D. L. DUNKERLEY

6th AUSTRALIA AND NEW ZEALAND GEOMORPHOLOGICAL GROUP MEETING

FIELDTRIP A
1 February 1994

ACTIVE TECTONICS AND LANDSCAPE EVOLUTION: HOPE FAULT - NORTH CANTERBURY

FIELDTRIP B
3 February 1994

LATE QUATERNARY TECTONICS, CLIMATE CHANGE AND LANDSCAPE EVOLUTION
AMURI-WAIPARA REGIONS - NORTH CANTERBURY

ACTIVE TECTONICS AND LANDSCAPE EVOLUTION
HOPE FAULT - NORTH CANTERBURY

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INTRODUCTION

In northern South Island oblique plate convergence is accommodated by a network of strongly segmented major strike-slip faults (Figure 1) referred to collectively as the Marlborough Fault System. This fault system connects the Hikurangi subduction zone offshore eastern North Island, to the Alpine Fault, along the West Coast of the South Island.

The Hope Fault is the southern element of this fault system, and data indicates it has been the most active of these major strike-slip faults during the late Pleistocene and Holocene.

The area to be visited during this half-day fieldtrip will be a section of the Hope Fault (the Hope River segment) between Hanmer and the Poplars Station (Figure 2). The emphasis is on the Late Quaternary geomorphic expression of the Hope Fault, and the "tectonic" and "climatic" factors important in shaping our landscape.

ROUTE NOTES

The trip departs from Hanmer, crossing the scarp of the Hanmer Fault by Queen Mary Hospital. The road extends south across the floor of the Hanmer Basin. The east segment of the Hope Fault bounds the south side and the scarp face is reached across the bridge over the Hanmer River. The route turns west onto Highway 7 to the Lewis Pass.

STOP 1: WEST HANMER BASIN: (Figures 3 and 4)

This roadside stop is to gain an overview of basin development at its western end. Last glaciation outwash gravels (approx. 14-15,000 years B.P.) are located above the road on the southern margin of the basin. Within the basin, however, early Holocene degradation terraces and extensive alluvial fans are at topographically much lower levels, and indicate more than 60 metres of relative subsidence of the basin floor since the early Holocene.

The western Hope River segment of the Hope Fault trends along the northwestern margin of the basin, and many discontinuous east-west trending normal faults have

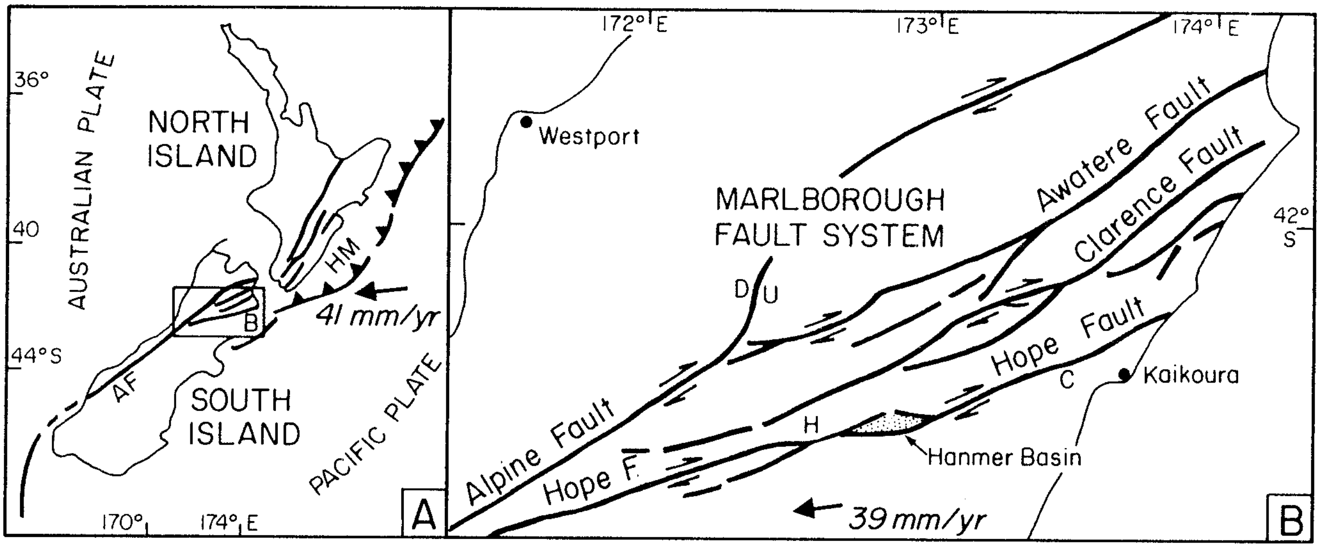


Fig.1 (A) New Zealand plate boundary setting. Abbreviations: (HM) Hikurangi margin oblique subduction zone; (AF) Alpine fault; (B) indicates region of the Marlborough fault system depicted in Figure 1B. Bold arrow is plate motion vector after de Mets et. al. (1990). (B) Marlborough fault system and location of Hanmer basin. Hope fault segments: H - Hope River segment; C - Conway segment. Arrows denote sense of relative horizontal displacement, and letters (U = up; D = down) sense of vertical displacement. Bold arrow represents plate motion vector (after de Mets et. al. 1990).

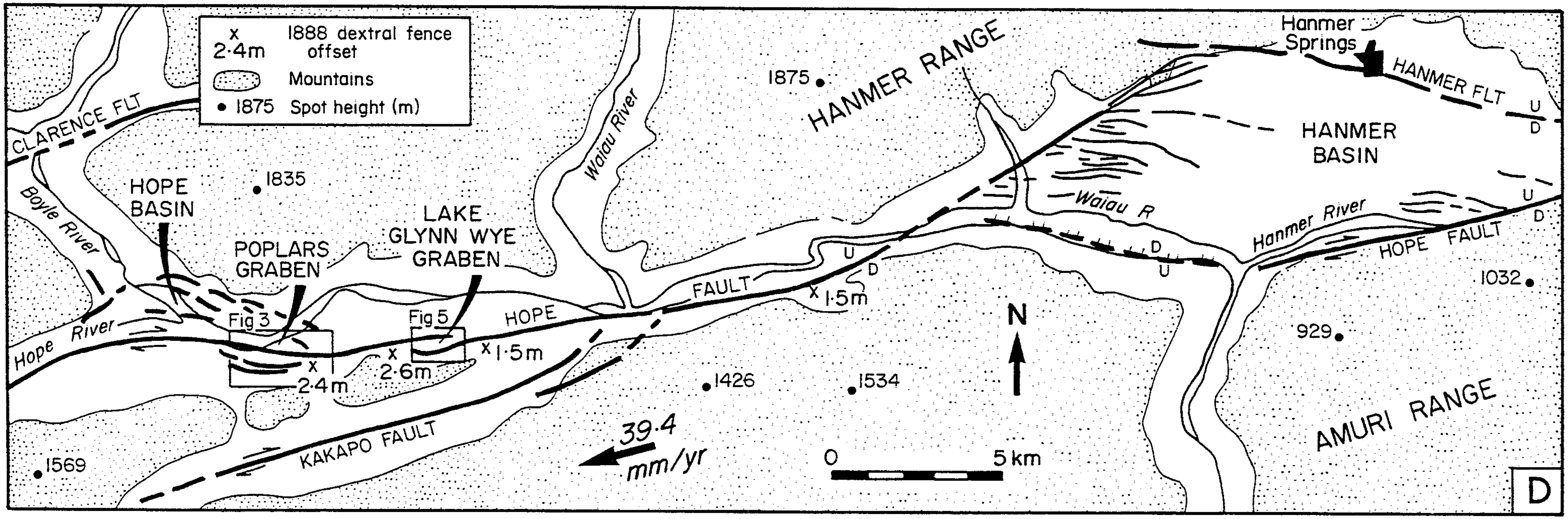


Fig. 2: Map of the Hope river segment of the Hope Fault and subsidiary faults, North Canterbury. Arrows denote sense of relative horizontal displacement, and letters (U = up; D = down) sense of vertical displacement. Bold arrow represents plate motion vector. From Cowan and Pettinga (in prep).

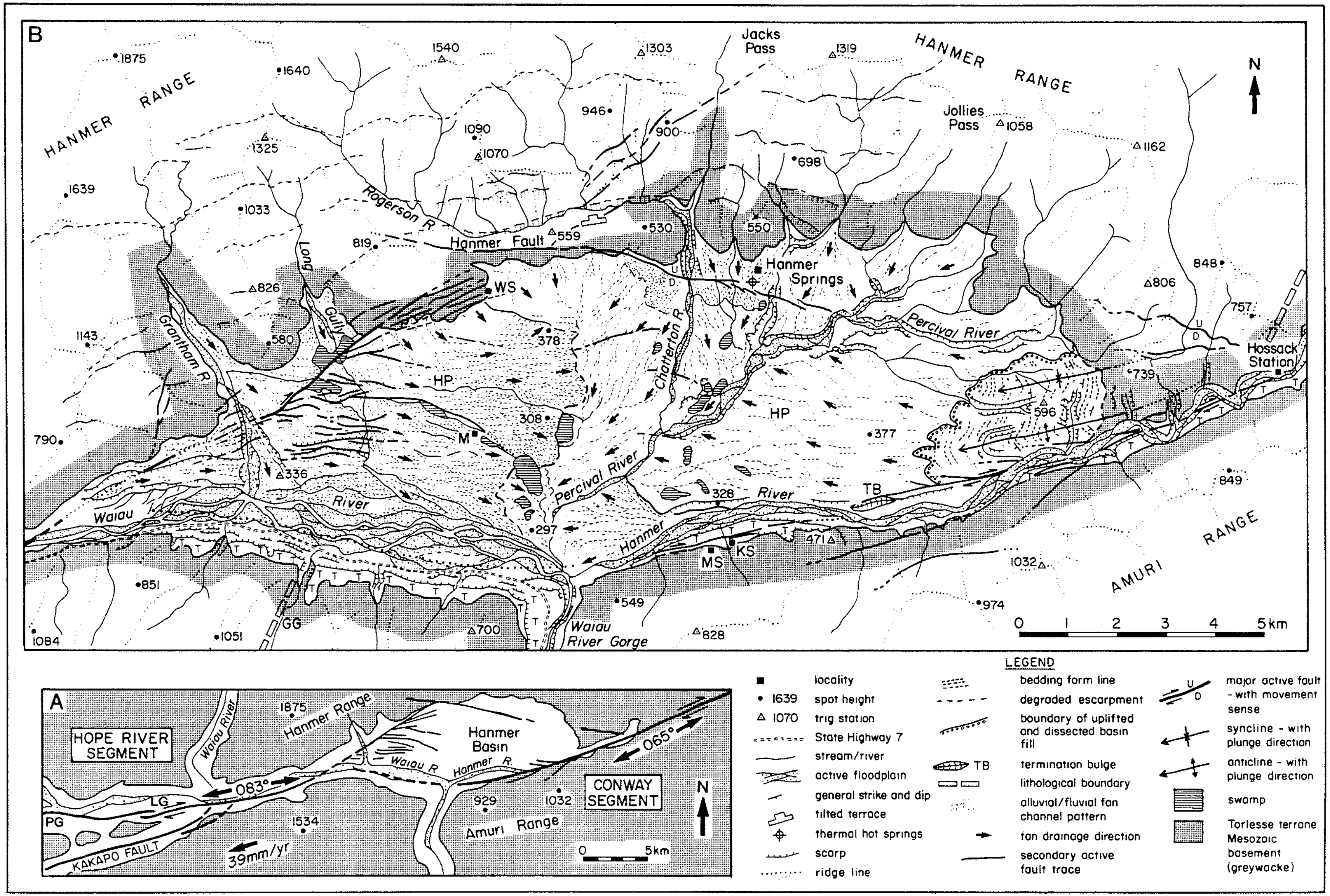


Fig. 3: (A) Structural setting of Hanmer basin at the step-over between the Hope River and Conway segments of the Hope fault. Shading indicates elevated mountainous terrain. Averaged strike of segments is annotated. Bold arrow indicates relative plate motion vector (after de Mets et. al. 1990). LG: Lake Glynn Wye graben; PG: Poplars graben. (B) Geoligic and geomorphologic map of Hanmer basin. Abbreviations: GG - Gabriels Gully; HP - Hanmer Plain; KS - Karaha Station; M - Marchmont Station; MS - Medway Station; TB - pop-up ridge or bulge; T - glacial outwash terrace; WS - Woodbank Station. Dashed/broken lines indicates projected and/or inferred continuation of structures.

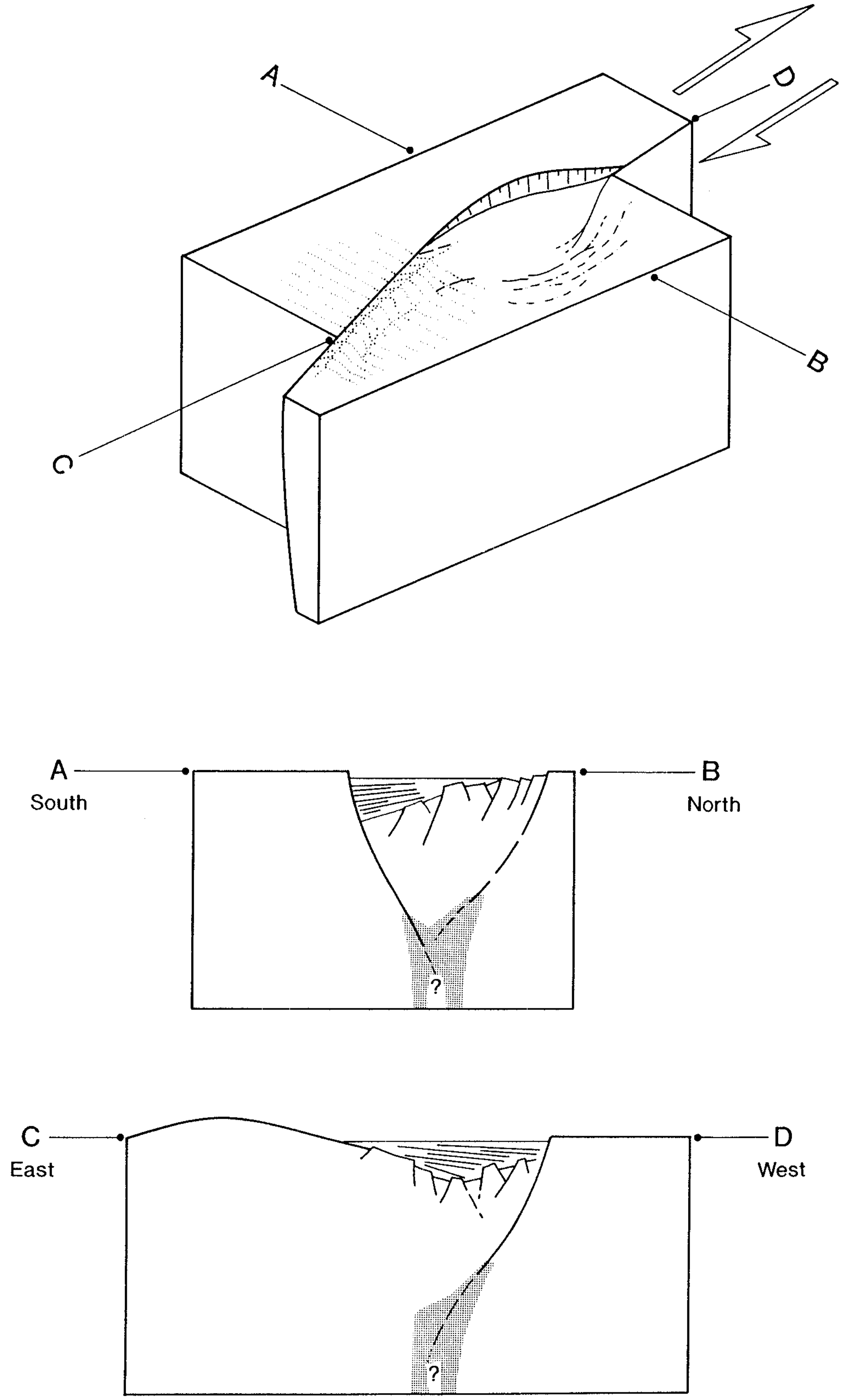


Fig. 4: Schematic block diagram of Hanmer basin depicting present day steady-state stage of evolution. Inferred position of Hope fault zone is indicated at depth by shading.

been mapped on the basin floor. These normal faults have disrupted the alluvial fans, deflecting rivers and sediment sourced from the mountains to the north. A major fault is inferred along the southern margin of the basin, and is hidden beneath the modern Waiau River floodplain.

Hanmer Basin has evolved at a major dilatational side-step or bend in the Hope Fault. The western segment of the Hope Fault is located along the northwest margin of the basin, and terminates in many complex splay faults near Appleby and Woodbank homesteads. The eastern segment of the Hope Fault is mapped along the southeast margin of the basin, east from near the Waiau River Bridge. The total horizontal right-lateral movement on the Hope Fault is probably about 20 kilometres (Freund 1971; McMorran 1991).

An M7.0-7.3 earthquake on 1 September 1888 ruptured the Hope River segment of the Hope Fault and terminated in the Hanmer Basin. About 30 ± 5km of surface rupture has been inferred from the reported effects of this event (Cowan 1991), and fault scarps and landslides attributed to this (and earlier) earthquakes may be viewed in the inferred epicentral area of Glynn Wye.

At Stop 1 observe:

1. Last glaciation aggradation outwash terrace on south margin of basin.
2. Coalescing Holocene alluvial fans sourced from mountains to north side of basin.
3. Fault scarps associated with the termination of the Hope River segment.

At Stop 1 discuss:

1. Tectonic development of Hanmer Basin (see Figure 4).
2. Effects of 1888 North Canterbury Earthquake.
3. Location of hot springs at Hanmer township.

West Hanmer Basin to Glynn Wye:

Our route now follows Highway 7 to the southwest, following the fault controlled valley for about 20km. We cross the Hope Fault trace several times.

Between Glynn Wye and west Hanmer Basin the Hope Fault (with strike of 083°) passes into a zone of transtension subparallel to the azimuth of relative plate convergence (approximately 264°). Several actively subsiding basins occur within this zone of faulting. These basins have a cross-strike dimensions ranging from several hundred metres (Poplars Graben and Lake Glynn Wye Graben) to several kilometres (Hanmer Basin), and are developed at bends and side-steps in the surface trace. Geomorphic evidence indicates a wider zone of transtension involving the mountainous terrain to the north and south of the main trace of the Hope Fault.

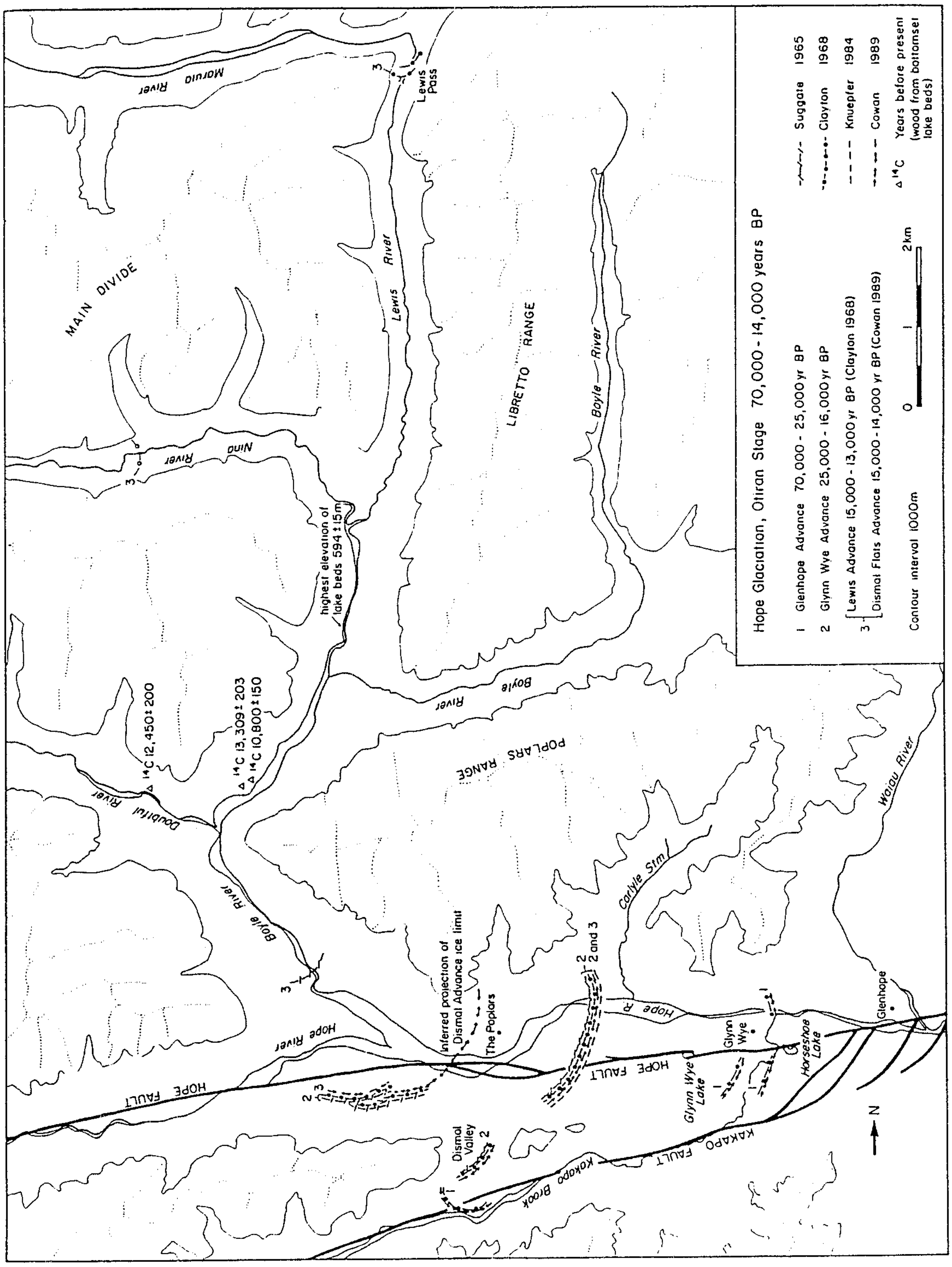


Fig 5: Late Pleistocene ice limits, Hope River catchment (from Cowan 1989).

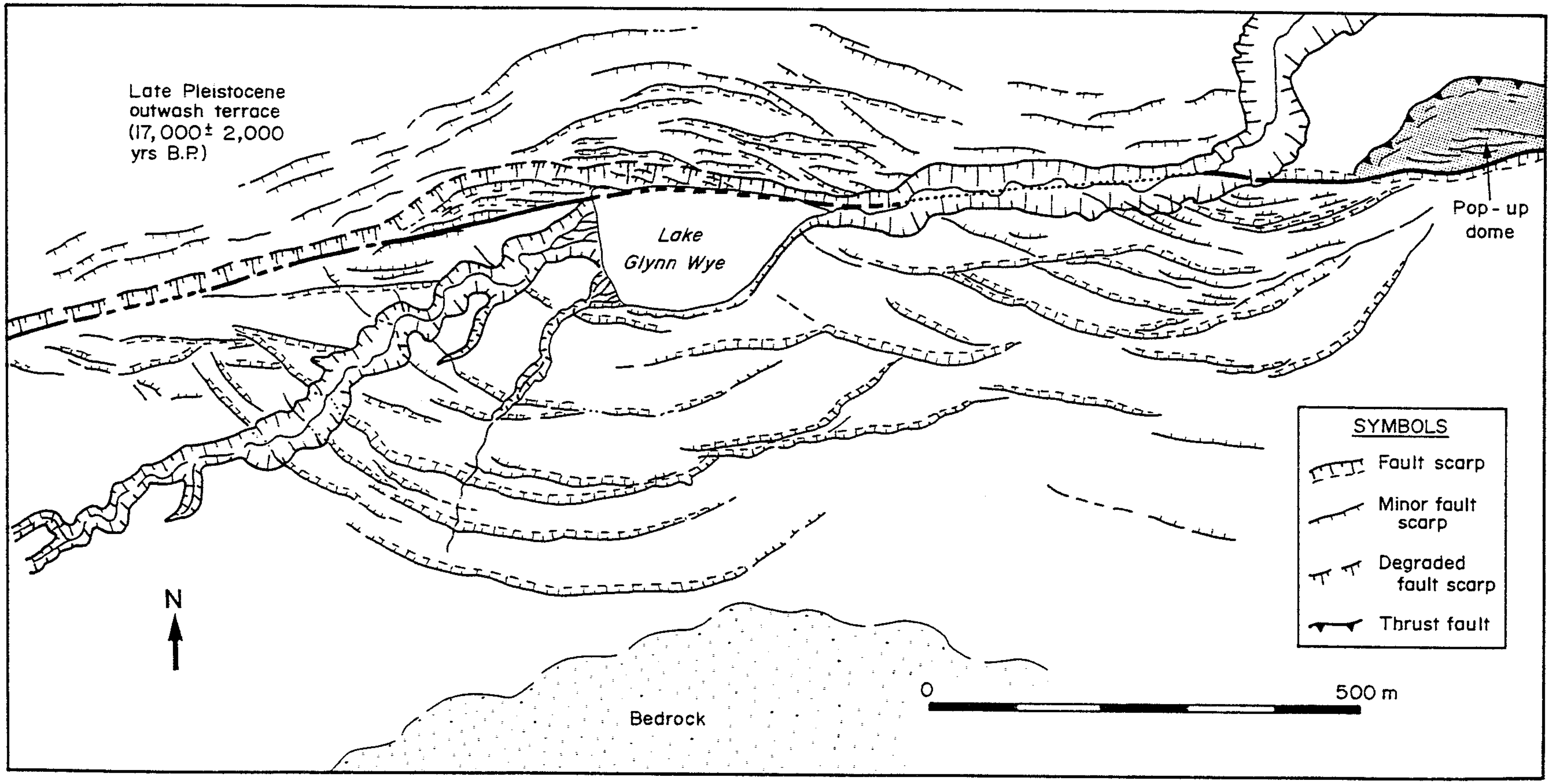


Fig. 6: Sketch depicting fault scarps forming the Lake Glynn Wye graben. From Cowan and Pettinga (in prep).

Introduction to the Geology of the Glynn Wye Area:

The rocks forming the mountainous terrain to the north and south of the Hope River Valley near Glynn Wye Station are Mesozoic greywackes (>100 million years old) and extensive last glaciation outwash and moraine deposits are located in the main valley (Figure 5).

In the Glynn Wye area the Hope Fault is located adjacent to the main valley axis, and displaces the late Pleistocene glacial deposits as well as post-glacial deposits (<12,000 years B.P.). Recent work by Cowan (1989; 1990) has shown a maximum slip-rate on the Hope Fault of 14 ± 3m/kyr at Glynn Wye, during the last 17,000 ± 2,000 yrs B.P, and a rate of 5-7.5 m/kyr on the sub-parallel subsidiary Kakapo Fault to the south west.

When considering the active tectonics of this area, we are "fortunate" to have a relatively well documented historic earthquake, the North Canterbury Earthquake of 1 September 1888 (Hutton 1888; McKay 1890). Cowan (1991) and Cowan & McGlone (1991) in re-evaluating this earthquake concluded it was possibly a characteristic event for the area with a return period of 80 - 200 years and a probable magnitude of 7.0 - 7.3. We will be reviewing some of the relevant data that supports the inferred recurrence interval at Stop 4.

STOP 2: LAKE GLYNN WYE GRABEN: (Figure 6)

At this locality we will stop adjacent to Lake Glynn Wye and walk a short distance up onto the Hope Fault scarp northwest of the lake. This offers us an excellent vantage point to review the geology of the area, especially to see the glacial aggradation outwash surface, the complex faulting which has disrupted this originally sub-horizontal reference plane to form the depression in which the lake is now situated.

At Stop 2 observe:

1. Extensive aggradation terrace of glacial origin, with inferred age of 17,000 ± 2,000 years B.P. (Evidence for the age of the terrace will be discussed at Stop 3).

2. Main trace of the Hope Fault, the 200m strike-normal step-over width of the graben; and

3. The many subsidiary normal faults which form the Lake Glynn Wye Graben, and extensional jog in the Hope Fault.

At Stop 2 discuss:

1. The relative horizontal and vertical displacements on faults;

2. The origin of the Lake Glynn Wye Graben, associated with a double releasing bend in the Hope Fault surface trace;

3. Glacial landforms and deposits

4. 1888 North Canterbury earthquake, and the decrease in recorded displacements from 2.6m west of, to 1.5m east of Lake Glynn Wye;

STOP 3: GLYNN WYE MORAINE AND POPLARS GRABEN (Figures 7 - 10)

East of the Hope and Boyle Rivers junction (see Figure 5) a late Pleistocene (17,000 ± 2000 yrs B.P.) terminal moraine forms a broad, subdued undulating ridge across the high terrace, at an elevation of about 160m above the Hope River. The west face of the moraine is a 12m high terrace riser (R1). The associated terrace tread (T1) (Figures 8 and 9) extends several hundred metres to the west, where a second riser (R2) drops to the tread of a second small terrace remnant (T2), which in turn drops to a former river channel (T3).

The Hope fault traverses and dextrally offsets the moraine and two terrace risers, but only a small remnant of R2 is preserved on the north side of the fault.

A large graben extends from the Hope - Boyle Rivers junction to the Glynn Wye moraine, and marks a change in the trend of the Hope Fault from about 069° to the west, to 080° to the east. Most of the graben is obscured beneath the active Hope River floodplain, but its eastern end disrupts the terrace surfaces and moraine, and is known as Poplars Graben.

Poplars Graben extends about 700 - 1,000 metres south of the Hope Fault, and at least 500m to the north (Figures 7 and 8). The graben is expressed at the surface by ridge-rents and large slumps on the bedrock slopes to the south, and numerous normal faults dissecting the terrace surfaces and moraine. These faults form a complex ramp and horst structure in the late Quaternary glacial cover deposits.

On the north side of the fault, and near the east end of Poplars Graben a 20m high, 300m long doubly-plunging pressure ridge has buckled up the meltwater terrace surface, this pop-up structure has formed at a minor 15° - 20° restaining bend in the Hope Fault (Figure 9).

A detailed summary of the geomorphology and structure of the Hope Fault and Poplars Graben is given in Figure 9. The variations in displacement of the equivalent age moraine and meltwater terrace risers is reconciled geometrically in Figure 10.

At Stop 3 observe:

1. 1888 North Canterbury earthquake rupture.

2. Ground deformation across a wide zone along the main Hope Fault trace.

3. Offset by up to 230 ± 20 metres of the depositional face of the terminal moraine.

4. Many normal faults, making up Poplars Graben.

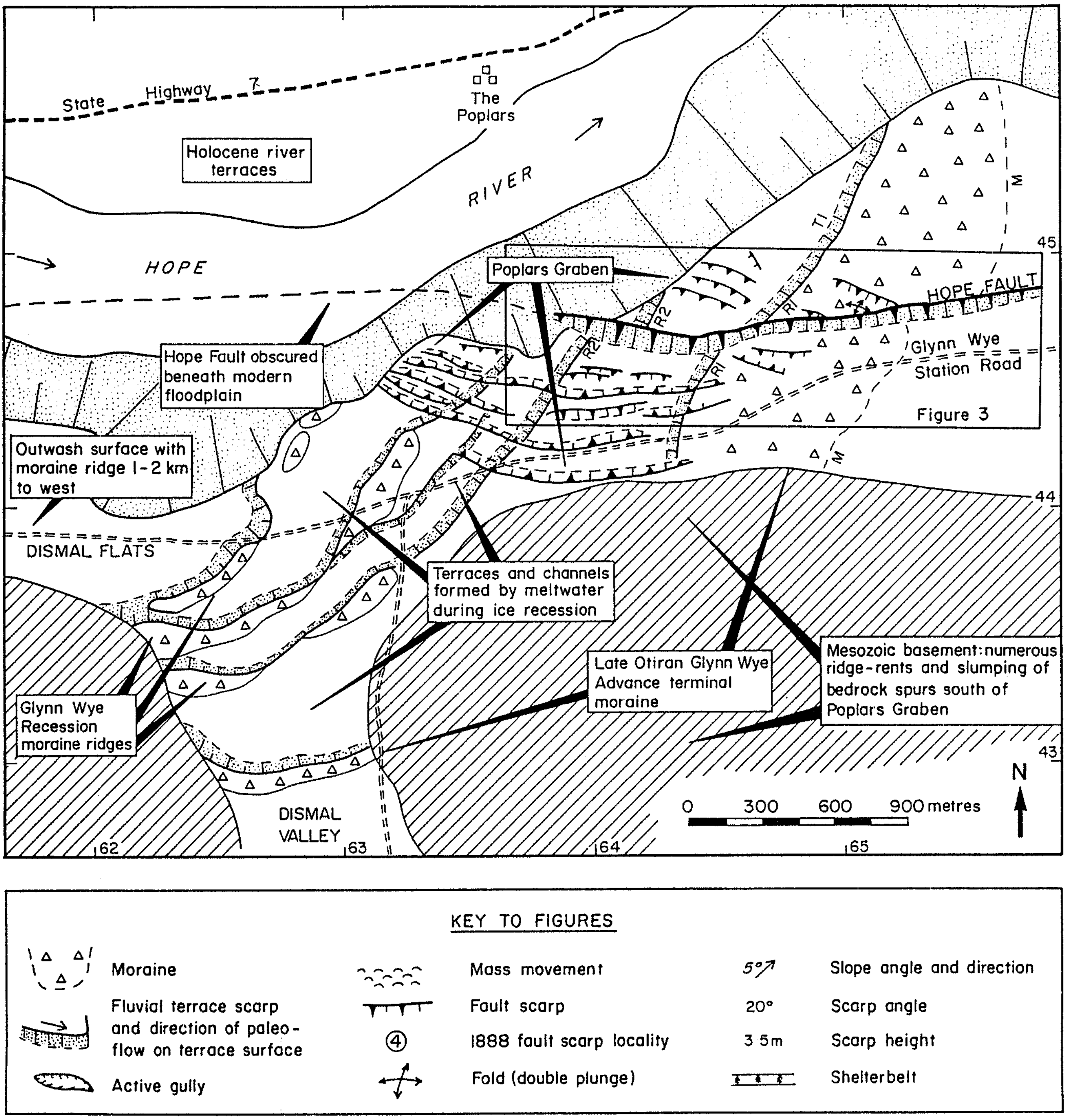


Fig. 7: **Geomorphic and structural elements of the Glynn Wye moraine complex, showing the relationship between the Hope Fault at Poplars Graben and the suite of faulted moraines and meltwater terraces (from Cowan, 1990).**

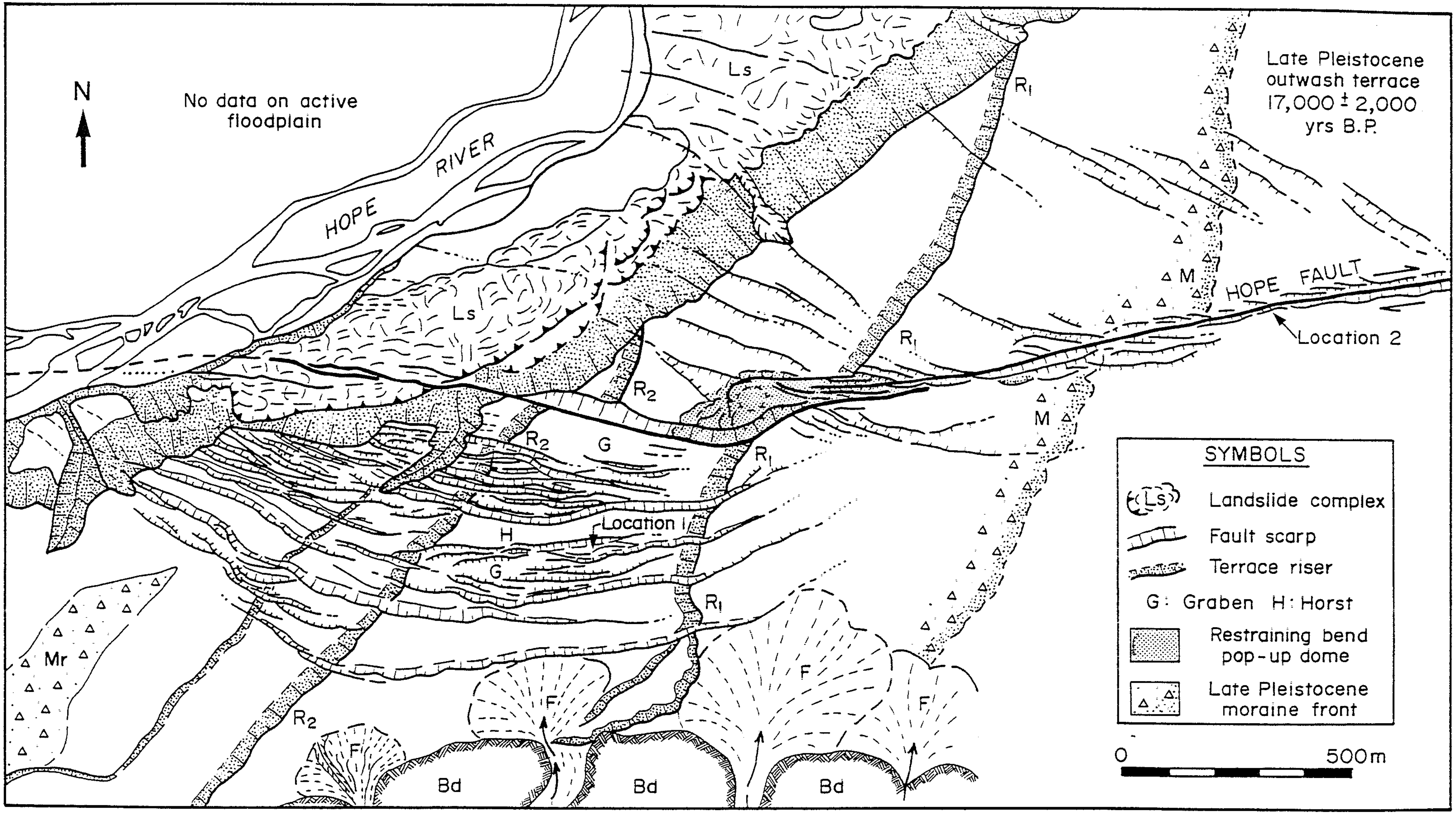


Fig. 8: Map depicting geomorphology and structure of the Hope Fault zone at Poplars Graben. Location 1: small-scale sag basin; Location 2: 1888 fence offset of 2.4m dextral strike-slip. Abbreviations: (M) - Late Pleistocene Moraine, and recessional meltwater terrace risers (R1) and (R2). Vertical aerial photo map base (Run CT184), courtesy of NZ DSIR Geology and Geophysics. Cowan and Pettinga (in prep).

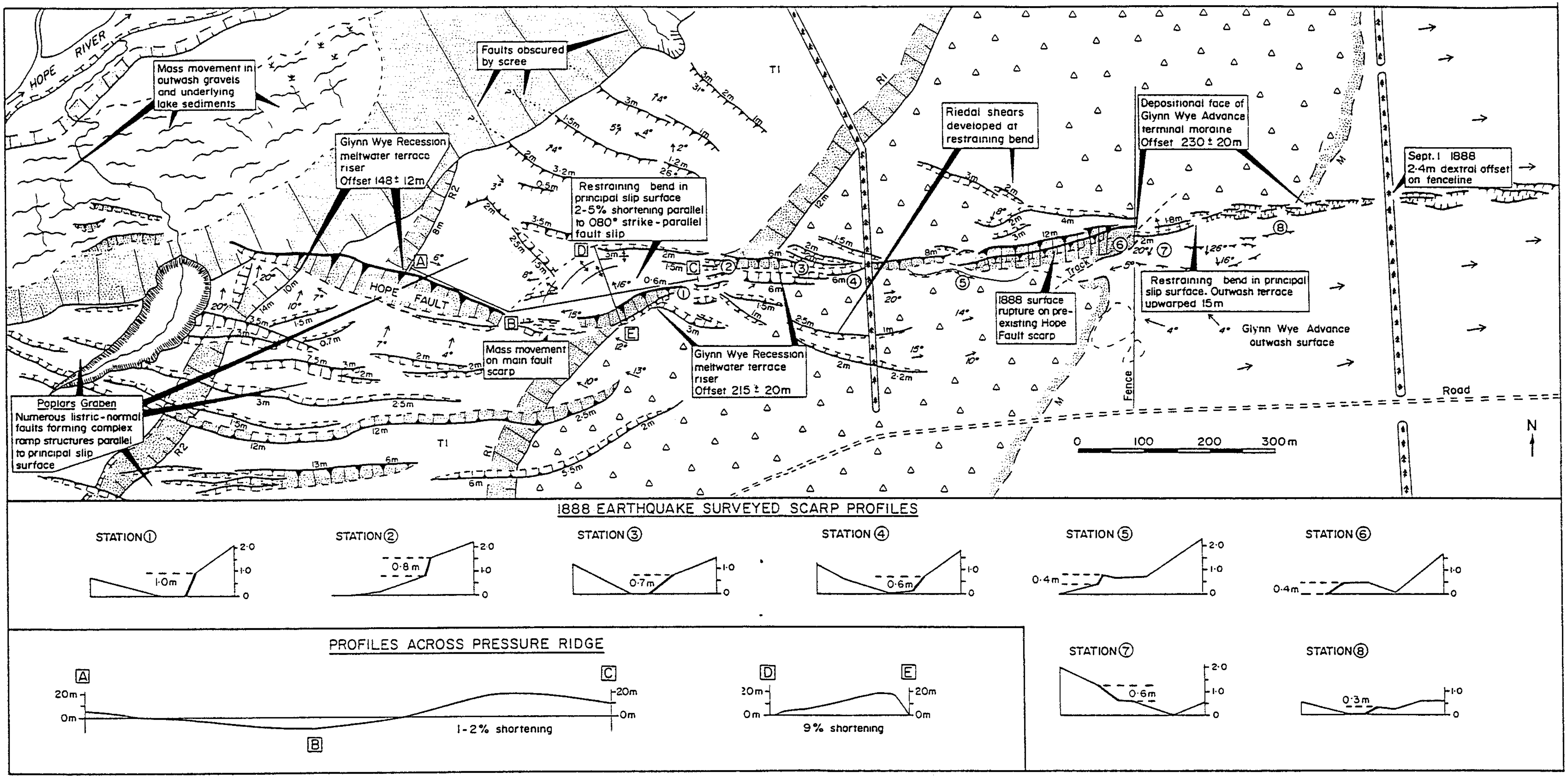


Figure 9: Geomorphology and structure of the Hope Fault at the Glynn Wye Moraine complex. The dextral offsets on moraine (M), and terrace risers (R1 and R2) are shown. Numbered localities 1-8 on this map refer to 1888 fault scarp profiles illustrated below. From Cowan (1990).

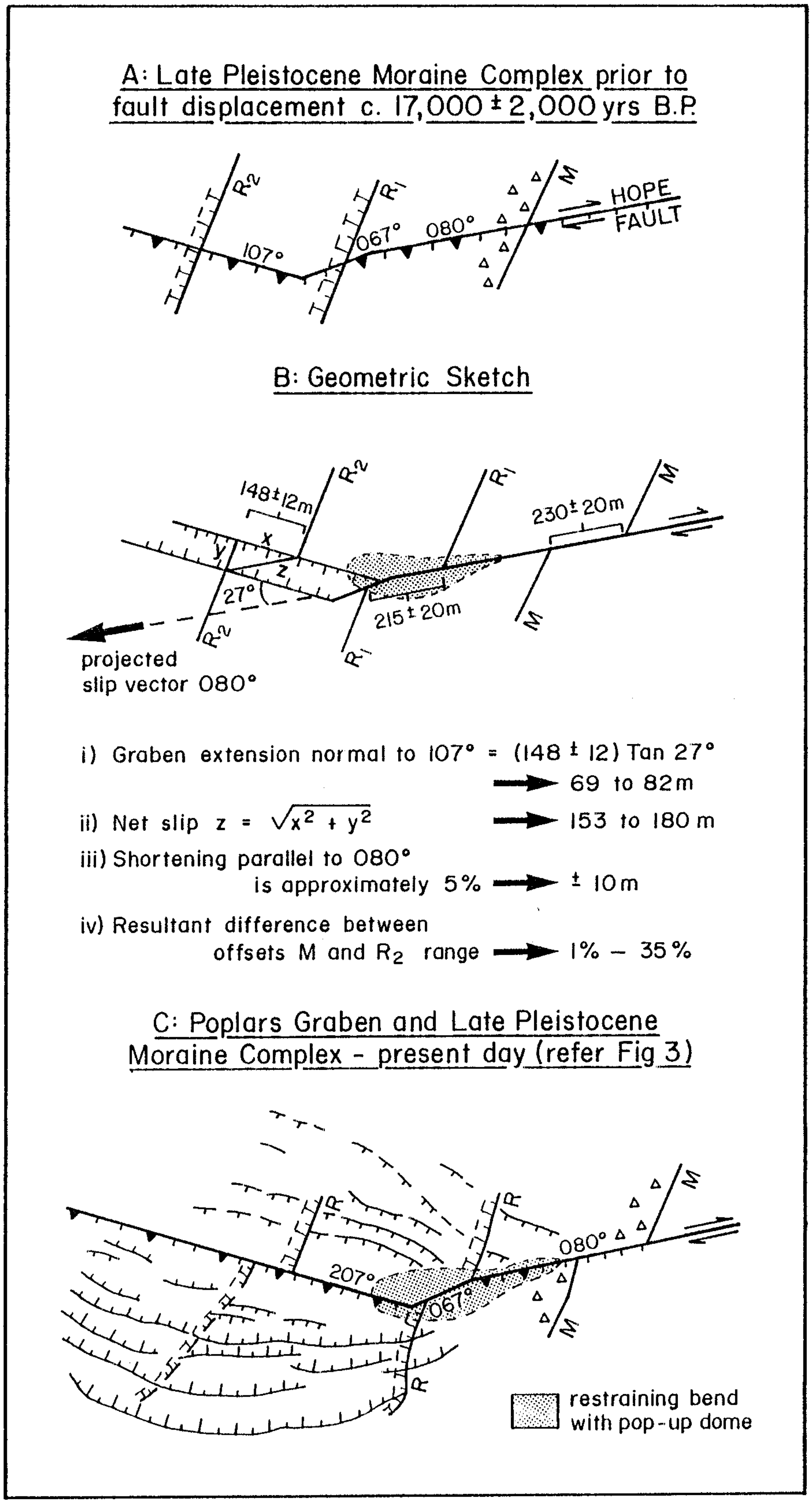


Figure 10: The dextral offsets at Poplars Graben showing partitioning of strike-parallel and strike-normal displacement, indicated by variations in strike-parallel offset on features of near equal age. Abbreviation: (M) - Late Pleistocene Moraine, and associated meltwater terrace risers (R1) and (R2). From Cowan and Pettinga (in prep).

5. Pop-up ridge formed at restraining bend in Hope Fault at eastern end of graben.

6. Offset of two meltwater terrace risers, R1 and R2 by 215 ± 20m and 148 ± 12m, respectively.

At Stop 3 discuss:

1. Position of the Hope Fault to the west.

2. Glacial chronology and evidence for various late Pleistocene glacial advances.

3. Reconcile the variations in right-lateral displacement of geomorphic features of near equal age.

Time permitting the group will traverse Poplars Graben and observe aspects of valley development since ice withdrawal. The adjacent slopes of the high-level terrace are affected by mass movement complexes, one of these has yielded C^{14} samples that probably date the landslide, which may have been triggered coseismically.

From this stop we will return to Highway 7 and return to Horseshoe Lake.

STOP 4: HORSESHOE LAKE TO MANUKA CREEK (Figures 11 - 15)

At this locality we have an opportunity to see the detailed micro-topography commonly produced by strike-slip faulting.

Horseshoe Lake is located in an abandoned channel of the Hope River and a tributary, Kakapo Brook (Figures 11 and 12). The lake formed in response to landsliding from the northern valley side. Two small swamps located a little further to the east (down valley) have recently been trenched (Figure 13) and yielded samples for radiocarbon dating of previous episodes of silt deposition. Based on the detailed trench stratigraphy on each side of the main trace of the Hope Fault, pollen analysis, and displaced degradation terraces it has been possible to estimate an average recurrence interval between characteristic earthquakes and also a well constrained slip-rate during the late Holocene (Last 3,500 years) (Figures 14 and 15) (Cowan 1989 Cowan and McGlone 1991).

The last movement on the Hope Fault at this locality occurred during the 1888 North Canterbury earthquake, and amounted to approximately 1.5 metres of right-lateral displacement.

At Stop 4A observe: (Figures 11 and 12)

1. the landslide forming Horseshoe Lake;

2. the Hope Fault trace at the western end of the lake, and the collapse depressions adjacent; and

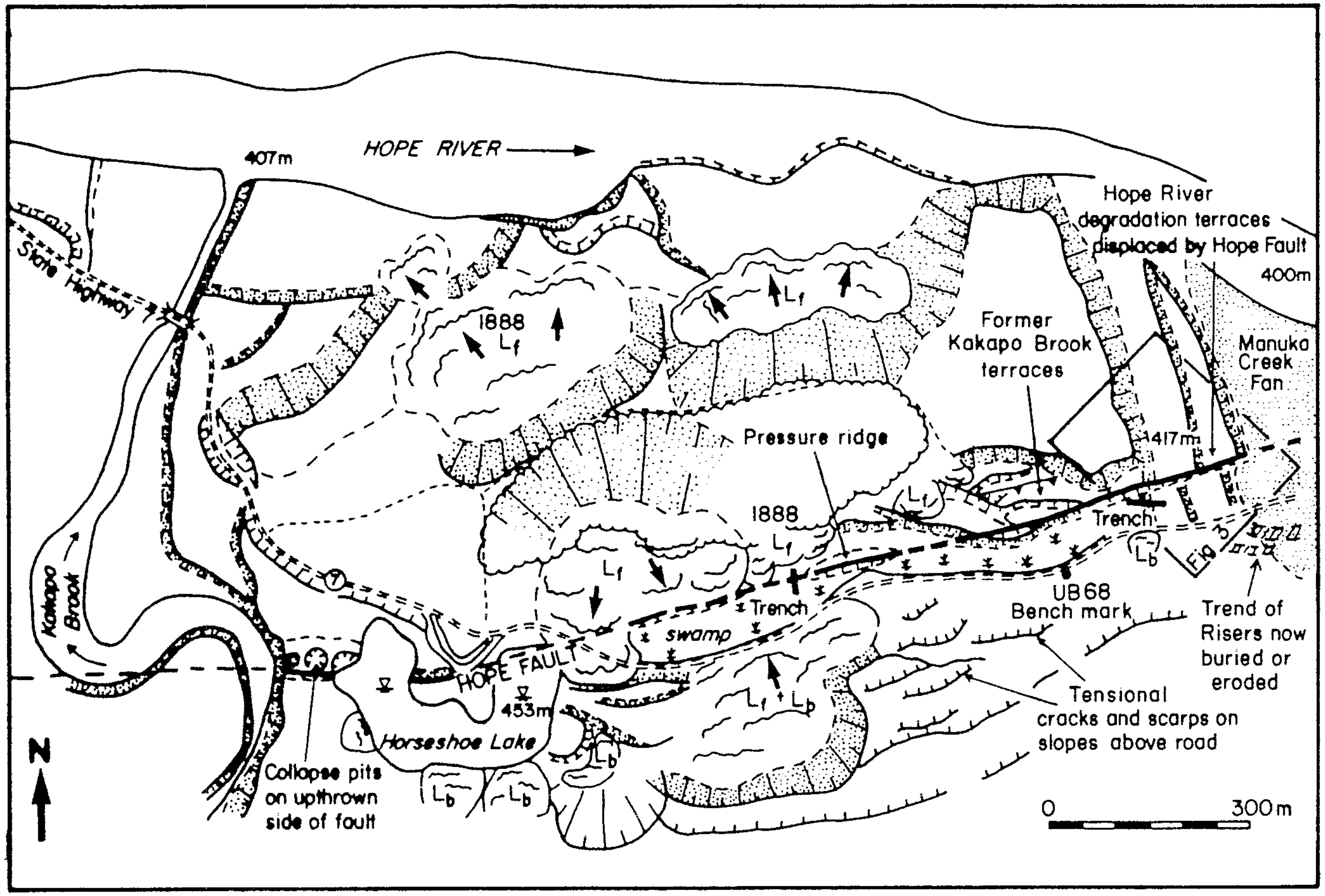


Figure 11: Geomorphic map of the area near Horseshoe Lake, where displaced late Holocene degradational terraces of the Hope River were formed across the abandoned ancestral mouth of Kakapo Brook. Also depicted is the landslide which dammed Horseshoe Lake. Landslides caused by the 1888 North Canterbury earthquake are labelled; the symbols Lf and Lb denote landslides in fluvioglacial deposits and sheared greywacke bedrock respectively. Trench sites are also shown. Cowan and McGlone (1991)

The Kakapo Brook and a braid of the Hope River occupy a floodplain more than 40 m above the present day and flow through the valley along the Hope Fault, forming an island in the centre of the valley.

River downcutting has lowered the floodplain level to approximately 17 m above the present and repeated faulting has moved the valley entrance away from the mouth of Kakapo Brook which is incised within a gorge south of the fault. Only a small stream is now active in the valley along the Hope Fault, but the valley may be subject to inundation by the Hope River during flood events.

During an earthquake on the Hope Fault a large landslide is triggered in outwash gravels mantling the ridge slopes to the north of the fault. The landslide blocks the valley and initiates the formation of Horseshoe Lake.

Kakapo Brook and Hope River have incised a further 17 m and a swamp now occupies the old stream channel to the east of Horseshoe Lake. The lake is impounded on its western margin by river gravels and lake sediments which have been upthrown to the north and tilted to the east during repeated faulting events.

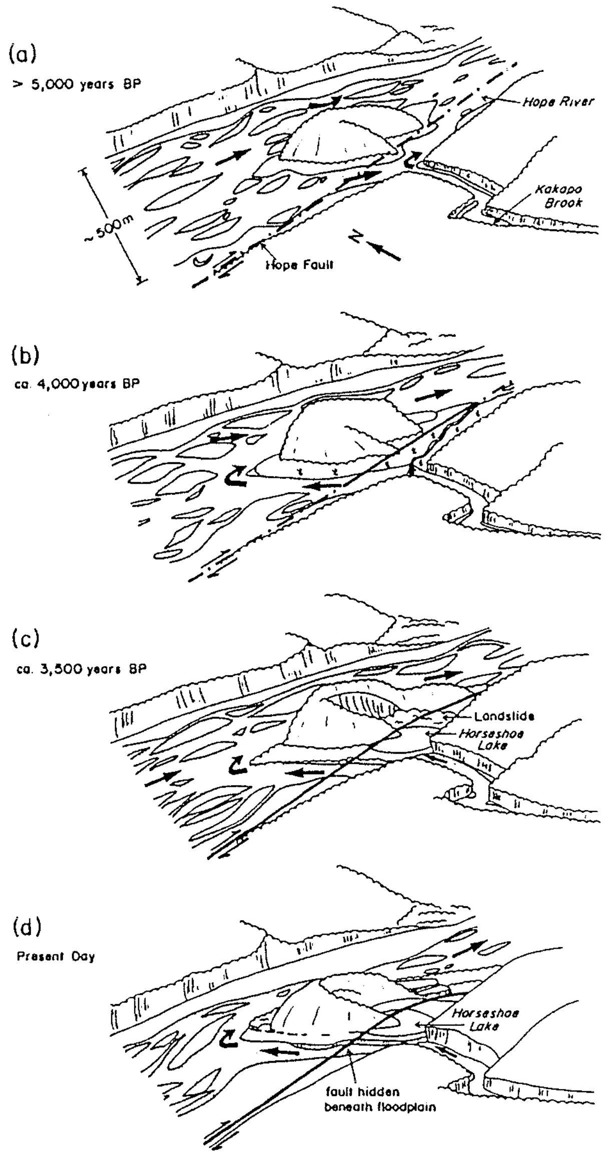


Fig. 12: **Interpreted sequential geomorphic history during Late Holocene of the area along the Hope Fault between Horseshoe Lake and Manuka Creek. From Cowan (1989).**

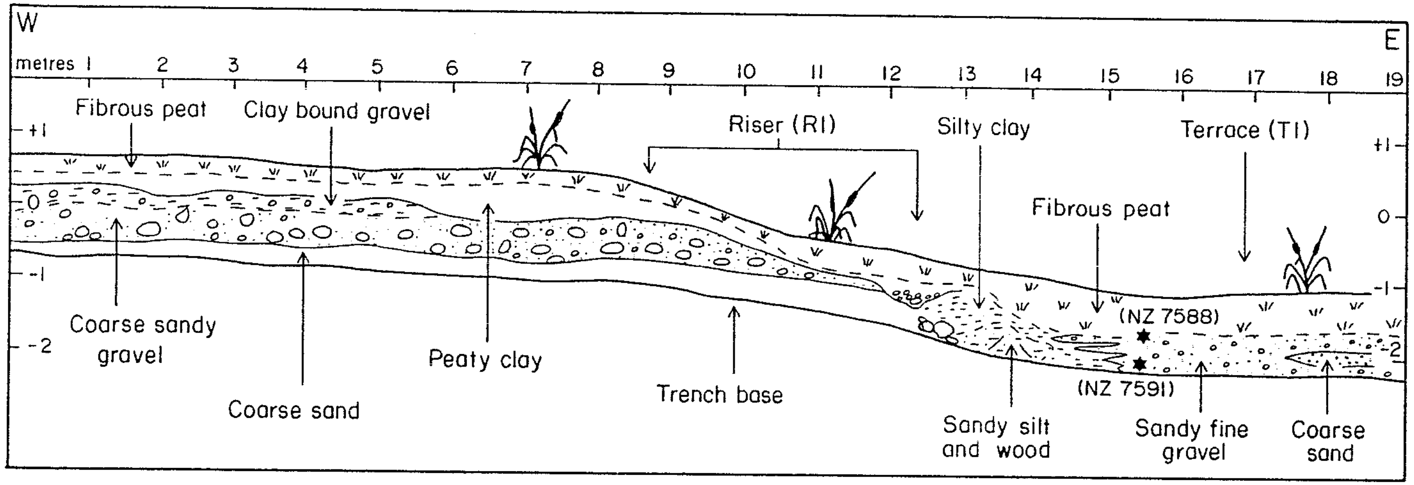


Fig. 13a: Logged section along the north wall of the trench shown in Fig. 15, showing the location of radiocarbon samples and cross cutting relationships between the abandoned Kakapo Brook channel stratigraphy (0-12m), and the Hope River degradation terrace (T1 (12-19m).

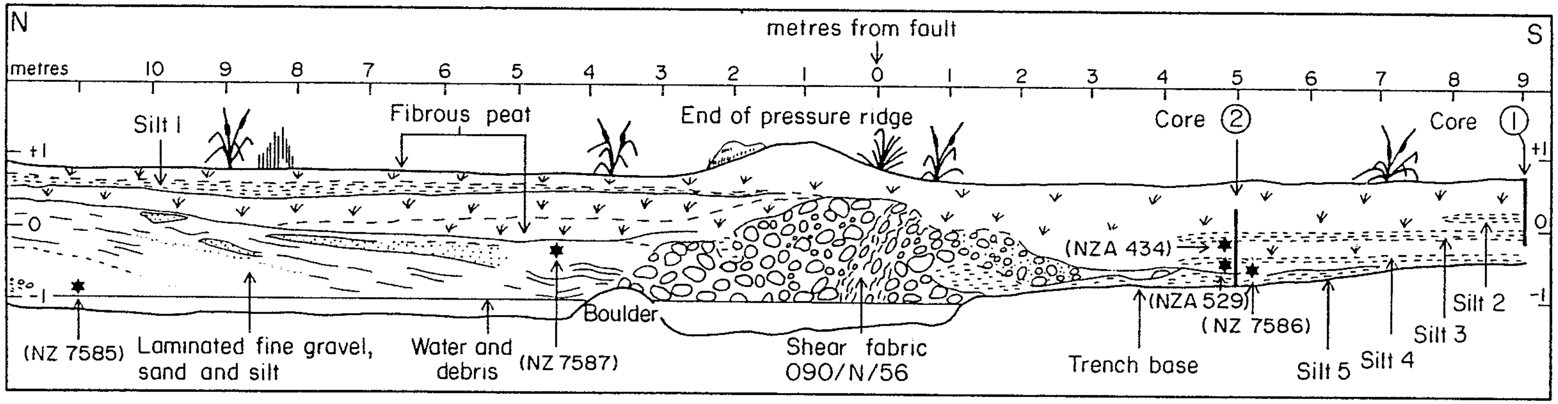
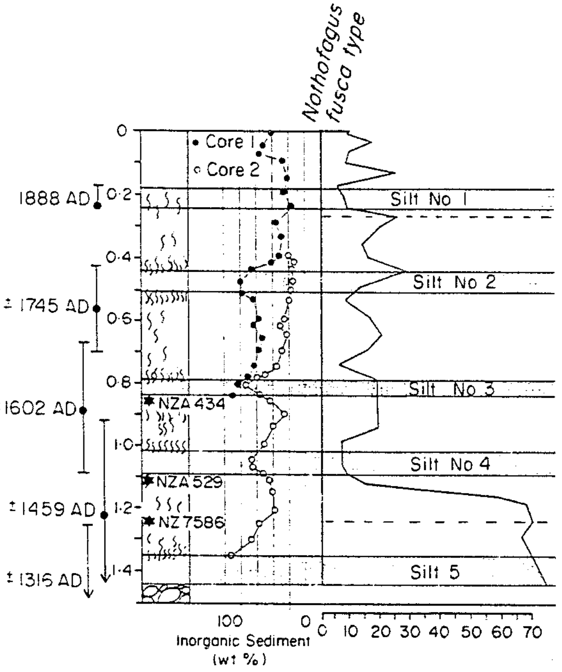


Fig. 13b: Logged section along the east wall of the trench dug across the Hope Fault and pressure ridge in the swamp east of Horsehoe Lake. Laminated sediments on the north side of the fault are more than 3,000 radiocarbon years old, and are inferred to have been deposited close to the time the channel was abandoned. The fluvial sediments are unconformably overlain by fibrous peat, which attains a maximum thickness of 1.5m on the south side of the fault. Radiocarbon dates from peat cores indicate that the base of the swamp is approximately 700 years old. Five layers of silt within the peat are attributed to sediment runoff from slope failures following the 1888 earthquake (Silt no. 1, north of fault) and four prehistoric events (Silts 2-5, south of fault).



Recurrence intervals for silt deposition at Horseshoe Lake[2] calculated from the thickness of peat between silt layers.

	Depth of mid-point in silt layer	Peat thickness between silt layers	Recurrence interval[1,3] for silt deposition
Silt No. 1	- 0.23 m	0.23 m	Elapsed time = 100 yr
Silt No. 2	- 0.47 m	0.24 m	+ 35 102 yr - 21
Silt No. 3	- 0.82 m	0.35 m	+ 51 149 yr - 30
Silt No. 4	- 1.06 m	0.24 m	+ 35 102 yr - 21
Silt No. 5	- 1.35 m	0.29 m	+ 43 123 yr - 25

1. Recurrence intervals estimated using mean peat accumulation rate of 2.35 ± 0.6 mm/yr from Table 2.
2. See Figs. 5 and 6 for stratigraphic locations.
3. Errors are the product of: depth divided by maximum accumulation rate (lower bound), depth divided by minimum accumulation rate (upper bound).

Fig. 14: **Recurrence intervals for silt deposition at Horseshoe Lake calculated from the thickness of peat between silt layers, related to composite diagram of peat and silt stratigraphy from cores taken in Trench 1. Radiocarbon samples are shown by stars. Results on loss-on-ignition tests are shown as variations in the amount of inorganic sediment within the samples peat cores. The inferred stratigraphic positions of "characteristic" earthquakes, estimated from the late Holocene terrace offsets and 1888 horizontal displacement are indicated by the calendar dates adjacent to column. After Cowan and McGlone (1991)**

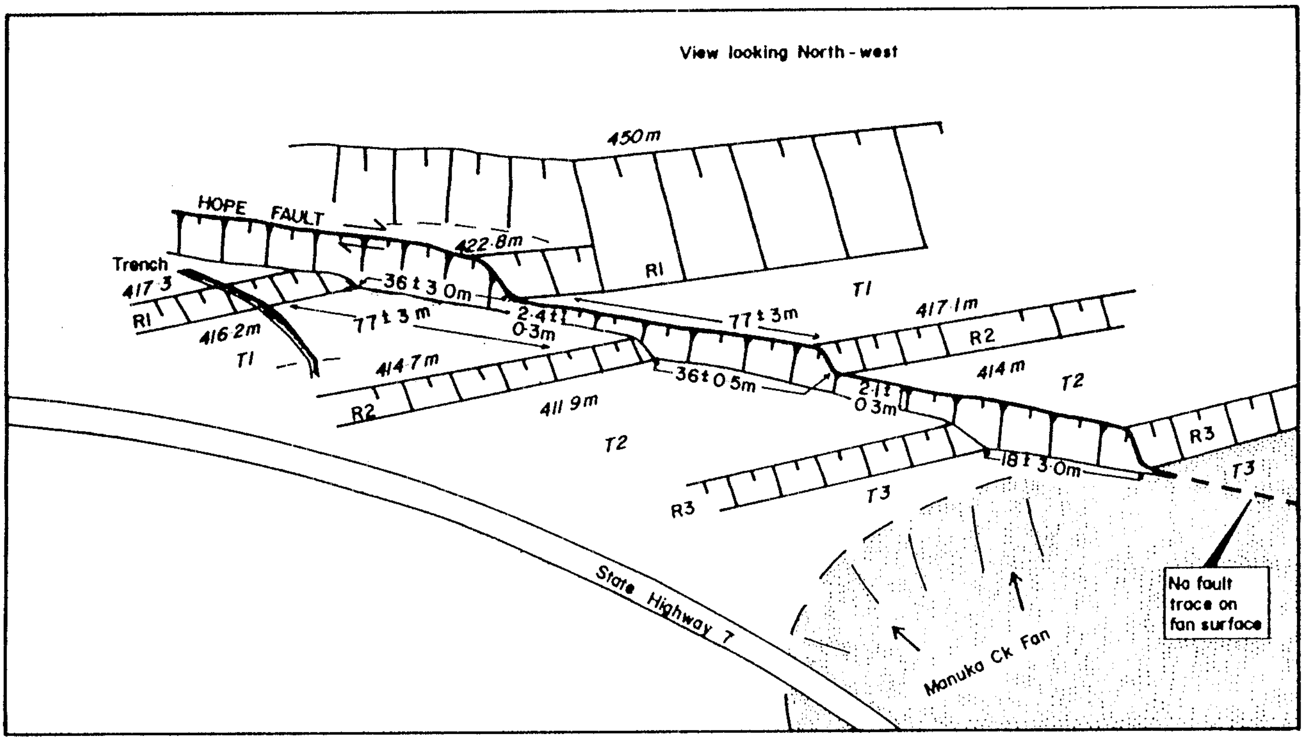


Figure 15: Late Holocene dextral fault displacements at Manuka Creek. From Cowan and McGlone (1991).

3. the amount of stream/river degradation since this small valley was abandoned by the Hope River and Kakapo Brook.

<u>At Stop 4A discuss</u>:

1. origin of Horseshoe Lake;

2. Mid Holocene Hope River - Kakapo Brook confluence, and subsequent degradation and abandonment of the valley.

<u>At Stop 4B observe</u>: (Figures 13 and 14)

1. Trench Site 2 in upper swamp;

2. trace of the Hope Fault;

3. pressure ridge along the Hope Fault trace, and its control on swamp development; and

4. flight of degradation terraces and low fault scarplets on the north side of the valley.

<u>At Stop 4B discuss</u>:

1. micro-topography associated with Hope Fault; and

2. trench logging and data interpretation, significance of 5 silt-layers within a 1.5m column of peat, 700 year base of swamp age determination based on radiocarbon dating giving a peat accumulation rate of 2.35 ± 0.6mm/yr, importance of pollen analysis reported by Cowan and McGlone (1991); recurrence interval for silt layer deposition between 81 - 200 years consistent with characteristic earthquake model; and

3. origin of terraces on north and south sides of valley

<u>At Stop 4C observe/discuss</u>: (Figure 15)

1. Evidence for progressive displacement of fluvial degradation terraces;

2. determination of 10.5 ± 0.5m/kyr slip rate based on 36m displacement of degradation terrace dated at 3,433 ± 130 years (from trench 1 - see Figure 13a), consideration of characteristic event displacement; and

3. paleoseismic history, recognition of 5 previous earthquake events, and their significance with respect of hazard assessment.

A full account of the relevant data obtained at this site is given in Cowan and McGlone (1991).

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LATE QUATERNARY TECTONICS, CLIMATE CHANGE AND LANDSCAPE EVOLUTION, AMURI - WAIPARA REGIONS - NORTH CANTERBURY.

TOUR LEADERS:

Philip J. Tonkin, Department of Soil Science, Lincoln University and
Jocelyn K. Campbell, Department of Geology, University of Canterbury.

INTRODUCTION

This tour traverses the Hanmer basin and gorge, Amuri plain, the MacDonald syncline, the Waipara gorge and plain, the Cass anticline and Glenafrick coastal marine terraces.

The northeastern region of the South Island lies immediately adjacent to, and southeast of the Australia-Pacific plate boundary zone. The Amuri and Waipara regions lie to the south of the Hope fault, and the basin and range landform evolution is primarily influenced by oblique thrust and reverse faulting and associated folds as well as a discontinuous hybrid system of strike-slip and thrust faults along the evolving Porters Pass Tectonic zone. Basement low-grade metasediments are exposed in the core of the ranges and are flanked by questa-like hills formed in the thin (up to about 1 km) sedimentary cover-rock sequence of Late Cretaceous to Early Pleistocene age. The basins have infills of gravelly alluvium, with multiple periods of sedimentation dating from the mid Pleistocene and adjacent rolling landscapes are mantled with coeval loess cover beds. Periods of valley and basin aggradation and associated loess deposition are interpreted as a response to global climate change, promoting episodes of erosion within glaciated and non-glaciated drainage basins. Sequences of fill, cut-fill and strath terraces are a feature of basin margins where base levels of erosion have adjusted to uplift rates (c. 0.5 to 1.5 mm yr^{-1}) between periods of valley aggradation. Late Holocene strath terraces predominate where rivers have cut gorges across the major uplift blocks and anticlines. Along the east coast, regional tectonic uplift has resulted in a flight of coastal plain and marine terraces dating from the last and possibly the penultimate interglacial. Sites have been selected that illustrate; the effect of the tectonic regime on the development of the basin and range landscape, episodes of basin aggradation and degradation, and the response of rivers to the combined effects of sediment storage and transfer and base level change, and of the uplift and dissection of the coastal plain and marine terraces.

The tour route, is shown on figure 1 and the tectonic setting illustrated in figures 2 and 3.

ROUTE COMMENTARY

Stop 1. HANMER GORGE - MARBLE POINT (figure 4).

The gorge is incised into Mesozoic Torlesse basement sandstones and siltstones and conglomerates and two Tertiary outliers. The dominance of strath terraces, indicates progressive valley incision in response to continued, intermitted tectonic uplift. At this site a folded outlier of lower Tertiary sedimentary rocks is bounded by thrust and oblique-slip faults. This site illustrates many of the features typical of the structural style south of the Hope Fault.

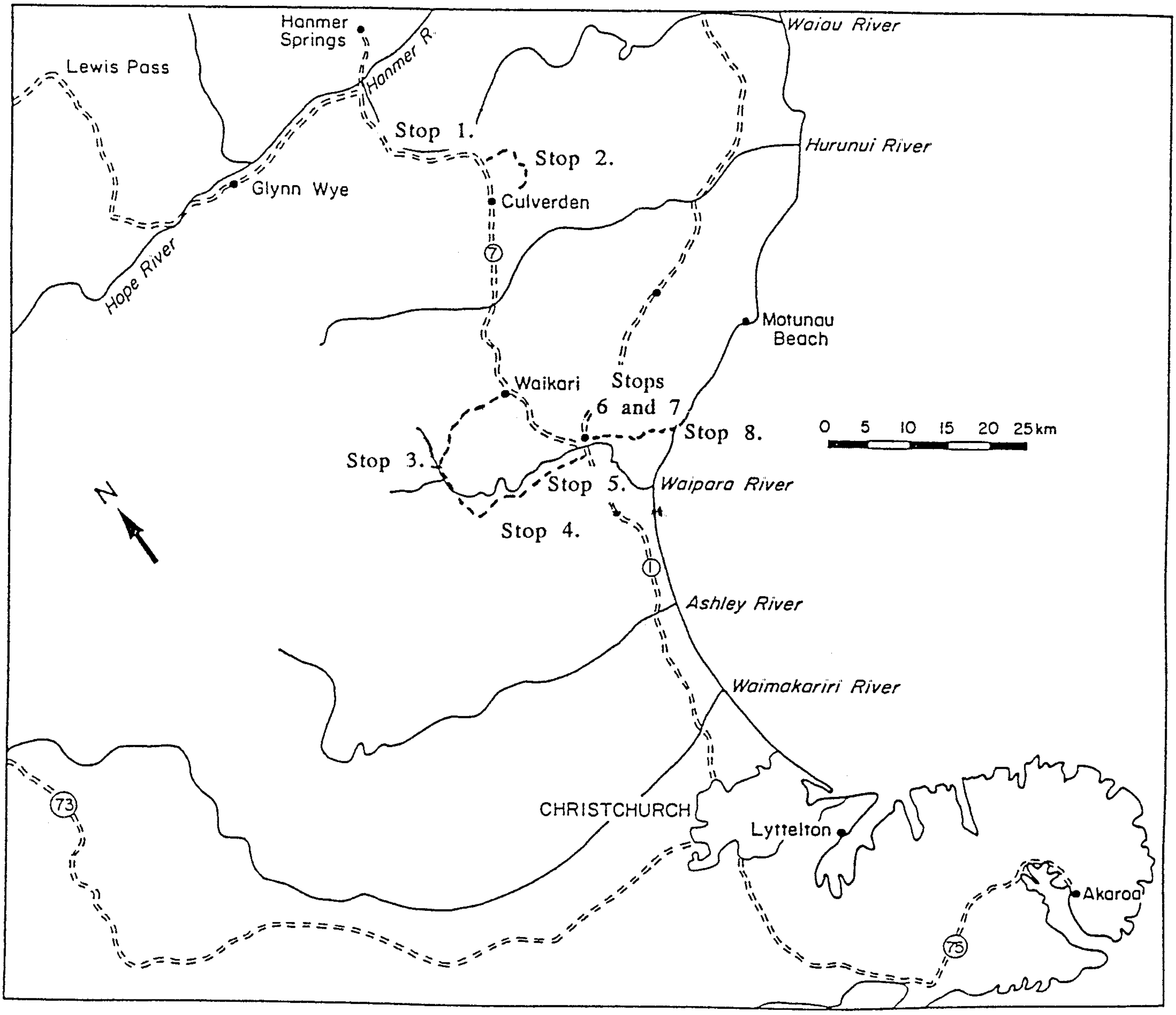


Figure 1: Tour route, Amuri - Waipara regions, North Canterbury.

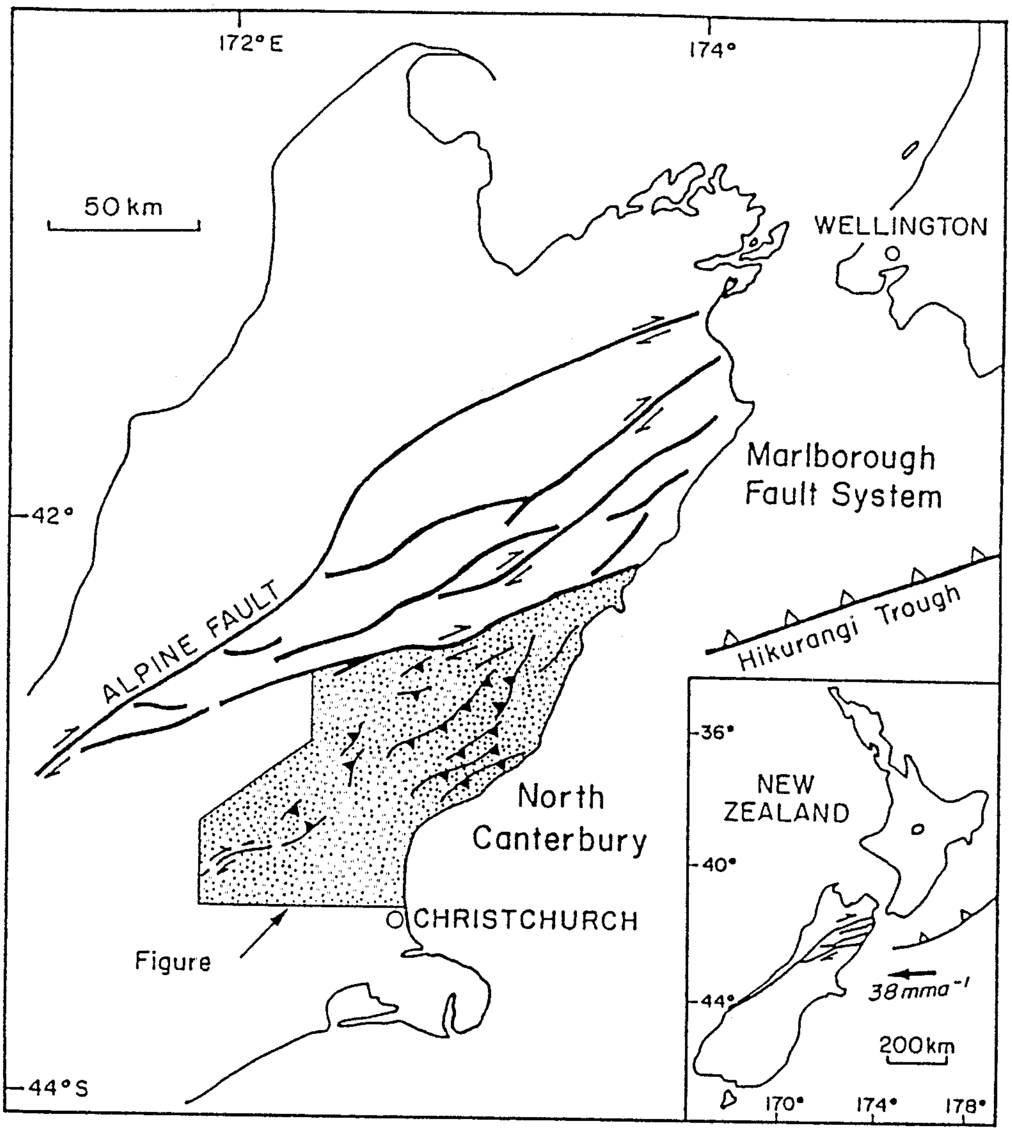


Figure 2: Plate boundary setting of the North Canterbury region. Major elements of the Marlborough Fault System in northern South Island are depicted. North Canterbury region is shaded (refer Figure 3); Hope Fault (H).

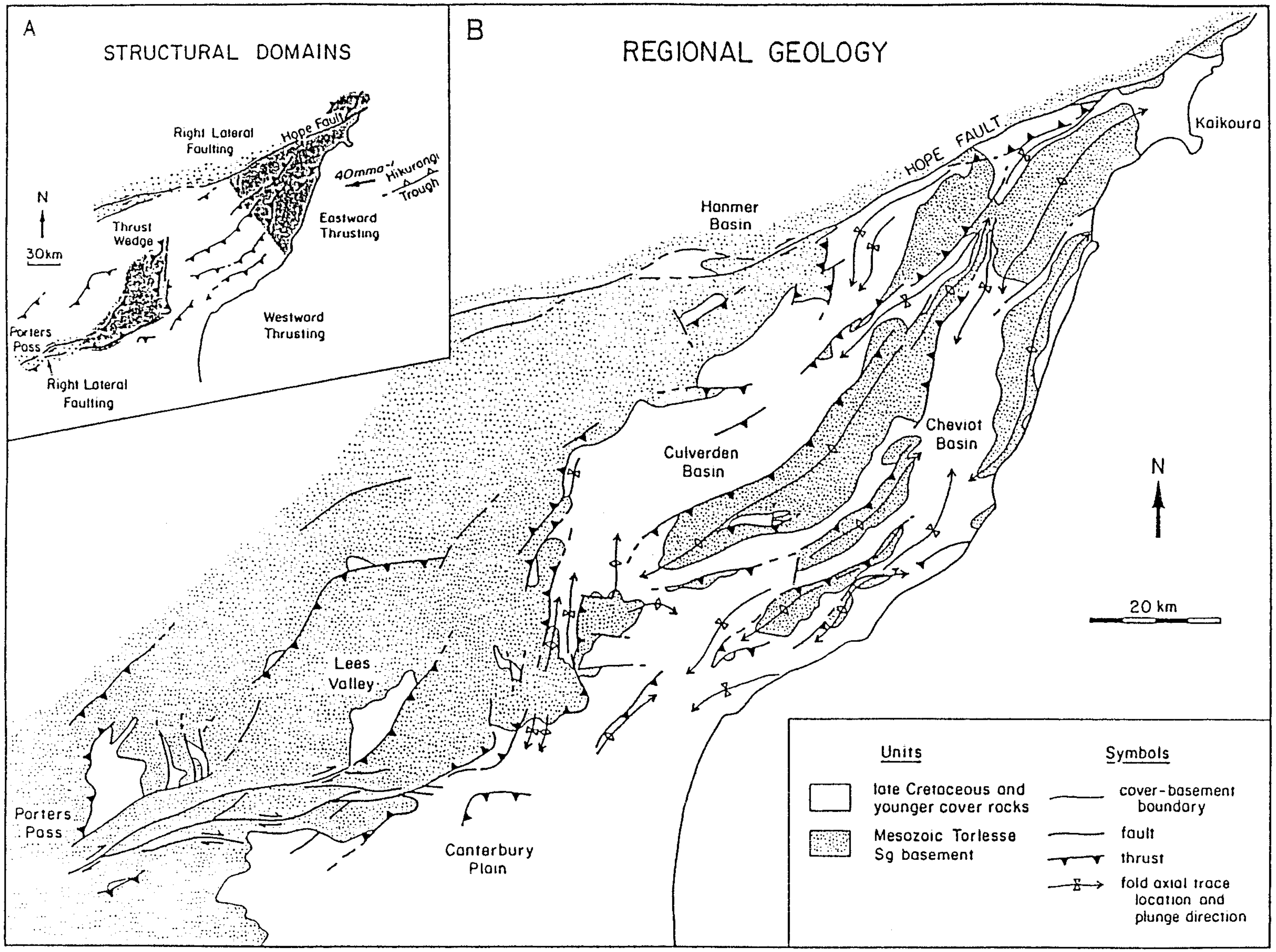


Figure 3: Summary map of North Canterbury regional geology (based on Nicol, 1991 and Nicol, et. al., in prep). Inset depicts structural domains.

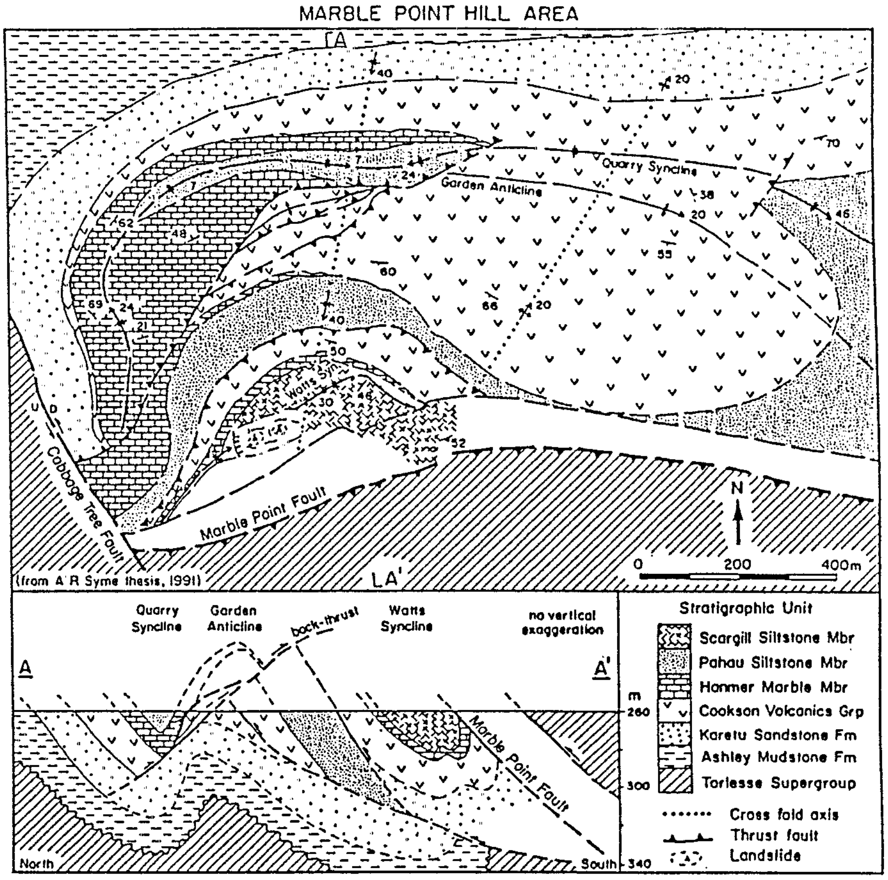


Figure 4: Hanmer Gorge - Marble Point.

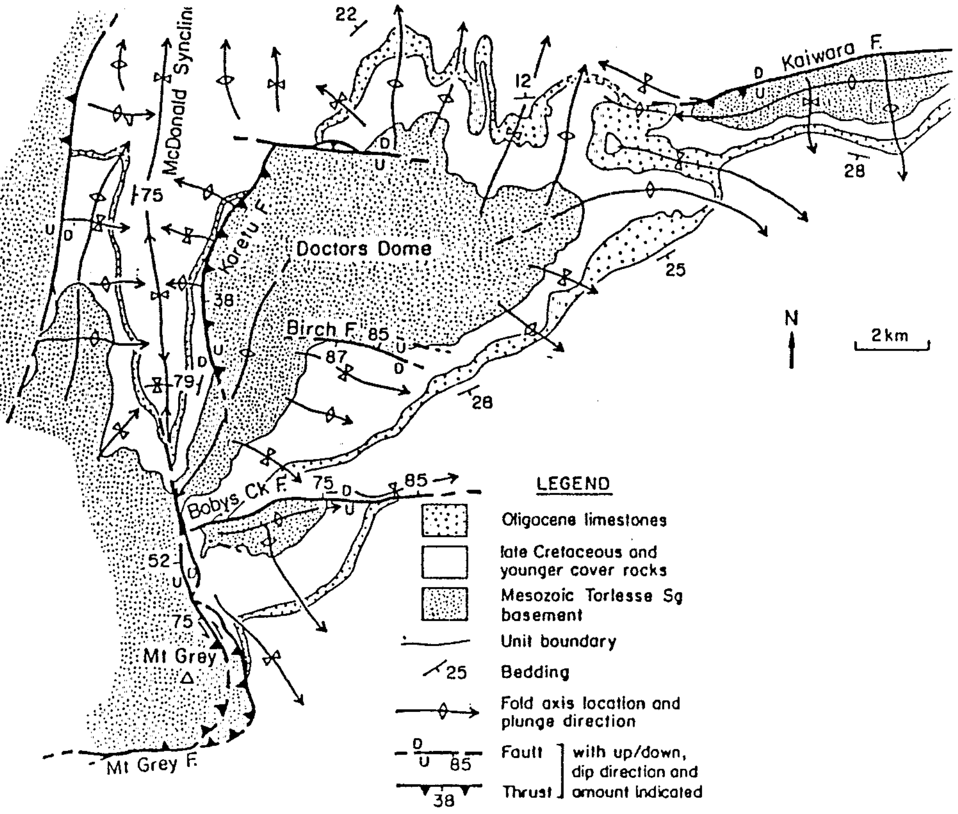


Figure 5: Geological map and structural features in the middle Waipara - Doctors Hills (dome).

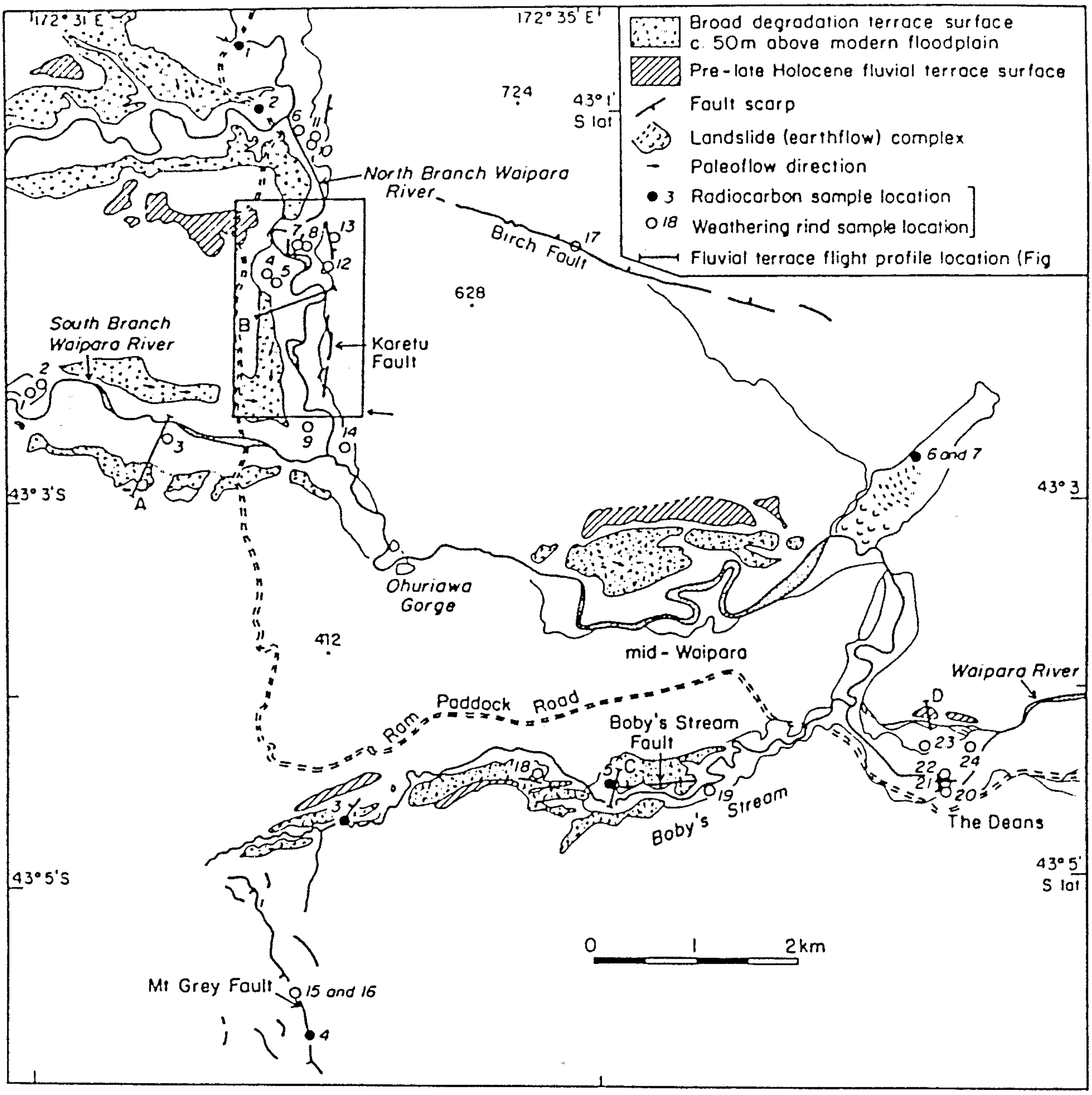
The outlier is incorporated into the footwall plate of the west-facing Marble Point Fault, an oblique thrust system striking northeast to merge into the Hope Fault system (Syme 1991). Recent down cutting and gradient anomalies on the Waiau river and surface fault traces are all indicative of ongoing tectonic activity. A large landslide can be seen on the north bank of the river against the western side of the valley, which was reactivated in the 1888 Glynwye earthquake and is the only related failure observed outside of the Hope catchment.

Stop 2. AMURI PLAIN - ST. LEONARD THRUST FAULT (Figures 3 and 5).

The Amuri Plain (Culverden Basin - figure 3) is a northeast trending depression floored by extensive coalescing aggradational surfaces. These were built by several rivers cutting across the basin axis in antecedent courses. While the structure of North Canterbury is dominated by west to northwest facing thrust fault systems (figures 2 and 3) there are two important exceptions. The east facing style characteristic of Marlborough (figure 2A) and the convergent margin of the North Island which extends beyond the Hope Fault as far south as the Cheviot Basin, where the boundary coincides with the limit of the subducting plate (Nicol, 1991). These will not be observed in this tour, but the second exception consists of a zone of east facing reverse faults bordering the west side of the Amuri Plain and extending as far south as the Doctors Dome and Mt. Grey (figure 5). A consequence of these opposing systems is that the Amuri Plain is flanked on both sides by convergent thrust faults which merge at the south end. This structure is complicated by active structures cutting across the floor of the basin in the form of actively growing anticlines and faults which splay off the basin bounding system at a high angle. One of these, the St. Leonard Fault is deforming and rupturing the aggradational plain and is associated with a growing anticline exposing Tertiary sediments in front of the eastern margin of the basin.

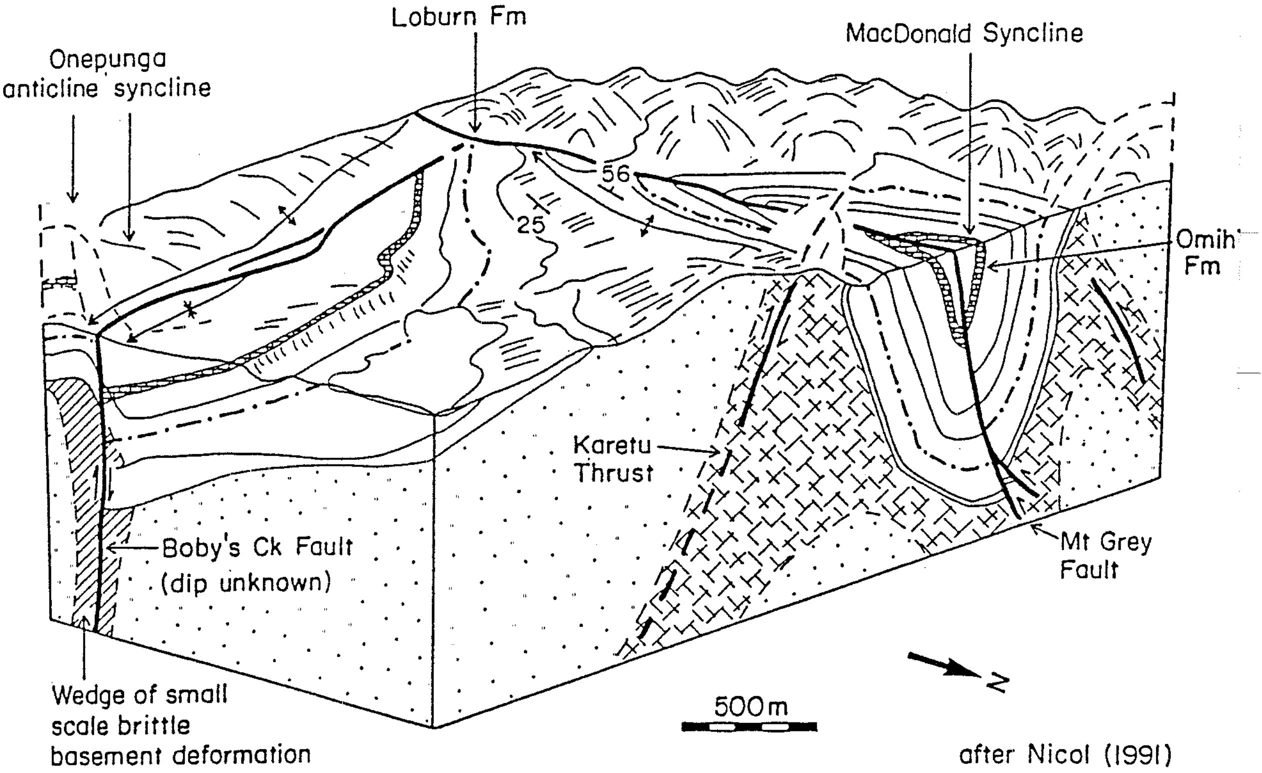
Stop 3. DOCTORS DOME, McDONALD SYNCLINE, WAIPARA TERRACES (Figures 5, 6, 7, 8, 9, and 10).

The structural relationships of the middle Waipara River are show in figures 5, 6, and 7. The terraces of the northern, middle and southern branches of the Waipara River parallel or cut across the axis McDonald syncline at the south-western end of the Culverden Basin (figure 2). To the southeast of the confluence of the south branch, the river enters Ohuriawa gorge, incised across the over thrust anticline at the south eastern end of the Doctors Dome (figures 5 and 7). The McDonald syncline is being compressed into a tight fold and over thrust from the east by the Karetu fault. This fault forms the the western boundary of the Doctors Dome. Near vertically dipping Tertiary limestones form strike ridges along the margins of the McDonald syncline. The limbs of the McDonald syncline are corrugated by longitudinal shorting and the core of the syncline is partly obscured by late Pleistocene aggradational gravels, the uppermost surface of which appears to be warped coincidently with the axis of the syncline. Although radiocarbon dates (figure 9) confirm the late Pleistocene age of the aggradation gravels, evidence from soils and weathering rind dating supports the view that no significant downcutting into this surface occurred until the late Holocene. Contrary to the general assumption that regional degradation in all catchments coincided with the late Pleistocene - early Holocene climatic amelioration, it appears that base level did not drop significantly throughout the middle Waipara catchment until gradually accelerating incision began between three and two thousand years ago. An interconnected pattern of field relationships tying together downcutting history, fault rupture events, episodes of landsliding (figure 8) and fluvial response to active folding and tilting indicates a strong element of tectonic control.



Nicol (in prep)

Figure 6: Principle terrace surfaces in the middle Waipara catchment, locations of Radiocarbon and weathering rind dates and of dated degradational terrace profiles. (Nicol and Campbell, in press).



MID - WAIPARA STRUCTURES

Figure 7: Block diagram of the MacDonald Syncline and Boby's Creek fault.

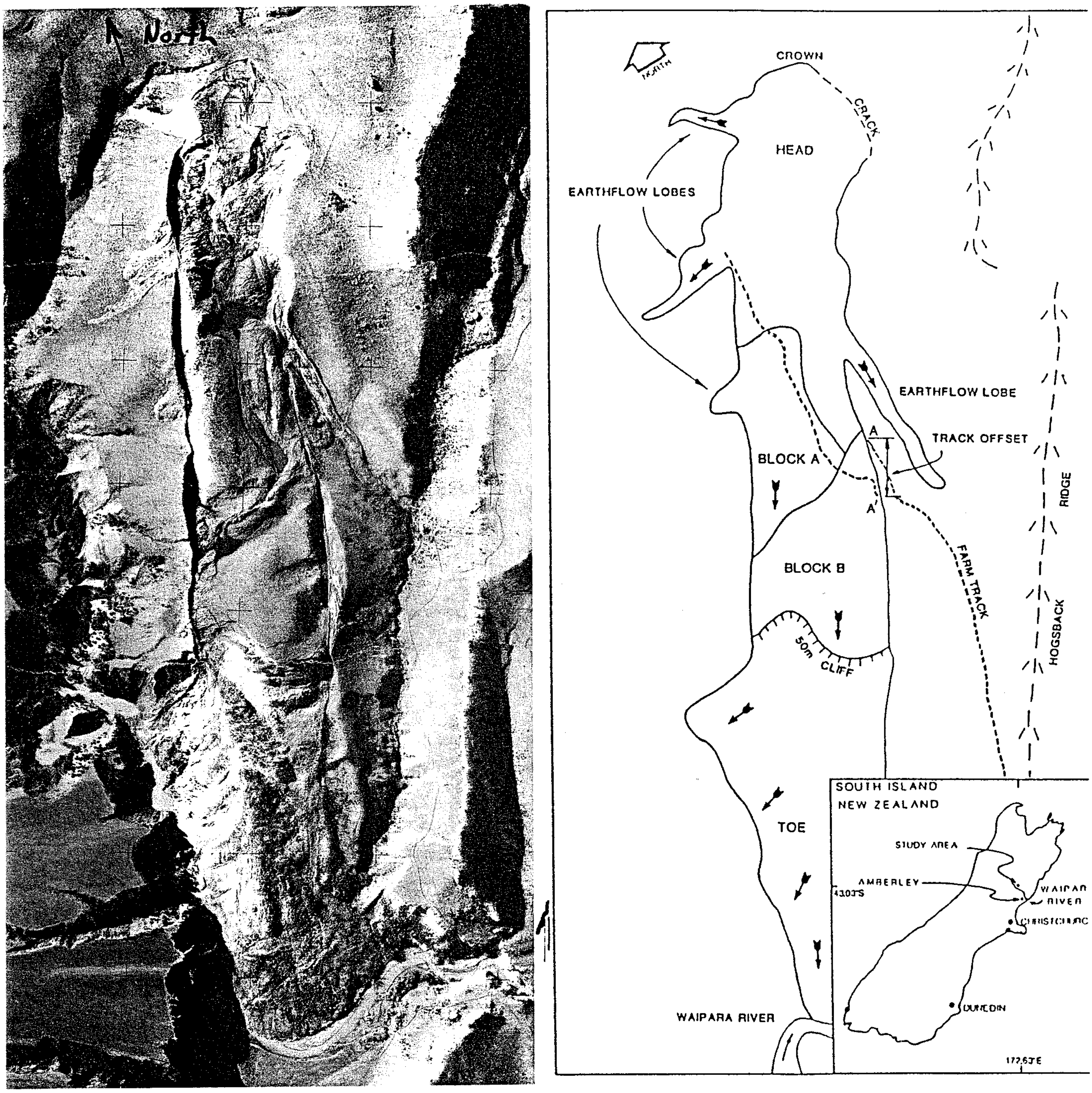
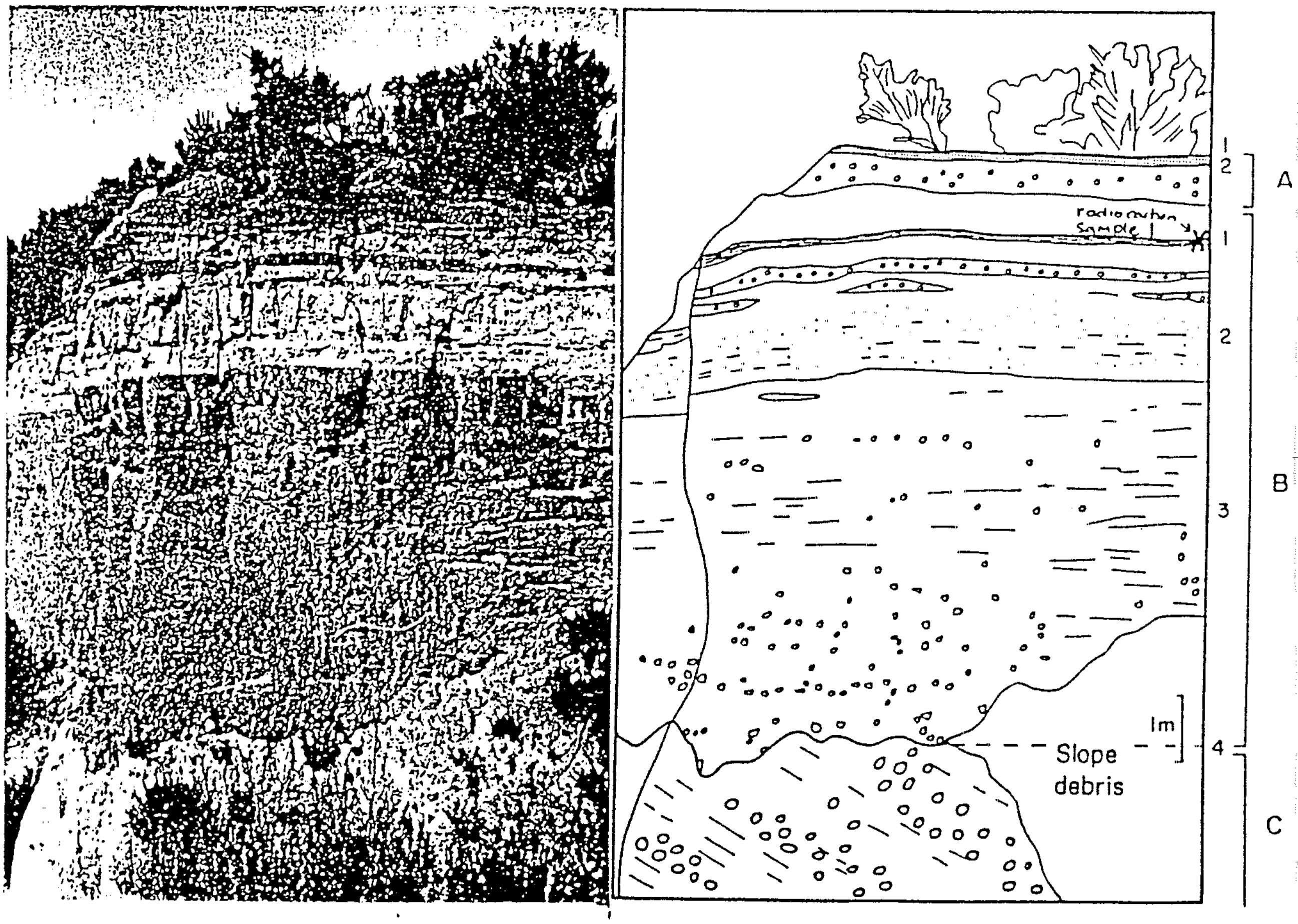


Figure 8: Vertical aerial photograph and summary map depicting earthflow complex Waipara River gorge, North Canterbury (From McSaveney and Griffiths, 1987). Landslide dimensions: width 275m; length 1750m; crown scarp is 250m above river level. Arrows denote direction of movement. A - A' marks displaced track where movement was measured by McSaveney and Griffiths (1987). Photograph by Lloyd Homer - New Zealand Geological Survey 1982.



A. Veneer of degradation gravels

1. Age of the degradation terrace surface 280 ± 50 yrs B.P. (inferred from down-cutting curve, (Fig. 10).
2. Thin (15 - 20 cm) soil 'A' horizon.

B. Aggradation gravels

1. Peat horizon dated at ≥ 43 600 years B.P. (N.Z. 7933).
2. Slack water interbedded quartz sands, mud and fine gravel.
3. Poorly bedded gravels.
4. Angular unformity.

C. Kowai Formation (Plio-Pleistocene sediments)

Figure 9: Section exposed on the north branch of the Waipara river - Broxton bridge, radiocarbon date site 1 (Stop 3) .

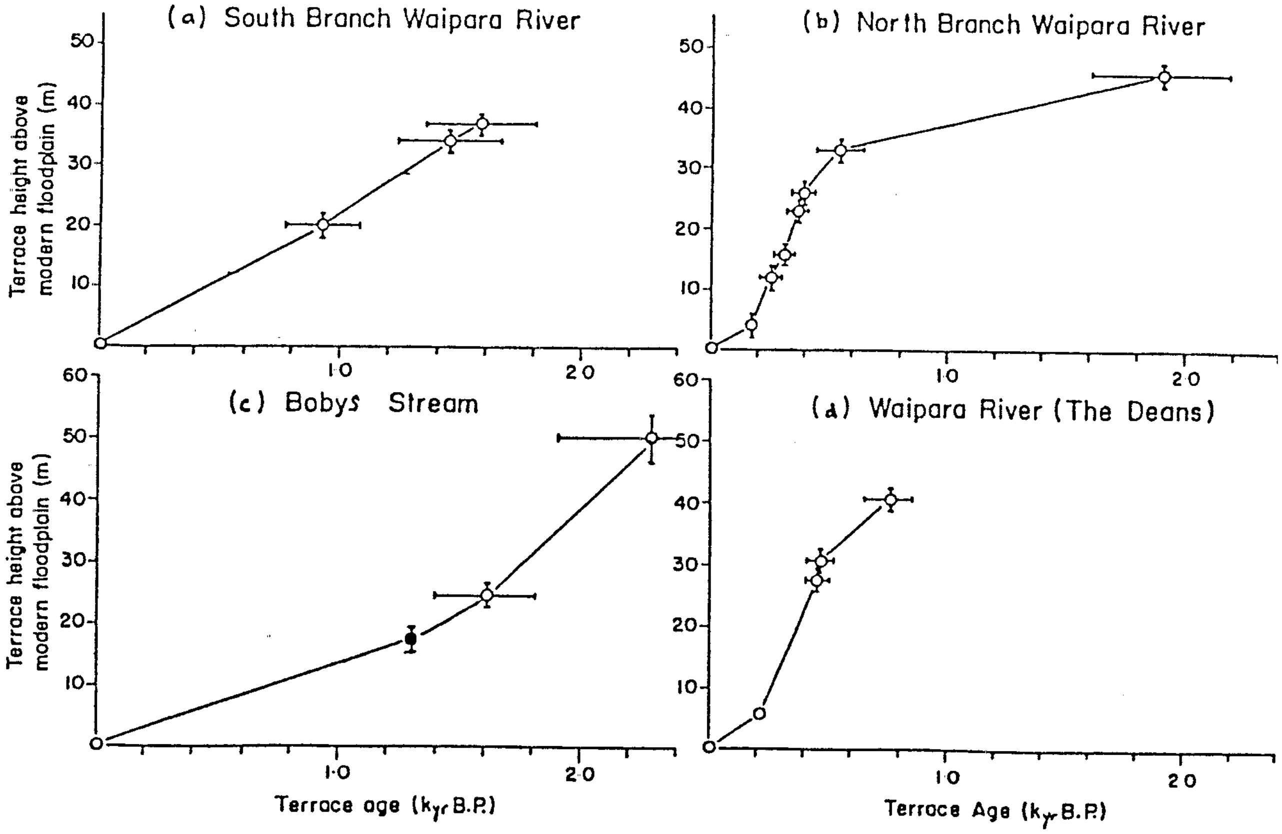


Figure 10: Downcutting curves for the middle Waipara catchment, constructed using Radiocarbon and weathering rind dates (Nicol and Campbell in press).

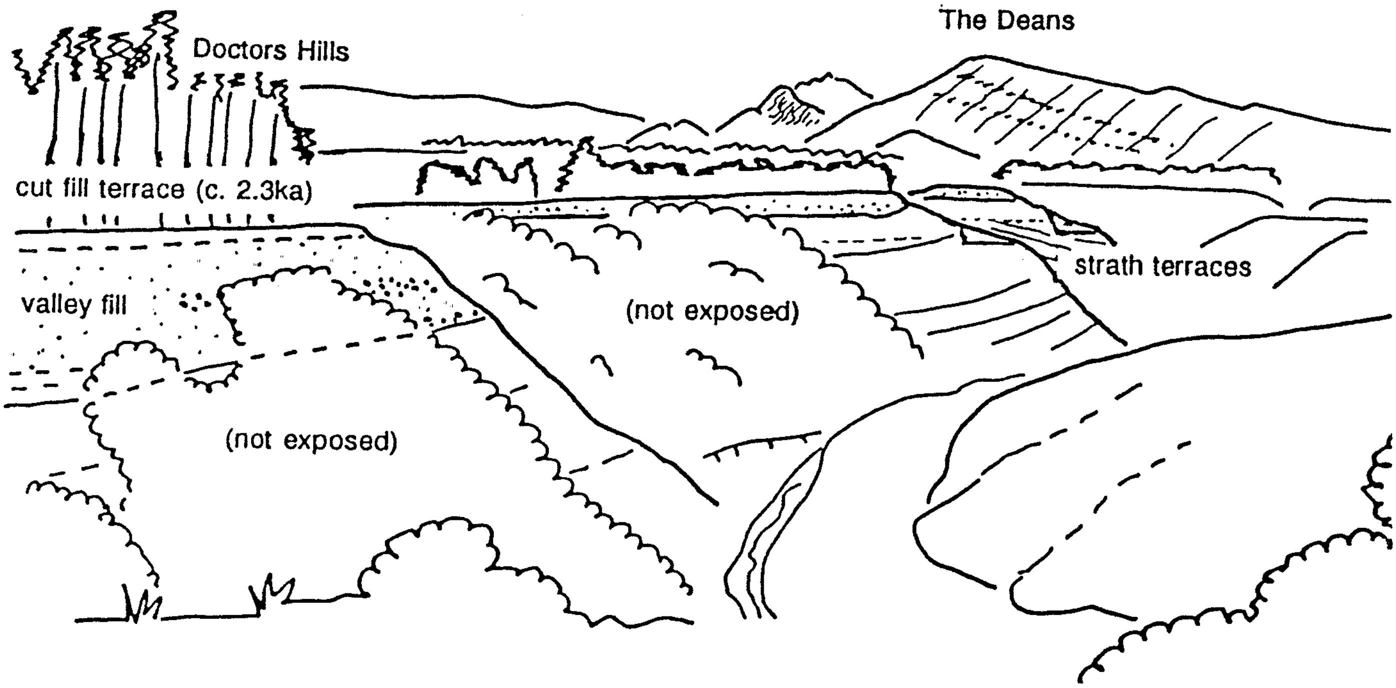


Figure 11: View north east along the strike of the Boby's Creek fault, toward the Doctors Hills and The Deans. The cut - fill terrace (highest surface) on the left (c. 2.3 ka), has been incised 50 m by Boby's creek.

Aggradation deposits in this part of the Waipara River (figure 9) represent the basal remanents of material that once filled an ancestral valley. Within this ancestral valley the Waipara River degraded to within c. 5 m of the present flood plain prior to 30 kyr, but subsequently aggraded to in excess of 100 m above the floodplain, the elevation of the highest terrace surface. Little remains of this aggradational terrace (figure 6) (Nicol and Campbell, in prep).

Down cutting along the middle Waipara River and its tributaries has resulted in the development of many young degradational cut-fill and strath terraces. These terraces can be observed up to 100 m above the modern floodplain and are characterised by an uppermost suite of laterally extensive and often paired terraces c. 40-50 m above the modern floodplain, below which up to 14 discontinuous and generally unpaired terraces step down to the modern floodplain. Terrace age data, provided principally by weathering-rind dates, indicated that the degradational terraces are late Holocene in age (c. 186±31 and 2300±393 yrs B.P.). Down cutting curves (figure 10) constructed using terrace age and height, above the modern floodplain, show that the rates of river downcutting are locally variable and are highest where the river crosses zones of faulting and anticlinal uplift. Close temporal relationships are observed between rapid river downcutting and folding and faulting for the Waipara River where it passes through the Doctors anticline (Ahuriawa gorge). It is suggested that anticlinal growth, reflected in part by secondary surface faulting, resulted in recent uplift, which in turn triggered river down cutting. Thus the locally young ages derived for the river terraces are a function of the young ages of folding. This segment of the Waipara River indicates that in regions experiencing localised tectonic uplift, where the climate is humid, river downcutting may approach 100 m/kyr for short periods of time (Nicol and Campbell, in press).

Stop 4. BOBY'S CREEK FAULT AND TERRACES (Figures 5, 6, 7, 10 and 11).

A complex junction formed where the west facing Karetu Fault and the Mt. Grey Faults converge and involve a pair of east-west striking faults, the Boby's Creek and Birch Hill Faults, is of rather enigmatic character (figures 5 and 6). As viewed from Boby's Creek, the skyline ridge to the south east is a strike ridge of Mt Brown, which can be traced to the Waipara River, just above the farm "The Deans" (figure 6). A similar strike ridge to the north west of this viewpoint (The Deans, figure 11) climbs to the north of the Waipara river and is has been commonly assumed to be left laterally displaced along the Boby's Creek Fault. Indications of upthrow of to the south on the fault were though to indicate that this separation was achieved by a significant proportion of dip slip, relative to strike slip motion. Reference to figure 5 shows a 4 km offset of the Oligocene limestones, conformably lower in the sequence and to be seen as a ridge in the middle distance (figure 11). The last movements on the Boby's Creek Fault (2100±200 and 310-390 yrs B.P.) to be seen in offset terraces at "The Deans" (figure 6) was dominantly right lateral. Far from being a simple tilted sequence of Tertiary sediments, folding in two directions complicates the structure by the reversal in plunge of the syncline (figures 5 and 7). A dome shape anticline, the Onepunga Anticline at the foot of Mt Grey, lies to the south of Boby's Creek Fault which cuts along the north flank, truncating the east plunging nose at an acute angle. The swing in trend of the syncline described above places it adjacent to the Onepunga Anticline as a pair; if so then the anticline facing us on the opposite side of the river might be the offset continuation of the Onepunga Anticline, providing a piercing point match. This would imply 2.25 km of dominantly right lateral movement with approximately 590 m of vertical component upthrow to the south, based on the stratigraphic thickness separating the base of the Mt Brown from the Conway Formation, the units exposed at the two respective cutoff points. The two folds may be quite unrelated.

Along the Boby's Creek (figures 7 and 11) the fault splits in two. The northern strand is probably the more significant in that all the Amuri and Weka Pass Limestones are missing from the well exposed section in the creek wall. This strand passes up a gulley marked by a belt of pine trees on the inner side of the highest terrace, but is not expressed as a surface break.

However, the terrace is warped and back tilted between the projected strike of this strand and the second strand to the south which is expressed at the surface by a north facing scarp reaching 2.5 m at the west end, but tapering away towards the east. Only the Loburn Formation and part of the Waipara Greensand are missing across the the fault (figure 7) which appears to be associated with a monoclinal drape fold picked out by the Loburn Formation before being truncated.

Immediately to the south of the Boby's Creek Fault trace, is a steep sided gorge cut 50 m deep across the trace of the Onepunga Anticline (figure 7), cored by the lowest Tertiary unit, the Broken River Formation. The bedding can be seen dipping away on either side. The terrace surface across the top of the anticline is underlain by no more than 1 m of bedload gravel. The river was actively cutting bedrock at the time, but uplift was insufficiently rapid to prevent lateral planation and the cutting of a strath terrace. A sudden change in base level must have induced this incision, trapping meanders on the anticline crest, as a notable feature are the incised abandoned meander loops. At the western end of the fault trace an incised meander cuts across the terrace intersecting the fault scarp. It may be offset with a horizontal component, or simply accentuated by scour at the fault plane as the meander was cut. Relatively indurated Broken River sands and cemented shell beds are juxtaposed against slump prone greensand across the cut off loop and a swamp fills the loop. Wood 5 m down in the swamp, sitting on top of greensand, yielded a radiocarbon age of 1294±32 yrs B.P.. The floor of the meander is 35 m below the top terrace on the downthown side. Weathering rind dating of the main top terrace gives a rather poorly defined oldest peak of 2.3 kyr. These and one other date are used to construct the down cutting curve for Boby's Creek (figure 10). The main Boby's Creek terrace grades northward from a strath terrace over the axis of the Onepunga Anticline to a cut-fill terrace underlain by 1-2 m of gravelly to sandy glauconitic sediments. This late Holocene alluvium is unconformably underlain by presumed late Pleistocene aggradation gravels (figure 11), similar to those exposed along the north branch of the Waipara River (figure 9).

Between Boby's Creek and "The Deans" (figure 6) the trace of the Boby's Creek fault can be seen cutting and displacing young strath terraces (figure 10). Immediately on the north side of the fault, a former channel filled with late Pleistocene aggradational gravels is exposed, with the base of this prior channel 5 to 10 m above present river level. At this location this provides a direct indication of the net lowering of baselevel since the onset of the last major aggradation event prior to c. 30 kyr. The full height of aggradation build up may be indicated by the tilted terrace remanents on the north side of the river. On the south side of the river landslides composed of distinctive, yellow brown blocks derived from the Mt Brown Formation on the ridge above rest on a former river terrace 10 m above the river. This terrace was eroded into the grey Waikari Formation that stratigraphically underlies the Mt Brown Formation and the there is evidence that this landsliding event occurred at the time when the river bed was at the level of this terrace. A little further down valley another displaced block of the Mt Brown Formation is capped by thin terrace gravels. At the eastern exit of the middle Waipara Gorge, Mt Brown Formation and overlying Kowai Gravels form prominent strike ridges and associated dip slopes. In places the remanents of tilted higher level terraces cut across (on the north side of the river) or subparallel (on the south side of the river) the dip of the Kowai Gravels. These terraces are veneered by one or more loess sheets although commonly on the north side of the Waipara River only remanents of this loess cover remain. The full extent and stratigraphy of this loess cover is yet to be studied.

Stop 5. WAIPARA PLAIN, TERRACES AND THE MOUND (Figures 12, 13, 14 and 15).

Analysis of the geometry and ages of faulted and tilted late Quaternary fluvial terraces and their associated cover beds provide evidence of active folding at three localities across the Waipara

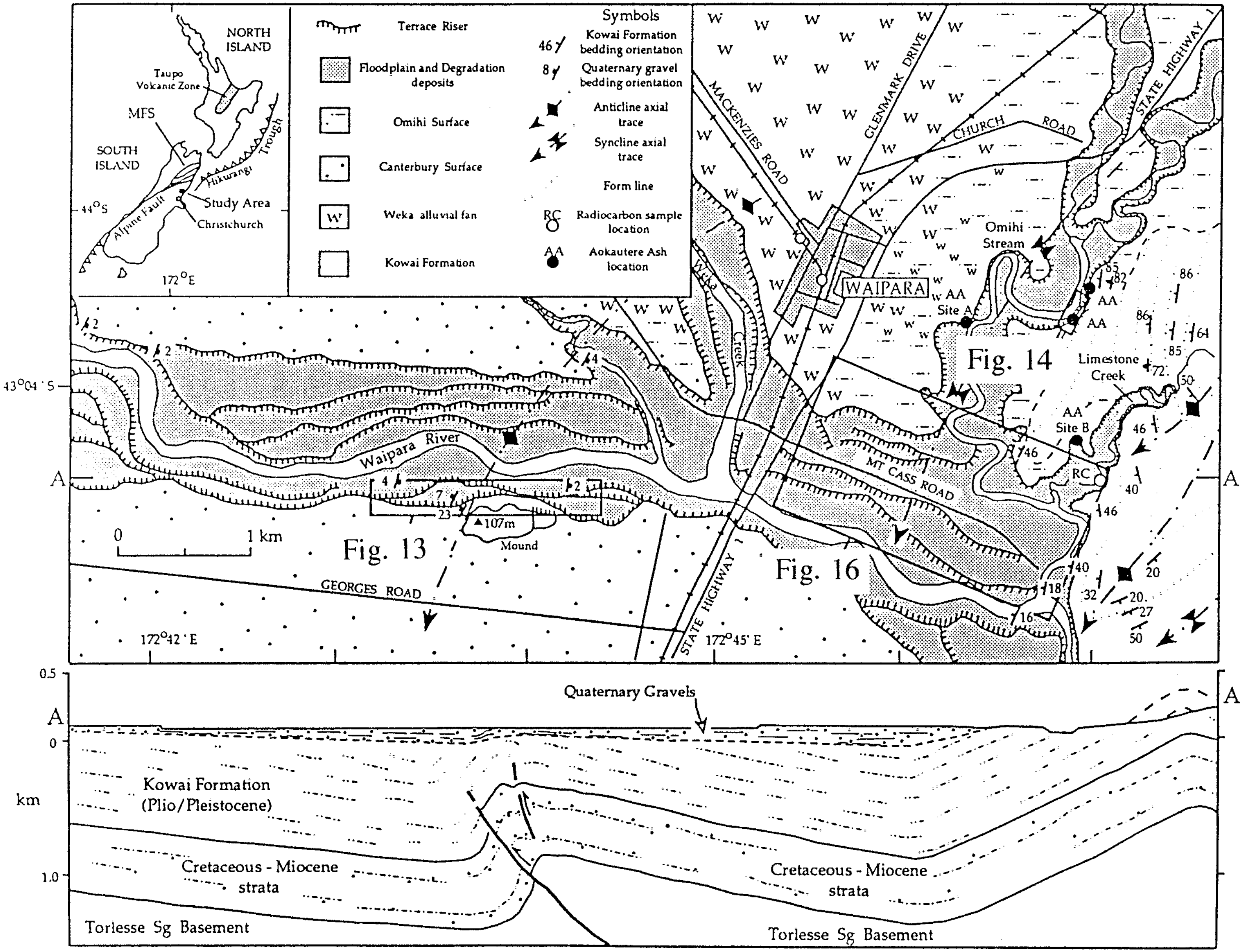


Figure 12: Tectonic setting, geology and geomorphology of the middle Waipara valley and locations of figures 13 to 16 (Nicol et.al. in press).

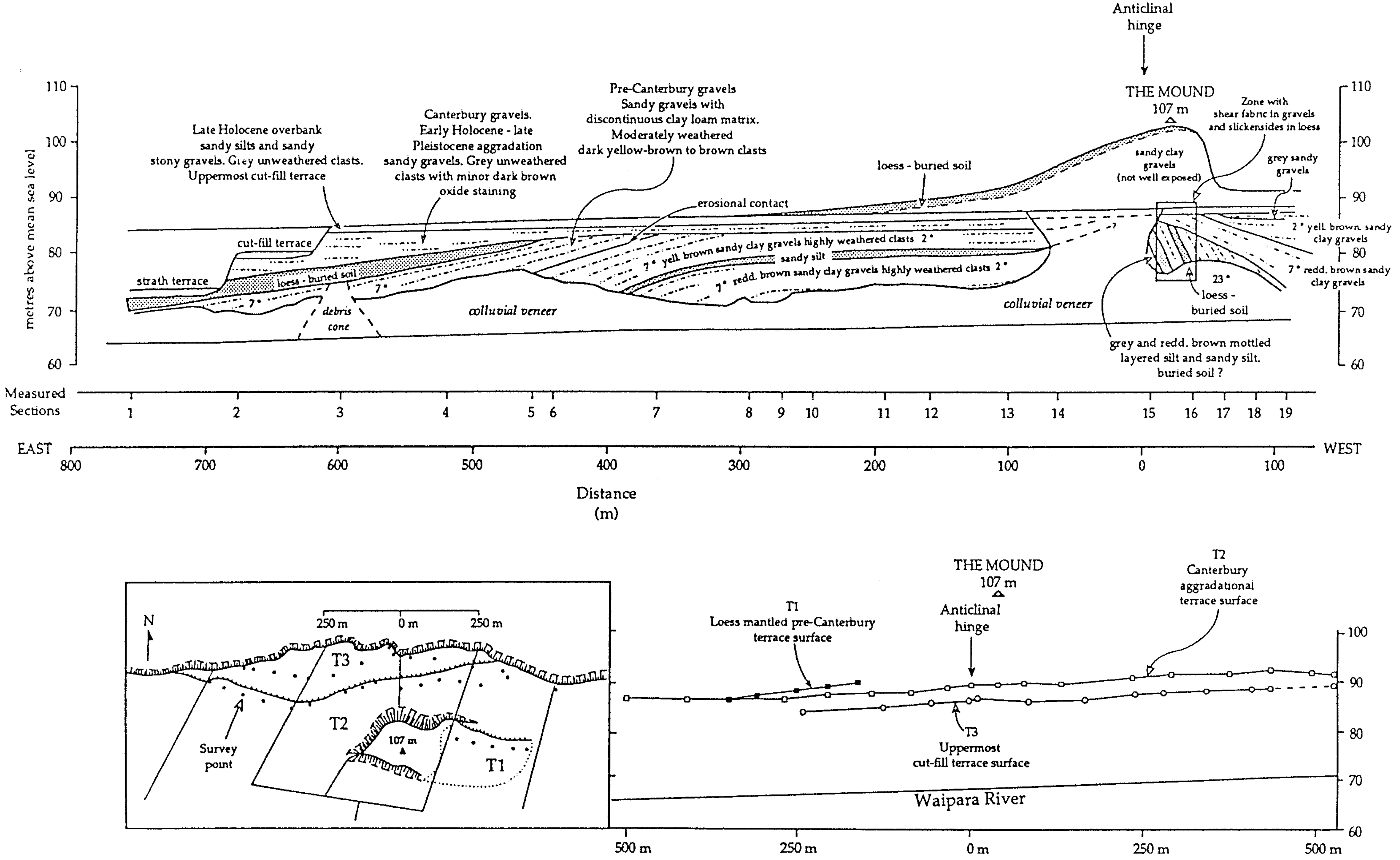


Figure 13: Detailed schematic diagram of tectonically deformed Quaternary gravels, loess and terraces surfaces at The Mound, south bank of middle Waipara river.

Syncline (figure 12). Terrace survey data and the occurrence of the 22.6 kyr Aokautere Ash and soil stratigraphy indicate that folding and sedimentation has continued into the late Holocene and that rates of deformation and sedimentation are locally variable. Rate of tectonic shortening locally range up to 5.57 %/100kyr, while uplift rates of 0-1.83 m/kyr are observed. Extrapolated over time of the rates of shortening suggest that locally, tilted and faulted cover beds (figures 13 and 14) are less than 100 kyr old, although, flights of fluvial degradational terraces, up to 20-30 m above the modern floodplain remain essentially undeformed. These cut-fill terraces are of late Holocene age and are significantly younger than the underlying and commonly deformed Pleistocene gravels and interbedded loess and fine textured alluvium (Nicol et.al., in press).

In the Waipara Plain the last aggradation terrace (Canterbury Surface) and flight of degradation terraces are underlain by stony gravels derived predominantly from basement Torlesse lithologies with minor contributions from Tertiary lithologies such as greensandstones, limestones and calcareous sandstones. An exception is the apparent terrace remnant, The Mound (figure 13) which rises 10 - 20 m above the last aggradation surface. The eastern flank of The Mound is a remnant of an eastward tilted terrace veneered by 2-3 m of late Pleistocene loess. This is possibly the lateral equivalent of a more extensive surface occurring on eastern side of the Waipara Syncline (figure 17). The uppermost surface of The Mound is an eroded remnant of older terrace gravels with a eroded loess cover of unknown thickness. Adjacent to The Mound, the Waipara River has incised below the Canterbury surface (T2) and the adjacent cut-fill terrace (T3) forming a 20 m scarp (figure 13). Exposed in this scarp, a sequence of seven gravel units and interbedded loess and fine textured alluvium and associated buried soils, display increasing deformation with age. The oldest beds exposed form the westward dipping limb of an asymmetric thrust fold anticline which appears to be the northern continuation of a seismically imaged fold associate with a reverse fault extending into the Torlesse basement (figure 12). The stratigraphy beneath The Mound illustrates a complex history of aggradation events filling progressively deforming synclinal basins separated by the minor anticlinal high of The Mound. The loess mantled pre Canterbury terrace (T1) dips eastward beneath the last aggradation surface (T2) toward the axis of the Waipara Syncline (figures 12, 13 and 17). Extrapolating from recently dated loess sequences on the Cust Downs in North Canterbury, the age of this gravel aggradation surface, veneered by one loess sheet, is no older than c.35 kyr (Berger pers comm 1994). The stratigraphic and geomorphological significance of the older gravel units in this sequence are yet to be determined. They have previously been included with the Kowai Gravels of assumed Plio-Pleistocene age, but are more likely of mid to late Pleistocene age. This structure is a further indication that surface irregularities on aggradational Plains may indicate deformation of the underlying gravelly sediments.

Stop 6. Mt CASS ROAD, WAIPARA - OMIHI TERRACES AND FAULT BANK SECTION, OMIHI STREAM (Figures 12, 13, 14, 15, 16, and 17).

The Omihi valley is formed along the axis of the Waipara Syncline, and lies between two compound anticlinal ranges to the northwest and east. The most extensive aggradational surface (Omihi Surface) is underlain by c. 3 to 6 m of upward fining calcareous and glauconitic gravels, sands, silts and clays (figures 14 and 15). At several sites (figures 12 and 15) the 22.6 kyr Aokautere Ash (Kawa Kawa Tephra Formation), occurs as a thin (20-30 mm) bed 4 to 6 m below the Omihi Surface. This silicic airfall tephra was erupted from Lake Taupo in the central North Island, and is extremely useful in soil stratigraphic and geomorphic studies because it defines an isochronous horizon for age control of loess, peat and valley fill deposits of the Last Glacial Maximum. This tephra occurs in the lower third of the late Pleistocene loess sheet throughout the southern North Island and northeastern and central South Island and has been identified in loess cover beds overlying the c. 60 kyr Tiromoana marine terrace on the Waipara coast (Carr, 1970; Kohn, 1979).

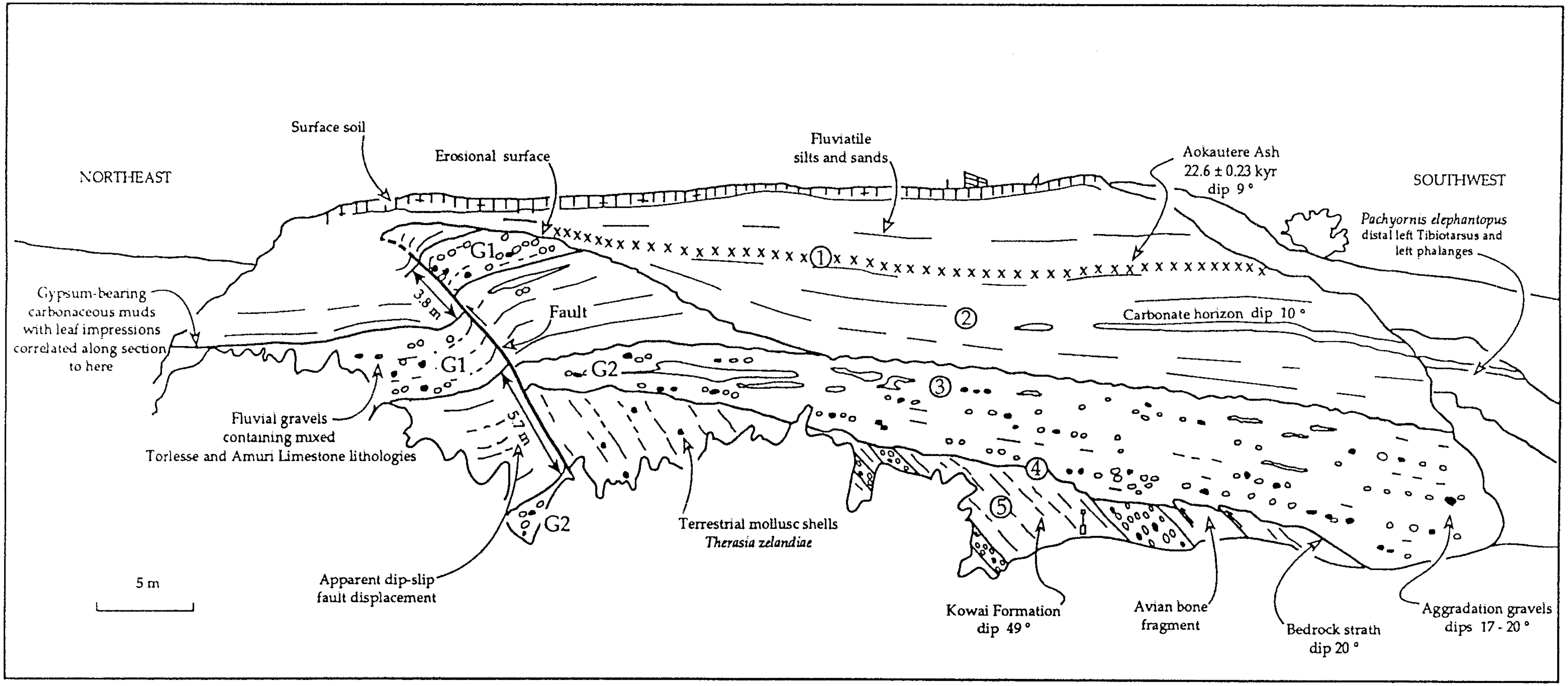


Figure 14: Fault Bank section, Omihi Stream exposing Late Quaternary valley-fill sediments and interbedded 22.6 kyr Aokautere Ash 4 m below Omihi Surface (Nicol et.al., in press).

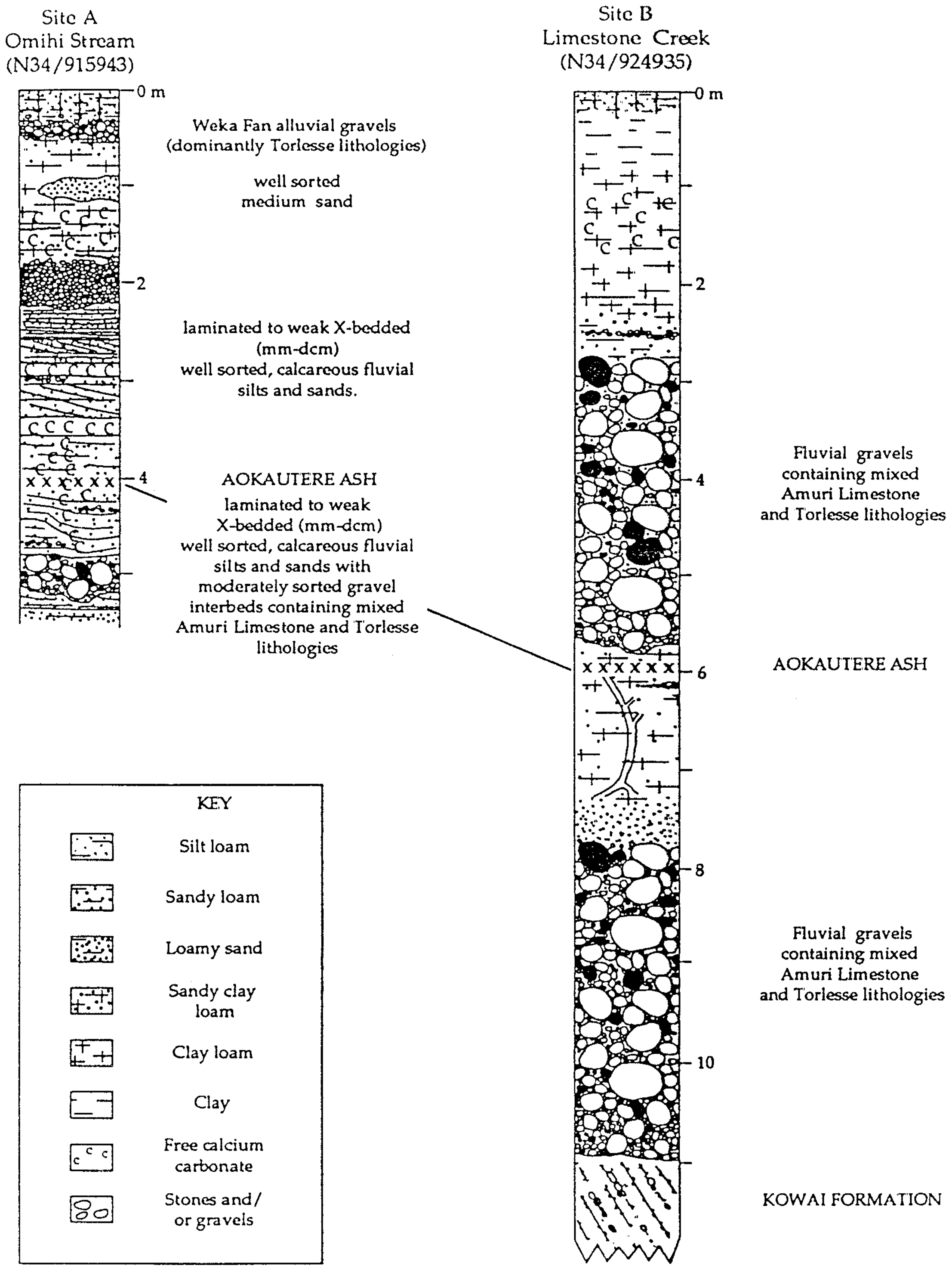


Figure 15: Stratigraphic sections of the Omihi valley-fill enclosing the 22.6 kyr Aokautere Ash at Omihi Stream (site A) and Limestone Creek (Site B), for locations fefer to figure 12 (Nicol et.al., in press).

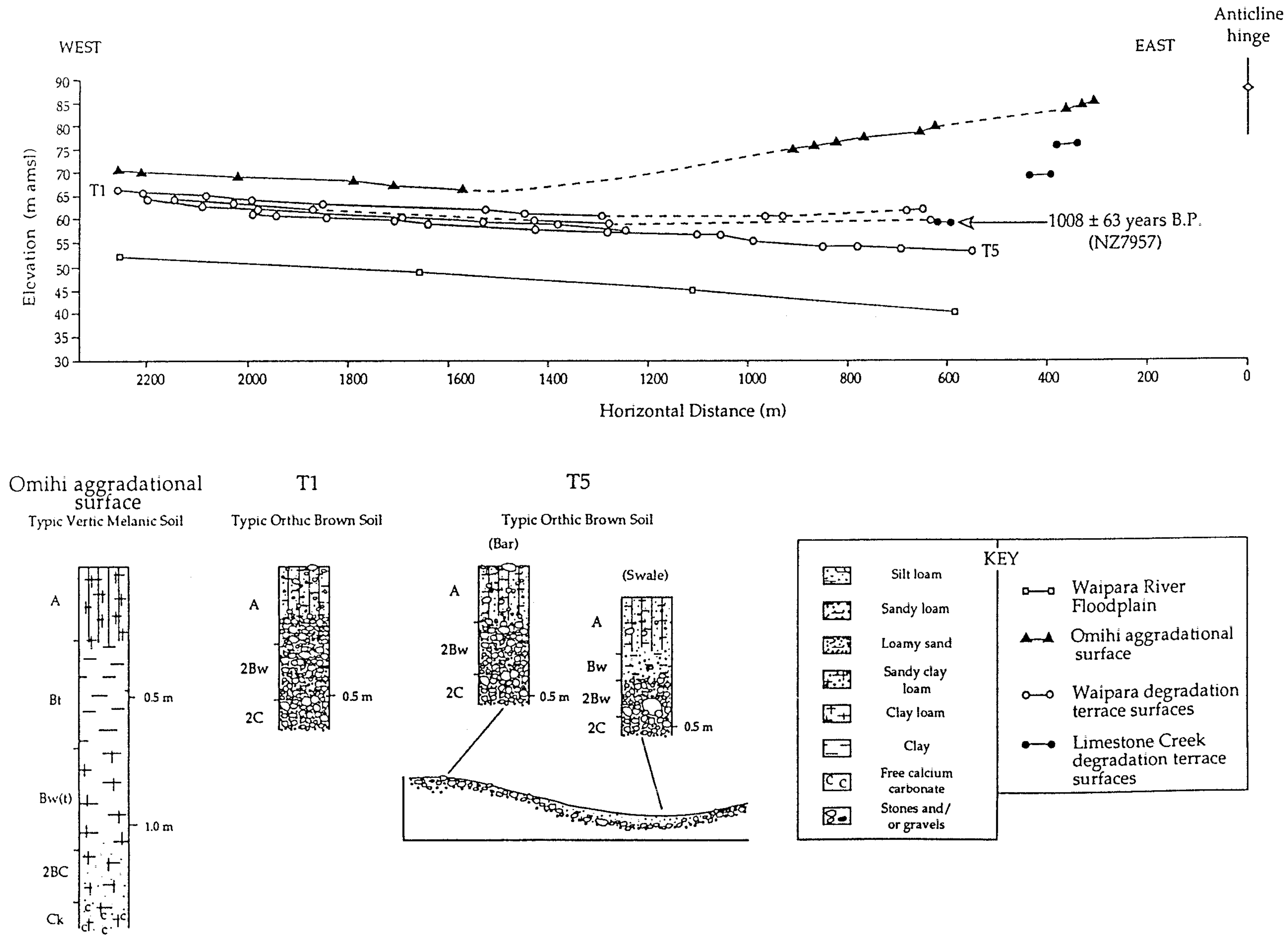


Figure 16: **Profiles of the Waipara River terraces and Omihi Surface along the Mt Cass Road showing progressive buckling with surface height and age from the Waipara Syncline eastward to the Black Anticline (Nicol et.al., in press).**

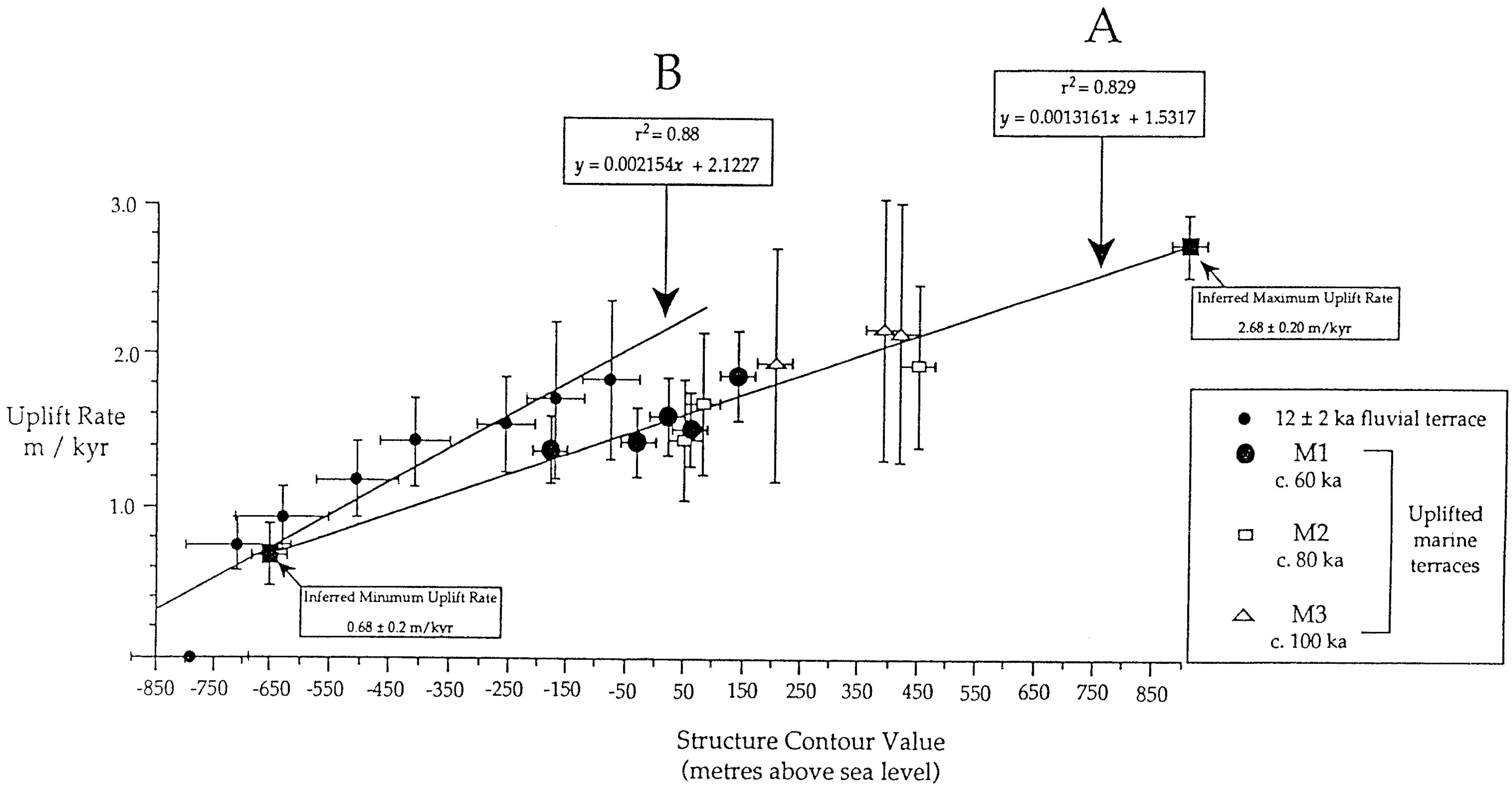


Figure 18: Plots demonstrating a positive correlation between uplift rates derived from (A) marine terraces and (B) the Omihi Surface, and their locations relative the macroscopic folds (figure 17) (Nicol et.al., in press).

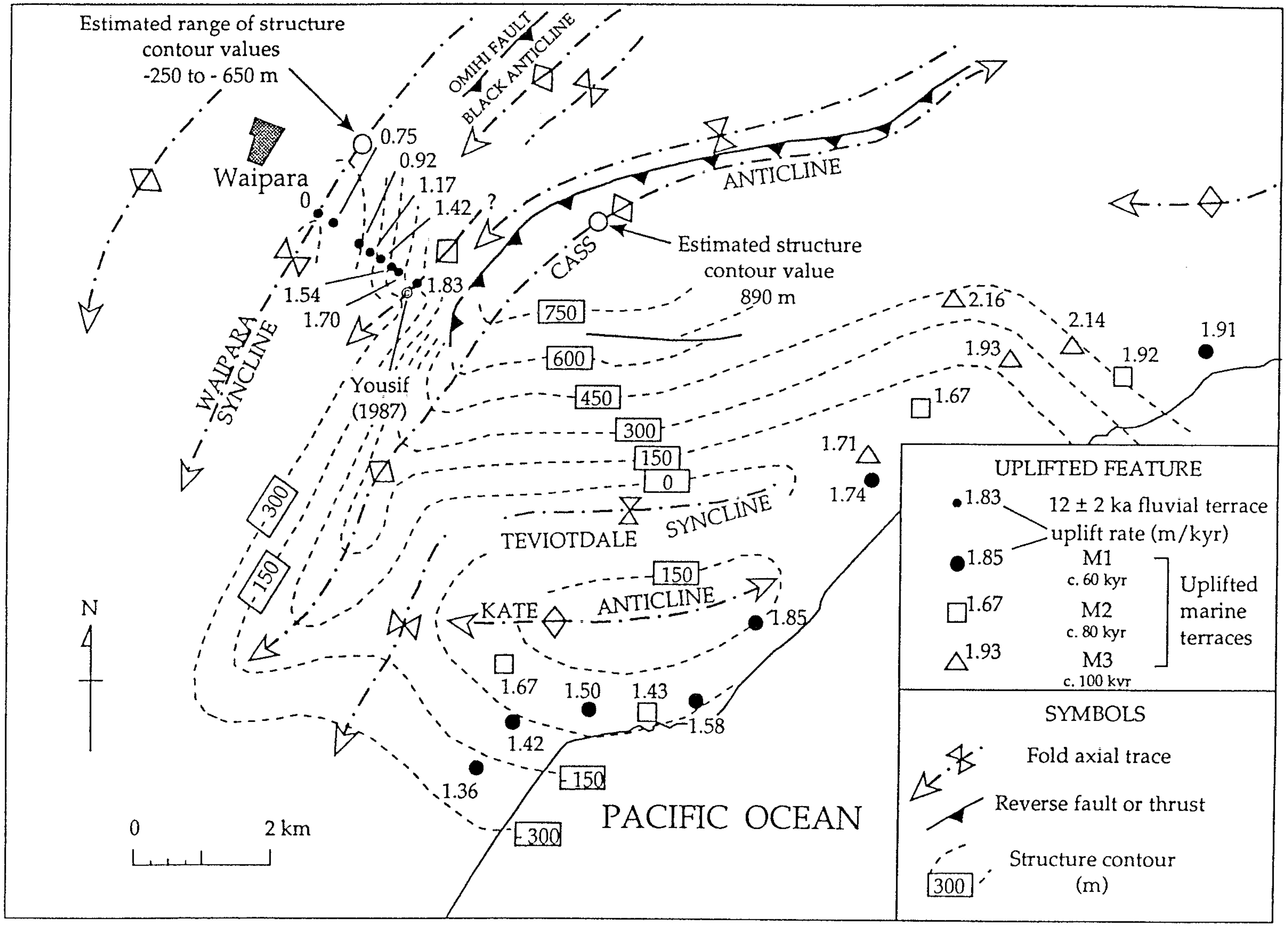


Figure 17: A comparison of the spatial disribution of uplift rates, derived from both fluvial and marine terraces, and fold locations as indicated by structural contour values. Structural contours are constructed on the base of the Pliocene - Kowai Formation (Wilson, 1963; Nicol et.al., in press)

The Fault Bank section, Omihi Stream on the eastern edge of the Omihi valley (figures 12 and 14) exposes 10 to 20 m of faulted and tilted late Quaternary fluviatile beds beneath the Omihi Surface. These sediments rest unconformable on steeply dipping Plio-Pleistocene Kowai Formation. Nicol et.al. (in press) have calculated that the strath cut across the Kowai Formation is c. 103±23 kyr. Uplift and faulting have been active during the accumulation of these sediments, and continues to deforme ' the Omihi surface, without rupturing along the southeast striking reverse fault. The carbonaceous sediments overlying G1 at the north eastern end of the section contain a cold climate pollen spectrum (McGlone pers comm 1992).

The flight of terraces on the north side of the Waipara River along the Mt Cass Road (figures 12 and 16) are increasingly tilted due to folding associated with the Waipara Syncline and adjacent Black Anticline. The terraces show increasing departure from the present stream gradients with vertical distance above the Waipara River floodplain. The most striking aspect of the terrace profile data is the marked eastward climb of the Omihi Surface toward the hinge of the Black Anticline. Assuming an age of 12±2 kyr for the Omihi Surface, uplift rates ranging from 0 to 1.54 m/kyr (±20%) are calculated for six points on the Omihi Surface (figure 17). However, if the gradient of the aggradation surface is extrapolated to the hinge of the Black Anticline the calculated uplifted rate would be 1.83±0.52 m/kyr (figure 18), this is close to the 1.7 m/kyr calculated for the Black Anticline exposed in Yellow Rose Creek (Yousif, 1987, figures 19 and 20).

Stop 7. VIEW POINT FROM MT CASS ROAD, AND BLACK, CASS AND KATE ANTICLINES

(Figures 17, 18, and 19, 20 and 21).

As the Mt Cass Road rises on to the Black Anticline, a good view is obtained of the incised Carrington and Yellow Rose Creeks to the north, and of the lower Waipara Gorge to the south east. The geomorphology of this area was studied by Yousif (1987) and illustrates the response of rivers to progressive tectonic deformation. Within the Yellow Rose and Carrington Creeks (figures 19 and 20), three bedrock straths occur above the present valley floors. The lower strath with a base level within a few meters of the present valley floor is overlain by up to 4-5 m of fine sediments, and buried wood yielded radiocarbon date of 1150±55 yr B.P. (Yousif, 1987), a similar age to the dated degradation surface on the Limestone Creek (figures 12 and 16). The middle strath occurs between 10 and 25 m above the present valley floor and has been deformed by shortening and reverse faulting across the Black Anticline (Yousif, 1987, figure 20). This strath is overlain by up to c. 5-15 m of upward fining sediments, that elsewhere include the Aokautere Ash between 4 to 6 m below the terrace surface. This terrace is the lateral equivalent of the Omihi Surface, with similarly developed soils. The highest strath is exposed along the Mt Cass Road and is folded across the Black Anticline. This strath is overlain by c. 10 m of upward fining sediments that are overlain by c. 11-12 m of loess, comprising two or three loess sheets separated buried soils. A feature of this loess is the occurrence of calcium carbonate (rare in New Zealand) and the development of distinctive carbonate enriched horizons in the soils and buried soils with a vermiform fabric (worm burrowed). The soil stratigraphy of this loess awaits detailed examination. The presence of two or three loess sheets indicates that the higher strath and valley fill may be coeval or older that the Tiromoana coastal plain (M1 of Yousif, 1987, figures 17 and 22), ie. 60 to 80 kyr.

The lower Waipara River gorge has been incised into the axis of the central of three anticlines (figures 17 and 21) that form the structure of the coastal hills, from west to east, the Black, Cass and Kate Anticlines (Wilson, 1963, Yousif, 1987). These are sigmoidal folds arranged en echelon in a manner typically generated in a dextral strike-slip zone. The evolution of the folds appears to conform predictably to models of evolution during cumulative shear displacement, with the oldest folds growing and rotating clockwise in the middle zone and

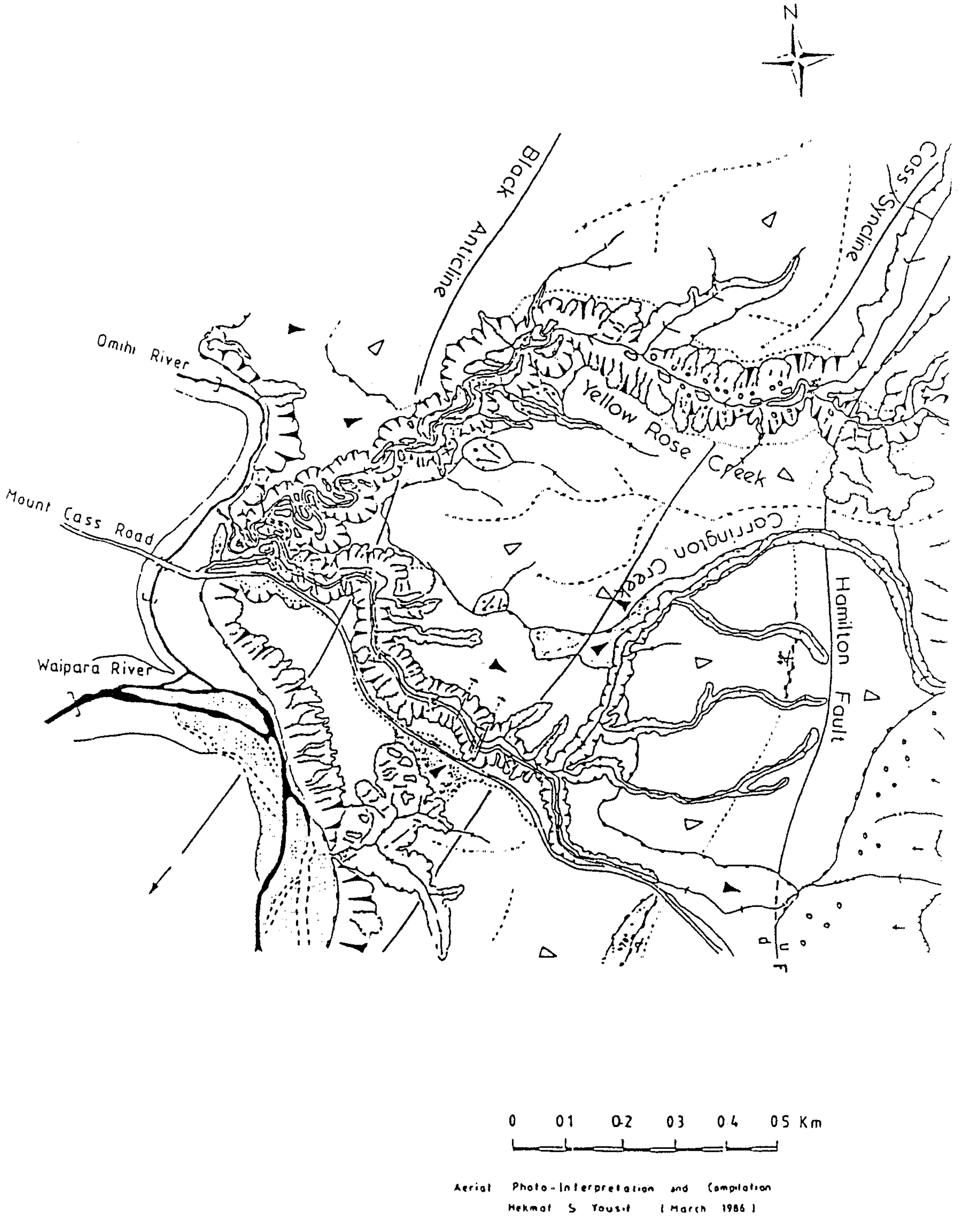


Figure 19: Incision of the Yellow Rose and Carrington Creeks across the rising Black Anticline (Yousif, 1987).

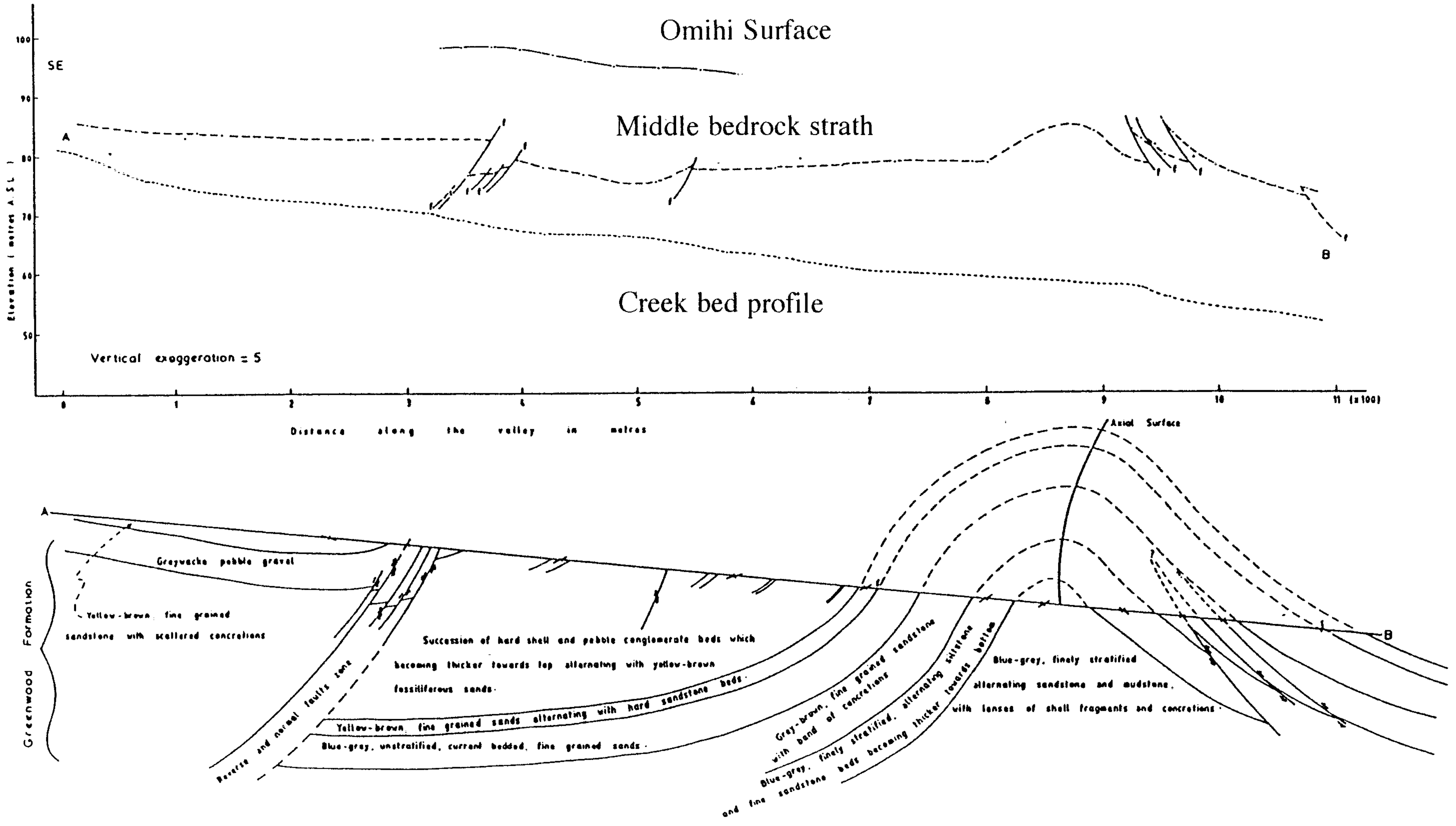


Figure 20: Geological cross-section along the Carrington Creek, and across the Black Anticline and Cass Syncline (Yousif, 1987).

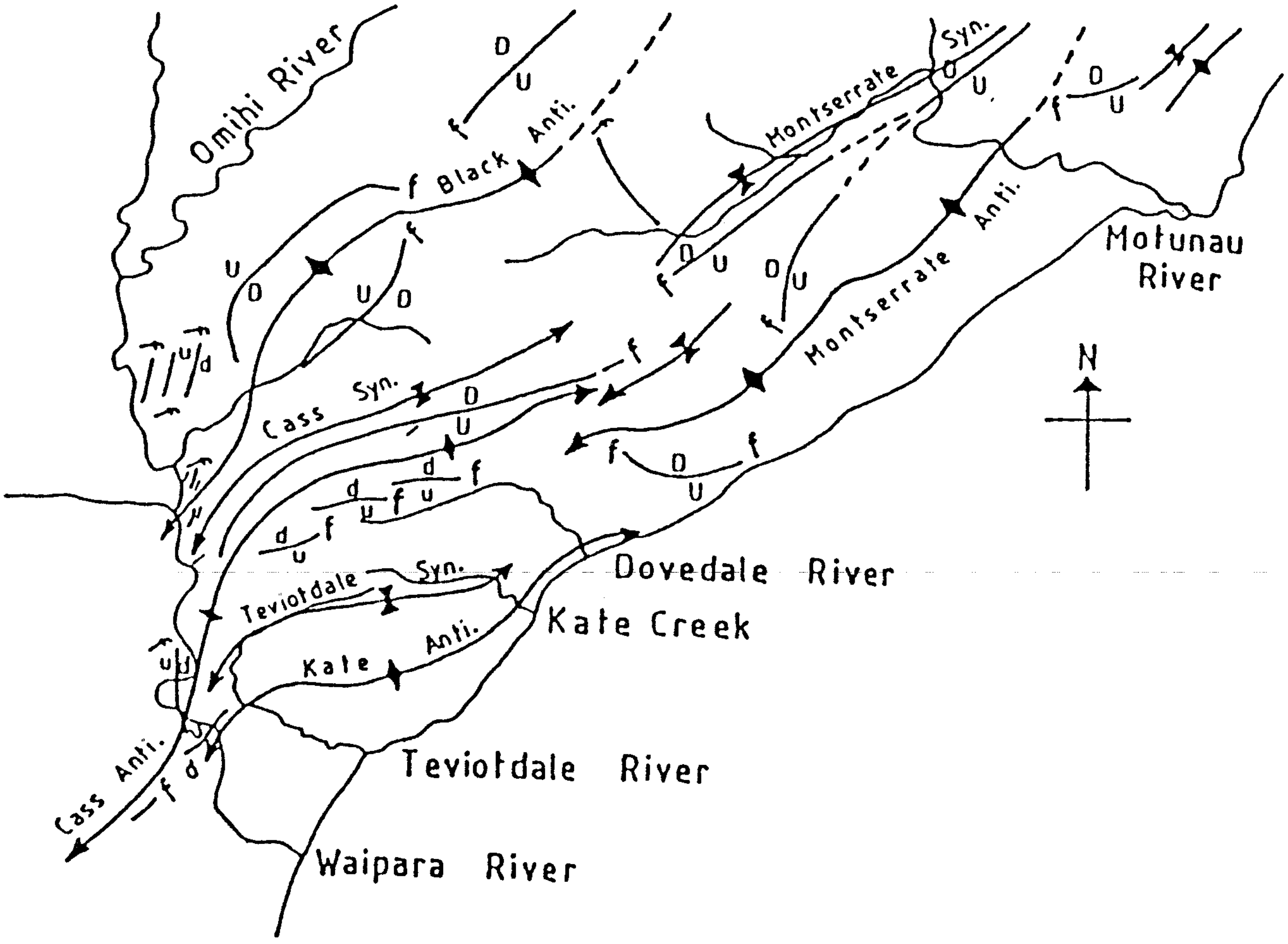


Figure 21: Principle elements of the structure and drainage, lower Waipara area (Yousif, 1987).

propagating longitudinally, followed by the younger outer folds. The principal period of fold growth at the time the Cass Anticline propagated across the Waipara River, seems to have been in the late Pleistocene and a significant proportion of the amplitude and limb dips were attained within the last 100 kyr. The evidence for this occurs at the coastal end of the Cass Anticline where the prominent triplet of marine terraces with assigned ages of 125, 105 and 80 kyr lie at altitudes above the elevation of the ridge formed by the crest of the Cass Anticline adjacent to the Waipara Gorge.

On the south side of the river a sloping surface can be seen immediately above a cluster of farm buildings; it climbs northeast into the gorge entrance rising to near the elevation of the ridge crest. This aggradation surface has a significant loess veneer (yet to be examined in detail) and may be the equivalent of the highest loess mantled aggradation surface across the Black Anticline along Mt Cass Road. Yousif (1987) correlated this high terrace surface on the south side of the river with the Teviotdale Surface occurring of the southeastern side of the gorge which is tilted southeast off the anticline to below the 80 kyr marine terrace (M2 of Yousif, 1987 and figure 17). The Teviotdale Surface is cut by the younger Tiromoana marine terrace with its two loess veneer and Aokautere Ash interbedded within the upper loess sheet (Kohn, 1979). The Teviotdale aggradation is thought to correlate with oxygen isotope stage 4 cooling at 70 kyr. The cold climate pollen assemblage above G1 in the Fault Bank section (Figure 14) may relate to the same cold climate interval (Nicol et.al, in press).

The implication is that most of the lower Waipara Gorge has been cut into a rising anticline during the last (Otiran) glaciation. At the time of the Teviotdale aggradation event and for some time afterwards, the Waipara "Gorge" consisted of a broad, flat-floored valley crossing a low ridge at the Cass Anticlinal crest. Accelerated uplift crossed a geomorphic threshold as the river, responded to back tilting of the upstream limb by becoming more meandering, and was not able to maintain grade and continue with lateral planation. The meanders became trapped and entrenched, the river downcutting rapidly into the inner gorge. Unmatched, degradational terraces became tilted as they were abandoned. Bedrock attitudes in the asymmetric anticline are steep and the folding is close, probably to the point of locking up. The river is again cutting a strath and lateral planation of the gorge floor is taking place, indicating continuing uplift.

Stop 8. GLENAFRICK, DOVEDALE STREAM, KATE CREEK COASTAL MARINE TERRACES (figures 21, 22 and 23).

Coastal marine terraces occur along the North Canterbury coastline from the Ashley northward beyond the Hurunui River (figure 1) to coastal Marlborough. The Waipara to Hurunui segment was studied by Carr (1970), who recognised three surfaces above the Holocene coastal plain and beaches. These surfaces show an increasing degree of fluvial dissection with increasing elevation. At Glenafrick at the end of the Mt Cass Road (figure 21), a large seaward sloping segment of the Tiromoana coastal plain (M1 of Yousif, 1987), is underlain by two loess sheets, which interfinger with fan alluvium. These cover beds in turn overlie floodplain to lacustrine muds, beach and shallow marine sediments (figure 22). Inland and to the north of the Tiromoana shoreline, two and possibly three higher terraces Bobs Flat (M2 of Yousif, 1987) and Leonard (M3 and M4 of Yousif, 1987) occur as broad accordant interfluves. Elsewhere these higher terrace remnants are underlain by gravelly beach alluvium with discoid pebbles (Carr, 1970). Yousif (1987) assigned ages of 60 kyr to M1, 80 kyr to M2, and 105 and 125 kyr to M3 and M4 respectively. Other than the loess stratigraphy and occurrence of the Aokautere Ash there is little other direct evidence for determining the age of these marine terraces. Opportunities may lie in the coverbed stratigraphy beneath the older terraces and dating of sediments and subfossil manuka wood in the basal sediments beneath the Tiromoana terrace (figure 22). The marine terraces are deformed around the flank of the Kate and

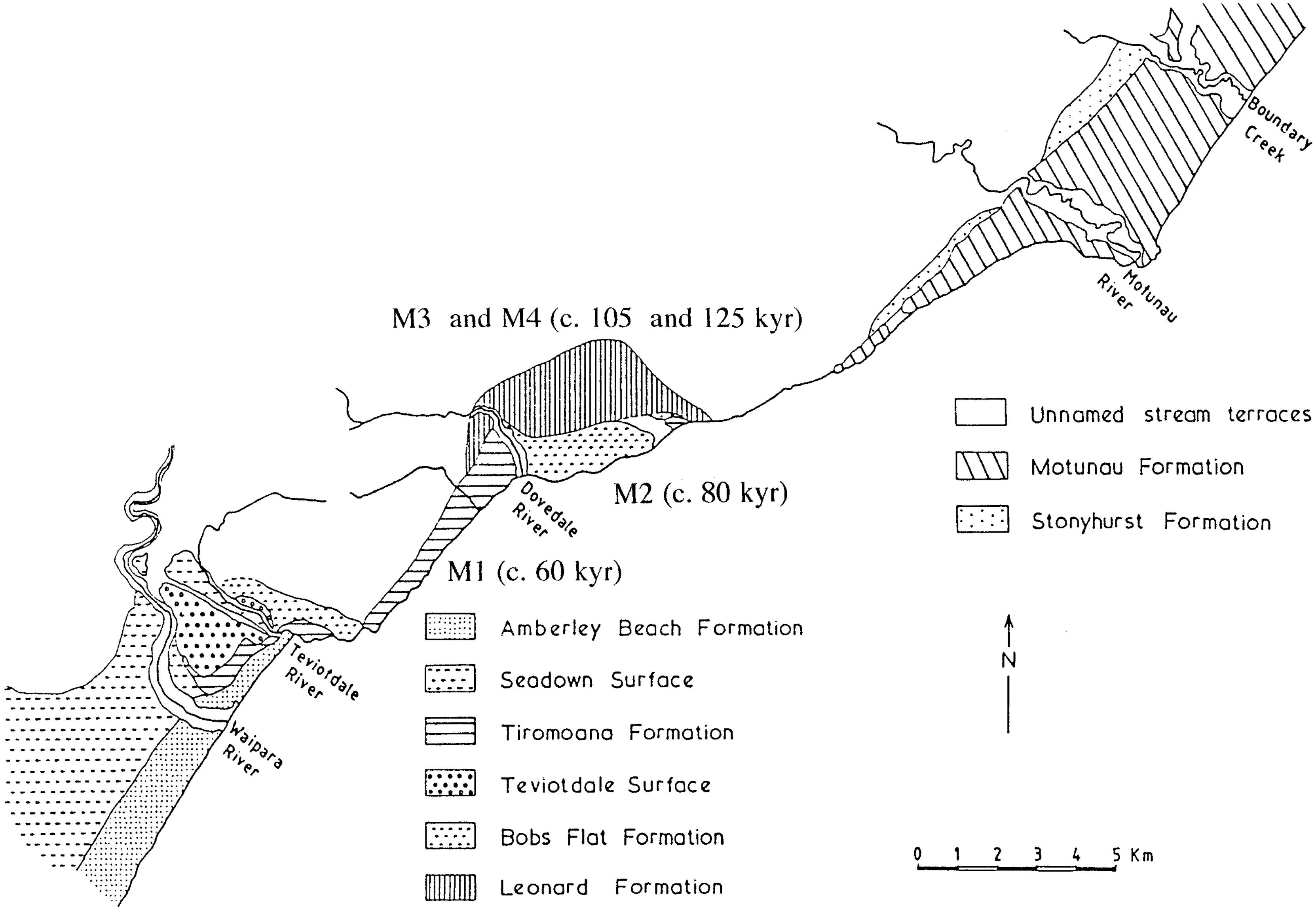
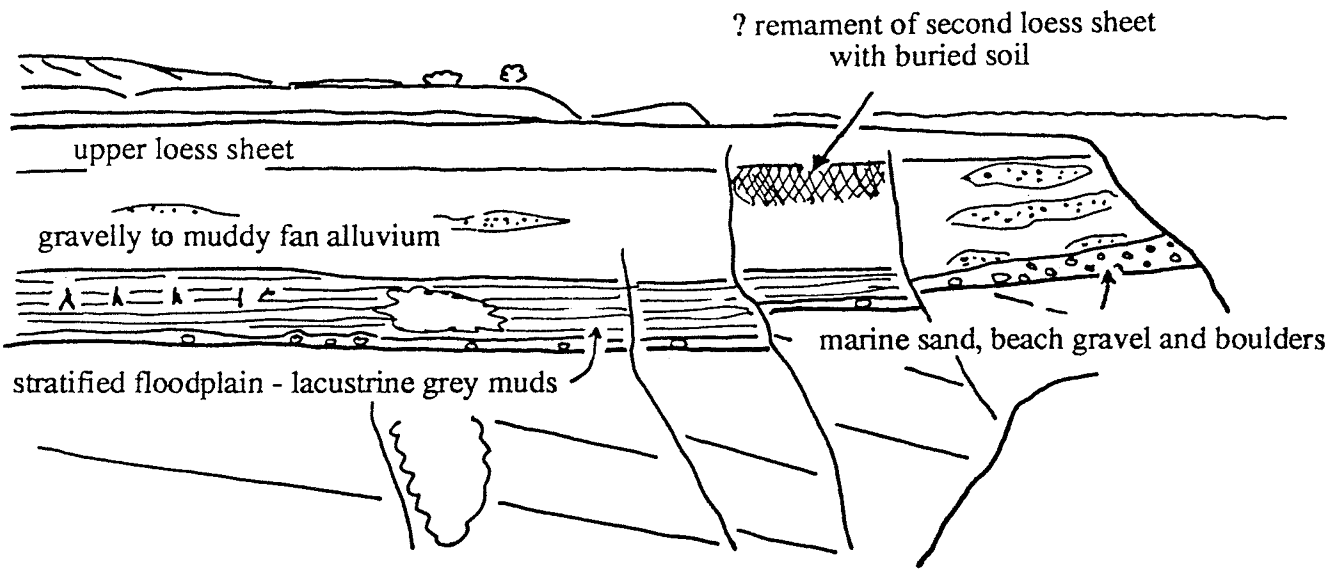
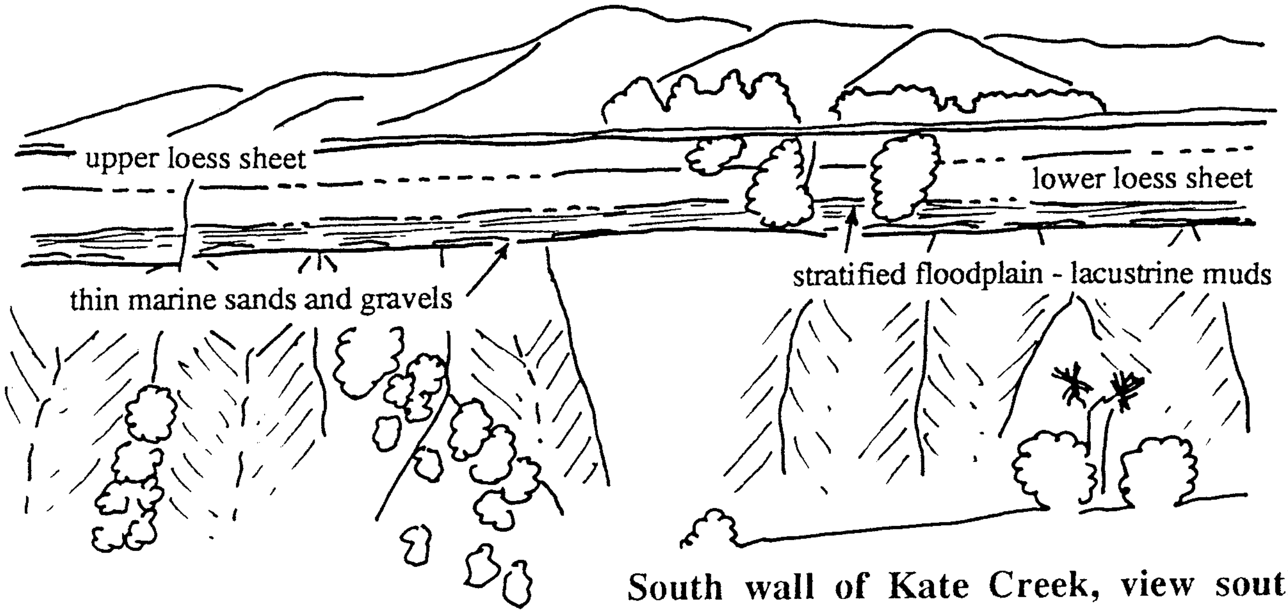


Figure 22: Distribution of fluvial and marine formations and associated surfaces, north of the Waipara River (Carr, 1970; Yousif, 1987).



North wall of gulley south of Dovedale stream, view north.



South wall of Kate Creek, view south.

Figure 23: Uplifted marine terrace (M1 c. 60 kyr), Tiromoana coastal plain - Glenafrick, Waipara (Carr, 1970).

Monserrate Anticlines (figure 21). Between the Waipara River mouth and the Dovedale Stream the outer edge of the Tiromoama surface is defined by a cliff 34 to 65 m above the modern beach.

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