surveys oriented normal to the fold axis in a water gap revealed a well-defined anticline with evidence for surface rupture from a youthful, east verging thrust. Along the plunging tip of the fold, evidence for anticlinal folding is absent in the seismic data as well as the deformed terraces; instead, deformation appears to be localized along a surface rupturing thrust resulting in block tilting. The transition from broad anticlinal folding to block tilt occurs over a relatively short distance (~200-300 m). Evidence for tear faulting to accommodate this transition is not apparent. We will use an elastic dislocation model to quantify the change in fault geometry required to generate the observed pattern of deformation. In addition, we will use the model to constrain the relative importance of along-axis fold rotation and lateral fold propagation. These investigations will be used for seismic hazard assessment and also to constrain the fault-fold geometry and its structural evolution.

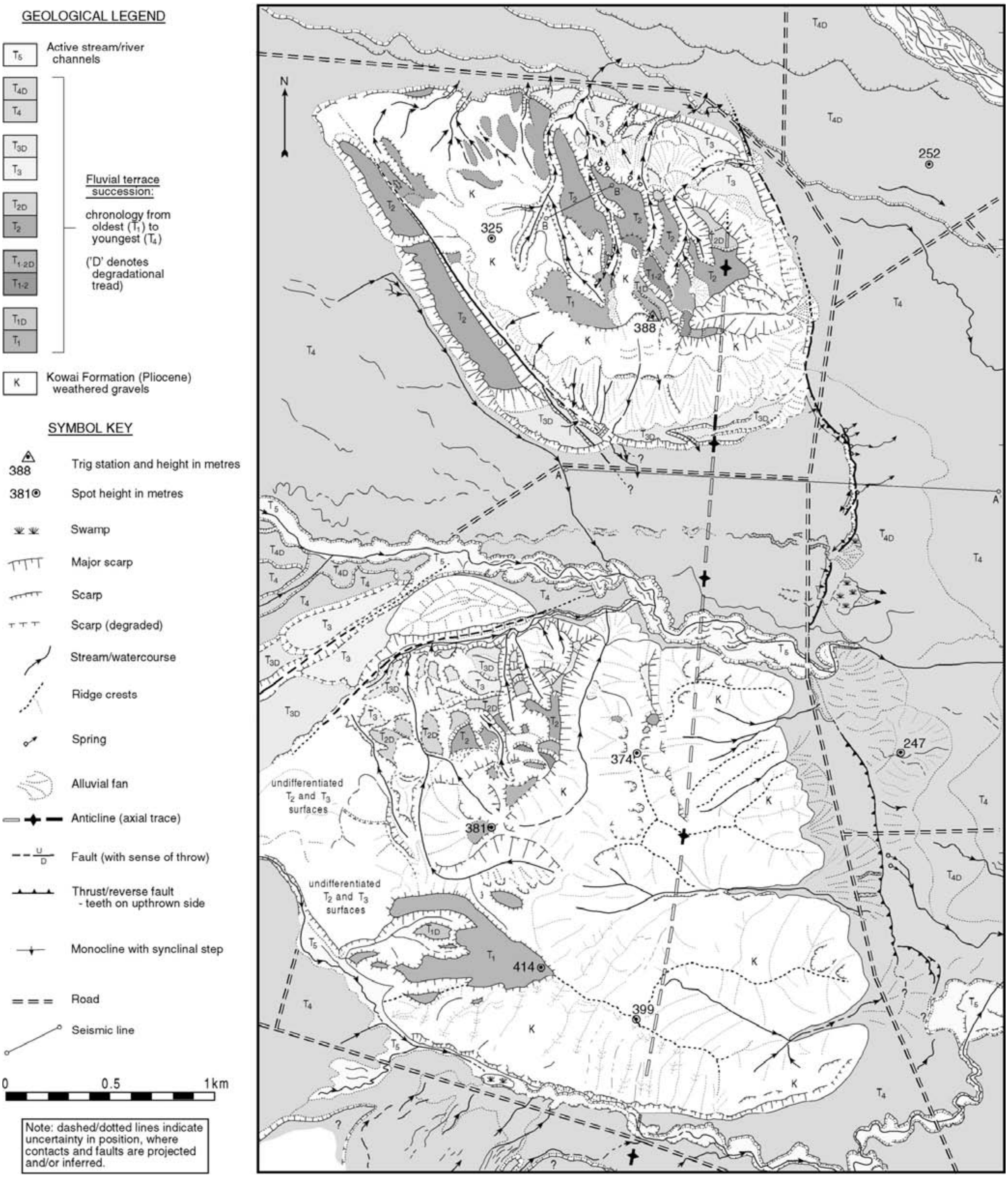


Figure 2: Geomorphic Map of the Hawarden Anticline (Unpublished Pettinga and Roering)

LEONARD MOUND AND QUATERNARY TECTONICS OF THE CULVERDEN BASIN

(based on Armstrong, 2000)

Situated on the eastern margin of Culverden Basin, Leonard Mound (Fig. 1) is an active, thrust-driven, asymmetric anticlinal ridge propagating obliquely into the basin (Figure 2). Torlesse greywacke basement, Cretaceous-Tertiary cover strata, as well as Pleistocene and Holocene fluvial gravels and range front alluvial fan gravels are involved in the thrust driven deformation which is clearly expressed by the geomorphology of the Leonard Mound ridge and associated fault controlled western range front of the Lowry Peaks range.

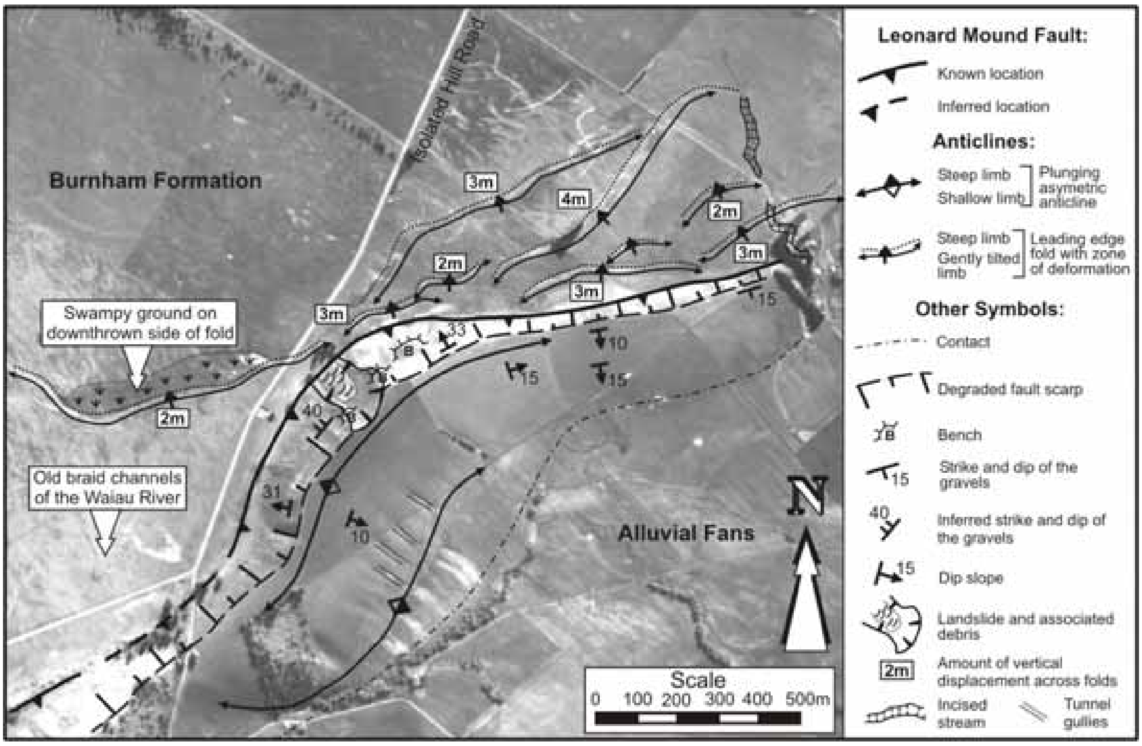


Figure 1: Annotated aerial photo of Leonard Mound at the Willows Section, showing the fault propagation anticline, main fault scarp and secondary fold zone on the northern side. The swampy ground on the west marks the location of a second fault system striking west across the floor of the basin.

At Leonard Mound the majority of uplift is related to thrust propagation folding. Thrusting is expressed by a single scarp that varies in height from approximately 5 to 20 metres. Where the main scarp is low, deformation is accommodated on one or more smaller splay thrusts situated in front (west) of the main scarp. These splays are inferred to reflect footwall imbrication. These smaller footwall thrusts generally do not daylight to the surface, but are expressed as a series of small leading edge asymmetric folds. Ground penetrating radar profiles have provided corroboration for the geomorphic interpretations, by showing that the near surface gravels have indeed been folded into asymmetric anticlines. In addition to the GPR data, transient electromagnetic (TEM) profiles run across the Leonard Mound fault zone indicate there has been approximately 200 metres of relative uplift. Unfortunately, because of poor age constraints on the gravel sequences, a precise uplift rate is as yet not available.

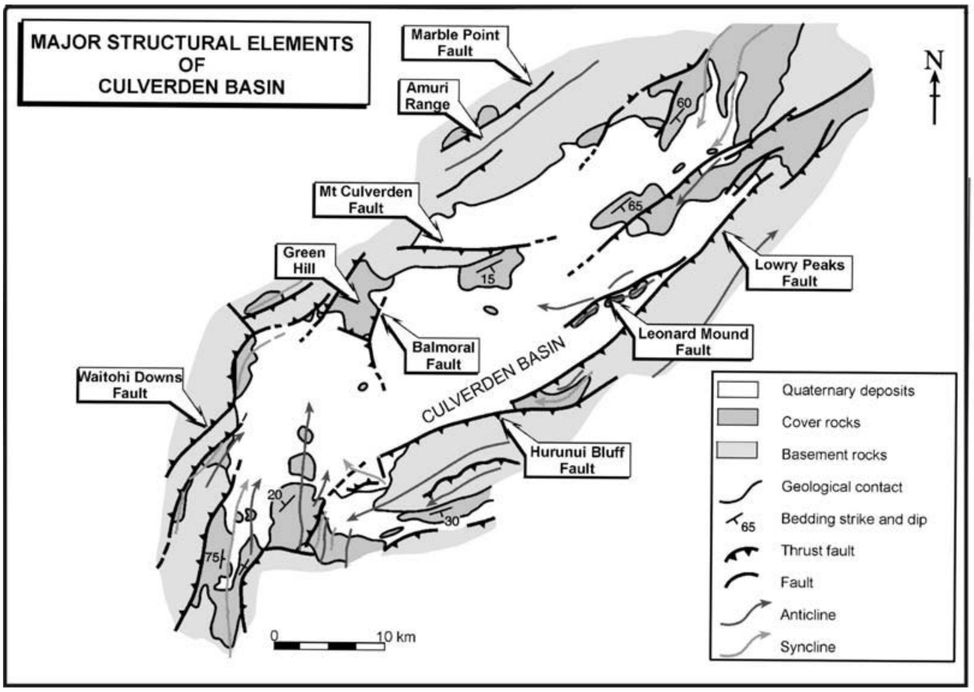


Figure 2: At the south end where the structure disappears beneath the late Pleistocene aggradation surface of the floor of the Culverden Basin a low fault scarp can be traced for 2 to 3 kilometres beyond the solid line shown on Figure 3, decreasing in height to a slight rise in the outwash plain surface. Backtilted terraces trimmed into the southern end of the anticline testify to the interaction between ongoing uplift and fluvial activity on the emergent structure. The Mound also coincides with the intersection of a second fault set which strikes west, right across the floor of the basin as a 1- 2 m high scarp to culminate in another anticline, exposing limestone, close to Culverden township.

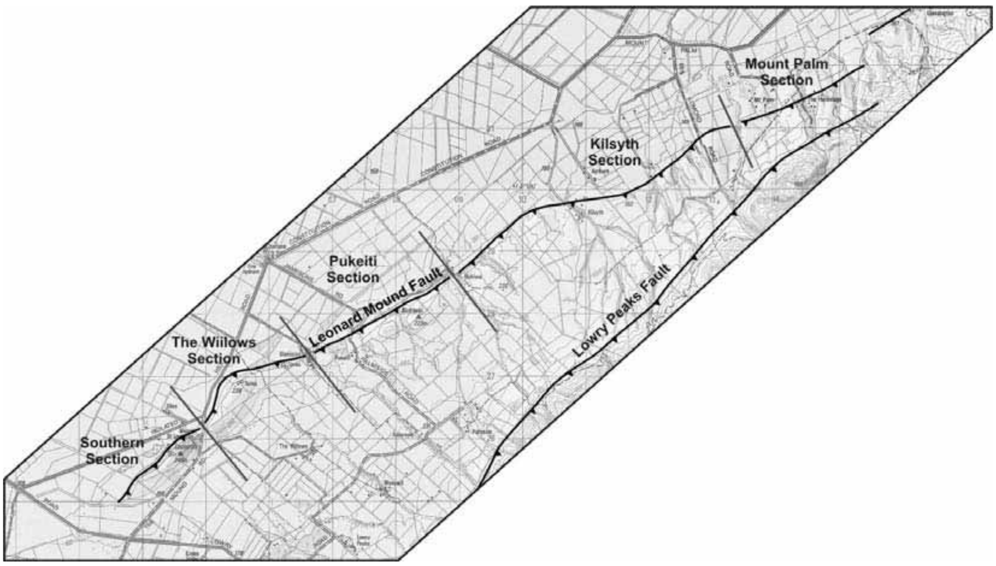


Figure 3: Location of the Leonard Mound Fault enclosing the piggy-back basin in front of the range-bounding Lowry Peaks Fault. At the northern end, streams draining alluvial fans filling the basin do maintain antecedent drainage across the emergent ridge, but at the south is diverted around the anticline.

The Leonard Mound structure is a classic example of a thrust isolating a piggy back basin on the margin of a larger thrust basin (Fig. 2 and 3). Typically structures such as this will develop progressively from footwall splays propagating in the basin margin progressively breaking up the larger basin. In the case of the Culverden Basin the orthogonal faulting and structures such as the Hawarden Anticline further separate out sections of the basin. The net crustal thickening and uplift of the whole north Canterbury convergence related shortening does not induce inversion of former extensional basins in the classic sense since these basins are bound by outward dipping thrust faults. However, it has the effect of lowering regional base level, so that the basins eventually lose their fill to erosion, stripping out the cover beds around the margins, but continuing until a late stage to provide sediment traps that become progressively more locally controlled by the basin floor structures.

The Culverden Basin is an example of the last stages before uplift will eventually remove all the remaining underlying Cenozoic cover, but the short term effects of large influxes of Pleistocene gravels have produce emphemeral periods of sediment accumulation and complex drainage switches. For example the Waiau River created sufficient aggradation of Burnham (Last Glacial Maximum) gravels to avulse into the present outlet of the Hurunui River.

Armstrong has documented this process of transition from a basin wide fill of Plio-Pleistocene Kowai Gravel to progressively more isolated, structurally controlled packets of late Pleistocene aggradation deposits. In this case the objective was to consider the implications for the interconnection and architecture of aquifers and local groundwater resources.

Late Quaternary surfaces in the Amuri basin, North Canterbury.

P.J. Tonkin

The late Pleistocene fans extend from the Hurunui River in the south and the Waiau River in the north to occupy most of the Amuri basin. Gravel alluvium underlying the fan surfaces is considered to be the equivalent of the late glacial Burnham Formation in Canterbury (Wilson and Browne, 1988). This geomorphic surface is dominated by Balmoral and Lismore soils. The only loess on this surfaces is a wedge of inferred Holocene loess of limited distribution extending south east from the Waiau River (T. Webb pers. comm. 2005). The Pahau fan lies between the Hurunui and Waiau fans, and has two recognisable geomorphic surfaces. In the upper part of this fan the Burnham surface with its pattern of Lismore soils predominates. In the mid fan the Burnham surface forms low ridges along former channels and interfingers with elongated 'islands' of an older surface that are orientated down slope in an easterly direction. The gravel alluvium underlying the older surface is inferred to be the equivalent of the Windwhistle Formation in Canterbury (Wilson and Browne, 1988). Pahau and Darnley soils occur on this geomorphic surface. These soils are formed in fine textured alluvium overlying gravels, and both have distinctive clayey subsoil horizons (T. Webb, pers. comm). The Pahau soils may have c. 40 to 60 cm of loess forming the upper part of the profile.

References

Armstrong, M 2000: Geomorphological and geophysical investigation of the effects of active tectonic deformation on the hydrogeology of north Culverden Basin, North Canterbury. Unpublished Ph.D. thesis. University of Canterbury

Brown, L.J., Wilson, D.D. 1988. Stratigraphy of late Quaternary deposits of the northern Canterbury Plains. New Zealand Journal of Geology and Geophysics 31, 305-335.

T. Webb (pers. comm.) 2005: Unpublished soil survey of the Amuri Plains, North Canterbury. Landcare Research, Lincoln.

TERRACE AGES AND OFFSETS ON THE HOPE FAULT AT CHARWELL RIVER

Figure 1: Aerial view to northwest across the Charwell River where it crosses the Hope Fault into the piedmont area. Degradation terraces down to the present river from the Stone Jug surface occupy the foreground. The beheaded older channel offset 2 km dextrally in the middle distance is the Flax Hills surface. The Dillondale grade from the higher surfaces just visible at the far left of view. (*Photo J.R. Pettinga)*

This area will be visited more extensively on Field Trip 7 and more detailed information on the whole range front along this section of the Hope Fault is provided in the related field guide. Some additional notes on recent work on the stratigraphy and soils of the late Quaternary terrace are provided here.

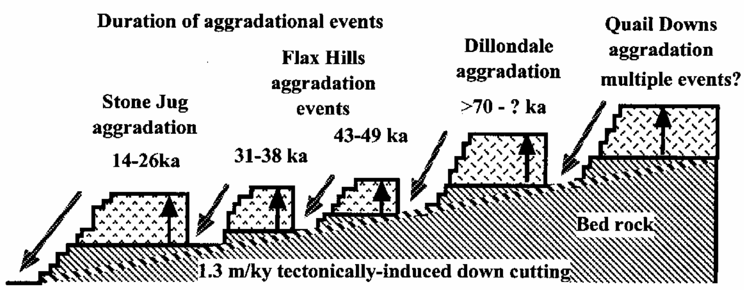
The two branches of the Charwell River have their sources in the Seaward Kaikoura Ranges, emerging across the Hope Fault to a broad, intramontane piedmont valley where a number of old aggradation surfaces, fans, abandoned channels and flights of degradation terraces are preserved. Further downstream the valley narrows again and the Charwell joins the Conway River to flow to the sea through a deeply entrenched gorge. Estimated uplift rates of 3.8 mm /yr for the Seaward Kaikouras suggests that much of the topography is very young and evidence for the large Quaternary glaciers to have been expected from the present elevations is lacking.

A detailed discussion of the history of aggradation events, terrace formation and the effects of uplift and strike-slip movement along the Hope Fault is given by Professor William B. Bull in Chapter 5 of his textbook “Geomorphic Responses to Climatic Change” (Oxford University Press). Strike-slip movement during the late Quaternary has been sufficient to detach the head waters of the Charwell from its downstream reaches and two former channels are now totally beheaded. These channels lie 2 and 4 km west of the present river respectively, associated with distinctive aggradation surfaces into which the channels are incised through flights of degradation terraces. Further to Bull’s original discussion, more recent work has been undertaken on the loess and soil sequence through this area and summarized below.

Late Quaternary aggradation and degradation of the Charwell piedmont, NE South Island.

P.J. Tonkin

The Charwell piedmont is bounded to the northwest by the Hope Fault and beyond by the Seaward Kaikoura Range. The piedmont has shifted southwest relative to the Charwell River watershed because of ~30 m/ky right-lateral slip on the range-bounding Hope fault. Base-level falls provided sites for the accumulation and subsequent incision of a succession of late Quaternary piedmont fans. These fans are preserved in part as a series of offset ridges and terraces with fill, fill-cut and strath terraces along the present and inferred prior valleys of the Charwell River (Bull, 1991). The aggradation event gravels and associated fill terraces have been described and named Stone Jug, Flax Hills 1, Flax Hills 2, Dillondale and Quail Downs. Figure 3 presents a hypothetical model of the late Quaternary aggradation and degradation events on the Charwell piedmont (Bull, 1991; Tonkin and Almond, 1998). This partially dated sequence is included as a fragmentary record in the climate event stratigraphy for New Zealand over the past 30,000 years. It records a similar event history to the other dated major fluvial aggradation events in New Zealand (Barrell et al., 2005; Litchfield and Berryman, 2005).



Maximum thickness of loess on fill terraces				
Stone Jug	**Flax Hills 1**	**Flax Hills 2**	**Dillondale**	**Quail Downs**
0.4 m thin loess + overbank deposits	1.9 m one loess	3.15 m two loesses	7.80 m three loesses	no loess erosional landform

Figure 2: A hypothetical model of the late Quaternary aggradation and degradation on the Charwell piedmont (after Bull, 1991, and Tonkin and Almond, 1998).

The maximum thickness of the loess increases from a thin discontinuous cover forming the upper horizons of the soil on the Stone Jug terrace, to one loess on Flax Hills 1, two loesses on Flax Hills 2 and three loesses on the Dillondale terrace (Figure 1). Each of the loesses has a characteristic soil or buried soil morphology by which it is identified (Tonkin and Almond, 1998). The Stone Jug fill and fill cut terrace flight has been dated using weathering rinds on surface greywacke boulders (Figure 3), and the differences in terrace age are shown by changes in total element depth distributions in their respective soils (Bull and Knuepfer, 1987;

Knuepfer, 1988). There is a significant area of the Stone Jug and Flax Hills 1 fill terraces, very little of Flax Hills 2 terrace, and the dissected Dillondale terrace has a downland topography and a reduced area of the original fill terrace. The thickness of the loess on the Dillondale downland is variable and there has been significant erosion particularly from sideslopes, both during and between intervals of late Quaternary loess deposition. The erosional modification of a terrace landform is complete on the Quail Down ridge, where the soils are formed in weathered gravels and no loess remains.

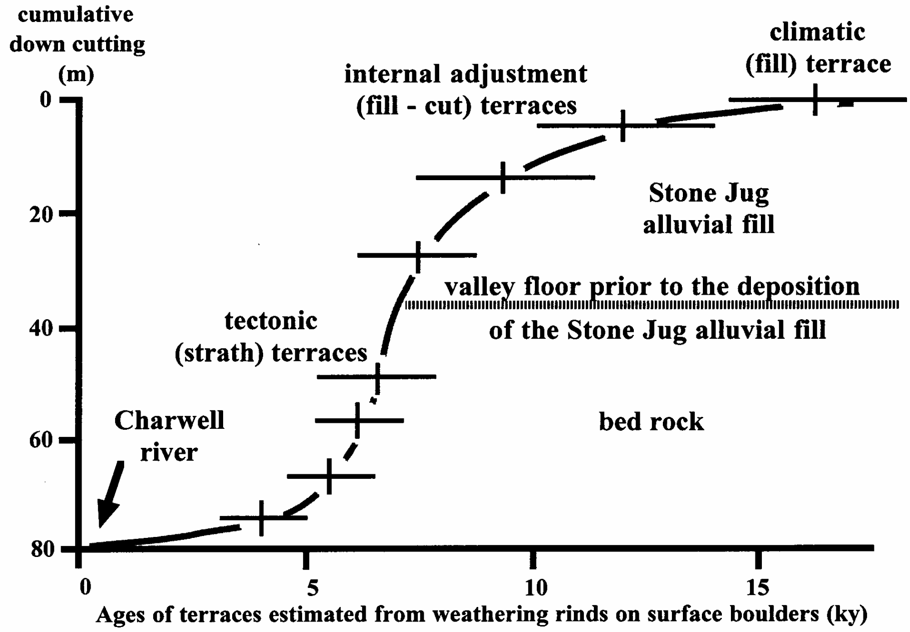


Figure 3: Tectonic, climatic and internal adjustment terraces of Charwell River (adapted from Bull and Kneupfer, 1987)

The 22.6 ky Kawakawa tephra occurs in the upper loess and has been used as a marker horizon to model slope development (Roering et al., 2002; Roeing et al., 2004). Hughes et al. (2005), studied the depositional record in a Dillondale downland gully, using phytolith analysis to reconstruct vegetation changes during infilling and horizons of known age to quantify infilling rates. They showed that infilling during the last glacial maximum (LGM) was coeval with loess accumulation and continued during the Holocene when loess deposition was negligible. Phytolith analysis in the hollow shows grassland dominated during the LGM to be replaced, at about 9 ka (from regional pollen data), by forest. Sediment thickness between the Kawakawa tephra primary emplacement horizon in the hollow and depth of the uppermost grassland/forest transition was used to calculate the infilling rate under grassland. The grassland/forest transition depth was used to calculate the infilling rate under forest. Hollow infilling rates under grassland and forest are 0.05 mm yr^{-1} and 0.1 mm yr^{-1}, respectively. Increased tephra concentration in the hollow fill deposits after Holocene forest established and the greater infilling rate indicate deeper soil mixing and greater transport under forest.

References

Barrell, D.J.A., Alloway, B.V., Shulmeister, J., Newnham,, R.M. (editors) 2005: Towards a climate event stratigraphy for New Zealand over the past 30,000 years. Institute of Geological & Nuclear Sciences science report 2005/07, 12p. and poster.

Bull, W.B. 1991: Geomorphic responses to Climatic change, 326pp., Oxford University Press, New York.

Bull, W.B., Knuepfer, P.L.K. 1987: Adjustment by the Charwell River, New Zealand, to uplift and climatic changes. *Geomorphology, 1*: 15-32.

M.W. Hughes, P.C. Almond and J.J. Roering., 2005: Quaternary environmental changes influence soil transport rates on a dissected loess mantled terrace. 6th International Conference on Geomorphology - Geomorphology in Regions of Environmental Contrasts, September 7-11, 2005 Zaragoza (Spain). Abstracts Volume, p63.

Knuepfer, P.L.K. 1988: Estimating ages of late Quaternary stream terraces from analysis of weathering rinds and soils. *Geological Society of America Bulletin 100:* 1224-1236.

Litchfield, N.J., Berryman, K.R., 2005: Correlation of fluvial terraces within the Hikurangi Margin, New Zealand: implications for climate and baselevel controls. *Geomorphology, 68*: 291-313

Roering, J.J., Almond, P., Tonkin, P., McLean, J. 2002: Soil transport by biological processes over millennial time scales. *Geology, 30*: 1115-1118.

Roering, J.J., Almond, P., Tonkin, P., McLean, J. 2004: Constraining climatic controls on hillslope dynamics using a coupled model for the transport of soil and tracers: Application to loess-mantled hillslopes, South Island, New Zealand. *Journal of Geophysical Research, 109*: F01010.

Tonkin, P., Almond, P. 1998: Using the soil stratigraphy of loess to reconstruct landscape histories of north-eastern and western lowlands of South Island, New Zealand. 8th biennial Conference of the Australian and New Zealand Geomorphology Group, Goolwa, South Australia. November 15th - 20th 1998. Abstracts volume p55.

THE HOPE FAULT TRACE AT GREENBURN STREAM

Figure 1: Shutter ridge of Torlesse sandstone across the outlet to Greenburn Stream. View looking north. The ridge has ponded a fan and in the past the stream outlet was forced west (to the left) around the end of the advancing ridge. The former outlet lies in the shadows at the end of the ridge, spilling a secondary fan back across the foot of the scarp. The present stream course exposes gouge and sheared sandstone in the ridge. This site has been trenched at both ends of the ridge.

A visit to this site is scheduled for Field Trip 7 and more detail is included in that guide. A discussion of the stratigraphy of the trenches, dates and paleoseismic history is referred to that source and is also published in Langridge et. al.(2003).

From the vantage point on the road opposite this site, a good view of the topography associated with the active trace of the Hope Fault can be seen. To the east of the Greenburn stream, now incised into the shutter ridge, an elevated area of swamp has accumulated behind the ridge where the tip of the adjacent spur is drawn across the drainage. Elsewhere, the fault trace is expressed as a furrow on the hillside 10 to 20 metres above the valley floor. Drainage coming off the hillslopes is interrupted and frequently shows clear offsets which have been documented by Pope (1994), suggesting increments of approximately 5 to 6m associated with each displacement event. The furrow along which strike-slip is concentrated is on the upslope side of a wedge of sheared bedrock gouge and capping gravel which appears to be extruded from beneath the footwall. Undoubtedly the Hope Fault is transpressional and uplifted on the north side with the fault zone dipping underneath. However the wedge effect produces a superficial appearance of normal faulting along the trace, uplifted on the south side.

This effect is clearly seen in the trench stratigraphy where accumulation of fan material behind the shutter ridge wedge shows all the stratigraphic geometry of normal faulting on the north dipping bedrock interface. Thick accumulations of sediment show backtilted wedges of onlapping gravel packages, interestingly, showing features of slow growth faulting during syndepositional displacement, suggestive of some aseismic deformation. The change in stratigraphy which marks the transition from uninterrupted fan deposition to interference by the advancing shutter ridge is also clear in the eastern of the two trenches close to the river bank. This transition has been dated at approximately 4,000 years ago.

Water injection associated with sandblows and fluidized mass flows of crushed bedrock are seen in the trenches, indicative of elevated pore pressures and saturated conditions in the upper levels of the shear zone.

Another of the characteristic features of these footwall wedges is the presence of regular rounded ridges cutting obliquely across the top. Trenching has shown that these are underlain by normal faults and the orientation is consistent with the extension direction if the wedges are also undergoing internal dextral simple shear. The overthrusting at the base of the wedges out onto the valley floor produces the oversteepened fault scarp often subject to small slumps and slides.

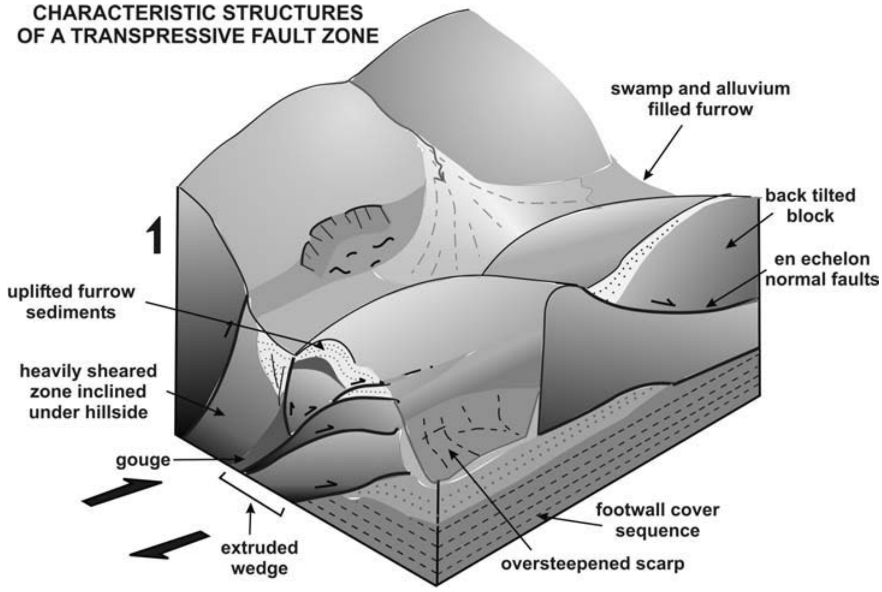


Figure 2: Conceptual block diagram of extruded footwall wedge showing relative upthrow on downhill side of bedrock cored ridge and accumulation of sediments in the furrow. Shearing the wedge also generates secondary extension and en echelon ridges oblique to the ridge axis.

References

Langridge, R., Campbell, J.K., Hill, N., Pere, V., Pope, J., Pettinga, J.R., Estrada, B., and Berryman, K. 2003: Paleoseismology and slip rate of the Conway Segment of the Hope Fault at Greenburn Stream, South Island, New Zealand. *Annals of Geophysics, 46*: 1119 -11139

Pope, J. 1994: Secondary structures, Holocene displacements and paleoseismcity of the Conway segment of the Hope Fault Greenburn Stream to Sawyers Creek. Unpublished BSc. Honours project. University of Canterbury.