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In Search of the Source of the 1934 Pahiatua Earthquake

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is a substantial bouguer gravity high and deep (160 km) seismicity within the Fiordland region. In addition the exposed middle crustal rocks in concert with the gravity high indicate that the mechanical support of high elevations in Fiordland differs from the mechanisms at work in the Southern Alps. The differences between the Fiordland and Southern Alps segments of the plate boundary are the result of differences in the plate geometry prior to the current transpressional interval and the nature of the Pacific and Australian lithosphere which interact at the boundary. In particular we infer from plate reconstructions that the 3-D geometry of the plate boundary during the Miocene translational stage included an offset between the near surface plate boundary structures and the deeper plate bounding shear zones. This initial condition of lithospheric geometry at the start of transpression allowed the region to accommodate transpression without the concomitant thickening in the superjacent crust, as has occurred further north in the Southern Alps. The lithospheric transition zone between Fiordland and the Southern Alps thus becomes a crucial locale to study the consequences of the two distinct styles of accommodation of lithospheric transpression.

T41B-22 0830h POSTER

Lithospheric Accomodation in the Transpressional Regime of Fiordland, New Zealand

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The past history of the Indo-Australian/Pacific plate boundary since 6 Ma in the New Zealand region has been characterized by a movement of the pole of rotation that increased the compressional component along the Alpine and Puysegur faults, changing their regime from translational to transpressional.

The effects of this transition to transpression are very pronunced in the Fiordland region where the lithospheric interaction had led to a subduction like regime manifest by deep earthquakes (deeper than 150 km), large gravitational anomalies and rapid uplift.

To understand the evolution of this lithospheric boundary to the increasing compressive component we have used a 3D-FEM model (TECTON). In particular we have tested the conditions which can lead to the present situation of a localized region of deep earthquakes and significant bouguer gravity anomaly. The model using about 3300 nodes and 2900 elements covers an area between 44S 167E and 48S 170E and is delimited by two major fault (Alpine and Puysegur). It is parametrized to allow us to evaluate the response of the lithosphere to different geometries, rheologies and thermal states, to see how these parameters can affect geophysical observable such gravity, topography and seismicity providing an important constraint on dynamics of the area.

T41B-23 0830h POSTER

Ductile Fabrics in Zones of Active Transpression: Mechanism of Uplift of the Alpine Schist, Central South Island, New Zealand

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The Alpine Schist in central South Island, New Zealand is a ~12 km wide zone of amphibolite-facies and lesser grade schists. Rocks at the surface have been uplifted from depths of 20-25 km in the past ~3 Ma on the hangingwall of the oblique-slip Alpine fault between the Pacific and Australian Plates. Peak metamorphism accompanied the onset of the last major phase of ductile deformation. During this, a steeply NW-dipping foliation formed oblique to the Alpine Fault, crenulating and deforming an older, subhorizontal(?) LS-tectonite into km-scale asymmetric folds that have SW-pitching hinges. Microstructural analysis of the youngest fabric in the attenuated planar limbs of these folds indicates oblate finite strain with a down-dip elongation and minimum strain ratios of ~1.4: 1.4 : 0.5 since peak mineral growth. Deformation involved a component of down-to-the east normal shear (shear strain of ~0.6), but was dominated by co-axial flattening (kinematic vorticity number of ~0.2). Dextral-reverse shear related to the late Cenozoic Alpine mylonite zone overprints the crenulation fabric.

We infer that uplift of the delaminated mid-crustal layer of the Alpine Schist involved ductile deformation to accommodate its translation through the Alpine fault ramp, a conclusion that cannot be confirmed until the high-temperature metamorphic fabrics are dated unequivocally. Our preliminary model invokes an early phase of inclined shear and minor layer-parallel shortening of the layer as it encounters the rigid toe of the ramp. Near the surface, oblique-reverse slip occurs on west-dipping backthrusts (pro step-up shears), such as the Main Divide fault. At depth, the inherited, older foliation is ductilely shortened and rotated parallel to the Alpine fault ramp. Strain modelling indicates that this process would require bulk shortening strains of <0.4 and oblate extensions of >0.6. As the schists are translated up the ramp (retro step-up shear), the foliation is oversteepened by ~22° in response to shear distal to the mylonite zone (shear strain of ~1.0). Deformation was partitioned into rotation of schistose packets, pure shear stretching of those packets, and antithetic normal-shear between them. A likely effect of this domino-like deformation process is shortening orthogonal to the Alpine fault and extrusion parallel to its dip, predictions that accord with evidence for isograd thinning and for maximum uplift rates several km to the east of the Alpine fault. Anisotropy of pre-existing fabrics plays a crucial role in the kinematics of transpression.

T41B-24 0830h POSTER

Historic Seismicity of the North Island, New Zealand, and its Relation to Oblique Subduction Along the Hikurangi Margin

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Waveform modeling, first motion analysis and earthquake relocations have been used in conjunction with geologic and isoseismal information to study a highly active interval of North Island seismicity occurring between 1917 and 1961. During this time period 7 earthquakes of Ms greater than 7.0 occurred, including the Ms 7.8 Hawke's Bay earthquake, the most destructive earthquake in New Zealand this century. Most historic earthquakes of the southeastern North Island appear to have occurred within the Australian plate (above the plate interface) on NNE trending strike-slip faults. One event in August 1942, represents normal faulting within the subducting Pacific plate, and a Mw=6.4 event in 1961 may have occurred on the plate interface. In the central North Island the 1931 Hawke's Bay earthquake and its aftershocks occurred on predominantly strike-slip faults, with focal depths (20-25 km) suggesting much of the Australian plate was ruptured during the sequence. In 1947 several earthquakes offshore in the northeast of Hawke Bay produced tsunamis. The events have long duration and low amplitudes, making resolution of focal depths and focal mechanisms difficult. However, at least one event may have occurred on a very low angle (less than 5 degree dip) fault. Results of our analysis to date suggest that much of the slip between 1917 and 1947 occurred along strike-slip faults within the upper plate, whereas the few, smaller (magnitude less than 6.5) earthquakes that have occurred since 1947 appear to have involved rupture along the plate interface. Thus oblique-slip within the North Island appears to partitioned both in time and space.

T41B-25 0830h POSTER

Active Tectonics and Paleoseismology of the Southern Hikurangi Forearc, New Zealand

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Oblique subduction in the southern Hikurangi margin, North Island, New Zealand, is partly accommodated by forearc strike-slip and reverse faulting, but the rate and distribution of active deformation in the upper plate is poorly known. Seismic hazard analysis in the region is hampered by incomplete knowledge of rupture parameters for historical surface-rupturing earthquakes. Field and paleoseismicity studies on faults in a segment of the forearc at 40.5° S latitude define the geometry, kinematics, and rupture parameters of earthquakes in this region. The faults in the area form a northeast-trending, east stepping en echelon array east of the main range-bounding strike slip faults. Mapping of offset features constrains rupture length (L) and single-event displacement (s) on several faults, with L=5-20km and s=3-7m dextral or dextral-reverse. Historical and paleoseismological evidence suggests that historical (i.e., <100-150y old) earthquakes occurred on the Alfredton and the Waipukaka faults despite a lack of contemporary reports of surface rupture.

Trenching and ^{14}C dating provide constraints on paleoseismicity. Near Alfredton, trenches on the Alfredton fault reveal that two earthquakes occurred since 642±91yBP, with the most recent event <330±65yBP, and possibly <200yBP. Trenches 5 km south of Alfredton also constrain the two most recent ruptures, one at ~400yBP and one at <240±70yBP. Analysis of historical evidence suggests the fault ruptured in 1855 during the M8.2 Wairarapa earthquake, and extends the ~100 km surface rupture length of the Wairarapa fault NE across a 10km wide right-step for ~16km.

Trenching along the Waipukaka fault indicates the youngest event postdates a charcoal horizon containing European artifacts (i.e., <100y old). Analysis of historical evidence suggests the earthquake occurred in 1934, consistent with a ^{14}C age of <200yBP on the charcoal horizon and location of the fault within the MM9 isoseismal and within error of the relocated epicenter of Downes et al. (1998) for this M_s 7.6 earthquake. ^{14}C dates establish that at least four earthquakes have occurred since 7300±70yBP and three since 2762±57yBP. The net dextral-reverse slip rate is 1.6-3.8 mm/yr (over 7.3 ka) or 3.3-7.7mm/yr (over 2.8 ka).

Constraints on rupture parameters, slip rates and recurrence intervals suggest a larger component of strike slip than previously suspected is occurring within the forearc at this latitude and that future earthquakes of M>7 are possible. Seismic hazard estimation is made difficult by the inconsistency between surface rupture lengths and slip-per-event (i.e., fault scarps are short relative to single-event slip). Further complication derives from the tendency of faults in the region to be highly segmented, disconnected, and probably structurally immature, implying that 1) geometric discontinuities at the surface may not be barriers to rupture propagation and 2) a large component of seismic slip may not be reflected in the surface rupture.

T41C MC: Hall D Thursday 0830h
Plate Tectonics and Rifting Posters

Presiding: **P Sharfstein**, University of California, Santa Barbara

T41C-01 0830h POSTER

Imaging the Magallanes Fault System in the Tierra del Fuego Region (Southernmost South America): Results from a Geophysical Reconnaissance

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The present-day boundary between the South America and Scotia plates is located along a 3000 km-long strike-slip fault, running from the western part of the North Scotia Ridge, to the southern Chile trench. Sparse geological evidences of transcurrent fault and associated thrusting found onshore in the Tierra del Fuego Island have been interpreted as the surface evidence of this plate boundary. The largest of these fault zones is know as the Magallanes Fault System (MFS), extending for over than 600 km across the Tierra del Fuego in both the Argentinean and Chilean territories. This interpretation is based mainly on seismological data (few and low-magnitude earthquakes) and geometrical extrapolations (onshore westwards prosecution of the South Scotia Ridge), but lacks of detailed and systematic geological investigations and petrologic information. The precise age of the deformation associated to the presence of the MFS, and the distribution of relative movement between the two plates along its length, are also poorly known. In particular, it is not clear the role that the MFS had in the more general context of the Drake Passage opening and the successive development of the western Scotia plate during Oligocene time.

A geophysical and geological investigation have been carried out from 19th February to 4th April 1998 in the Tierra del Fuego Island, with the collection of 225 GPS-fixed gravimetric and magnetic data points, the execution of field structural geology transects and petrologic samplings, in an area 25 km x 40 km wide, located just on the east of the Fagnano Lake. This research project, called TESAC (Tectonic Evolution of the South America-Scotia plate boundary during the Cenozoic), is part of a scientific collaboration between Argentina and Italy for the study of the Antarctic region and adjacent seas. Main aim of this program is to analyze the geological structure of the segment of the MFS in the Tierra del Fuego region both onshore and offshore, and to reconstruct the principal aspects and timing of the strike-slip activity occurred in the area during the Cenozoic. The offshore part of the survey is planned for the Austral summer 1999-2000.

Preliminary magnetic and gravity maps of the studied area have been produced, and a deep structural model was constructed across the supposed location of the MFS. Two Synthetic Aperture Radar (SAR) images, acquired by ERS-1 and ERS-2 (Earth Resource Satellite), have been used to recognize the main structural lineations of the area. The topographic correction for the Bouguer anomaly map has been computed using the digital elevation model derived from interferometry of a pair of SAR images, because of the unavailability of extensive and precise altitude information. Analyses performed on the acquired data furnished important indications on the presence of a main lineation elongated in an E-W direction in prosecution of the trend of the Fagnano Lake, in some parts deeper than 500 m, where the South America-Scotia plate boundary is supposed to be located. Preliminary correlation between the structures found onshore and those present offshore, as seen from available seismic profiles, have allowed to map the main strike of the MFS in the surveyed area, and tentatively reconstruct the tectonic framework of the South America-Scotia plate boundary in the Tierra del Fuego region.

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IN SEARCH OF THE SOURCE OF THE 1934 PAHIATUA EARTHQUAKE

Final report on EQC Research Project 97/320

by

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PROJECT SUMMARY

The March 5, 1934 M_S 7.6 Pahiatua earthquake (epicentre 40.51 S, 176.29 E) caused severe damage (MM8 and MM9) in a large part of the southern North Island. Although investigations immediately after the earthquake failed to identify a surface fault rupture, no direct observations were made of the faults in the area. In this study we present the results of field work and paleoseismicity studies on several of the major faults within the 1934 MM9 isoseismal to assess the likelihood that there was surface rupture on these, or other, faults in 1934, and to describe the geometry, kinematics, and rupture parameters of the recent historic and/or prehistoric surface rupture earthquakes in this region. We discuss the implications of our results for seismic hazard assessment in the area.

We conducted an airphoto survey of the 1934 MM9 isoseismal region and compiled existing published and unpublished data to identify known and likely active faults. Field work examined several of the more prominent scarps in the region, with geomorphic and structural mapping designed to quantify the length, type of faulting, and offset characteristics, as well as assess the relative recency of faulting by an examination of scarp morphology and continuity. Of the faults studied (Alfredton, Saunders Road, Waitawhiti, Oporae Road, Waipukaka faults), the Alfredton and Waipukaka faults were identified as having extremely fresh scarps and these were chosen for more detailed analysis via mapping, trenching and ^{14}C dating.

Mapping of the Alfredton fault, the northern continuation of the Wairarapa fault, revealed fresh scarps over a strike length of 12-16km from just north of Mauriceville to ~5km north of Alfredton. The fault is a dextral fault; mapping in this study and compilation of previous work suggest that the single-event displacement on this fault is at least 4 m and possibly as high as 7m. Data from trenches dug in 1991 (unpublished data from IGNS) and in this study reveal evidence for the last two surface rupture earthquakes. The 1991 trenches reveal two surface-rupturing earthquakes occurred since 642±91 yBP (years before present=1950), with the most recent event occurring after 330±65 yBP, and possibly after AD1750. The trenches dug in this study also contain evidence for the two most recent surface ruptures, one at ~450 yBP and the other at <240±70 yBP. Photographs taken of the fault scarp in December, 1935 by Ongley of the NZGS show a scarp that appears fresh, but does not look like a surface rupture that is only ~1.5 years old. Preliminary evidence thus suggests the Alfredton fault may have ruptured the surface in the 1855 earthquake. If our interpretation is correct, the surface rupture for the 1855 earthquake ruptured across a major geometric barrier, a large right step in the fault trace.

The second fault investigated in detail, and mapped for the first time, is named here the Waipukaka fault zone. The fault is a west-dipping dextral-reverse fault comprising ~8 km of extremely fresh scarps near the northern end of the 1934 MM9 isoseismal and within the error estimate of the earthquake epicenter of Downes et al. (1998). The few offset features identified suggest a dextral to reverse ratio of ~5:1 to 2:1, with single event slip components on the order of 3-6 m dextral, 1-3 m reverse (4-7 m oblique slip). Two trenches along the fault reveal evidence for multiple surface-rupturing earthquakes. The youngest event in both trenches is interpreted to post-date a charcoal horizon that contains European historical artifacts (such as shoes and pottery) and thus is considered to be an historical event. Analysis of historical seismicity and evidence on settlement of the area suggests the most likely time of the earthquake is 1934. Radiocarbon results establish that at least four earthquakes have occurred since 7300±70 yBP and three since 2762±57 yBP.

Evidence from this study suggests that historical earthquakes occurred on both the Alfredton and the Waipukaka faults. Preliminary analysis of the historical and geological evidence suggests that the Alfredton fault may have ruptured in 1855 and the Waipukaka fault most likely ruptured in 1934. We also present an analysis of the implications of the rupture parameters, including the geometry, length, displacement, and recurrence interval, for seismic hazard estimation on the east coast of the North Island.

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INTRODUCTION

The March 5, 1934 M_S 7.6 Pahiatua earthquake is the fourth largest earthquake in the recorded history of New Zealand and caused severe damage (MM8 and MM9) in a large part of the southern North Island. Recent analysis of the earthquake by Downes et al. (1998) establishes the epicentre at approximately 40.51 S, 176.29 E and indicates an elongated mesoseismal region approximately 50-65 km long in a NE-SW direction (Fig. 1). Although investigations immediately after the earthquake failed to identify a surface fault rupture, no specific observations were made of the known faults in the area (Ongley, 1934, unpub.). More recent work (e.g., Berryman and Cowan, 1993; Lensen, 1969; Berryman and Beanland, unpub.) suggested the presence of fresh scarps in the epicentral region, but little detailed work had been done and the age(s) of most recent ruptures on the faults were unknown.

Paleoseismicity-based seismic hazard analyses rely on estimating earthquake magnitude from rupture parameters such as fault length and slip, via moment magnitude calculation (Hanks and Kanamori, 1979) or regressions such as those of Wells and Coppersmith (1994) for earthquakes worldwide. However, the quantitative relationships in New Zealand may vary from the global ones, and assessing their validity relies on accurate knowledge of rupture parameters, which in New Zealand is hampered by the paucity of large, historical surface-rupturing earthquakes. Thus, detailed studies of known surface ruptures are necessary in order to better estimate seismic hazard. Further, the 1934 earthquake is one of a set of possibly related earthquakes in the upper plate of the Hikurangi subduction zone, including the temporally clustered 1931 Hawkes Bay (M_s 7.8), 1932 Wairoa (M_s 6.9), 1934 Porangahau (M_l 4.6-5.6), and 1942 Wairarapa (M_s 7.2, 7.0, 6.0) earthquakes, and the nearby 1855 Wairarapa (M_s 8.2), 1904 Cape Turnagain (M_s 6.7) and 1990 Weber (M_l 5.9, 6.2) earthquakes. Analysis of its relationship to other large events and aspects such as the possible stress triggering of large earthquakes and the time-variability of seismic hazard (e.g., King et al., 1994; Robinson, 1994) requires basic geological and seismological data on the 1934 earthquake.

In this study we present the results of field work and paleoseismicity studies on the major faults within the MM9 isoseismal of the 1934 earthquake to assess the likelihood that there was surface rupture on these, or other, faults in 1934, and to describe the geometry, kinematics, and rupture parameters of the recent major historic and/or prehistoric surface rupture earthquakes in this region. We discuss the implications of our results for seismic hazard assessment in New Zealand and active tectonics of the Hikurangi margin.

Specific objectives of this study included:

(1) Locate all active faults within the epicentral region of the 1934 earthquake.

(2) Identify the fault "most likely" to have ruptured in 1934.

(3) Determine whether or not the "most likely" fault did, in fact, rupture the ground surface in 1934, and determine rupture characteristics (including style of faulting--reverse, normal, or strike-slip-- surface rupture length, single event displacement size, and recurrence interval) of surface rupture earthquakes on this fault during the recent past.

We conducted an airphoto survey of the 1934 MM9 isoseismal region (Fig. 1, Table 1) and compiled a map of existing data (e.g., Beanland, 1995; Kelsey et al., 1995; Lensen, 1969; Neef, 1974, 1984, 1992, 1997a, 1997b, and unpublished data from the Crustal Dynamics Section of IGNS) to identify known and likely active faults (see objectives 1, 2 above). Field work examined several of the more prominent fault scarps in the region, with geomorphic and structural mapping designed to quantify the length, type of faulting, and offset characteristics, as well as assess the relative recency of faulting by a general examination of scarp morphology and continuity (objectives 2, 3). Two faults were identified as having extremely fresh scarps and these were chosen for more detailed analysis via detailed mapping, trenching and ^{14}C dating (objectives 2,3). We also analyzed historical evidence on early settlement of the region and the field notes of geologist Ongley in an attempt to constrain dates more recent than can be obtained by ^{14}C dating. Throughout this work "historical earthquakes" are considered as occurring after 1840, the time of earliest European settlement of the North Island.

GENERAL TECTONIC SETTING AND RECENT EVOLUTION OF THE HIKURANGI MARGIN

The Hikurangi margin is the southern part of the Tonga-Kermadec subduction zone, where the Pacific plate is being subducted beneath the Australian plate (Fig. 1). The area presently exposed in the forearc region of the North Island has evolved throughout the Cenozoic from predominantly subsidence and tectonic quiescence during the Miocene to uplift and deformation in Quaternary time. Numerous studies have focused on the stratigraphic and structural evolution of the margin during the Tertiary, and have shown that the area comprised a broad submarine forearc basin with an accretionary prism to the east from early Miocene onward (e.g., Lewis, 1980; Pettinga, 1982; Delteil et al., 1996; Kelsey et al., 1995; Neef, 1997a, 1997b; Rait et al., 1991). Emergence of the forearc did not occur until latest Neogene or Quaternary (Lewis, 1980; Pettinga, 1982) and development of the axial ranges occurred after ~1-1.6Ma (Nicol and Van Dissen, 1997); or 0.7 Ma (Shane et al., 1996).

The recent history of the margin is one of oblique subduction , accompanied by dextral and reverse faulting in the forearc region and normal faulting in the arc-back-arc region (Figs. 1, 2). Dextral faulting began in the southern Hikurangi forearc within the last ~0.5 m.y., evolving from an earlier, predominantly reverse faulting environment (Beanland, 1995; Kelsey et al., 1995). Quaternary geological and geodetic studies show that the upper plate is deforming at varying rates from north to south with predominantly dextral slip of ~21 mm/yr in the south, decreasing to less than ~2mm/yr in the north (Fig. 2). Clockwise rotation of part of the forearc is occuring at ~7-8°/m.y. with respect to the Australian plate (Beanland, 1995; Beanland and Haines, 1998; Walcott, 1984).

Major faults of the eastern North Island are shown in Fig. 2, and comprise two main active dextral fault zones, the Wellington-Mohaka-Ruahine fault system in the west, and the Wairarapa-Alfredton-Makuri-Poukawa fault system in the east. A wide zone of smaller, discontinuous faults occur east of the main faults; but other than the study of Cashman et al. (1992), little was known about these eastern faults prior to this study (Figs.2, 3).

Geological Evolution of the Northern Wairarapa

Basement units in the study area comprise mainly Neogene marine to nonmarine sedimentary sequences in the south (herein termed the Alfredton region; Fig. 3), and Cretaceous to Miocene marine sequences in the north (termed the Pongaroa region; Fig. 3) . These rocks were deposited over Jurassic greywacke which crops out only in a few areas in the cores of folds or in fault blocks.

Geology of the Alfredton region

The Alfredton region records general subsidence and marine sedimentation from ~10 Ma to 3.75 Ma, followed by gradual shallowing in the late Pliocene to emergence in early or mid Pleistocene time (Kelsey et al., 1995; Neef, 1984). The first important deformation is a period of east -vergent reverse faulting and folding from late Pliocene (~2.5 Ma) to middle Pleistocene time (Kelsey et al., 1995). The reverse faults have west side up dip-slip displacements of up to two km, and asymmetric hangingwall anticlines (Kelsey et al., 1995). Seismic reflection surveys by Lamarche et al. (1995) indicate a period of reverse faulting (resulting in uplift, erosion, and facies differences) in late Miocene to early Pliocene time. This deformation, however, was not intense and did not result in widespread emergence or uplift of ranges (Beanland, 1995)

Deformation in the Alfredton region changed to dextral strike slip faulting before late Pleistocene time (Kelsey et al., 1995). Although the late Neogene reverse faulting extended from the Wellington fault east to the present coast, many of the reverse faults are now inactive, and the strike-slip faults in general reactivated only some of the older structures. The Alfredton and Pa Valley faults are in part reactivated structures, although some of the youngest traces have stepped east or west from the older fault trace. These faults are interpreted to be subvertical from their straight traces across topography; dips at the surface are both southeast and northwest (Kelsey et al., 1995). Seismic data show that the Alfredton fault exhibits an upward-fanning structure that produces the several mapped surface traces. The westward step at the southern end of the Alfredton fault, called the Dreyers Rock fault zone, connects the Alfredton fault with the Wairarapa fault (Fig. 3), and consists of several short north-, east- and northeast-striking faults with dextral-normal slip (Kelsey et al., 1995). The north end of the Alfredton fault steps westward to the Pa Valley fault, and from there northward connects to the Makuri fault (Figs. 2, 3). Cumulative Quaternary strike slip on Pa Valley and Alfredton fault is less than a few hundred meters (Kelsey et al., 1995).

Neef (1992, 1995, 1997a, 1997b) envisions a more complicated deformational history for the area east of Eketahuna, including normal and reverse faulting (related to dextral transpression during Miocene forearc deposition), and dextral faulting in the late Miocene. Neef (1997b) recognizes Quaternary faulting only on the Makuri fault.

Geology of the Pongaroa region

In the Pongaroa area (Fig. 3), the absence of rocks younger than Miocene makes it difficult to interpret the late Neogene to Quaternary history. Delteil et al. (1996) outline the Miocene history of the region, but no other detailed structural studies have been done, and we briefly summarize information shown on the 1:250,000 sheets of Kingma (1962, 1967). The bedrock consists of Whangai formation (latest Cretaceous) grey siltstone overlain by Early to Late Miocene mudstone and sandstone. Delteil et al. (1996) infer a period of large scale dextral faulting during the early Miocene along several northeast-striking faults in the region, with most displacement along faults near the coast southeast of Pongaroa. The amount of dextral slip, if any, however, is debated (Rait, 1997). In the study area northwest of Pongaroa, the Cretaceous rocks form a southeast-vergent, northeast-trending antiform with relatively steeply dipping limbs The anticline is faulted on the southeast side against Oligocene and Miocene strata (Kingma, 1967). This fault, the Pongaroa fault, is inferred from facies differences on either side to have early Miocene transcurrent movement (Delteil et al., 1996; Ridd, 1967). However, from the mapped relationships (Kingma, 1967), a younger period of reverse or dextral-reverse movement is indicated in post- early Miocene time, consistent with the studies of Delteil et al. (1996) and Neef (1997a, b) suggesting ongoing shortening during and after Miocene time.

GEOMORPHOLOGY, STRUCTURAL GEOLOGY, AND PALEOSEISMOLOGY OF THE MAJOR FAULT ZONES

Field and airphoto observations of faults in the MM9 isoseismal region of the 1934 earthquake were used to determine the distribution and character of Quaternary faulting in the study area (Fig. 3, Tables 1 and 2). We examined the earliest airphotos available, taken in 1943 and 1944, to best assess fault scarps formed prior to that time. In the following sections we discuss some general geomorphologic characteristics of the area, followed by descriptions of the major fault zones, including the Alfredton, Saunders Road, Waitawhiti, and East Puketoi faults (Fig. 3).

GENERAL GEOMORPHOLOGY

Typically scarps in the entire study area are underlain by bedrock siltstone or mudstone with a thin (<0.5 m) soil developed on top. Only a few of the mapped traces cross major streams in the area; where a scarp is developed on the terrace surface, the height is indicated (Tables 1, 2, Figs. 5, 9) Terraces in general are not widely developed and the most extensive terrace (probably formed during the last glacial) is still occupied by the streams during floods, as the modern channels are typically extremely narrow and incised at most a few meters. Topography in the region is not controlled by the active faults (which appear to have developed too recently to result in significant topographic uplift or lateral offset), or by stream erosion in this relatively arid climate, but mainly by extensive landslides and the overall westward tilting due to regional uplift; as a result, drainage patterns are very complex (Figure 3).

The frequency and abundance of landslides recognized from aerial photo surveys suggests rapid change of hillslope morphology, such that nearly all preserved geomorphic fault scarps can be interpreted to be post-glacial even where the age of the surface is not known precisely. Hillslope erosion has likely increased significantly following deforestation during settlement of the area, and the preservation of scarps is in part related to the age, method, and intensity of clearing and cultivation. Downhill-facing scarps are considerably less well preserved than uphill facing scarps, as the former are more prone to modification by slumping. As a qualitative estimate of relative age of faulting, we divide the scarps in Table 2 into three classes, similar to those used by

Lensen (1969), recognizing that our age estimates could be in error by at least a factor of 2-3. We interpret well-preserved scarps with moderately steep faces (>25-30°) and continuity across steep, landslide-prone hillslopes to have been active within the last ~1 ka (ka = thousand years before present); these are labelled class 1. Those that have more subdued scarps and that are somewhat eroded by streams and landslides are considered to have been active within the last ~10 ka (Class 2), and those that are highly eroded or appear as traces on elevated or dissected Quaternary surfaces are designated Class 3. All of the faults shown as bold, unbroken lines on the maps (Figs. 3, 5, 9) fall into Lensen's Class I (repeated movement in the last 500 ka or single movement in the last 5 ka); those shown as dashed lines are Class 3; these would fall into Lensen's Class II (single movement in last 5-50 ka and/or repeated movement in 50-500 ka). In the following sections we describe the major active faults from south to north, incorporating observations made by previous workers and those made during this study.

ALFREDTON FAULT

Geology and Geomorphology

The Alfredton fault appears to be the northern continuation of the Wairarapa fault zone via an eastward step between Mauriceville and Ihuraua, an area of short, dextral-normal fault traces termed the Dreyers Rock fault zone (Fig 3; Kelsey et al., 1995). Lensen (1969) mapped several locations along the southern Alfredton fault where Quaternary features are offset dextrally (Figs. 4, 5), however none of these features are of known age. Lensen (1969) stated that post-glacial features are offset an average of 40 m. He recognized that historical displacement was likely along part of the fault because the scarps are so fresh, a finding confirmed in this study.

From Ihuraua northward, the fault strikes ~040° and is composed of two late Quaternary traces in the south and one in the north (Fig.5). Surface exposures of the fault dip both southeast and northwest, but the trace across topography indicates a subvertical dip. Displaced features are summarized in Table 2 and illustrated in Figs. 4 and 5. In several locations along its length the Alfredton fault consists of two or more parallel or subparallel faults; locally these features form graben, in other places the upthrown side changes along strike of one or both faults (Fig. 5). The western strand typically has a larger dextral component than any of the eastern strands. The eastern strands are subparallel to bedding and may represent flexural slip faults related to folding in the footwall of the main Alfredton fault. A major strike change occurs at the southern end of the Alfredton fault zone, where the fault curves to a more easterly trend and contains a significant normal component (Kelsey et al., 1995), and another occurs at Alfredton township where a left step causes bulging of the terrace along the Te Hoe stream (Fig. 5).

Scarps in the ~4 km long segment of the fault between Ihuraua and where the fault crosses Bartons Line are extremely fresh and unvegetated, with face angles typically >40° and locally subvertical. There is a segment ~1 km long to the northeast of Bartons line where the scarp is obscured (even on the 1944 airphotos), and then another ~8 km of relatively fresh scarp further to the northeast that cuts stream terraces of probable Holocene age (~7ka, McCallion, 1996). North of the Tiraumea river, the scarp becomes increasingly difficult to identify although the fault can be recognized by the juxtaposition of different Tertiary bedrock units (Kelsey et al., 1995). The length of relatively continuous distinct scarps is 12-18 km (Figs. 3, 5), with the larger value including scarps in the Dreyers Rock fault zone interpreted by Kelsey (pers. comm.) to be very fresh.

The good preservation, steep scarp faces, and apparently young age of offset features along the Alfredton fault can be interpreted to reflect recent, possibly historical, surface rupture based on geomorphologic estimates alone. Photographs of scarps formed during the 1855 earthquake on the Wairarapa fault (Grapes and Wellman, 1988; Ongley, 1943a) show very similar morphologic characteristics. We leave detailed evaluation of the different possible historical events that may have ruptured the Alfredton fault to the discussion section of this report, following presentation of age data and comparison with other faults in the 1934 MM9 isoseismal region. However, based on the similar geomorphology along the 12-18 km fault length described above, we interpret it to represent the minimum rupture length of the most recent earthquake. North of the Tiraumea river, a fresh trace ~500m long was mapped by Lensen (1969) near Nikatea (Table 1, fault #18, Fig. 3) and interpreted by him as a possible historic rupture; if this trace also ruptured in the most recent earthquake, it would extend the rupture length to 25 km and within ~3 km of the Pa Valley fault. The entire length of the Alfredton fault zone, from the southern end of the Dreyers Rock fault zone near Mauriceville to its northernmost mapped trace near Nikatea, is 30 km, which would represent a maximum rupture length for an earthquake that was confined to the Alfredton fault. The fault scarp is very difficult to find between the Nikatea trace and the Tiraumea river, however, and the Nikatea trace appears to have been freshened by recent landslides; the scarp is also obscured for several km near the southern end near Mauriceville (Fig. 3); thus we believe it is unlikely that the most recent surface rupture on the Alfredton fault exceeded ~18 km in length.

Paleoseismic Investigation

Trenching at two sites along the Alfredton fault reveals evidence for the age of and displacement during the last two earthquakes, and confirm our inference of historical surface rupture. Two trenches were dug in 1991 where the fault crosses near the school and golf course at Alfredton (Fig. 6), and a small hand-dug trench and a larger machine-dug trench were investigated in 1998 along a more southerly section of the fault west of Barton's Line (Fig. 7).

Golf Course Trench sites.

The golf course trench sites were dug across an uphill-facing scarp segment where two laterally offset channels of 12-14 and 8.5-13 m occur and ponding of the drainage has formed swampy areas along the hillside (Fig 6a). The scarp trends 040° and has a fairly constant height of ~1.5m, NW side up, where not obscured by slope movements or artificial fill.

Trench ALF-1 (Fig. 6b) contains a single peaty mud layer 10-20 cm thick deposited above mottled grey silt which in turn lies above weathered yellow-brown siltstone interpreted as bedrock. In trench ALF-2 (Fig. 6c) a peat horizon of similar thickness lies above silt interpreted either as weathered bedrock or alluvial silt. The peat layer in both trenches is deformed adjacent to the fault, and in ALF-1, a sliver of peat occurs dragged down along the fault plane. Both trenches have a mixed unit of sheared clay, silt and mud along the fault. The fault plane in both trenches dips southeast, and has a normal component of slip. Above the peat layer is a thin silt horizon, followed by topsoil which is seen to overlap the fault in ALF-2.

Radiocarbon dates obtained for samples are shown in Fig. 6b and Table 3. Dates, in radiocarbon years before present (AD 1950; yBP, 1σ errors), of 330±65 and 483±38 yBP were obtained from the peat layer in ALF-1; and 642±91, 370±50 yBP, and "modern" from the peat in ALF-2. Wood along the fault zone gave an age of 2822±34 yBP.

The two trenches can be interpreted to record the last two surface-rupturing events on the Alfredton fault. The most recent rupture must post-date the youngest peat date of 330±65 (1644 AD). If the "modern" date from Alf-2 represents material that is <200 yBP old rather than contamination, then the last earthquake could have occurred after 1750 AD. The peat horizon is interpreted to record ponding of the channels at the scarp during or shortly after a previous earthquake. The mottled, oxidized, and Mn-stained bedrock and silt below the peat may represent a soil horizon that would indicate the ground surface prior to burial by the swamp. With this interpretation, the penultimate rupture should closely predate the oldest date of the peat, and would be ~642±91 yBP (AD 1270 - 1450). Given that there are several dates from the peat that are within a few hundred years of each other, the much older age of the wood in the fault zone (sample Alf 1/3) is anomalous, and is here interpreted to represent a sliver faulted from along strike and possibly from greater depth along another part of the Alfredton fault, and has no direct relationship to the age of rupture along this segment of the fault.

Since the trenches record two earthquakes and the channels are offset by 8.5-14 m, the single-event slip on this segment of the Alfredton fault is interpreted to be 4.25-7 m. This value is consistent with the smallest lateral displacement observed at a number of sites along the entire length of the fault trace between the Dreyers Rock fault zone and Nikatea, and is indicated by the cluster of observations at 4-7 m shown on the histogram (Fig. 4).

Table 3. Summary of Radiocarbon Ages

Location, sample No.*	14C age† y.B.P.	Calibrated age§ cal. y.B.P. 1σ range	2σ range	δ13C %	Labß	Sample Material
Alfredton fault						
Golf Course trenches						
Alf 1/3	2822±34	2930-2800	2940-2790		NZ 7896	wood in fault sliver
Alf 1/2	330±65	440-280	500-0		NZ 7897	peat
Alf 1/1	483±38	520-470	540-330		NZ 7899	peat
Alf 2/11	642±91	650-520	700-480		NZ 7913	peat
Alf 2/2	modern	<200	<200		NZ 7898	peat
Alf 2/10	370±50	470-300	500-290		Beta 54176	peat
Percy trench						
Percy 1/2	324±72	460-160	500-140	-25.5	NZA 9094	wood (burned)
Percy 1/3	450±62	510-330	540-300	-26.4	NZA 9095	wood
Percy 1/6	240±70	300-0	430-0	-29.4	Wk-6261	wood (burned)
Waipukaka fault						
Hendricksen Trenches						
Hend 1/2	710±130	700-530	900-470	-27.4	Wk-6262	wood (root)
Hend 1/4	7300±70	8120-7940	8140-7910	-24.9	Wk-6263	wood (large branch)
Hend 1/5	Modern	<200	<200	-26.8	Wk-6264	wood (burnt)
Hend 1/3	195±57	280-0	300-0	-23.6	NZA 9096	wood (root) with bark
Hend 2/2	2762±57	2850-2760	2940-2750	-27.3	NZA 9097	wood (fine material in organic soil)

*For sample descriptions and locations, see text and trench logs.

† Conventional radiocarbon age before present (A.D. 1950) calculated using a Libby half-life of 5568 years, and corrected to $\delta^{13}C$ of -25%. Quoted error is ±1σ.

§ Calendar years before present (A.D. 1950) using calibration of (Stuiver and Reimer, 1993), and references therein), southern hemisphere correction of -40 radiocarbon years, lab error multiplier of 1.217 for Wk samples and 1.0 for NZ and NZA samples. Age ranges listed are the minimum and maximum values of the calibrated age range.

ß Laboratory: Wk, University of Waikato Radiocarbon Dating Laboratory; NZ and NZA, Institute of Geological and Nuclear Sciences Rafter Radiocarbon Laboratory; Beta, Beta Analytic dating laboratory.

Percy trenches.

Two trenches were excavated across the western strand of the Alfredton fault ~5 km south of the Golf Course site, in an area where the fault consists of two active traces (Fig. 5). The western trace contains abundant evidence for dextrally offset features whereas the eastern strand appears to have mainly a dip-slip component and was interpreted by Neef (1976) as a bedding-plane parallel fault (Fig. 5). A hand-dug trench across a small graben (Percy 2, Fig. 7a,b) reveals evidence for faults and fissures that post-date a soil horizon within which charcoal is concentrated. Vertical offset of the weathered bedrock and the charcoal horizon is similar, suggesting only one earthquake is represented in this trench. No ^{14}C samples were collected from this trench.

A larger trench (Percy 1) was dug across a steep section of 4 m-high scarp in a ponded area ~100m south of the smaller trench to look for further evidence of timing of the most recent and past surface ruptures (Fig. 7a). Fig 7c shows the trench log. The most important features of the log are: 1) the presence of two different bedrock units in the hangingwall and footwall; 2) the presence of two gravelly silt units, interpreted as colluvial wedges, deposited above fine massive silt on the downthrown block (units 7 and 8); unit 7 is not cut by any faults but unit 8 is cut by fault A; 3) two layers of concentrated charcoal, with the younger layer at the base of unit 12 and an older layer along the top of unit 9 and the base of unit 13; and 4) three faults (A,B, and C), one of which (A) cuts nearly up into the topsoil, which itself is fractured.

Radiocarbon dates were obtained on three samples from the Percy 1 trench (Table 3). Samples 1/2 and 1/6 from the lower charcoal horizon give ages of 324±72 and 240±70 yBP, respectively. Sample 1/3 from within wedge unit 8 is dated at 450±62 yBP.

At least two surface-rupture earthquakes are interpreted to be recorded in the Percy 1 trench. The most recent event is represented by movement along fault A and deposition of colluvial wedge unit 7, which appears to be ongoing as remobilization of similar material in unit 2 is occurring downslope. Although fault A does not cut all the way through unit 8, it must largely postdate unit 8; we cannot determine if slip decreased upward on that fault during the earthquake that formed colluvial wedge unit 7, or if slip on Fault A occurred near the end of unit 8 deposition. Unit 7 overlaps the older of two charcoal horizons, which we interpret to represent the initial forest burning for land clearing in the area, but predates the younger charcoal layer. Thus the most recent event postdates 240 ±70 yBP. The penultimate event is represented by fault B and colluvial wedge unit 8 which appears to overlap fault B but is cut by fault A. This colluvial wedge appears to predate the first charcoal horizon and contains detrital charcoal and wood dated at 450±62 yBP, which would approximately date this event. A possible third event is represented by fault C, overlapped by unit 5, but displacement on this fault may just die out upward or the timing of displacement could be coeval with either of the other faults as the age of unit 5 is not known. Further evidence of a third event is provided by the buried soil of unit 11, which may represent subsidence during the earthquake followed by ponding at the site (unit 10). The juxtaposition of different basement units suggests significant long-term cumulative displacement (~1km vertical throw, Kelsey et al., 1995), but we cannot determine how much of that displacement is earlier reverse slip rather than strike slip. Since the charcoal unit in the Percy 2 trench is cut by faults, it is probably correlative with the older charcoal horizon in Percy 1, located at the top of unit 9.

Historical evidence suggests that the charcoal horizons represent land clearing by both Maori and Europeans, as burning was the common method of clearing bush, although natural fires are also a possibility. The history of the Alfredton area and northern Wairarapa (Bagnall, 1976; Edmonds, 1987) suggests that there were Maori present in the area around Alfredton township prior to the arrival of the first European settlers in the 1860's, but no mention is made of how long the tribes had been there. Pa sites and cleared land are indicated on the maps of surveyor John Kelleher in 1879 (in Edmonds, 1987) but these may have only encompassed the area near the junctions of the Ihuraua, Tiraumea, and Te Hoe streams. The first European settlers in the study area west of Bartons line were the Percys, ancestors of the current landowners, who report having to clear the bush in the area in the late 1870's to 80's (Edmonds, 1987), but do not mention specific localities that might have already been cleared. The ^{14}C dates on samples 1/2 and 1/6 from the lower charcoal layer (Table 3) suggests that there was some prehistoric burning at the site, and constrains the last earthquake to have occurred since that time (~450 yBP).

Although the Percy trench sites are not located in areas that constrain the amount of dextral slip in each event, an estimate can be derived from the scarp height of 4 m and comparison with a stream offset just south of the trench site (Fig.7a) which has a scarp height of 7m and a lateral offset of 37-39 m. If two events produced the 4m scarp height, the 7m scarp could represent three or four events; the lateral offset would then represent single event displacement of 9.25-13 m (and a minimum of 7m based on uncertain location of the original channel wall east of the fault; Fig. 7a). A younger terrace riser offset 4.6 m reported by Lensen (1969, site 94) a few meters northwest of the trench site, but which has apparently been obscured or destroyed by construction of the track and stock pond (Fig. 7a), would represent a minimum single-event displacement which we can not confirm .

Further constraints on the amount and rate of displacement on the Alfredton fault is provided by a recent study by McCallion (1996) in the area north of Alfredton. Trenching in an area where terrace risers are offset laterally by 20 ± 2 m and dating of the gravels is interpreted to give a net slip rate of 2.6 mm/yr when corrected for the vertical component and the strike of the fault. The trench logs shown by McCallion (1996) contain evidence for two surface-rupture events, including: 1) a faulted buried soil that is overlain by a younger topsoil that is also faulted and 2) units below the buried soil that are offset more than younger units. A minimum single-event lateral slip of 9-11m is suggested by the terrace riser offset, but this value may be in error if other earthquakes are not recorded in the trench. Faulting of the topsoil in both trenches suggests fairly recent rupture; while the soils are not dated, terrace gravels dated at 6000-7000 yBP are faulted. However, neither the date of any particular event nor the slip rate is well constrained by the trenches, as all the ^{14}C samples are well below the youngest unit affected by fault. The slip rate calculation must be a minimum for three reasons. First, any terrace riser offset is a minimum because of the possibility of trimming by river erosion after the event. Secondly, although the gravels are dated at ~7000 yBP, there is ~1m of alluvial silt and some sand and gravel above the dated gravels indicating the age of the riser could be significantly younger. Further, the slip rate determined is not likely to be representative of the fault as a whole because the location of the trenches in an area where deformation is distributed off the fault by folding and thrusting at a restraining jog, and thus displacement measured at the fault would not record the entire slip component. However, the study does provide some important constraints on the age of gravels forming the Hukanui surface in the area (e.g. as mapped by Neef, 1974).

SAUNDERS ROAD FAULT

The Saunders Road fault occurs as a series of discontinuous en echelon traces that trend more easterly (050°-065°) than the Alfredton fault and extend for at least 13 km northeast from the northern end of the Alfredton fault (Fig. 3). The northeast end of this zone may connect with a ~7 km long zone of similarly oriented short traces near Mangatiti and Puketoi (Fig. 3) as there is only a gap of ~5 km between them, and then further northeast to the East Puketoi fault zone (described below). The southwest end would intersect the Alfredton fault in the vicinity of the left step north of Alfredton, but no traces have been identified that would connect the two faults (Fig. 5). The faults appear to dip steeply as they have straight trends across ridges and valleys. The longest well-preserved scarp is ~4 km, but traces of 1-2 km are more typical. Scarps have fairly steep (20°-40°) grassy faces and are composed of bedrock with a thin soil cover. Most traces are eroded by the larger modern streams, gullies and landslides, but are preserved as uphill-facing segments across steep slopes in between the gullies and on ridge crests. Some individual scarp segments appear very fresh, where small (~30 cm high), or very steep (up to 60°) scarps and complex and fine-scale fault features (e.g. bifurcations, open fractures, sharp curves) are preserved (Table 2, sites SRF 98-4 and 98-7).

Few offset features are preserved along the Saunders road fault (Fig. 5, Table 2), but the smallest dextral offsets are 3.5-6m, with a vertical component of 0.5-1m, typically with northwest side upthrown. One strand of the fault at Kaitawa (Fig. 5) displaces the terrace riser on the Hukanui surface by 9-13 m dextral, 2-2.5 m vertically; the scarp on the lowest terrace is 1-1.5m, but no dextral offset can be measured there (Table 2, site SRF 98-1). Thus, we interpret the older terrace offset to be the result of at least 2 events which would give an approximate maximum single-event slip estimate of 4-6 m and a maximum recurrence interval of ~3000 years if the terrace is equivalent in age to that near Alfredton (McCallion, 1996). The largest measured offset is of channels on the Hukanui (?) terrace of 100-125m (Fig. 8; Table 2, SRF98-2), however the channel correlation is at present uncertain and the site will require further study. None of the surfaces displaced by the fault have been dated, but if the channel offset is correct and the terrace is 6000-7000 yBP, a high slip rate of ~14 mm/yr is implied. An alternative channel correlation on the same surface (see Fig. 8), offset 18-26 m, would imply a minimum slip rate of ~2.6 mm/yr. The Saunders road fault juxtaposes identical bedrock types of the Eketahuna group (Saunders siltstone; Kelsey et al., 1995; Neef, 1974) and thus has little cumulative displacement.

The locally fresh geomorphology suggests the possibility that part of the Saunders road fault ruptured in recent or historical time, but we interpret the last rupture to be within the last few thousand years rather than a few hundred due to the overall somewhat eroded nature of the trace. It is however difficult to tell whether the short length of individual scarps may be in part a real feature of the Saunders Road fault rather than due to erosion, as the fault clearly is a broad zone of subparallel traces rather than a single fault. It is intriguing that the compilation of 1934 earthquake damage (Downes et al., 1998) lists particularly severe cracking on the Alfredton-Pongaroa road at Kaitawa, where one trace of the Saunders Road fault crosses the road (Fig. 5). The Saunders road school closed after the earthquake because damage from chimney collapse was too severe to repair (Edmonds, 1987). Without further detailed study of the Saunders Road fault, however, we can not distinguish between cracking due to shaking of poorly consolidated road fill and fault displacement, or whether any strands of the fault might have ruptured in historical times.

WAITAWHITI FAULT

The Waitawhiti fault is the easternmost active fault mapped in this study, although other possible fault traces were identified on aerial photos (Fig. 3, Tables 1, 2). The fault trends 040°-060° and has a trace length of 5-6 km. One exposure of the fault has an orientation of 058°/77° NW; however, the trace across topography indicates subvertical and locally steep southeast dips.

The upthrown side changes along strike, with the southeast side typically upthrown in the central section, but northwest side up at the southwest and northeast ends. The fault dies out to the south where it appears to splay into two subdued scarps across terrace surfaces ~5 m above river level but does not cut the lowest two terraces. The scarp is similarly subdued and splayed at the northeast end and it does not appear to extend north of the Waihoki valley road. The northern half of the fault is mostly in gorse and scrub and is difficult to follow, but the scarp can be located at track and ridge crossings. Berryman and Cowan (1993) showed a possible further northeastern extension of the fault suggested by traces evident on air photos. Detailed mapping for this study indicates the traces are the result of preferential erosion along strike ridges of sandstone interbedded with mudstone in Miocene turbidites and there is no demonstrable fault offset.

In the central section of the Waitawhiti fault the scarp face, developed on mudstone with thin soil, is fairly fresh, with scarp face angle of up to 45°, typically ~20-25°, and shows minimal erosion by streams and landslides. These characteristics suggests the last rupture was within the last few thousand years, however no direct dates are available. The scarp face is somewhat lower angle and more degraded than scarps along the Alfredton fault and the Waipukaka fault (discussed below), despite being in similar materials on similarly steep slopes. Scarps are rarely preserved on northeast-facing sides of ridges in the area, where dextral offset would produce a downhill facing scarp or a smaller uphill-facing scarp.

Offset hillslope gullies and ridge lines are the only markers for lateral offset on the Waitawhiti fault since it does not cut any terrace channels or risers, and data on quantitative offsets are limited despite careful field study. There are several locations where offsets of ~4 and ~8 m are observed, and one location where a gully is offset 4±2 m, (Fig. 4), thus the single event slip appears to be ~4m. The lateral to vertical component is 4:1 on all measured offsets. The largest geomorphic offset is a pair of streams laterally offset by 50m; this is the same as the measured offset of the contact between two Miocene bedrock units suggesting the fault has accumulated very little net slip, and thus has formed very recently.

Berryman and Cowan (1993) suggested the possibility of rupture within the last 1000 years, and the fairly large single-event displacement of ~4m suggests the fault is capable of producing large earthquakes. However, our comparison of the Waitawhiti fault with other faults in the region suggests that the Alfredton and Waipukaka faults were more likely to have had historical surface rupture. Thus, although we did not trench the Waitawhiti fault in this study, further detailed work would be useful in characterizing the importance of this fault in a regional seismic hazard analysis.

EAST PUKETOI FAULTS

The East Puketoi faults, a zone of distributed short fault traces east of the Puketoi range front, were described in the reconnaissance study of Berryman and Cowan (1993) as the northern extent of the Saunders Road fault. They described the faults as dextral-normal, however little was known about the faults prior to this study. Although many of the traces do appear to have a normal component of slip, the largest fault in the zone, the Waipukaka fault (new name; Fig. 9) has a reverse component. The faults trend north-northeast to northeast and at least locally appear subparallel to bedding in the underlying Whangai formation, which dips moderately to steeply northwest in much of the zone (Kingma, 1967). However, most of the active fault traces trend somewhat more northerly than either the bedding or the older (Miocene) faults (Delteil, et al, 1996; Kingma 1967). The Miocene faults juxtapose Late Cretaceous Whangai formation against Miocene units and thus have significant cumulative slip, however none of the Quaternary traces appear to reactivate the older faults (except possibly for very short distances). The Quaternary traces do not juxtapose different bedrock units and do not significantly offset the contacts of bedrock units (shown on Kingma 1967) and thus appear to have limited (<few hundred meters) cumulative slip. There is also a possible example of earlier Quaternary fault trends that are more easterly being cut through by the more northerly-trending Waipukaka fault (Fig. 9, dashed lines).

Several of the freshest traces of the East Puketoi zone were examined in this study. The northwest dipping Oporae road faults have a dominant normal component of displacement (Fig. 9). Scarps along these two faults are well preserved, with moderate face angles of 20-30° but they do not cut terraces at the major stream crossings. There are no direct age constraints on rupture along these faults so we can only estimate activity within the last few thousand years. The Weber fault, another fault possibly related to the East Puketoi zone, appears to reactivate an older fault and has measured dextral offsets of 6 m and 13 m of channels cut into a landslide (Berryman and Beanland, 1990; Berryman and Cowan, 1993). Scarps on this fault are substantially more subdued than those on Oporae road faults or the Waipukaka fault, but Berryman and Beanland (1990) report a 1-2 m high scarp on a Pleistocene terrace 30 m above river level indicating Quaternary activity.

Waipukaka Fault

The Waipukaka fault is the longest, most continuous fault in the East Puketoi zone. The active trace extends along a northeast to north-northeast trend, but is marked by several right and left steps which consist of zones of several shorter subparallel traces (Fig. 9). The fault dips west at moderate to low angles in the central section but appears to be steeper at the northern end. In between the Waipukaka and Waihi streams, the youngest trace is a thrust that dips 25°W that has propagated east from an older, straighter, and thus apparently subvertical, fault (Fig. 9). Because the fault trace appears to be curved even on flat terrace surfaces (e.g., the bulge area along the Waipukaka stream, Fig. 9), it is difficult to obtain reliable dip constraints from the trace pattern alone.

The mapped extent of the active trace of the Waipukaka fault is ~10 km. The southern termination is uncertain as no scarps were observed crossing cultivated terraces east of Korora (Fig. 9); it is possible the fault steps westward to join somewhat subdued traces southwest of Korora but if so, it is obscured by slips along the hillsides north of the valley or is older than the terraces. The northern end appears to die out gradually as the fault crosses a meander loop in the Waihi stream (Fig. 9), as both the scarp height and apparent lateral offset (although a minimum) appear to be significantly less than further south. North of the meander loop there appears to be a fault in fractured bedrock but there is no scarp on the surface, and no scarps are visible further north on air photos, with the exception of ~1 km of ridgeline fractures and landslides northeast of Oporae that appear very fresh on 1943 airphotos (Fig. 9). In the central section, scarps along the

Waipukaka fault appear extremely fresh and well-preserved even where downhill-facing and where the fault crosses the lowest stream terraces. These characteristics led us to excavate two trenches across the fault along this segment (see below).

Only a few offset features were observed along the Waipukaka fault (Figs. 4, 9), and many of these are offsets of deeply incised gullies with landslid walls, such that the streams could be in part deflected rather than tectonically offset. Nevertheless, the few high-quality features that were observed point to a combination of dextral and reverse (locally normal) slip, with a lateral to vertical ratio of ~5:1 to 2:1, somewhat lower than for faults further south. There are not enough data to provide a well-determined single-event slip estimate, however minimum slip on the order of 3m dextral seems likely, and is consistent with the reverse offset of ~2 m and the obliquity of faulting determined by the trenching studies, resulting in net slip-per-event estimate of ~4-5 m.

Two trenches were excavated along the Waipukaka fault southeast of Horoeka where there is a 2-4 m high scarp cutting a young alluvial surface (Figs. 9, 10a). Vertical displacment along the fault dammed a small stream to produce a broad swamp; the ephemeral stream has more recently cut through the scarp in a narrow channel (Fig. 10a). No lateral offset markers are apparent at the site but it was chosen as a trench site based on the high probability of finding ponded organic material in the swamp, and thus potential dating past surface rupture earthquakes along the Waipukaka fault. The presence of large trees prevented us from trenching at a location dextrally offset from the outlet channel. Other swamps along the fault have been significantly modified by the construction of stock ponds.

The logs from the Waipukaka fault trenches on the Hendricksen property are shown in Fig. 10. The important features of trench 1 (Fig. 10b) include: 1) juxtaposition of Cretaceous bedrock over Quaternary deposits along two low-angle thrust faults; 2) the presence of three units of gravely silt that thicken and coarsen toward the fault and are not present on the upthrown block except at the scarp face (units 4, 6, 7); and 3) a horizon of concentrated charcoal that overlies a buried soil developed on unit 7 and underlies unit 4. The thrust faults exhibit oblique striae (rake 65-75°) consistent with dextral-reverse slip. In the log for trench 2 (Fig. 10c) similar features are represented, including: 1) three thrust faults juxtaposing bedrock over Quaternary units; 2) three gravelly silt units that thicken and coarsen toward the fault (units 1, 3, 5); the fourth gravelly silt, unit 4, exists near the fault but does not appear to thicken or coarsen westward; 3) a buried soil with a concentrated layer of charcoal and historical artifacts deposited above it. The artifacts found in this layer include glass bottles (one made in Germany), glass and china fragments, and the leather sole of a shoe. The very eastern tip of unit 1 appears to overlie and interfinger with the sediment that contains the charcoal and artifacts at its base.

Radiocarbon ages from Hendricksen samples are shown in Table 3 and in Figures 10b and 10c. The "modern" date for 1/5 indicates the sample is <200yBP (after AD 1750). Sample 1/3, within colluvial wedge unit 6, appears to be a root that grew into the wedge material and may have been cut off by fault B; this sample is dated at 195±57 yBP. The age of sample 1/4, the oldest unit dated, indicates that all of the earthquakes recorded in the trench post-date 7300±70 yBP. We collected sample 1/2 because it appeared to be a root that was truncated by reverse displacement on the lower-most fault plane, and would thus provide a constraint on the timing of one of the older fault movements at the trench site. However, a sample of detrital wood from the same unit, albeit lower in the unit, yielded the 7.3 kyBP date. The much younger date of 1/2 thus suggests that this sample is a root that grew after formation of the lower-most fault plane, and that it does not, unfortunately, help constrain the timing of an earthquake at the trench site. Sample 2/2 from an organic-rich soil horizon yielded an age of 2762±57 yBP (Fig. 10c, Table 3).

We interpret the evidence from both trenches to record at least the last three, and possibly four or five earthquakes on the Waipukaka fault since 7.3 kyBP, with the most recent rupture being after European settlement of the area. At least three events are recorded by the gravelly silt units, interpreted as colluvial wedges (Fig. 10b,c), that are cut by younger faults; a possible fourth event could be interpreted from gravelly silt unit 4 in trench 2, although it does not have a wedge geometry and hence is conservatively interpreted as an alluvial unit. There is a suggestion of an older event in trench 1 that did not produce a colluvial wedge visible in the trench, where fissured bedrock is overlain and infilled by alluvial sediment, and a faulted or possibly tilted tree root (unit

9) is present at the top of the bedrock. This fourth event could be present in trench 2 with alternative interpretation of the colluvial wedge stratigraphy (Table 4, interpretation B). The oldest event may also be interpreted in each trench from the silts and clayey silts in the western parts of unit 8 in both trenches, which could be produced from faulting and initial damming of the stream. The oldest event would thus be dated at 7.3 kyBP in trench 1. The organic rich horizon at the top of unit 8 in trench 2 may represent a soil buried during the event that produced colluvial wedge unit 5, which would thus shortly post-date 2.8 kyBP. A comparison of inferred event stratigraphy in the two trenches and alternative interpretations of trench 2 are shown in Table 4, based on the correlation of the uppermost colluvial wedges in the two trenches and the interpretation that they represent the most recent surface rupture.

Table 4 Interpretation of Surface Rupture events on the Waipukaka fault

Event Designation	Date (1+2A)	Trench 1 Units, Faults	Trench 2 Interpretation A (min. # events)	Date (2B only)	Trench 2 Interpretation B (max. # events)
a, most recent	<195 yBP	Unit 4, fault B	Unit 1, fault C	<100	Unit 1, fault C
b, penultimate	>195 yBP	Unit 6, fault B? (reactivated in event a)	Unit 3, fault B		Unit 3, fault B
c, ante-penultimate	~2762±57 yBP	Unit 7, Fault A	Unit 5, fault A, bury sample 2/2		Unit 4, fault B? (reactivated in event b)
d	~7300±70 yBP	? Units 8a, 9 (ponding, bedrock fissuring)	?Units 7, 8, 9 (ponding)	~2762±57 yBP	Unit 5, fault A, bury sample 2/2
e					Units 7, 8 (reworked colluvial wedge, ponding)

Evidence from the trenches points strongly towards an historical age for the most recent rupture. The charcoal horizons can be interpreted as a time of forest clearing by burning, which was the common method of clearing land in New Zealand. Landowner D. Hendricksen reported that a bush hut had originally been present on the upthrown block of the scarp; remnants of the stove and other implements can be found there today. Thus the site was occupied by Europeans who apparently used the swamp as a rubbish tip. If we correlate the charcoal horizons in the two trenches (unit 5 in trench 1 and unit 0 in trench 2), the evidence from trench 1 is clear that the most recent colluvial wedge postdates forest clearing, while the evidence from trench 2 is clear that forest clearing was done at the time of occupation of the site by the Europeans whose debris is found interlayered with the charcoal. The "modern" radiocarbon age from sample 1/5 is from unit 5, correlative with unit 0 in trench 2 that contains European debris, thus the evidence from both trenches points to a young, historical age. Further consistency is provided by the young (195±57 yBP) age of sample 1/3, post-dating the penultimate event and pre-dating the most recent event. Evidence for the time of European settlement and land clearing in the Horoeka area is provided in (Wilson, 1976) and in a series of unpublished school centennial histories and manuscripts held in the Pongaroa district historical society. (Wilson, 1976) indicates that the area between Horoeka and Pongaroa was bush-covered in 1874. No Maori were settled in the area other than near the coast, and when the first settlers arrived in about 1896 they followed surveyors who cleared routes into the area. The settlers cleared the land shortly after arriving. A school was established at Horoeka in 1900 and a store was present at Waimiro by 1915. Raging bush fires are reported frequently in the early part of the century, and although shaking and extensive chimney and building damage is reported at the time of the 1934 earthquake (Downes et al., 1998; Whitta, 1990), no fault or surface ruptures were reported (although we have not been able to contact any of the people who actually lived along the fault zone at the time). Former local resident Margaret Hall, who lived nearby at Mangatiti, said the bush hut was not there when she moved to the property adjacent to the trench site in 1942, but that family stories suggested it had been there until at least the late 1920's, which was when logging activity in the area was waning (pers. comm. 1998). A local school had been built in 1904 at Pukehinau just across the road from the trenches but school records indicate it closed in 1933 due to lack of students and remaining students merged with the Horoeka school, ~1km from the fault. Records from 1934 indicate all the chimneys in the immediate area collapsed but no details of any structural damage are provided (Downes et al., 1998). Ongley's 1934 field notes indicate that he surveyed the area between Pongaroa and the coast after the 1934 earthquake, but did not go to the Horoeka area.

The minimum slip in each event can be constrained by restoring the bedrock fault slivers along each fault back to the level of the bedrock in the footwall (as determined from augering, Fig. 10). This reconstruction indicates minimum thrust slip values of 2m in trench 1 and 1m in trench 2 in the most recent rupture, 0.7m in both trenches in the penultimate event (assuming fault B was reactivated in trench 1), and 2m in trench 1 and 2.5m in trench 2 in the antepenultimate (and possibly one prior) event. If the lateral to vertical ratio is similar to locations a few kilometers to the south along the Waipukaka river where the strike of the fault and the scarp heights are similar, we can estimate 3-6m lateral slip per event (Figs. 4, 9). Combining the geomorphic evidence with the trench measurements gives a net slip range of 3-7m per event, while using the oblique striae and dip-slip displacement measured in the trenches gives a average minimum net slip of ~2m per event.

DISCUSSION

The evidence from mapping and trenching in the Northern Wairarapa suggests that significant surface-rupture earthquakes have occurred in historical and prehistorical time. In this section we discuss the possible magnitudes of the events and analyze the historical evidence for earthquakes of appropriate magnitude to determine which faults are most likely to have ruptured in known historical events. We combine the data on rupture parameters and timing of earthquakes to evaluate some aspects of the seismic hazard in the region.

EARTHQUAKE RUPTURE PARAMETERS

Rupture parameters such as length, area, and slip are typically used in paleoseismic studies to estimate the magnitude of a likely event on the fault (maximum credible earthquake, MCE) from relations of such rupture parameters to magnitude assessed from studies of earthquakes worldwide (e.g., Wells and Coppersmith 1994), or from moment magnitude calculations that require knowledge of fault area and displacement (Hanks and Kanamori, 1979). As described above, the most recent surface rupture on the Alfredton fault occurred along a 12-18 km long segment of the fault, and the likely single-event displacement was 4-7 m. On the Waipukaka fault, the surface rupture length is interpreted to be 8-10 km and the single event slip can be estimated at 3-6 m dextral, 1-3m vertical (net slip 3-7 m). The only way we can estimate fault area is by using the fault length together with an estimate of earthquake depth provided by the body-wave modelling of earthquakes in the upper crust of the North Island (Webb and Anderson, 1998) and in the study area (Doser and Webb, in prep). Although studies to date in New Zealand suggest that the regressions may be different for New Zealand earthquakes, since specific regression parameters for New Zealand earthquakes have not yet been established, in this paper we use the established global relationships to discuss some aspects of the most recent rupture along the Alfredton and Waipukaka faults. We consider the possibility that each fault ruptured independently, although, as is discussed below, it is likely that the Alfredton fault was a small segment of the much larger 1855 rupture. We also consider the scenario, yet to be tested, that during the Waipukaka fault earthquake, coeval rupture also occurred along the 30 km-long Saunders Road fault, as is suggested by the apparent map continuity of the faults. The results are shown in Table 5.

Table 5 Calculation of magnitude from inferred rupture characteristics

Fault	Rupture length (km fresh scarp)	Maximum net slip (m)	MCE: M_w Calc. from length, area[1]	MCE: M_w Calc. from slip[2]
Alfredton (dextral)	12-18	4-7	6.3-6.6	7.1-7.4
Waipukaka (reverse-dextral)	8-10	3-7	6.1-6.4	7.0-7.2
Waipukaka and Saunders Rd. (reverse-dextral)	38-40	4-6	6.9-7.0	7.3-7.4

[1]calculated using the rupture length and area given a depth range of 17-23 km from locations of historical earthquakes, and regressions of Wells and Coppersmith, 1994

[2]calculated from maximum dextral slip using regressions of Wells and Coppersmith, 1994

It is evident from Table 5 that there is a large mismatch in magnitudes calculated from slip vs length considerations for the individual faults. In other words, the faults are shorter than would be expected for their slip, and short faults typically do not generate large earthquakes. If, as discussed below, the Alfredton fault ruptured as a segment of the 1855 earthquake, neither the maximum slip (13m for the Wairarapa fault; Grapes and Wellman, 1988) nor the rupture length considered here is applicable to a calculation of MCE for the entire fault. Using a combined rupture length for the Waipukaka and Saunders Road faults, the calculated magnitude is more consistent with the slip-based estimate. It may be that the rupture parameters of this earthquake do not fit the relationships of Wells and Coppersmith (1994), but we cannot really test this without further investigation of the Saunders Road fault. If the Waipukaka fault is a newly-developing fault, a short surface rupture length relative to slip might be expected until a system of through-going faults can connect along strike and at depth (e.g., Wesnousky, 1988). Furthermore, the reverse fault component of this fault could imply that significant rupture at depth is not expressed at the surface, either because of "blind-thrust" or fold-related components of slip, or because of surface rupture complexity that appears to be typical of reverse faults worldwide (e.g., Rubin, 1996; Stein, 1983)

SLIP RATES

Calculation of a slip rate on the Alfredton fault is important for consideration of the regional strain because it is the largest fault in the region besides the Wellington fault. Although we do not have data on either several (>2) well-dated offsets or a large offset that reflects slip over several thousand years, we can establish minimum and maximum slip rates. It is difficult to calculate an accurate slip rate from the golf course trenches because the offset of the dated peat unit does not correspond directly to the geomorphic offsets (8.5-14 m) of the channels. Based on the trench stratigraphy, we can interpret the 700 cal yr BP (max) base of the peat to immediately post-date the first event, which dammed the channel and formed the peat. Thus only half the total channel offset would correspond to deformation of the peat. If this interpretation is correct, and we further interpret the last event to be between 500 yBP (max) and "yesterday", we can calculate a range of slip rates of 8.5-35 mm/yr, with the lower value made more likely by evidence for 1855 rupture discussed below. However, a minimum slip rate can be obtained by considering the penultimate event to be just after the 2822 yBP age of the wood caught in the fault zone, which gives a slip rate of 1.4-2.5 mm/yr. If the date of 7 ka for the Hukunui terrace is correct (McCallion, 1996) and if the other terraces along the Te Hoe and Tiraumea rivers are of the same age, we can also calculate a minimum slip rate from the average 20-30m offset risers observed, which gives 3-4 mm/yr, consistent with McCallion's (1996) estimate of 2.6mm/yr for the offset risers at the trench site.

Along the Waipukaka fault, a slip rate can be estimated from the trench data and the estimated single-event displacement. Given four or five earthquakes in the last 7.3 ka with net (dextral-reverse) slip from 3-7 m each gives a range of slip rates from 1.5-4.4 mm/yr. Calculation of the rate since 2.8 ka yields 3.1-10 mm/yr. Even the minimum slip rate represents a significant addition to the known dextral shear in the region (Fig. 2; Beanland, 1995).

WHICH HISTORICAL EARTHQUAKE?

Since the single-event displacements on the Alfredton and Waipukaka faults suggest large-magnitude earthquakes occurred on both faults, and given the geomorphologic and paleoseismic evidence from both fault zones for a recent or historical event, we can examine the record of large historical earthquakes in the North Island to assess which, if any, events are likely to have ocurred on faults in the study area. Inasmuch as no dating methods we have been able to employ will distinguish between events in the last few hundred years, we must look to historical evidence to establish the most likely timing of rupture. The threshold for surface-rupture earthquakes in New Zealand outside the Taupo volcanic zone appears to be M 7, thus suggesting an approximate minimum magnitude for the earthquakes discovered in this study. Figure 1 shows the large historical events on the North Island; those that are near enough and large enough to be considered as surface rupture candidates for this study include 1855, 1904, 1931, 1934, and 1942. Slip on the faults in the study area during the 1931 Hawkes Bay event is ruled out by the extensive studies on surface rupture and geodetic displacements done contemporaneously and later (Henderson, 1933; Hull, 1990) which show the southern extent of the rupture at Poukawa, 70 km north of the northern limit of the Waipukaka fault zone. Within our study area--the 1934 MM9 isoseismal region (Fig. 3)-- damage was considerably more severe in 1934 than in 1931 (Downes, 1995), although local memory of the Hawkes Bay event is better (e.g. Edmonds, 1987), perhaps because of the severity of damage in Napier and Hastings and the resultant wide media coverage. The 1904 Cape Turnagain earthquake appears to have an epicenter offshore and a magnitude of M_S 6.7

(Downes, 1995), thus we consider it unlikely to have produced onshore surface rupture. Below we consider the possibilities for rupture in 1855, 1934, or 1942, since the area of the Alfredton and Waipukaka faults was not examined for surface rupture in the immediate aftermath of these three earthquakes. Although Ongley (Ongley, 1934; Ongley, 1934 (unpub.); Ongley, 1935) visited the 1934 epicentral region to look for fault scarps immediately after the earthquake, his field notes indicate that he did not go to the area of the Waipukaka or Alfredton faults at the time. He did return to the Alfredton fault in December, 1935 (Henderson, 1936); we discuss those observations below.

Probable Historical Earthquake on the Alfredton Fault

If the last earthquake on the Alfredton fault is historical, two likely possibilities in addition to 1934 are the 1855 (M8.2) and 1942 (M_S7.2, 7.0) earthquakes because of their location in southern Wairarapa. Grapes and Downes (1997) and Grapes and Wellman (1988) summarize the geological and historical evidence for rupture along the Wairarapa fault in 1855. The rupture is conventionally regarded to have had a northward termination at Mauriceville, where the fault steps eastward to become the Alfredton fault. However, the slip observations summarized by Grapes and Wellman (1988) show that although the vertical component decreases northward to become nearly zero at Mauriceville, the strike slip component remains at ~10m (compared to a maximum of 13m), suggesting there may be a further northward extension of the rupture with decreasing dextral slip. Inasmuch as the area was unoccupied and covered by thick forest at the time, any rupture would have been extremely difficult to find for several decades after the earthquake. Grapes and Wellman (1988) include on their map the sites along the Alfredton fault that Lensen (1969) had recorded as extremely fresh, but the age of displacement as unknown. A contemporaneous settler's report of a continuous rupture from 97-145 km from Palliser Bay cited by Lyell, (1856), which would include the Alfredton fault, is regarded by Grapes and Downes (1997) as suspicious because the same report contained other errors in distance measurements. However, Ongley (1943a) shows the 1855 rupture extending north of Mauriceville as discontinous scarps to near Alfredton; he visited scarps that were found by early settlers in the area and interpreted to be 1855 traces, but there he had neither independent dating of the scarps nor contemporaneous accounts. Thus the historical evidence remains equivocal whether rupture could have occured on the Alfredton fault in 1855.

Neef (1976) noted that the fault scarp east of the main Alfredton fault (that he named the MacKay fault) appeared extremely fresh on airphotos taken in 1944, and suggested that this ~2 km segment of fault moved as a bedding plane parallel fault in the August 1, 1942, "Wairarapa II" (M_S 7.0) earthquake, with ~1-2 m of reverse displacement and 0.6m dextral displacement. However, our observations are that the main Alfredton fault trace is at least as fresh, and probably moved at the same time with likely greater slip. Contemporaneous reports of rupture in the earthquakes during June ("Wairarapa I", M_S 7.2) and August, 1942 are limited to some extremely short scarps northeast of Masterton (Ongley, 1943b) ; Fig. 3). In this study we examined airphotos from 1943-44 in the northern part of the area of 1942 ground disturbance and rupture reported by Ongley. The ruptures occur only on steep slopes and ridgelines in areas where no continuous, active, or long-lived fault trace can be seen on the airphotos. Although ground shaking features are described north to Bideford, no other ruptures are reported by Ongley, and are not evident on the photos between Bideford and the Dreyers Rock fault zone within the 1934 MM9 isoseismal (Fig. 3). Thus we suggest that the 1942 rupture described by Ongley (1943b) instead represents the effects of ground shaking rather than fault slip.

In the course of examining historical evidence for this study, we discovered photographs taken by Ongley in December of 1935 (some published in Ongley (1943), others in IGNS archives) and by Combes in 1947 (IGNS archives) at several sites along the Alfredton fault. These photographs show fairly fresh scarps, but the amount of vegetation and scarp degradation are comparable to other sites along the 1855 trace (Ongley, 1943) and do not suggest rupture in the previous few years, e.g., in 1934 or 1942. Thus it appears that 1855 is the most likely date of the most recent earthquake along the Alfredton fault. This conclusion extends the rupture length of the 1855 earthquake by ~18 km added to the 97 km previously recognized south of Mauriceville (Grapes and Wellman 1988), and suggests the rupture had to propagate across a ~10 km wide right-step, the Dreyers Rock fault zone (Fig. 3). The actual surface slip north of Mauriceville must have been heterogeneous, however, as there are several kilometers where the scarp is subdued or difficult to locate on airphotos taken in 1944, and probably reflects the decreasing slip at the northern end of the 1855 rupture. Our estimate of 4-7 m maximum lateral slip on the Alfredton fault, compared with 12-13 m on the Wairarapa fault (Grapes and Wellman 1988), is consistent with this inference. The implications of this revision in the 1855 surface rupture for seismic hazard analysis are discussed below.

Although no surface slip on the Alfredton fault in 1934 is evident in the few photographs taken by Ongley after the earthquake, there is a suggestion from the seismological and intensity data (Figs. 1, 3) that slip may have occurred along the fault. The largest aftershock (M5.8), 10 minutes after the mainshock, is located 10 km east of the Alfredton fault (Downes et al., 1998), thus leaving open the possibility that a small amount of surface slip and/or a potentially moderate amount of subsurface slip occurred along the Alfredton fault in 1934.

Likely Historical Earthquake on the Waipukaka Fault

Along the Waipukaka fault zone we can rule out 1855 rupture since the most recent earthquake rupture exposed in the trenches (Fig. 10) postdates European settlement which did not occur in this area until considerably later. Furthermore, Horoeka is nearly 150 km north of the interpreted epicenter of the 1855 earthquake and >50km north of the northernmost recognized slip at Mauriceville (>30km north of the northernmost Alfredton fault rupture). Isoseismals for the 1942 earthquake suggest that damage was too slight near Horoeka in that event to involve nearby fault rupture (MM6-7; Downes, 1995). Thus we conclude that 1934 is the most likely time of an historical event near Horoeka, a finding that is consistent with the newly determined epicenter location of (Downes et al., 1998) (Fig. 1), which is only 5 km (±20 km) east of the Waipukaka fault. The Waipukaka rupture appears to be 8-10 km in length and occurred on a highly segmented fault system composed in part of many short en echelon traces.

Possible Historical Earthquakes on the Saunders Road Fault?

The apparent gap in fresh scarp morphology between the northern end of the Alfredton fault and the southern end of the Waipukaka fault is ~30 km and coincides approximately with the known trace of the Saunders Road fault. Although we do not have precise dating evidence from the Saunders Road fault, geomorphologic characteristics suggest that the last rupture on the fault zone as a whole was older than to the north and south. There are however, some short (1-2 km long) segments of the fault that have scarps that appear to be as fresh as those we consider historical (Figs. 3, 5; Table 2), and the intense road cracking in 1934 occurred along one of the fault segments (Downes, unpub. data), thus it is possible that part of the fault did rupture in either the 1855 or the 1934 earthquakes.

IMPLICATIONS FOR SEISMIC HAZARD ANALYSIS

Although we can place meaningful constraints on the MCE on both the Alfredton and Waipukaka faults, as described above, it is considerably more difficult to evaluate other parameters related to the seismic hazard such as recurrence interval (RI) and the return times of various levels of seismic shaking. Because only the last two earthquakes on the Alfredton fault could be dated, and because we have poor constraints on slip rate, we cannot calculate a long-term recurrence interval, or evaluate whether the fault moves in a time-predictable manner. The golf course sites indicate two earthquakes in the last 700 years, the Percy site suggests two earthquakes in the last ~450 years. However, if one (or both) of the earthquakes reflects the northern end of the 1855 earthquake on the Wairarapa fault, any apparent recurrence interval does not apply to the Alfredton fault alone.

The probability of surface rupture on the Alfredton fault in 1855 has significant implications for assessing seismic hazard in the area. In addition to extending the rupture length by ~18 km, the rupture had to propagate across a ~10 km wide right step, the Dreyers Rock fault zone (Kelsey et al, 1995). This stepover is by far the largest geometric discontinuity in the Wairarapa fault zone with the exception of one similarly-sized left step ~20 km north of Palliser Bay (Grapes and Wellman, 1988), and would ordinarily be considered a barrier to rupture propagation in an analysis of seismic hazard based on mapped fault characteristics. Such analyses commonly rely on determination of fault rupture length to predict magnitude (e.g., as discussed above), and combine that with recurrence intervals to calculate hazard probabilities. Fault segment rupture lengths are usually determined on the basis of mapped geometric discontinuities such as stepovers, gaps, bends, or intersections with other faults that might act as barriers to rupture propagation (e.g., Schwartz and Sibson, 1989). This approach has proved useful in analysis of some strike-slip faults such as the Imperial fault of California (e.g., Sieh, 1996), but would not have been able to describe the 1992 (M_w 7.3) Landers earthquake, which ruptured across several pre-existing faults of different orientations and had significant stepovers and gaps along the surface rupture trace (Sieh et al., 1993). In the case of the Wairarapa fault, the MCE magnitude is not increased much by adding in the rupture length of the Alfredton fault (an increase of about 0.1 magnitude units), but if the Alfredton fault only slips in conjunction with the Wairarapa fault, the MCE in the Alfredton area increases by ~0.9 magnitude units if the length is considered, or by ~0.3-0.4 magnitude units if the maximum slip is used to calculate the MCE. However, paleoseismic data on the Wairarapa fault summarized by Van Dissen and Berryman (1996) suggest that the recurrence interval is 1160-1880 years (with a shortest measured interevent time of 1200 years), which is a factor of ~3-5 longer than the apparent interevent time on the Alfredton fault. These data suggest that earthquakes are smaller and more frequent on the Alfredton fault than on the Wairarapa fault. The data further suggest that although the Alfredton fault can rupture independently of the Wairarapa fault (e.g., the penultimate earthquake on the Alfredton fault), it can also rupture at the same time as the Wairarapa fault (e.g., 1855).

The Waipukaka fault trenches contain evidence for the last four or five earthquakes (Table 4). The average recurrence interval since 8 ka would be 2000 years; since 2.8 ka the recurrence interval would range from 710-950 years depending on the interpretation of trench 2. In either case, the recurrence interval does not appear to be regular, unless there are earthquakes between 8 and 2.8 ka that are not recorded in the trenches. The range of calculated recurrence intervals and the recency of the last event (1934) makes it unlikely that another earthquake will occur on this fault in the near future. Nevertheless, the difference in recurrence intervals calculated over 8 ka and 2.8 ka could suggest earthquakes on this fault may be clustered, a possibility which would need further investigation before meaningful hazard estimates could be calculated.

The surface rupture characteristics and geometry of the Waipukaka fault zone also present problems for seismic hazard analysis. The fault zone as a whole is composed of many small segments distributed over a wide zone (Fig. 9); until this study, the faults were not recognized as constituting either a continuous structure or a significant seismic source. The incompatibility between estimates of maximum slip vs length of the fault may be due either to the relative immaturity of the structure, or due to the significant reverse fault component and a tendency for more slip to be on buried faults or taken up by folding. There is also the possibility of 1934 rupture on the Saunders road fault that connected at depth with the rupture established in this study on the Waipukaka fault. The >50 km length of the MM9 isoseismal for the 1934 earthquake (Figs. 1b, 3) and the location of the epicentre and surface rupture at the northern end of the isoseismal suggest that significant slip occurred southwest of the Waipukaka fault trace. At present we cannot constrain whether this slip occurred as surface slip on the Saunders Road fault or as subsurface slip on the Saunders Road or other faults; however the lack of continuous fresh scarps southwest of Korora (Fig. 9) suggests that a significant amount of slip must have been in the subsurface.

A good argument can be made for the Waipukaka fault rupture as a newly forming fault in a region in which older faults are no longer favorably oriented. The Waipukaka faults and other faults in the East Puketoi zone strike more northerly than the NE-striking older faults, suggesting that in this area a vertical axis rotation may be important in causing misorientation. Kelsey et al (1995) present evidence for the young nature of strike-slip displacement on the Alfredton fault (<0.5 Ma) when other faults to the west were abandoned; they suggest this change in deformation is related to >10° clockwise rotation of the Wairarapa region with respect to more westerly parts of the Australian plate. Beanland (1995), Lamb (1988), and Walcott (1984) summarized paleomagnetic and geodetic evidence for clockwise rotation at a rate of ~7-8°/m.y. of the Hikurangi margin in Quaternary time. Perhaps the continual rotation prevents long, continuous faults from forming, and that there has not been enough time for the currently active faults to have coalesced since the older faults were abandoned. Wesnousky (1988) describes a seismological evolution of strike-slip faults which suggests that faults with more cumulative offset have fewer geometric irregularities. Cumulative strike-slip on the faults in this study does not exceed a few hundred meters suggesting recent initiation and/or low slip rates.

Our analysis of the Alfredton and Waipukaka faults suggests that: 1) independent constraints on timing of earthquakes at different locations along the fault, derived from paleoseismologic studies, is necessary to assess the rupture length/magnitude relationship and the efficacy of geometric barriers to rupture propagation; and 2) maximum slip values may be a better predictor of MCE than rupture length or area.

Further study of the Saunders Road fault is also needed to address the possibility that rupture in 1934 occurred there as well, and to assess the structural and seismological relationship between the Alfredton, Saunders Road, and Waipukaka faults. If the Saunders Road fault has not experienced historic surface rupture, and if it has a slip rate comparable to the Alfredton and/or Waipukaka faults, there could be a slip deficit relative to nearby faults that might indicate increased seismic hazard. Any timing relationships that can be determined for the Alfredton, Saunders Road, and Waipukaka faults could then be extended to examine the apparent temporal clustering of historical earthquakes along the Hikurangi margin from Palliser Bay north to Hawkes Bay (e.g., Fig. 1).

CONCLUSIONS

Field work and paleoseismicity studies on several of the major faults within the 1934 MM9 isoseismal indicates that the major faults in the area, including the Alfredton, Saunders Road, Waitawhiti, and Waipukaka faults, are capable of generating surface-rupture earthquakes of M 7. The faults form an northeast-trending, east-stepping array of en echelon segments that appear to accommodate a significant proportion of the dextral component of oblique subduction in the southern Hikurangi margin. Geomorphologic characteristics suggest surface rupture occurred on each of these faults within the last few thousand years, and along the Alfredton and Waipukaka faults in historical time. Detailed mapping of offset features constrains the rupture length and single-event displacement on each fault as follows: Alfredton, max length 30 km, last event rupture length 12-18 km, slip 4-7 m dextral; Saunders Road, length unknown but <30 km, slip ~3-6 m dextral; Waitawhiti, length 5-6 km, slip ~4 m dextral; Waipukaka, length 8-10km, slip 2 m reverse, 3-6m dextral (net 3-7 m).

Paleoseismology studies using trenching and ^{14}C dating constrain the rupture history of the Alfredton and Waipukaka faults. Along the Alfredton fault, data from trenches reveal evidence for the last two surface rupture earthquakes. The 1991 trenches reveal two earthquakes occurred since 642±91 yBP, with the most recent event occurring after 330±65 yBP, and possibly after AD1750. The trenches dug in this study also contain evidence for the two most recent surface ruptures; the most recent event post-dates 240±70 yBP and the penultimate event occurred at ~450 yBP. Analysis of published and unpublished historical evidence suggests the Alfredton fault ruptured in 1855 during the M~8.2 Wairarapa earthquake, and extends the ~100 km rupture of the Wairarapa fault during this earthquake north and east across a 10km wide right-step for an additional ~18 km. Along the Waipukaka fault two trenches reveal evidence for the past four or five surface-rupturing earthquakes. The youngest event in both trenches is interpreted to post-date a charcoal horizon that contains European historical artifacts (such as shoes, pottery). Analysis of historical evidence suggests the most likely time of the earthquake is 1934, consistent with a ^{14}C age of "modern" (<200yBP) on the charcoal horizon. Radiocarbon results establish that at least four earthquakes have occurred since 7300 ± 70 yBP, and three since 2762 ± 57 yBP.

Analysis of these data for seismic hazard estimation suggest future earthquakes of M>7 are possible in the region, but poor constraints on recurrence intervals make a probability assessment unwise at this time. However, the recency of events combined with crude estimates of slip rate suggest long (ky) recurrence intervals that would suggest a fairly low probability of an earthquake within the next century, at least on the Alfredton and Waipukaka faults. It is important to confirm or deny the possibility that the Saunders Road fault has experienced historic (or young) surface rupture because this fault could have a slip deficit relative to nearby faults that might indicate increased seismic hazard. Estimation of seismic hazard is made more difficult in the region by the apparent inconsistency between fault surface rupture lengths and slip-per-event, i.e., the known fault scarp lengths appear too short to have accommodated the estimated single-event displacements. Further complication derives from the tendency of faults in the region to be highly segmented, disconnected, and probably structurally/geometrically immature, which implies: 1) that apparent geometric discontinuities at the surface may not be significant barriers to rupture propagation and 2) that a large component of seismic slip may occur on subsurface portions of the faults.

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Table 1

Late Quaternary faults and other tectonic features in the MM9 isoseismal of the 1934 "Pahiatua" earthquake. See footnote for abbreviations.
Compiled by E. Schermer from airphotos, field work, and unpublished data from IGNS files 12/97-6/98.
Bold numbers, locations indicate faults that were field checked in this study. Revised following field work and 2nd photo check 5/98.
More detail on the following faults can be found in Table 2: Alfredton, Saunders Rd., Waitawhiti, East Puketoi (Waipukaka, Oporae Rd).

No.	location	photo	feature#	trend	dip (if not ~V)	sense*	offset surface†	relative age comments**	other comments** (detailed locations in Table 2 EPF98-1, AF98-1, etc.)	cross-ref^
1	U24 836 841	536/20	flt	ENE		NNW, ?D	H	fairly degraded but ponds drainage	several splays, small scarp	
2	U24 876 845	536/27	flt?	NE		SE	H	moderately sharp scarp	assymetric scarps suggest dextral but no visible offset of S,R	
3	U24 847 833	**537/21**	**flt Oporae Rd (ORF)**	NE		NW, D	H,S	sharp scarp, multi-event height; locally w/ L debris in/on it; not as fresh as WPF	ponded drainage, good trench site; loses ht and splays to NE; cut by stream to SW or dies; ?V=H? from scarp sizes EPF98-17-20	BB90
4	U24 870 822-882 835	536/27	series of en echelon flts Oporae Rd	NE-ENE		D?	H,S?	ponded gullies	dies out NE, SW; NW scarp assymmetric but no major R or S offsets. ?connects with WPF?	537/23, BB90
5	U24 805 802--828 827	**538/19, 537/8**	**flt or SL? ORF**	NNE		SE,N	H, L?	photo at loc 4 in BB90 shows v. fresh scarp; NF? N of rd; to S is more subdued. furthest N dies out and doesn't cut T1	some ponded drainage--trench site?; may cut young L to S but doesn't seem to cut terraces further S-may have died or be older, same to N of N-most stream xing;2 traces just N of rd., one to W is fresher EPF98-1,2	BB90
6	U24 855 830	537/22	SL or Flt? Oporae Rd	NE		??D	H,R	sag at scarp. Another strand to E is very fresh scarp and L		BB90
7	U24 925 822	537/28	flt, several left steps Weber flt	NE		SE, D may switch to NE	H,S?,T1? T4 or 5 main trace, L, T1 to NE	lowest T cut?;most obvious on high agg. T which is very eroded BB90 photos scarp is very subdued, no break 1990, not likely for 1934; more subdued than WPF, and ORF #3,5,6	ponded, defl streams JB9 doesn't connect w/JB 12 as shown on LQT--different ages, character trace to S runs into/cut by L; MISSING PHOTOS to N (run 536)	JB9, BC93, BB90
8 (N)	U24 818 747-845 798	**539/20**	**flt Waipuka-ka (WPF)**	NNE	mod W	NW,D	F?,T1, TC, H	F? surf graded to T1; sharp scarp in ctr, older to SW N of left step cuts T1	dies out to NE, smaller scarp; older scarps to NW,SE; bulge N of road, splays to N, cuts young T further N (Waihi meander) EPF98-21-23	
8 (S)	U24 835 765	**883/45-46**	**flt WPF**	NE to N	gentle NW?	NW,R	H,T0?	v. young-looking on modern floodplain nr Waipaukaka strm	more gentle dip (thrust) as curves to N? EPF 98-3-14, 16, 25	LQT
9	U24 825 784	**539/20**	**flt**	NE		NW, D?	H,T1	sharp scarp only for ~200m, rest subdued	parallel to bedding ridges; dies out NE, SW; EPF98-27	
10	U24 816 755	**883/45**	**flt**	NE	steep NW	NW,D?	H,S?	poss stream offsets; W of hilltop more subdued than to E	defl/dammed S, diff size scarps on opp H, curves to W at SW end; to SE is extensive RR from WPF	LQT
11	U24 837 763	883/46-47	flt	NE to ENE		NW?	H	older than WPF, may cut Qal on one stream (no T)	multiple L to SE	
12	U24 863 757-840 750	883/48-49	SL? or flt?	NE	mod steep SE	NW	H, S,L?	cuts some L, debris flows, cut by others; could be older bedding plane slips or flts, looks mostly older than WPF	L-related but more extensive?, uphill scarp or SL graben?, sags, dammed gullies; poss <10m offset debris flow margins	
13	U24/ 745 747	884/38	flt (Hillview)	NE to ENE		NW	H,T1	cuts youngest T; scarp not large or very sharp but cuts young surfaces	lose on H NE of stream, may initiate L to SW	LQT but extend to SW
14	U24/ 779 738	884/41	flt-several traces and ?SL	NE to NNE		NW, R,N	H,	part of scarp looks fresh in marsh; NW trace eroded, middle one youngest?; but looks older than WPF	cause ponding; more to SW are older/don't cut high T	LQT but revise

15	U24 806 736	**884/45**	**not a flt**	NE to ENE		W	H, S?	subdued morphology parallel local faults	many RR to NW of end of trace connect with WPF but S end is bedding strike ridge	LQT
16	U25 820 718	885/49	flt or RR? several traces	NE		generally UHS	H	very sharp scarps, en echelon traces	probably parallel to bedding, confined to hill, pond drainage	8?
17	U24/ 745 702	885/41	flt Saunders rd? 3 en ech. traces	NE		NW,D	H,?F1, T1?	doesn't cut modern river or T1 at SW, may cut T1 at NE?; sun angle in photo makes freshness unclear	opp-facing scarps Tararoa road	extend LQT to NE
18	T25 582 645	888/29	Alfredton Flt Nikatea	NE		NW,D	R,S,H	Lensen notes extremely fresh scarp	notes on photo: ridge offset 26±5, 12±4;S offset 4mH,2mV, good trench site in dammed gullies	LQT,K, SB,L
19	T25 666 641	888/38	3 flt traces Saunders rd?	NE		NW,D	H,S,T1?	freshest is S strace, N is most subdued	~10mH,2mV stream offsets, dammed	LQT
20	T25 700 635	889/50	3 traces	NE		SE	H,S	?old--high fan? surface cut (or peneplained bedrock?)		
21	T25 600 613	890/36	flts?	ENE		SE	H,S	trace mod subdued	lose trace in young-looking L but may cut stream terrace N of L	
	T25 615 636	**889/39**	**no flt**	ENE		N	H		aligned gullies	
	T25 612 630	**889/39**	**no flt**	NE		NW	H,S		erosion along bedding or lithologic contact?	
22	T25 638 620	**889/42**	**Saunders rd flt**	NE	steep NW	NW, RD	H,S	lose trace in active gullies, tree-covered L; may have cut T1 but is eroded @trace; mod. fresh scarp	one good D offset of fan, gullies SRF98-4 to SRF98-7	K,LQT but extend to NE
23	T25-U25 702 622	889/50	flt	ENE		SSE,D?	H	bounds surfaces of diff. ages- older to N	dammed gullies	
24	T25-U25 702 618	889/50	flt-controlled valley	NE		D	H,R	NE part of trace looks fresher, may cut T1; another trace to SE is mod fresh	up/dn switches= poss. dextral	
25	T25 623 606	890/39	flt (nr end Saunders Rd)	NE		up switches; D	?T1,older L,S	T1 modified; may have small scarp		LQT, K, 22
26	T25 642 612	890/41	RR	NE		NW	H, S?		prob L-related, small flt if at all	
27	T25 667 593	890/44	flt	NE		NW,D	TR,TC	?T1 cut, JB36 doesn't cut T1	?dammed channel on T1?; short trace; ?riser offset Tiraumea village	JB36 connects, but looks older
28	T25 515 591	891/30	Pa Valley Estcourt farm	NE		NW, D	H,?T1	smoothed scarp but may cut young T; plowed over	sm pull apart used for stock pond; 2 short traces	LQT, K
29	T25 532 566-- 545 589	**891/34**	**Alfredton flt Ihuraua, Tiraumea Rivers**	NE		W in south, E in north; D	H,several T,S	Ihuraua: cuts T1,T2 agg., more obvious on T2; Tiraumea: T1 is deg. T below T2;=T1 on Ihuraua?; may cut T0/T1 riser	notes show 5, 25m dextral channel offsets in S; to N T correl uncertain; possibly cuts youngest surfaces on Tiraumea xing; T0/T1 riser on down side; T0/T2 riser on up side? 2 parallel traces to S; very fresh scarps at AF98-3,5,6; mod. fresh at AF98-2,4,11-13	LQT; 21?,18, 40,41,45, 46
30	T25 565 582	**891/37**	**flt Saunders rd**	NE	NW	up switches; D?	H, ?T1,S	poss. T1 xing modified by track; sharp trace central part but subdued NE, SW, doesn't cut T1 to SW	traces into slumped H; SRF98-2 offset terrace channels ~100m but T channel correlation uncertain --possible slip rate trench site? (except modified by track)	19, 22, 25, 31, 33
31	T25 582 581- 627 599	**890/36 -39**	**Saunders Rd fault**	ENE		NW,D	H,S	fresh to mod. fresh scarp face, eroded in valleys. (SRF98-3)	ponded S	LQT,K, 19, 22, 25, 30, 33

32	T25 612 578	891/42	flt, en ech traces Forest Flat	ENE		D?, up switches; NE looks normal	H	no Q surfaces cut, but fairly sharp scarp; eroded by gullies E and W, cut by L to E, doesn't cut T1	dies and eroded to E; splays to W; dammed ponds on H, H sides look offset dextrally. NO sign of reported 20ft crack in ground in 31 or 34 eq here (Edmonds, 1987)	
33	T25 570 568	**891/37**	**Saunders rd flt 2 strands**	NE		NW, D	H, T,TR	1 strand eroded by stream, 1 crosses T2,T1 on Tiraumea R. T1 fairly low tce	T1/T2 riser offset ~12m; lose trace in hills W and E of river; Kaitawa station. SRF98-1 definite scarp on lowest T but can't tell dextral component	LQT, 19, 22, 25, 30, 31
34	T25 697 569	891/52	flt	NE		opp facing on opp slopes?	H	fresh but small scarp only on 2 short traces; N is fresher about the same as SRF; S trace not as fresh as SRF		KRB
35	T25 485 555	892/31	flt Pa Valley	NE		NW, D	H,T1,S	doesn't cut T0 in N but cuts T1 in S; mod fresh scarp, pull aparts at stepover pond drainage	lose trace to NE, another strand to NW more subdued scarp	LQT
36	T25 605 544--632 542	892/48-50	flt/fold?	EW	mod N	N,thrust	H	may cause young L?		
37	T25/ 674 555	892/56	flt?	NE,left steps			? old T?	small scarps but gullied and tree-covered	can't see anything offset; looks old	JB46
38	U25/ 683 536--715 558	**892/57-59**	**flt Waita-whiti (WF)**	NE	steep NW	SE + D?	H,R,S,T2 ?T1/T2 riser?	T2 cut but not sure about T1 fresh scarp in central section but not at S end; N end; not as fresh as AF or WPF overall	dammed gullies; lose trace in hills to SW but pick up again at S edge of photo 57; D from opp scarps on opp facing H; most recent 4mD, 1mV (BC93) WF98-1 to 6,10-16	KRB; JB48; my 67,65?
39	T25 633 517	893/46	flt ?several strands	~N20 W		E, D?	H, L,T	several sharp traces-morphology is sharp but ?tectonic contact	D from ?bedding offsets or TR?; some oblique en echelon fold? traces in S; but could be erosion along strike ridge not a fault	
40	T25 466 510	894/24	flt Alfredton-Dreyers Rk	SE		D	H,S	looks fresh, has sag, dammed stream	bends in trace; modified by new airstrip and roads?	LQT,K, 41, 45, 46, 29
41	T25 466 495	**894/24**	**flt-Dreyers rock**	EW			H,T1?	cuts youngest T and fields (plowed over)	connects to photo 26 Alfredton fresh small scarp AF98-20-23	LQT, K, 29, 40, 45, 46
42	T25 590 492	895/43	flt	ENE		D?	F1, T?	F1 is high above stream; subdued, forested scarp; old Q	lose trace on ridges N and S of stm. D component on T edge? but trimmed	
43	T25 664 492	895/52	flt?	NE		lateral uncertain	H,S	smoothed scarps suggest older than trace to E; not very fresh	dammed/deflected drainage; poss lateral offset (correlation uncertain dextral/sinistral). ?bedding or joints as above?	=44?
44	T25/ 688 489	894/47	flt or SL? several traces	NE		N strand: N up, S strand S up	H	mod fresh scarps; no LQ trace SW edge photo 46	S traces look slump but N cuts low surface, uphill facing; forms graben between irregular splays Neefs Blue Gum flt	JB51
45	T25 435 476	895/28	flt, RR Dreyers Rk	NNE	steep NW	SE,DN	H,?T1	V. fresh looking (as fresh as Waitawhiti, Alfredton)	dammed stream (modified to pond); opp-facing H have different height scarps	LQT,K
46	T25 445 470	895/29	flt	EW		N,D?	H	fresh looking but no Q deps cut; freshest where R crossed (as fresh as Alf)	sag ponds, young-looking L in area; may trace at L heads in W; another trace to E; SE up	LQT, K add to E
47	T25 603 467	895/45-47	flt?	NE		NW, D	H,R	mod smoothed scarp; eroded by L	opp scarps on opp H; left step to N has deflected streams and pressure ridges? Could be bedding or joint features as many small slips, gullies are parallel	
48	T25 695 450	896/52	flt	ENE		D?	H,S?,R?	doesn't cut T0,T1	poss offset ridge/gullies?, continues to W on /51 along RR; small scarp, not as sharp as "mod fresh" ones except a very short bit	
49	T25 665 434	897/45	flt?	NE		SE but switches?	H,L,T1?	T1 has linear gully (=flt?), is high, extensive agg. L is gullied: scarp not esp fresh--smoothed	offset unclear	896/50 N-trending RR splay?

50	U25 745 700	886/39	flt Saunders rd?	NE		SE,D on S trace, NW rest	H	Several fresh (but grassy) L nearby, fresh RR	several short traces, UHS; strike slip is not obvious on most of the strands	some on LQT,K
51	U25 715 683	886/37	flt Saunders rd?	NE		NW,D	H, S,L?	cut by L at end of S trace	splays to E	LQT,K
52	U25 730 666	887/43	flt	NE		S	H	mod. smoothed scarp	one trace might be SL	LQT
53	U25 745 660	887/43-44	flt	NE		N,D?	H,F,FC, L?	subdued scarp to W but young looking L, cuts older L; could be SL scarp to NE but fresher	uphill scarp dams channels, not as fresh as traces to NW	
54	U25 784 666	887/47	flt?	NE		SE	H	subdued scarp, probably old Q		JB30
55	U25/ 855 660	887/54	flt	ESE-E		N,?D; up switches	H,F?	F graded to T2, S trace fresher, N trace more subdued but cuts younger? terraces (?T1)	two traces w/ right step to E; pull-apart geometry	JB32
56	U25 733 650	888/46	flt	NE		NW,D	S,R,H	also Tertiary flt w/ SE up? rel subdued trace suggests older Q	~10-20m max offsets	
57	U25 865 652	888/60	RR or flt?	NE		D	H,S?	can't trace SW to T1		
58	U25 778 645	888/50	flt	ENE		N,?lateral	TR,T2	riser correl not clear, no scarp on T1?	# of risers different on up/down sides. To E, causes ponding in a cultivated paddock, then lose on H to E	
59	U25 793 640	888/52	flt 3 segments	NE(2), NNE		NW	H,S	not all 3 active?-smooth rounded scarps	2 NE flts connected by NNE; ponded streams; short scarp;poss fold to NE of southern flt	
60	U25 716 628	889/50	Flt or SL?	NNE		NW	H,L	cuts same surface as 23	to NE may cut L debris?	23
61	U25 805 628	889/62-63	flt?	ENE		NNW,D switches to S	H,S	may cut T2?; looks older than 20; eroded trace	dams?, deflects stream but may be covered by L to W; old (pre-Q)?, E part just a terrace riser not flt?	
62	U25 831 629	888/56	flt	ESE		N	R	old Q trace? offsets R but not fans to W,E, or T on Owahanga River		
63	U25/ 855 638	888/58-59	flt	NE		NW,D?	H, S?	doesnt' cut T1 on Owahanga, but T2 is tilted?; cuts high T only; Pleisotocene prob last event	eroded to E,W	JB35
64	U25 885 625	888/62	flt	NE			R,H,?S	?old Q or pre-Q? -subdued scarp w/trees on it	rugged topography	
65	U25/ 730 585-- 782 602	**890/50-55**	**E end not a fault--strike ridge**	NE in S to EW in N	NW?	NW,R	S,H	WF98-9, 17,18 thought to be NE extent of Waitawhiti but isn't	possibly is a fault at west end (where not field checked)	
66	U25 810 602	889/62-64	flt	EW		North, D?	H,S	may cut youngest stream valley walls on photo 62-63 but doesn't cut lowest T to SW or NE	dammed streams-good trench sites; possible older traces to ESE; To E, lose trace in L, may have large offset on a high surface	connects to JB38
67	U25/ 795 568	**891/54-56**	**flt Waita-whiti**	NE	?steep NW	NW, D	H; F,FC?	cut by L to SW , gullied but sharp face locally	splays, doesn't reach river to NE or SW; possible offset fan gully walls; opp facing scarps; 4-6m offsets WF98-7,8	KRB, JB44; my 38,65?
68	U25 716 560	891/54	?flt, RR, or SL?	ESE		NNE	H,S	N scarp looks fresher, similar to 67	en echelon traces; dams streams where uphill facing	
69	U25/ 737 557	892/63	?flt or SL?	EW		North	H	Old?; gullied, subdued exc where exposed in L scarp	graben @ slump head?	JB49, KRB

70	U25 708 513-- 712 538	893/54-56 poss. to 894/49	flt? or erosion along contact?	N	W	E,normal, D	H,S,R	cuts active gullies, sharp scarp	diff scarp hts on opp facing H, local shutterridges; large offset on highest ridges; N>D component parallels bedding and is near lith contact of sst/mst (Neef, 1996)	KRB
71	U25 717 499	894/51	flt	NE	NW	?lateral	H,F,?S		uphill scarps, very short trace; Tawhero stn.	
72	U25 720 491	894/51	flt	NE	steep NW?	NW;R,D	H,R,?S	doesn't cut incised fans to SW; cut by L to NE?	opp facing scarps suggest D offset of H; dams small crk	KRB
73	U25 710 467	895/56	fold?	ENE			F? or B	scarp in W not fresh; cuts smooth slightly incised F or bedding plane, not stream to W or T's	?old fault-line scarp to E? fold form passes to W to scarp; LQ but older than others. bedding or joint features?	
74	T26-T25 482 400- 485 410	898/28	flt or very large SL?	NS		norm, ??D	H	scarp somewhat eroded/gullied	in part uphill scarp, may cut low T but could be a TR or a bedding plane feature	
75	T26/ 560 395- 584 403	898/37	flt	ENE		N, ??D	H,T1,TC, S?	more subtle to SW; T1 here = T4 or T5 on bigger stream to E (high, extensive, prob Pleisto.)	can't trace flt to E stream T's	
76	T26/ 463 402	899/26	flt?, RR	NE			H,	smoothed scarp, runs into L	RR connects SW to flt?	
77	T26/ 450 374	900/27	flt	NE		NW,D?	H,R	smoothed scarp, eroded by streams locally but some ponded		
78	T26 382 346	901/21b	flt	ENE		NW	T2,H	fairly fresh scarp but poss cut by L; to SW cuts T2 but not T1	UHS, splays to E, no lateral component visible at R or S crossings; poor photo	outside MM9
79	T26 467 265	904/26	probably L,SL	ENE-NE		NW	H	fresh in photos, many fresh L in area	reported by Ongley as 1942 rupture in Wairarapa eq no flts in area; looks like a ground-shaking feature	
80	T26 469 237	905/30	flt Carterton	ENE		NW, D?	H,T,S	T1 has small scarp, older T's have larger scarp	discontinuous scarp, dies to SW; possible dextral S offsets	outside MM9
81	T26 505 253	904/32	flt Carterton	NE		SE,D	H,S,L	fairly sharp scarp cut by some L, cuts others	UHS ponds drainage, possible dextral S offsets; trace ends to NE in large, fresh L	outside MM9
82	T26 583 268	904/36	flt Carterton	ENE		up switches	H,T	small but mod sharp scarp		outside MM9

Abbreviations:
#RR=ridge rent, SL=slump-head-scarp
*upthrown side listed first; D=dextral, R=reverse, N=normal
†H=hillsides; R ridgelines,S streams or gulliesT terrrace (numbered from 1=lowest on the local stream); TR=terrace riser, TC=channel on terrace; F=fan; FC=fan channel; B=bedrock (only); L=landslide
^LQT, LQT map compilation (mainly Kelsey et al 95); JB=Begg's Eastern Tararua District report with inventory #;KRB Kelvin's field sheets, other #'s this list--connections from other photo runs; BB90: Berryman and Beanland 1990 Weber eq report; BC93: Berryman and Cowan 93 Client report; K: Kelsey et al, 1995; L:Lensen 1969 map; SB=Beanland 1995 thesis
**Other abbreviations: N,S,E,W, NE, etc compass directions; Q=Quaternary; stm=stream; defl.=deflected; ht=height; agg.= aggradation

Notes on airphoto compilation:
DOES NOT include slump scarps or ridge rents that don't connect to faults or extend beyond a single slump; DOES include if several slips are aligned with likely connections of fault scarps.
DOES include ridge rents that are extensive and aligned and likely connected by fault traces
DOES NOT include lineations in bedrock only; must have topo. expression
DOES NOT include gentle folds (didn't look for tilts of Q surfaces), only where folds are rel. tight and may be along-strike extension of a fault scarp.
Difficult to locate traces in forested and rugged topo areas, so these are likely under-represented.
Difficult to see pure strike-slip, so nearly all have some vertical component (or apparent vertical formed by strike-slip of ridges).
Difficult to see low-angle faults if not fresh scarps, so probably missed any older low-angle scarps, and most traces in compilation are high-angle or subvertical.

other information:

List of #'s and photos by fault zone name. See 1:250,000 compilation (Fig. 3) for overall fault trends and groupings of traces.

Alfredton-Dreyers Rock

18	888/29
29	891/34
40	894/24
41	894/24
45	895/28
46	895/29

Saunders Rd.

19	888/38
22	889/42
25	890/39
31	890/36-39
30	891/37
33	891/37

Waitawhiti

65?	890/50-55
67	891/54-56
68?	891/54
38	892/57-59

"East Puketoi faults" of BC 93, including Oporae Rd. flts of BB90 (ORF) and Waipukaka fault (WPF)

1	536/20
2	536/27
4	536/27
3 ORF	537/22
6	537/22
5 ORF	537/18, 538/19
8 WPF	539/20
9	539/20
10	883/45
8 WPF	883/45-46
11	883/46-47
14	884/41
13	884/38
17	885/41
16	885/49
50	886/39
51	886/37

missing photos (as of 15/1/98) mainly Weber area
Run/photo
535/30-35
536/30-38
537/30-34
538/30-39

Table 2. Fault data, 1934 earthquake study N. Wairarapa (~Ihuraua to Weber) compiled by E.R. Schermer 5/98

Alfredton fault

1. Field exposures: also see Figure 5 for map of offset features

site #, loc.	data type (offset, scarp, trace, exposure); some sites also see Lensen (1969) or Neef (1976)	dextral offset min-max, m	dipslip offset, min-max, m (scarp ht=sh)	relative quality of offset (A= best; E= worst)	est age of feature (±2-3x): 1=<1000y, 2=<10 ka 3=Q>10ka 5=bedrock n/5=underlain by rock w/thin soil or Q dep	est age of last event (LE) ±2-3x: 1=<1000y, 2=<10 ka 3=>10 ka	strike/dip, dip dir (/- if trace); up side; SA=scarp angle	slicks trend/ plunge	feature descrip (S=stream, T=terrace, TR=terrace riser; exp=exposureUHS=uphill facing scarp; H=hillslope; agg.= aggradation, deg.= degradation; L=landslide; Q=Quaternary; LE=last event; flt=fault
AF98-1 T25 488 503	scarp				?/5	2			older trace (? inactive but Q-not as sharp trace as main one) is longer than shown on LQT map; good sag pond, flt valley W of road
AF98-2 T25 492 505					?/5				trace E of road N end of E strand E side up; older, more subdued than main trace
AF98-3 T25 496 516	scarp		0.5-2		1	1	048/ SA55-80		UHS bounds graben 20-25m wide on steep H with abund L; facing scarp eroded by L
AF98-3b T25 493 514	offset stream Lensen site 101	25	1.6	A	1/5	1	E up to N, W up to S		site includes ridge to stream offset--possible LE bench on scarp is 1m high, stream offset obscured by stock pond now; measure from Lensen (1969); complex ground disturbance preserved along trace
AF98-3c T25 492 514	offset ridge	33-41	~4	C	?/5		W up		ridge crest not well defined west of fault
AF98-3d T25 492 512	offset stream	65-75		B	?/5		W up		channel somewhat curved; UHS-shutteridge with large ponded area would be great for long-term eq/slip study via coring (or trench if dried out but unlikely); likely LE scarplet at top of big scarp is 0.5-2m high (ridge slope)
AF98-4 T25 490 510	offset gully; ridge	4-6 2.5-4.5		C	1	1	W		ctr of channel correl uncertain
AF98-5 T25 495 512	ridge offset, scarp (Neef trace)	1-1.5	1.5-2	B	1/5	1	E; SA 65°		similar measure for crest and break in slope on side of ridge. Scarp generally 1m high on low surfaces to S near lake but doesn't cut modern swamps; scarp shapes indicate V H; mostly sharp because bedrock exposed. Neef (1976) inferred 1942 rupture.
AF98-6 T25 496 515	exposure (Neef trace)				5		022/57SE	135/48; subhorz nearby	bedding plane fault looks reverse faulted over soil; but slicks wrong for dextral component so could be older fault; to S scarp in bedrock goes from vertical at surface to overturned--also a reverse geometry (E up, E dip); to N of road trace not as fresh. Neef (1976) inferred 1942 rupture.
AF98-7 T25 500 522	scarp, ?stream offset from photo				?/5	1			trace on H SW of lake/valley obscured by L and track; better trace on photo; NE of lake is distinct UHS but face not fresh, cut by L; not distinct to N even on photos. Stream offset pre-dam from photo but can't measure in field due to stock pond
AF98-8 T25 486 507	offset stream Lensen site 96	29-37 (32)	6-8 sh 1.8	B	?/5	1	040 W up		See detailed map Fig. 7a; strat exposure in track cut show Q gravel over bedrock; UHS with good pond (mod. by stock pond so now can't measure V). Lensen site 97 N of here destroyed by road
AF98-9 T25 485 505	offset ridge N, S edges	14-18 14-17		B-C	?/5	1?	W up		min offset because L modify slopes either side of crest
AF98-9b T25	offset gullies	21-24 or 39-41		D	?/5	1	W up		gully correlation uncertain, but more likely is 40m offset; trace extensively modified by L and track
AF98-10 T25 517 542	offset gullies	10-12		A	?/5	1	W up		Golf course trench site 1991--see map and logs (Fig. 6)
AF98-11 T25 488 501	scarp		0.3-0.4 SH; ~0.2 net V		?/5	1	040/47 SE W up		UHS with slight ponding; sharp but small scarp; scarp morph suggests V>H but permissible small dextral component
AF98-11b T25 487 500	gully offset	0-4		D	1/5	1	W up		broad channel immediately uphill, so have to extrapolate for 10m; narrow downhill of scarp; indicates permissible dextral, not sinistral

AF98-12 T25 486 499	gully offset	0-2	sh 0.4-0.6	D	1/5	1	SA30-40 W up		max could be due to L widening channel wall; scarp heights vary to 0.8m S of here; net V ~1m until splays to 2 strands, each ~0.5m V
AF98-13 T25 483 495	ridge offset	12-15	~1	C-C+	?/5	1	W up		
AF-13b T25 489 504	several gullies	0-3	0.2-0.3 sh	C-D	?/5	1	W up		locs N of 11 to valley (where quarry road is to W); scarp in general not quite as fresh as AF west strand; does not cut paddock in big stream valley to N; must step W to Neefs 1942 break
AF98-14 see 3b T25 492 513	auger site	~70	sh 6						3 and 6m from scarp ~3-5m from outlet stream; peaty layers intercalated with silty clay and charcoal horizon at 40cm but too wet to trench
AF98-15 see 3b T25 491 512	hand dug trench		~1m for bedrock	A	5; 1	1	040/45 E W up		flt in hand trench is at bedrock/soil contact; dug on the ~1m SE scarp atop big scarp at ~70 m offset; bedrock offset is ~1m V; charcoal layer on down side; location is just N of right stepover
AF98-16 T25 473 491	scarp		sh~1m		?	1?	fairly low angle SA ~20?		no scarp on cultivated terrace but is on H; UHS with swampy trough (Ihuraua/Dreyers rock flt)
AF98-16b T25 476 493	ridge offset	8-14	sh 0.5 at crest	B			060/E dip, W up		offset evident on photo but broad in field
AF98-17 T25 477 494	ridge crest, NE edge	11-17 13-17	2m at crest, 3m side	B	?	1			broad crest, sharper edge; trace seems to die out to NE or is obscured by L
AF98-18 T25 478 498	scarp, gully	0-2	sh 0.4			1	060/E W up SA25-40		incredibly fresh trace in field and on photos; poss end of LE rupture as dies out to S and bends to W; can see scarp height decrease from 0.6-0 m over ~15m; may step W to become a warp but no scarp, then no trace; no offset of sm gully
AF98-19 T25 480 498	scarp in L				1	1	W up		possibly cuts very young (historic) L; certainly cuts older L material beneath and at toe; fresh scarp even though downhill facing
AF98-20 T25 472 493	trace					1-2			no trace on modern floodplain, subtle trace on hill
AF98-21 T25 466 494	trace on terrace	0-2	0.2-.3	D	1?	1	N up		very subtle scarp on ground, possible riser offset but riser not straight. Scarp evident on photo; stream is very narrow slot ~2.5 m deep so T probably is modern floodplain
AF98-22 T25 466 494	flt exposure		~0.5	D	1?/5		N up		dug out flt exposure; thicker Qal and charcoal on down side but no charcoal on upthrown side
AF98-23. T25 467 494	trace on terrace		sh 1m		1?	1	085/ N up		very gentle scarp on T surface, scarp is sharper to SW across road
AF98-23b T25 463 494	scarp, ridge offset	3-6 (5+1/-2)	1-1.5	C			100/ N up		sharp trace on E side of ridge, more subtle on W suggests dextral offset; ridge offset confirms this but S side is v. broad crest
AF98-24 T25 539 578	ch offset Moroa	5±1	0.5	A	1	1	NW up		ch in young L; intended trench site but ran out of time; mainly downhill scarp

Miscellaneous notes from field observations

Alfredton fault trace is freshest where V component enhanced by steps/jogs, possibly also due to nature of bedrock siltstone, but still fairly continuous and preserved even on landslid slopes

2. trench sites and previous work

site #, name	data type	feature	dextral offset min-max, m	dipslip offset, min-max, m	strike/dip, dip dir (/- if trace); up side	age of last eq min-max ka pre 1950	age of 2nd to last eq min-max; ka pre 1950	age det type	slicks trend/ plunge	feature descrip (S=stream, T=terrace, TR=terrae riser; exp=exposureUHS=uphill facing scarp; H=hillslope; agg.= aggradation, deg.= degradation
Percy 1 T25 487.5 506.5	scarp	trench		4m scarp ht	046/68 NW 050/65 NW	0-0.43	0.3-0.54	cal bp		2 events, see text for details; don't know lateral offset for site; 32m stream offset is to S but older surface (AF98-8); 4.6m riser offset is to N but younger (Lensen site 97)
Percy 2 T25 488 507	scarp (graben)	hand trench		0.2m E side	050/					1 event cuts charcoal horizon in thin soil over bedrock; no material collected for dating as thought to be too young
sites from	Beanland	1995	thesis							
3 Alf. 1	dext offset	trench	8-16	0.5-1.5	50/62 se; nw	0.27-0.52		cal bp		uhs in pond; 2 dates eq1, wood along flt 2822±34ybp. (see reinterpretation in text)
4 Alf. 2	dext offset	trench	41-51	0.5-1.5	35/60 se; NW	0-0.42	0.55-0.73	cal bp		uhs; peat defm against flt, deeper spl along flt
5 Moroa	dext offset	trace	33-43	0.8-2.8	30/ NW					S offset; uhs; good trench site to N at gully? (AF98-24)

6 Tiraumea	dext offset	trace	18-26	1-2	25/ NW			agg. T. correl.		Hukunui TR offset; slope offset at riser?, age wrt Hukunui T uncertain
7 Por	dext offset	trace	13-23	0.5-2.5	40/ nw					H,R?
8 Nikatea	dext offset	trace	23-33	0-0	50/					S?; offset in 4 m increments?
210Pahau	architecture	exp			38/80 nw					road cut
211 Sweep	architecture	exp		1-3	65/ se; NW				rake 50-71 S	exposure; oblique normal/dextral flt, tear fault between Wairarapa and Alfredon

Saunders Road fault

1. field exposures

site #, loc.	data type (offset, scarp, trace, exp	dextral offset min-max, m	dipslip offset, min-max, m (scarp ht)	relative quality of offset det.	est age of feature (±2-3x):	est age of LE ±2-3x: 1=<1000y, 2=<10 ka 3=>10ka	strike/dip, dip dir (/- if trace); up side; SA=scarp angle	slicks t/p	feature descrip (S=stream, T=terrace, TR=terrace riser; exp=exposureUHS=uphill facing scarp; H=hillslope; agg.= aggradation, deg.= degradation; L=landslide
SRF98-1 T25 570 568 98-1b 572 569 Kaitawa	terrace riser offset; scarp on lowest terrace	9-13	2-2.5 1-1.5	B	1 1	1 1	NW up		riser of terrace ~8-10m above stream/~5m above (t2/t1) base somewhat modified by track;measured on top; not totally straight riser; scarp on lowest terrace (t0-modern floodplain) stream incised on up side; no lateral offset visible as ch crossing modified by stock pond, stream meanders alot; ?possibly same site as SRB#93 Higginson?
SRF98-2 T25 571 583	scarp on T2,T1 ch2 offset ch1 offset	18-26m OR 100-125 >75	1-1.6 <1 but modified	C	1	1	NW up		old Saunders rd, Turnberry farm. See Fig. 8. Not sure of channel matches; scarp modified by old road; 75 m is a min because modern stream has captured and eroded flt intersection of channel on upthrown side
SRF98-2b T25 567 582	trace		2-3				SA 30-40		ridge-rent type scarp with ponding in trough, 2-3m high scarps either side with fairly fresh-looking scarp faces (in small clearings in gorse/scrub)
SRF98-3 T25 604 589	gully offset	8.5-11.5 max	0.5-1	C-D	1?/5	1?	SA20-25 NW up		UHS cuts gullies on H with extensive L; max slip because of possible deflection. Splays to 3 strands to S.
SRF98-4 T25 635 617 Haunui	scarp		sh 6m		1?/5	1?	065 NW up SA 40-60		no fresh trace across valley N or rd or just S of road but across ridge to S is a fairly sharp steep scarp; 98-4 is further S across river where scarp well developed for several hundred meters
SRF98-5 632 615	scarp		2-3 m bulge, scarp		"	"	065 SE up		~10m left step with SE side up and bulged ground on N side of ridge crest; steps back to right after~50m
SRF98-6 T25 631 614	scarp		1.4-2 sh net V 0.3-1.3		"	"	055 NW up		scarp cut by L to S; ridge too broad to get lateral component; ponding of stream between 98-5,6 but now cut through
SRF98-7 T25 638 621	ch offset ctr to ctr	3.2-5.6 4.7	1.8-2.5 sh; scarplet 0.5-1?	B-					possible deflection but 3.2 is real minimum for offset edge; ponding at UHS scarp ht decreases to 0.2-0.3m to S at ridgecrest, flt seems to bifurcate but cut by large L on S face of ridge

In general Saunders Road fault scarp not as well preserved as Alfredton or Waitawhiti; is distinct and fresh/mod angle where UHS on ridges, but eroded in gullies, larger valleys, and by landslides. Probably is discontinuous trace anyway (can see this locally), but a lot of discontinuity may be due to erosion.

Waitawhiti fault

1. Field exposures

site #, loc.	data type (offset, scarp, trace, exp	dextral offset min-max, m	dipslip offset, min-max, m (scarp ht)	relative quality of offset det.	est age of feature (±2-3x):	est age of LE ±2-3x: 1=<1000y, 2=<10 ka 3=>10 ka	strike/dip, dip dir (/- if trace); up side; SA=scarp angle	slicks t/p	feature descrip (S=stream, T=terrace, TR=terrace riser; exp=exposureUHS=uphill facing scarp; H=hillslope; agg.= aggradation, deg.= degradation; L=landslide; IF=interfluve ridge; LE=last event
WF98-1 T25 697 545	small IF-ridge offset	6-9	0.5-0.1	E-F	?	1+	055/ SE up; SA45		crests are really warps on hillside, RVD thinks not justified match; but KRB's small gully offset is just a few m to NE of this site (1b)
WF98-1b T25 698 545 (SB#148)	shallow gully offset	2-6	0.5-1.5	A-		1+	55/ NW? SE up		ch offset at H scarp; pond; stream to N offset 10-20m ~4 is LE estimate
WF98-1c T25 697 544	deep gully offset	48-52	3.5-4.5 sh	A-			"		offset channel now captured by next one, so there are 2 offsets
WF98-1d T25 696 544	large ridge offset	~12		B-C			"		crest hard to define

WF98-2 T25 683 533	2 traces on high terrace; riser app. offset	3.3-4.3		E	2-3/5	2-3	040/ S strand is NW up, N strand is SE up		if riser is offset (RVD doubts it as N of flt is short and not straight and a side-stream cuts into main stream), it's T3-T0 riser, otherwise just surface of T3 is offset; scarp is subdued and doesn't cut low terrace to NE; channels atop T3 are broad and apparently not offset, but max lat offset is 4m
WF98-3 T25 687 537	3 gully offsets	max 3-4 m		E		1?	W up		deflection rather than offset a possibility; SW end of clear scarp after a zone of no scarps NE of 98-2 (cut by L or splayed?)
WF98-4 T25 688 537	ridgeline offset	26-30	0.3-1.5	C		1?			ridgeline is curved nr scarp; measurement includes curve and straight segment extrap over ~20m NW of scarp; if just offset is measured, its 6-10m
WF98-5 T25 692 539	gully offset	4-5		C-D					stream could be deflected; scarp is in L to N and S
WF98-6 T25 693 540	gully offset	4.3-6.5		C-D			040/steep SE; W up		possibly deflected not offset but ridge to N is offset 4±3 (broad crest) further N trace obscured by L, erosion
WF98-7 U25 735 572	scarp, ridge offset	7-9 N edge 4-6 S edge	1.5	C-			062 NW up		broad crest of ridge; scarp somewhat smoothed and eroded; possibly 2 traces here; 1 to SE is more subdued to SW possible ridge IF offsets of ~2-3m but D-E quality
WF98-8 U25 727 567	gully offset	3.4-4.9		B-B-			060 NW up		stream is ponded; site is in scrub
WF98-9 U25 781 603	no flt-terrace riser								apparent trace on photo is a riser though there are sheared bedrock otcps here and to S; bedrock flt seems to be up on slope to S
WF98-10 T25 698 547	stream pair offset	55-65	~2m sh	D-E			055/ 058/77 NW at exp. to N; SE up		correlation with outlets uncertain but edge of stock pond could be good trench site as well-dev ponding and scarp is unmodified by digging pond
WF98-11 U25 702 547	bedrock, contact offset	~50m	~few m	C-D	5		SE up		contact of turbidites and mudstones strikes ~N; bdding 008/25E; contact offset ~50m but NW of flt is in gorse; probable left step at stream crossing in 98-12
WF98-12 U25 701 547	T0 terrace ?scarp or warped				1				strange deflection and incision in stream in an area between 2 traces on hillsides--adjacent to a left step, probably a pushup but no scarp where flts should cross stream
WF98-13 U25 703 548	scarp		sh 0.3-0.6			1-2?	SE up?		scarp fairly degraded at crest; fresher N and S; but covered in gorse mostly
WF98-14 U25 705 551	scarp		sh 1-2						gorse-covered ridge, scarp adjacent to track
WF98-15 U25 706 553	scarp						NW up		downhill facing and eroded by L and track; hard to locate precisely
WF98-16 U25 712 555	trace, bedrock flt		sh 1.5			>2	SE up		can't locate exactly as scarp very degraded but bedrock is different either side
WF98-17 U25 775 602	trace on photo-no flt								apparent UHS is strike ridge of sst in sandy turbidites at contact with muddy turbs; bedding 065/26S; gentle slope to "scarp"
WF98-18 U25 769 598	scarp?	0-2	<1	E			NW up		UHS, possible dextral offset of gullies and ridges within L, but correl uncertain and topo not straight across trace
WF98-19 U25 756 592	scarp?		<1				NW up SA<10		possible strike ridge but stock pond built at UHS; very gentle rise on broad ridge crest; evidence for no lateral offset of ridge edge

Waitawhiti fault is generally not as fresh as Alfredton despite being mostly in bedrock (mudst) with thin soil; scarp angle is lower and trace is more eroded by gullies and larger streams even where UHS, but still probably <1000 yBP LE. Worse preservation may be a function of H:V ratio; generally scarp not preserved on NE-facing slopes unless slope is very gentle, but is sharp on SW facing slopes--on NE facing slopes could be downhill facing scarp or very small UHS that is quickly eroded. H>V but not H>>V. Flt seems to be more degraded/older N of stream xing N of Puketawa (but heavy scrub there); just S of Waihoki valley road there is a scarp but not as fresh as the southernmost part. Definitely dies out as a Q rupture before reaching Waitawhiti rd in south. No flt north of Waihoki valley road either in Q or bedrock--just an eroded sandstone/mudstone contact along strike ridges of sandstone. Strike length of fresh scarp (=LE RUPTURE LENGTH??) =~4km. Total offset of Tertiary contact is ~50m; similar to largest stream offset observed, indicating a very young flt. (But contact is shallowly dipping, so not a good piercing point).

East Puketoi faults

1. Field exposures: also see Fig. 9 for map of offset features

site #, loc. Fault name*	data type (offset, scarp, trace, exp	dextral offset min-max, m	dipslip offset, min-max, m (scarp ht=sh)	relative quality of offset det.	est age of feature (±2-3x):	est age of LE ±2-3x: 1=<1000y, 2=<10ka 3=>10 ka	strike/dip, dip dir (/- if trace); up side; SA=scarp angle	slicks t/p	feature descrip (S=stream, T=terrace, TR=terrace riser; exp=exposure; UHS=uphill facing scarp; DHS=downhill-facing scarp; H=hillslope; agg.= aggradation, deg.= degradation; L=landslide; IF=interfluve ridge
EPF98-1 U24 812 806 ORF	scarp-ridge rent		sh 1		?/5	?1-2	N45E/ W E up SA~20		not really fresh scarps but forms good grassy trough generally 1-2m wide, up to 3-4 on H and some landslides/collapse features with scarps perpendicular to flt look fairly fresh (?*are these folds or tension features?)
EPF98-2 U24 ORF 809 805	scarp-ridge rent	0-0.6	sh~1m		?/5	?1-2	045/ W E up		circular and semicirc slip scarps perp to ridge rent, with "crestal graben" collapse-located consistently on upthrown side, coincide w/ ridge crest while flt is just to W of crest. Soil may be bent or folded over crest?
EPF98-3 U24 832 763 WPF	scarp on T1, T2		sh high T: 1.5-2m steep face; 4-5 total; ~1m onlower T		1		bends NE-NS, 025-050 W up		scarp is lower S of bend, but may cut to lower terrace; also is more of a broad warp there (T1)
EPF 98-4 U24 827 794 WPF	1 of several scarps; offset gully	2.3-4.4	sh ctr 0.3-0.5; 0.5(N), 2 (S)	C-D	?/5	1	028 E up		short discontinuous and en echelon traces; all UHS pond drainage and deflect/offset streams. Several are fairly fresh but smoothed/grassy scarps. This one clearly dextral by scarp assymetry even though some of stream offset may be deflection not flting: min reflects amt of ponding by shutterridge
EPF98-5 U24 826 754 WPF	scarp				?/5	1	028 E up		strand in 98-4 cut by large L
EPF98-6 U24 825 754 WPF	gully offset	3-15		E-F			028/ dip steep NW; E up		possibly 2 traces, offset measure affected by major L on both stream edges; this scarp fresher than 98-3,4 below and to E of here
EPF98-7 U24 831 757 WPF	terrace channel offset	4.1-6.1	1.4-2 in ch; sh 3.7-4.2 on edges	B	1? gully may be young but T fairly high	1	035/ dip mod NW; W up		flt traces S into steep hillside and steps left (E) around E face of it with a nearly 90° bend; to N crosses stream, steps E again (right) and becomes a broad bulged area as this part of trace bends left to W; has a low-angle dip or very irregular strike if high-angle
EPF98-7b U24 832 758 WPF	exposure of shears, Q/5 contact		1-2 (bulge height)	C	?/5		032/75SE	?sub-horiz?	sheared,polished planes in K bedrock shales; slicks not very clear; rock is very sheared but this is a predominant fracture set. 1m colluvium on rock mostly, but up to 2m alluvial gravel in stream; bulge ht measured from gravel/bedrock contact
EPF98-8 U24 823 748 WPF	scarp, offset	0-1	~1				045/		no obvious lateral offset of ridgeline or creek though abund L may obscure this; scarp not as fresh as others nearby
EPF98-9 U24 821 747 WPF	scarp (assymm) gully offset	0-1	0.6-0.8 (crest); 1 S, 0 N				050-045/ E up		UHS scarp is sharp on photo but this NE end is subtle, disappears in valleys and is fairly low-angle face; assymmetric scarp hts suggest dextral offset though stream not offset laterally
EP98-10 U24 818 748 WPF	scarp	0-1	5m total sh, steep face 3m (both ±0.3)	A (ht) D (lat)		1	043/ E steep dip; W up, SA35 at steep face		ht decreases to NE and SW of here; forms a graben with ponding between sites 9,10; scarp 10 much fresher than 9 and looks reactivated by a younger LE; no offset of stream in bush but it's a fairly incised one that is very curvy so cant' be sure of offset vs deflection vs meanders
EPF98-10b U24 819 749 WPF	scarp on high fan; lower fan or T; lowest swamp		2.7-3.3 ~1m 0.5-1.1						scarp decr in ht stepping down towards stream/swamp/stock pond to NE but some bulldozer modifications so can't be sure of exact original trace/scarp; otherwise would be excellent trench site
EPF98-11 U24 817 756	graben, gully offset	5 +5/-1	1.5-2 E 0.5-1.5 W	C-?		1-2?			trough on hillside 15-25m wide with opposite facing scarps; uphill (DHS) ranges 2-8m in general, and reactivated by L; downhill (UHS) ~1m; gully is narrow above and below trough, but because of possible change in direction within trough, ± is assymetric; neither scarp is very fresh (low angle, smoothed) except where freshened by L

EPF98-12 U24 836 768 WPF	scarp		0.3-0.8				020/28W NW up (from V's of trace)		can see trace V into valley; may splay to 2 here, 1 lower angle to E (98-13) and 1 steeper to W; if flts connect as apparent through valley from 98-12 to 98-13, dip is <30°; may cut an older fault bounding swamp in valley floor (or this may be an imbricate flt in footwall)
EPF98-13 U24 837 775 WPF	scarp		2.8-3.5 steep part; ~4 total			1	"		sharp face on scarp; could be edge of L, but looks more like a flt scarp; must bend at top of ridge; lose trace on N flank of ridge but pick it up again in field below to N adjacent to rd
EPF98-14 U24 835 775 WPF	trace						020		no scarp at ridge xing but can see scarp and trend lower down on ridge
EPF98-15 U24 835 774 WPF	?exposure				5		020/90, 355/90		shears in bedrock and "flattening" of spheroidal weathering fabric(frx planes); can't see gouge or offset of soil/bedrock contact but abundant L here so nothing is continuous or flat
EPF98-16 U24 836 784 Waihi river bend WPF	terrace channel offset riser	9-11 min; 27- 33 max 11-13	1.3-2.2 in ch. sh 5-7	D B?	1	1	005-008/ W W up		very fresh scarp; channel offset not very accurate because is a broad swamp on downthrown block flt splays to 2 smaller gentler scarps to N scarp ht is larger at S river xing than on middle of terrace--?developed after topo on bend formed, not during tce fm? also good fissuring in Qal chip gravels at roadcut (fissure 015/80E-see 98-25)
EPF98-17 U24 848 833 ORF	2 parallel scarps ?offset channel?	2-4 (max 12)	sh E 0.2- 0.7 sh W 1-3	D			049/ 50- 60 E W up		well-dev ponding at both UHS, fairly fresh scarps (examined in Berryman & Beanland, 1990); western one is longer and more cts and has a fresher higher scarp; ch is dammed for stock pond so max measure reflects unknown trace below pond
EPF98-18 U24 850 834 ORF	scarp, offset gully	3-5	1-1.5	D?			049/ W up SA20-30		deflected? Dextral offsets obscured by pond but this one more convincing than others; scarps on H not assymmetric however
EPF98-19 U24 852 836 ORF	offset channel	0-2	0.2-0.4		1	1	049/ W up		no offset of stream; scarp height decreases to N
EPF98-20 U24 851 835 ORF		7-10 max	1.3-1.7	D?	1		W up		gully adjacent to younger L above flt; well-defined gully below flt but have to extrapolate over ~10m wide swampy area at UHS
EPF98-21 U24 846 798 (WPF @ Waihi meander loop)	T1/T2 riser offset	2.1-2.9	0.2-0.5?; 0.6-0.8 sh on T2 edge; 1.4 in ctr	B	1 (T1); 1-2 (T2)	1?	055/ W up SA<15		T2 terrace is ~5-10m above stream and has thin soil over bedrock; scarp not as fresh as further S; can't trace at all to N of stream xing; riser ht E of flt 7m; possibly slightly higher to W; can't see scarp on T1 because eroded out in a gully; T1 very narrow (<13m at widest)
EPF98-22 U24 844 797 WPF	offset channel on T2	4-5? 3 min 11 max	0.5-1	D	1	1	"		broad channel on terrace just N of southern river crossing of big bend
EPF98-23 U24 842 795 WPF	scarp		0.5-0.9		?/5	1	030/ W up		very fresh UHS; from 98-22 to 98-23 flt curved W around base of ridge; no lateral marker but scarp not assymetric on ridge flanks or at gully xing, suggesting V>>D
EPF98-24 U24 825 784	no scarp on T, no lateral offset	0-1							followed trace to NE of stream and can't find flt scarps--probably is bedding strike ridges on photos; channel widens below "scarp" but N edge shows no offset; 1 trace probably is a flt (see 98-26)
EPF98-25 U24 835 780 WPF	2 scarps, fissure in tce roadcut		2.7-3.3 E 3.7-4.3 W		1,2	1			scarps cut terraces >10m above river but fissures and frx cut up into soil; fissures 015-020 subvert; shears in bedrock in river are 340-005 subvert
EPF98-26 U24 832 759 WPF	2 riser offsets	1.3-1.8 4.5-6.5	0.3-0.6 >1?	C C	T1/T2: 1-2 T2/H: 2?				T1/T2 riser ht=1m, 2.5m incision below to modern stream; measure is base to base; ctr to ctr is 1.1-1.7; equivalent riser opposite side of river is 1.3-2.3 but flt scarp not so clear there T2/H riser: top surface is ridge, not a T, so vertical not well defined; ridge crest to crest is 6±2; also scarp is subdued here as is transition to the bulge. Note this is in a bend area between sites 98-7 and 98-3
EPF98-27a U24 826 785	scarp, no ch offset	0-1	sh 1.2- 1.6	D			W up		scarp is distinct but not fresh (low angle face) UHS ht varies 1-2.5m; most gullies show no lat offset except 27b; scarp disappears a few tens of meters N of here

EPF27-b U24 826 785	scarp, possible ridge offset	0-4	0.5-1.5	D	T2-equiv? 2? ~10m above river	1-2?	W up		ridge edge offset but not a riser so original shape not clear; could be no lateral. Fresher and higher angle scarp here and to S adjacent to river, but only for <100m. Scarps don't look assymmetric so probably little lat. offset; could be strike ridge freshened by erosion but looks v. sharp on photo
EPF98-28 U24 806 735	no flt								looking for S extent of WPF at UHS on photo but trace is very subdued; barely a wet greenish line on H; probably a bedding contact; no lat offset of gullies; also can't see connection to known S end of WPF--definitely no scarps on cultivated terraces N of here--if WPF continues S it must bend/step to west >1 km towards Korora

*Fault names: ORF=Oporae Road fault; WPF=Waipukaka fault

Hillside scarps at Oporae rd (ORF, W strand) and Waipukaka fault (WPF) have interesting perpendicular landslide scarps/initiation--due to folding/shortening on upthrown block? or just ground failure during LE? Are fresh on photos and fresh today. Not all flts in zone are as fresh as Alfredton except WPF. WPF short scarps definitely have dextral component from scarp assymetry, though nearly impossible to measure accurately because of steep stream incision and landsliding. Probably generally have normal component from traces ridge to valley (steep NW dip). Can't measure bedding in these massive and intensely fractured rocks but locally what seems to be bedding is subparallel to flt trends so could be controlled by bedding?

WPF trace is fresh and young: cuts young terraces and surfaces for several kms length (~8); trenching confirms at least part of trace has LE that is post-settlement. LE rupture length at least from river bend N of road (site 98-16) to S of Bowie farm (site 98-10 S to ridge line) but could go as far north as site 21 (Waihi river bend) with decreasing displacement. Can't find flt to S of Waipukaka stream. Significant reverse component--2m dip-slip events; possibly up to 5 dextral, but could be as little as 2 if D:V is only ~1:1. Young (unevolved) fault likely since K/T contact not offset significantly on map (I didnt' map it) and since trace steps and wanders about so much, avoiding hills in favor of lowlands. Possible connections to Saunders Rd. flt, but N traces of SRF don't look so fresh on photos, so I didn't field check them. If there is a connection its not during the LE; SRF scarps seem to be mostly somewhat older (~1ka?).

ORF scarps not very assymmetric so could be dominantly normal; also are subparallel to bedding 040/42SE; channels may be deflected rather than faulted

2. trench sites and previous work

site #, name	data type	feature	dextral offset min-max, m	dipslip offset, min-max, m	strike/dip, dip dir (/- if trace); up side	age of last eq min-max ka pre 1950	age of 2nd to last eq min-max; ka pre 1950	age det type	slicks t/p	feature descrip (S=stream, T=terrace, TR=terrace riser; exp=exposureUHS=uphill facing scarp; H=hillslope; agg.= aggradation, deg.= degradation
HEND1 U24 834.0 764.0	scarp on T1	trench		sh 2.8 m dipslip 2m LE	trace 018/ NW up 010-056/25 NW	0-0.3 bp AD1934	0.3-7.9	cal BP	255-265/20	3 or 4 events; LE colluvial wedge is post-burn horizon; ~2m dip slip each event (s/s not known here) See text and Fig. 10 for details.
HEND2 U24 834.4 764.4	scarp on T1	trench		sh 4m	trace 025/ NW up flts 010/33NW 022/31NW 030/16NW	0-0.1 AD1934	0.1-2.8	cal BP and histo-rical evidence		>3 events, possibly 5; LE colluvial wedge overlies burn and artifact horizon See text and Fig. 10 for details.
149 Weber Beanland (1995)	dext offset	trace	11-15	0.5-1.5	50/ SE up					2 channels offset at UHS on L, pond behind, offset 6,13 m (N150/767 267, loc. 2 in Berryman & Beanland 1990)

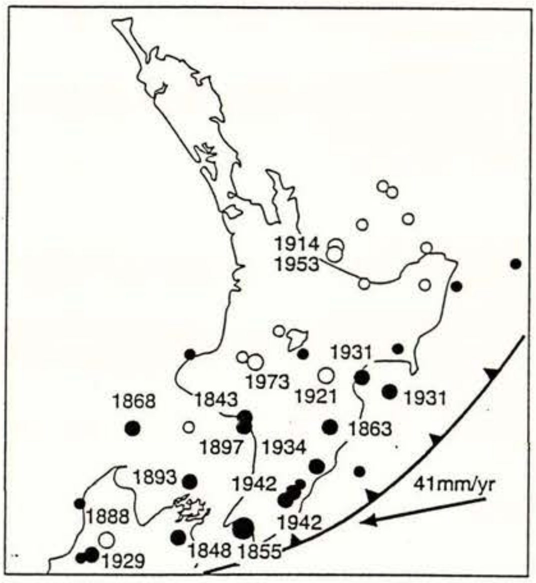

Fig. 1a

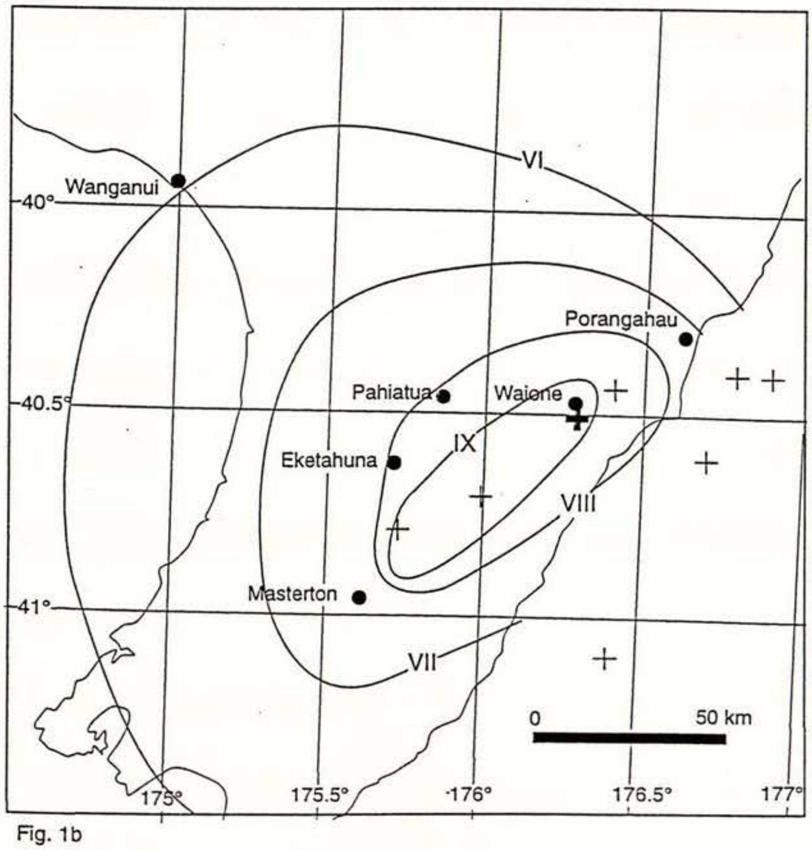

Fig. 1b

Figure 1. A. Historical seismicity of the North Island, New Zealand. Largest circles represent M 8.0-8.9, smallest are M 6.5-6.9. Filled circles indicate depth ≤45km, open circles depth >45km. Location of subduction trench shown as barbed line; convergence vector and rate is from DeMets et al., (1990). B: Isoseismals of the 1934 earthquake from Downes et al. (1998), with epicenter location shown in bold cross and aftershocks shown in light crosses.

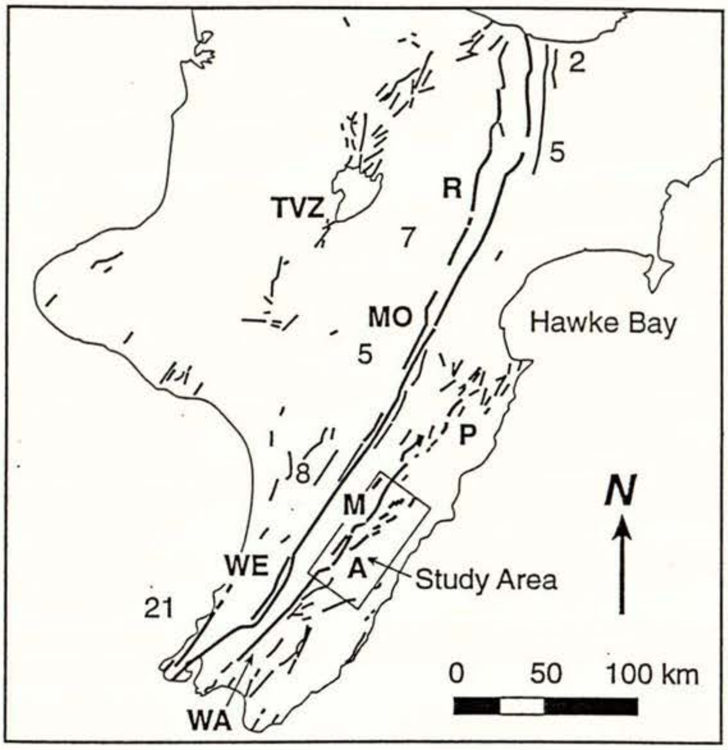

Figure 2. Major active faults of the North Island shown as bold lines, with total dextral slip rate in mm/yr for several transects across North Island Dextral fault belt (from Beanland, 1995). Fault abbreviations: WE-Wellington, WA-Wairarapa, A-Alfredton, M-Makuri, P-Poukawa, MO-Mohaka, R-Ruahine; TVZ-active volcanoes and normal faults in Taupo Volcanic Zone.

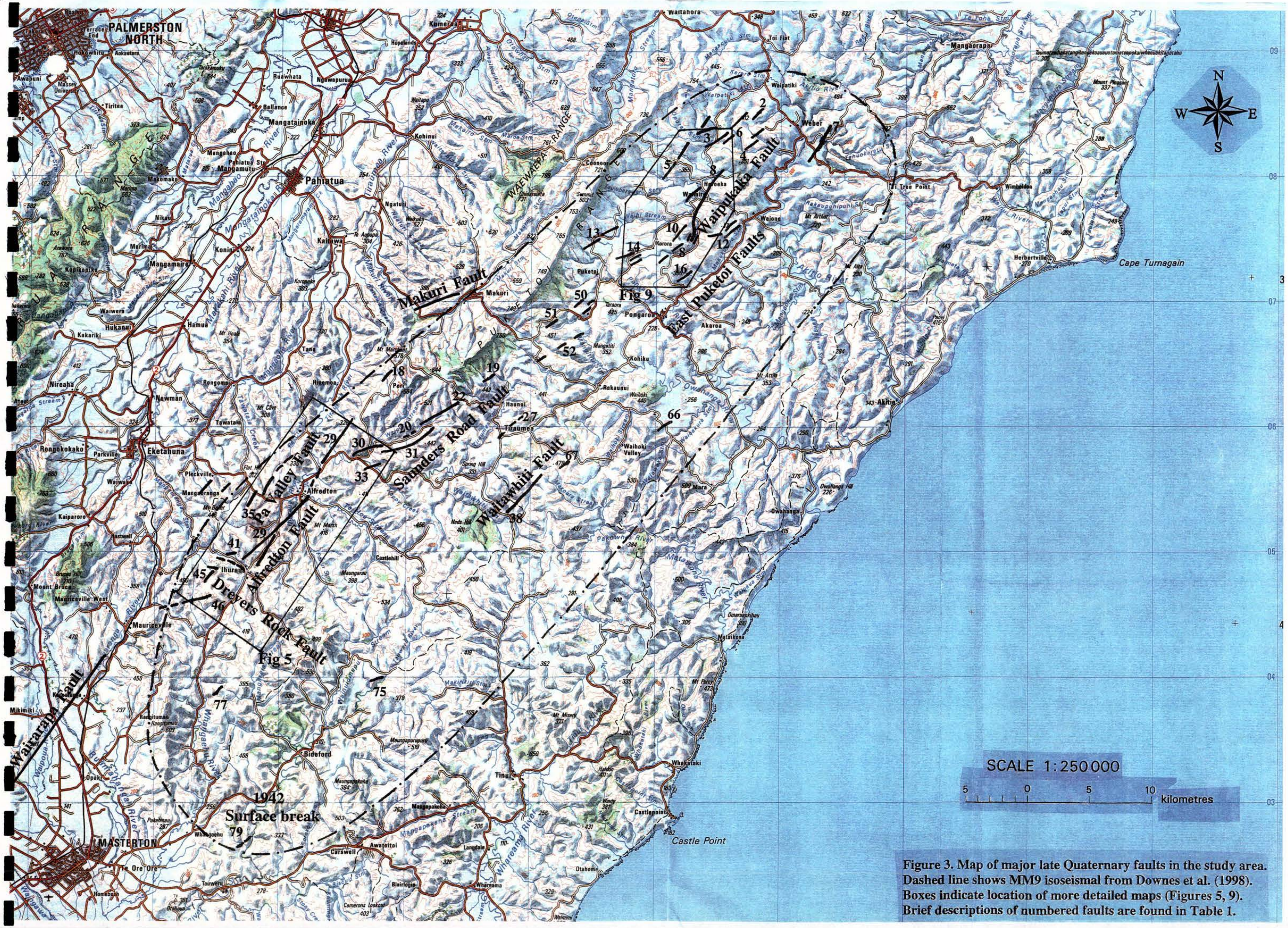

Figure 3. Map of major late Quaternary faults in the study area. Dashed line shows MM9 isoseismal from Downes et al. (1998). Boxes indicate location of more detailed maps (Figures 5, 9). Brief descriptions of numbered faults are found in Table 1.

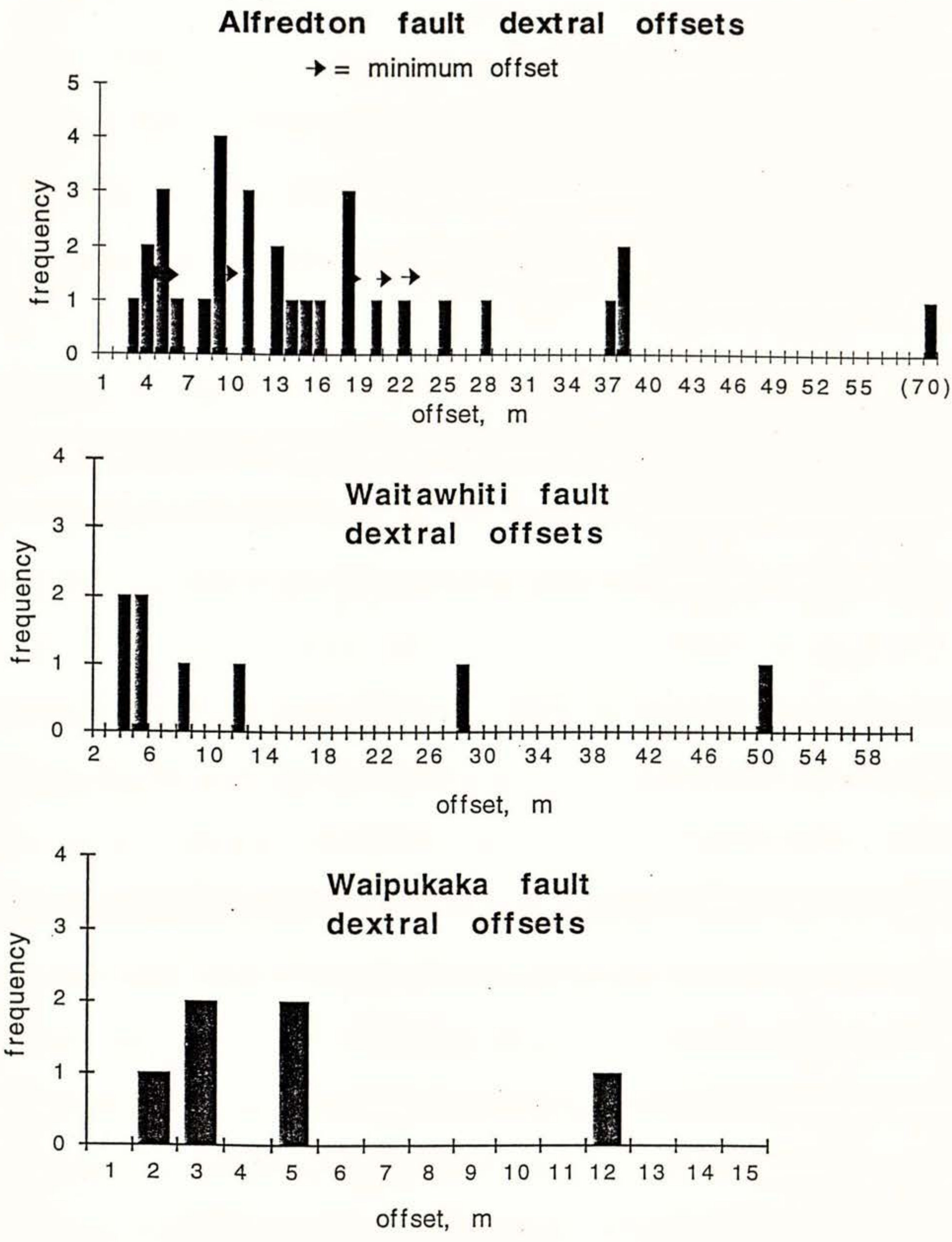

Figure 4. Histogram of "best quality" (A-C in Table 2) dextral offsets. Data from Lensen (1969), Beanland (1995), McCallion (1996), and this study.

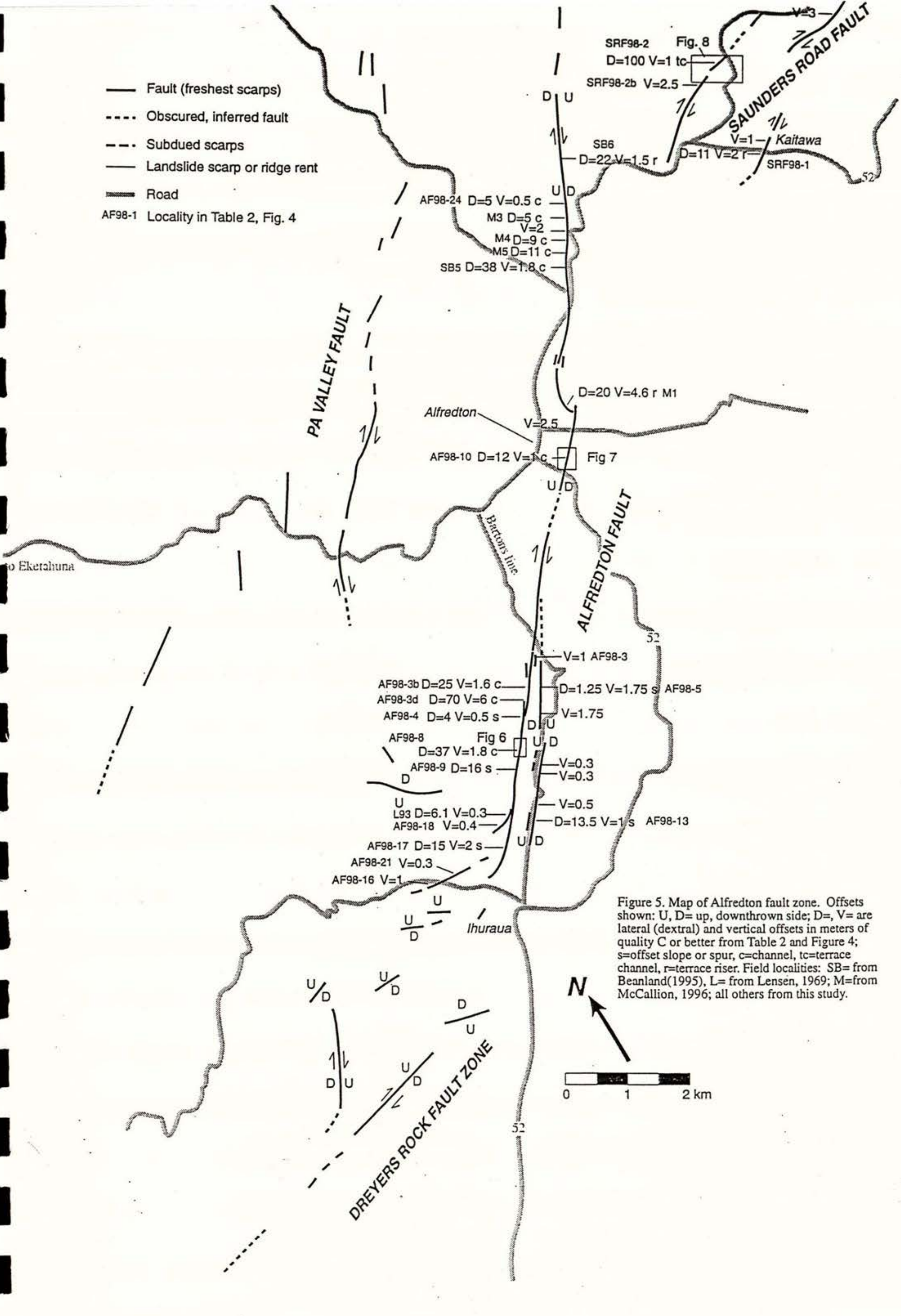

Figure 5. Map of Alfredton fault zone. Offsets shown: U, D= up, downthrown side; D=, V= are lateral (dextral) and vertical offsets in meters of quality C or better from Table 2 and Figure 4; s=offset slope or spur, c=channel, tc=terrace channel, r=terrace riser. Field localities: SB= from Beanland(1995), L= from Lensen, 1969; M=from McCallion, 1996; all others from this study.

MAP OF ALFREDTON GOLF COURSE FAULT TRENCHES

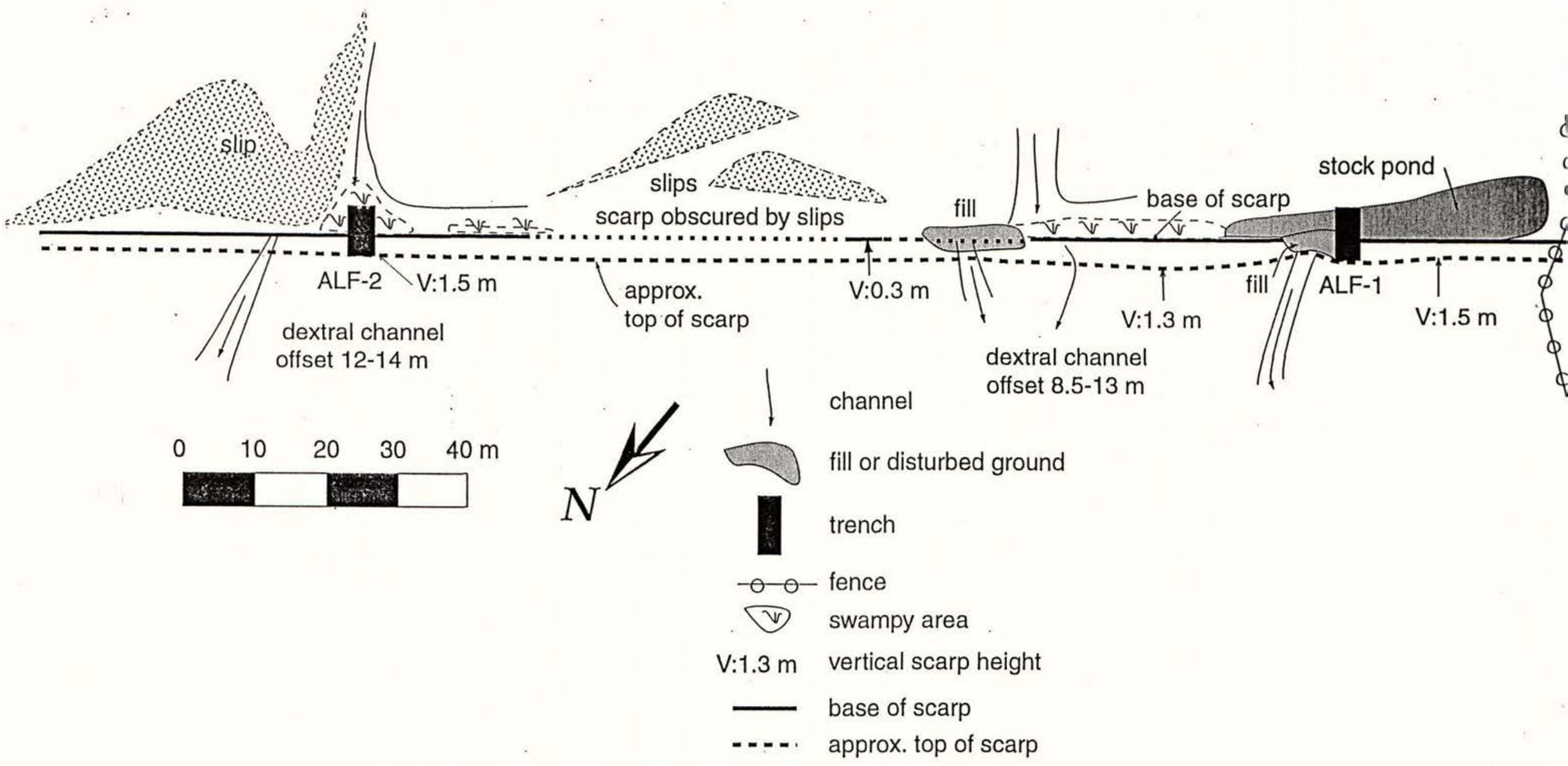

Figure 6a: Map of Alfredton fault at golf course trench site. Location shown in Figure 5, trench logs shown in Figure 6b.

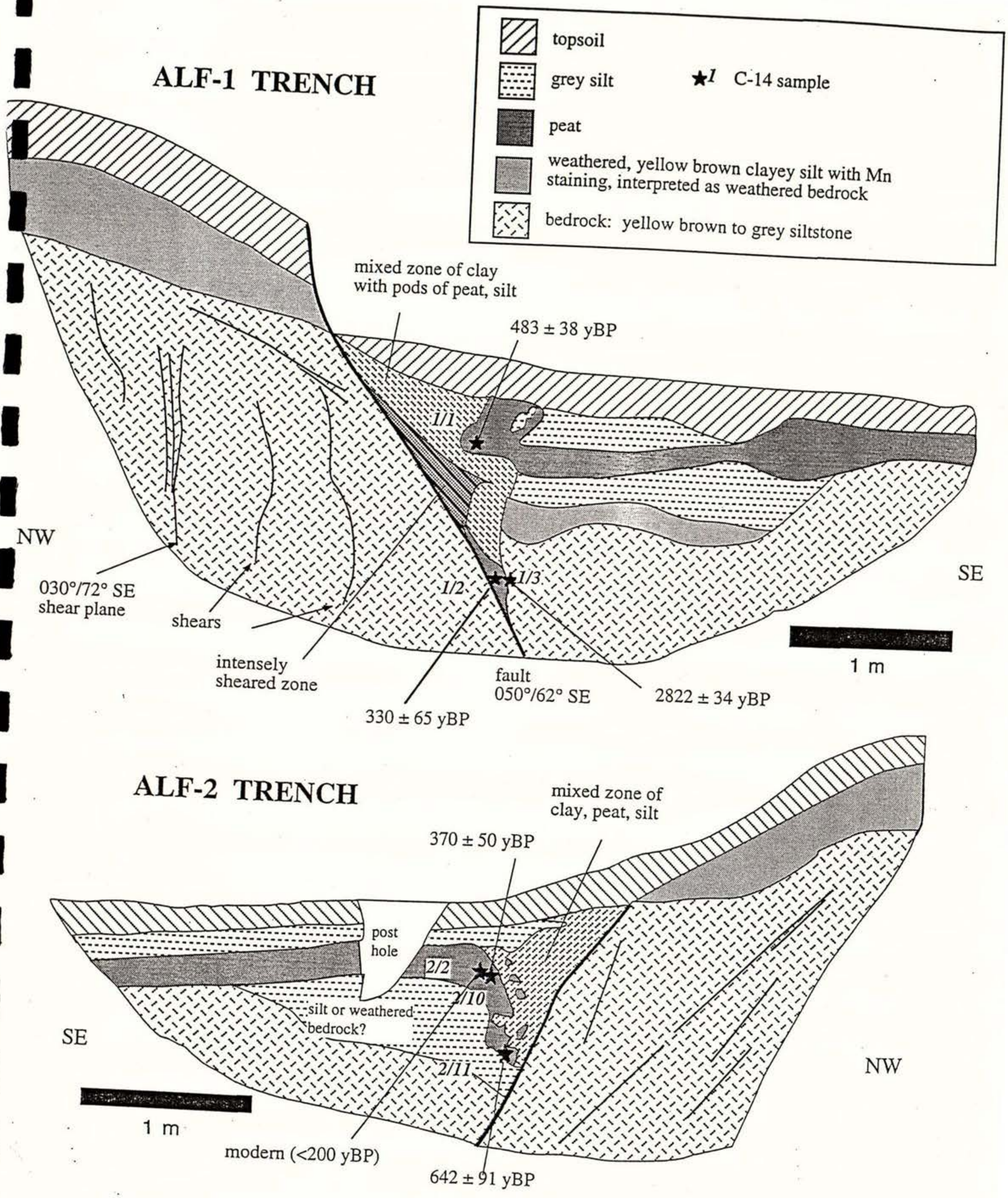

Figure 6b. Trench logs for Alfredton golf course trenches. Radiocarbon ages are conventional ages in years before present (1950); see Table 3 for calibrated ages. Sample 2/11 collected from opposite wall of trench.

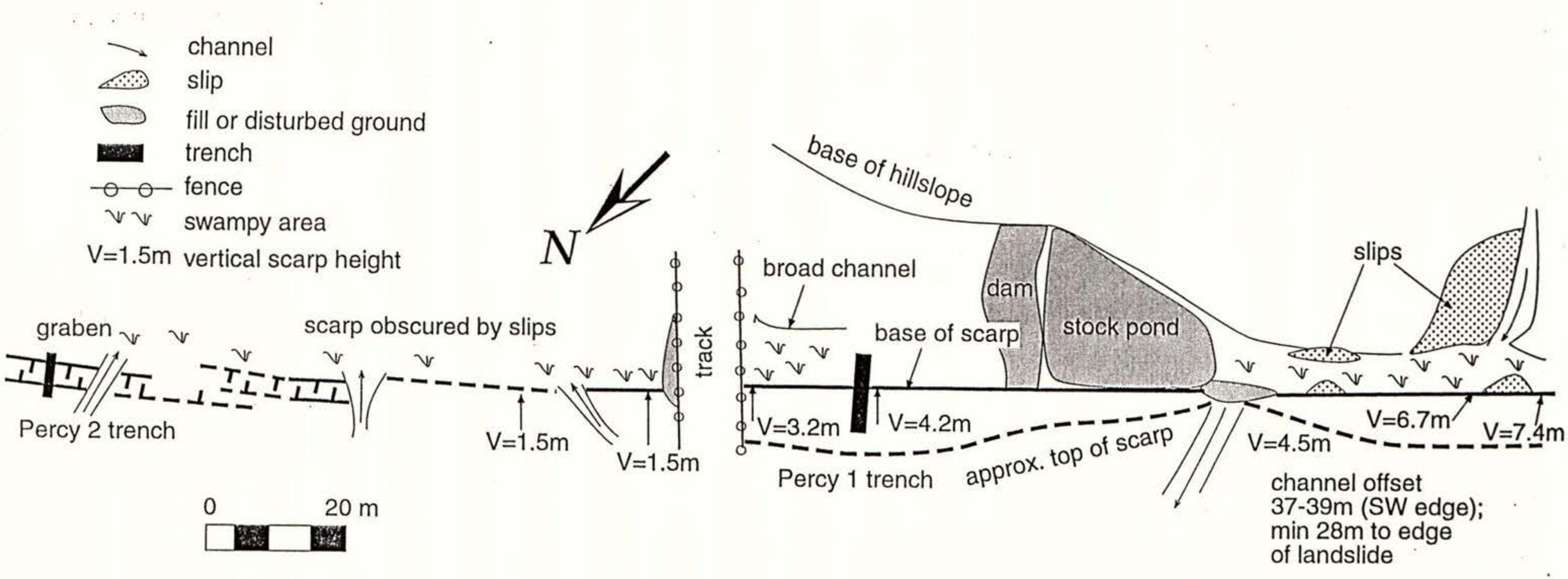

Figure 7a . Map of Alfredton fault at Percy trench site, constructed by tape and compass. Location shown in Figure 5, trench logs shown in Figures 7b and 7c.

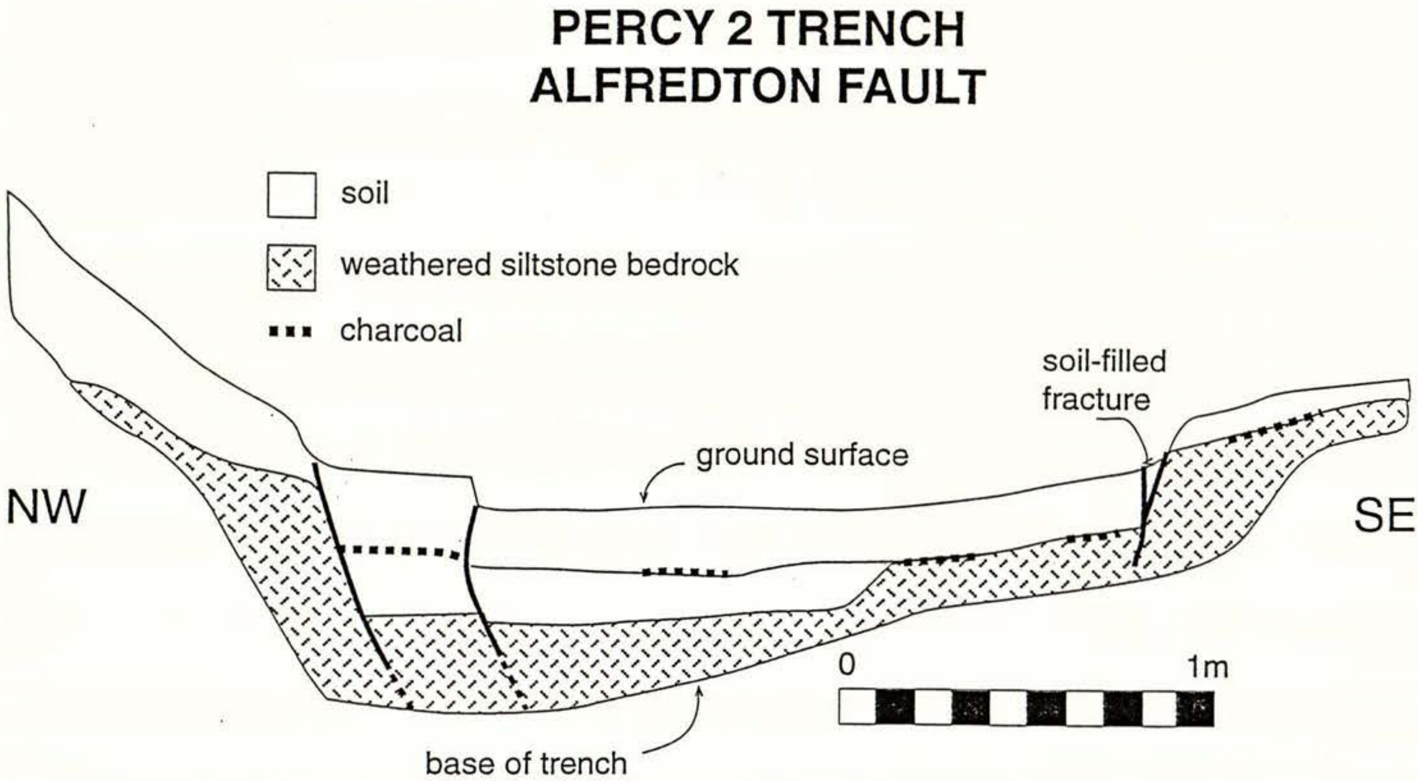

Figure 7b. Percy 2 trench log.

PERCY 1 TRENCH
ALFREDTON FAULT

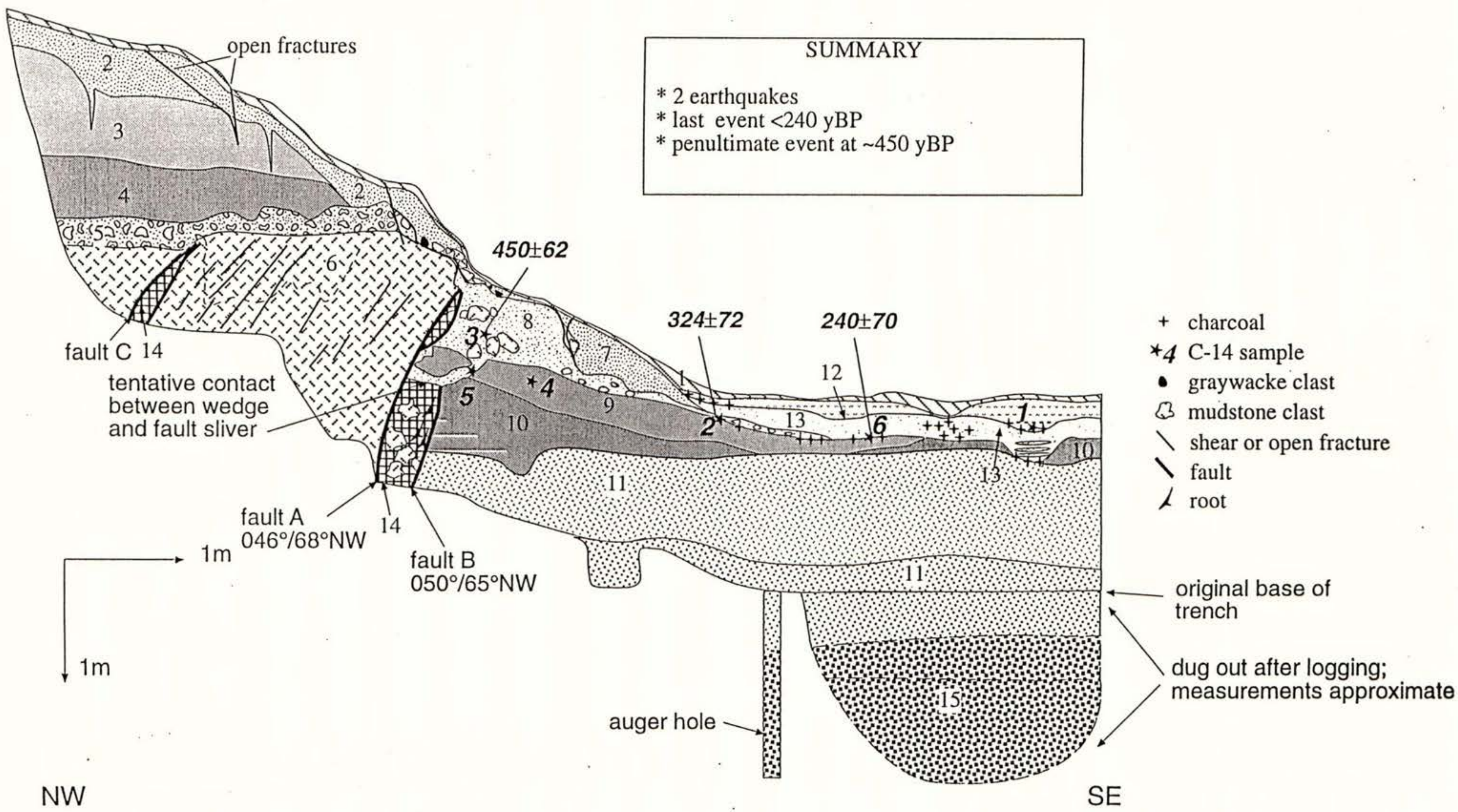

Figure 7c. Percy 1 trench log. Sample ages are conventional radiocarbon ages in yBP, with 1σ errors. See Table 3 for calibrated ages and following page for explanation of units.

Unit	DESCRIPTION		INTERPRETATION
1	Very dark greyish brown soft silty clay to loose clayey silt with >70 % organic matter (mainly modern roots).		Topsoil
2	Brown to yellowish brown moderately loose slightly clayey silt with modern roots and nutty soil structure. Manganese nodules 1 to 5 mm scattered at the base.	Hanging wall units	Subsoil developed on alluvial? silt. No dateable material.
3	Light brownish grey to brownish yellow massive, moderately dense slightly clayey silt to silty very fine sand. Mn nodules 2 to 15 mm concentrated at top.	Hanging wall units	Alluvial silt ? No dateable material.
4	Brownish yellow moderately dense silty very fine sand to dark yellowish brown sandy silt. Mn nodules 1 to 50 mm concentrated in top half, scattered to the bottom. Prismatic soil structure.	Hanging wall units	Paleosol developed on alluvial silt. No dateable material.
5	Brown moderately loose matrix-supported massive gravel with very rounded greywacke clasts 3 to 100 mm. 100 mm clay clasts at the base. Matrix is clayey fine sand.	Hanging wall units	Alluvial gravel reworked from Miocene conglomerate. No dateable material.
6	Dark grey very firm mudstone. Weathered at top, sheared throughout.	Hanging wall units	Late Miocene bedrock (Soren Group).
14	Sheared gravel and mudstone blocks in silt and clay matrix.		Fault breccia and gouge.
12	Light brownish grey moderately loose slightly fine sandy silt with modern roots and scarce charcoal. Incipient blocky soil structure. Base is laminated, iron stained, and charcoal-rich.	Footwall units	alluvial silt, developed above second burn horizon due to forest clearing; postdates most recent rupture (LE); dated by sample 1/1 (not submitted for dating)
13	Light brownish grey moderately loose laminated fine sand to sandy silt; silt clasts, charcoal, manganese and iron staining at base.	Footwall units	alluvial silt, developed above first burn horizon due to forest clearing; interfingers with and overlies wedge formed in LE, dated by 1/6 at 240±70 yBP.
7	Brown loose slightly sandy silt with modern roots, charcoal, and nutty soil structure. Fe-stained silt clasts 5-20mm at base.	Footwall units	Colluvial wedge formed during LE. Pre-sample 1/1, post-dates 240±70 yBP.
8	Yellowish brown moderately loose sandy silt to fine sand with clasts (5-15 cm) of rounded graywacke gravel, weathered mudstone,brown silt, and light grey to brownish yellow silt; burned roots and detrital charcoal.	Footwall units	Colluvial wedge formed during penultimate rupture. Contains clasts of bedrock, gravel unit, paleosol, and silt units from hangingwall. Dated by samples 1/3 (=450±62yBP) and seed 1/5. (not submitted), predates 1/2 at 324±72 yBP)
9	Brown moderately dense massive clayey silt with burned roots and very scarce detrital charcoal. Fe mottling and very rare Mn nodules.	Footwall units	Paleosol developed on alluvial silt. Pre-penultimate event; silt dated by sample 1/4 (not submitted), soil surface by 1/2=324±72yBP.
10	Light grey and brownish yellow massive, moderately dense slightly clayey silt with burned roots, Fe staining, and patches of gleyed silt (shown with horizontal lines).	Footwall units	Paleosubsoil developed on alluvial silt. No dateable material.
11	Strong brown massive, moderately dense slightly clayey silt with 1-5 mm Mn nodules concentrated at top and scattered throughout. Brownish yellow to light grey at base.	Footwall units	Paleosol developed on alluvial silt and/or weathered bedrock? No dateable material.
15	Massive grey fine sand. Gleyed at top.	Footwall units	Pliocene bedrock (Makuri sandstone).

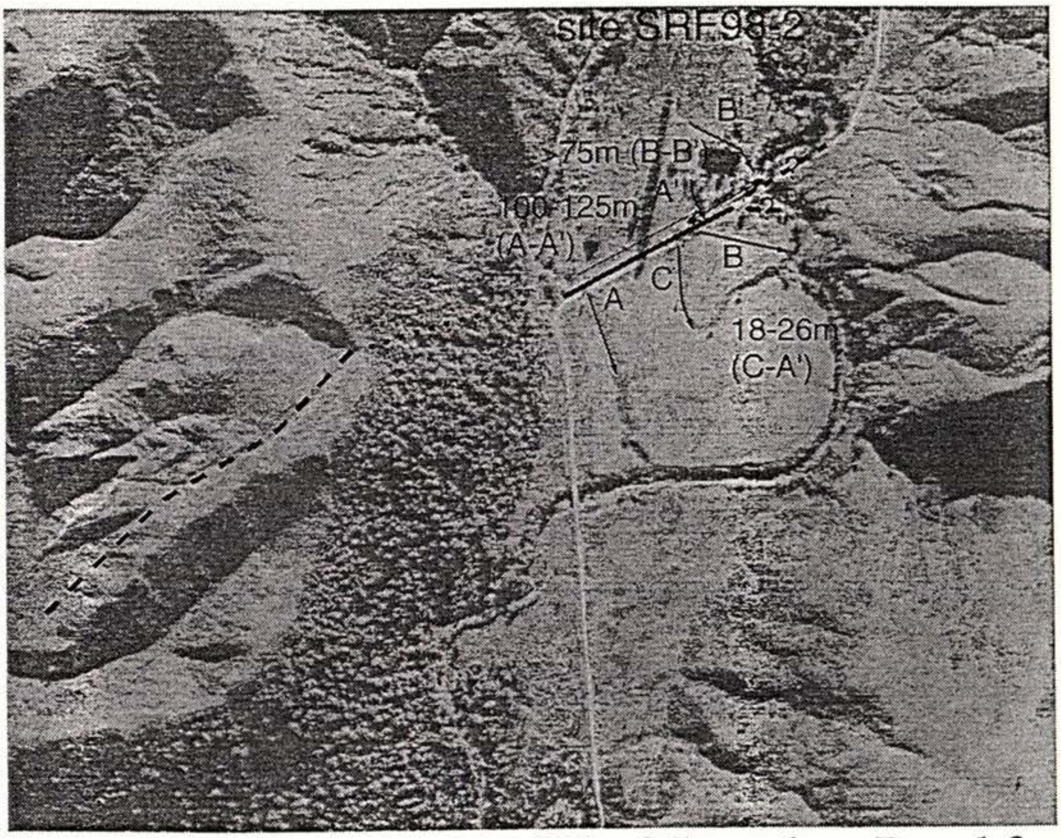

Figure 8. Air photo 891/37 of Saunders Road fault
with proposed channel correlations across the fault.

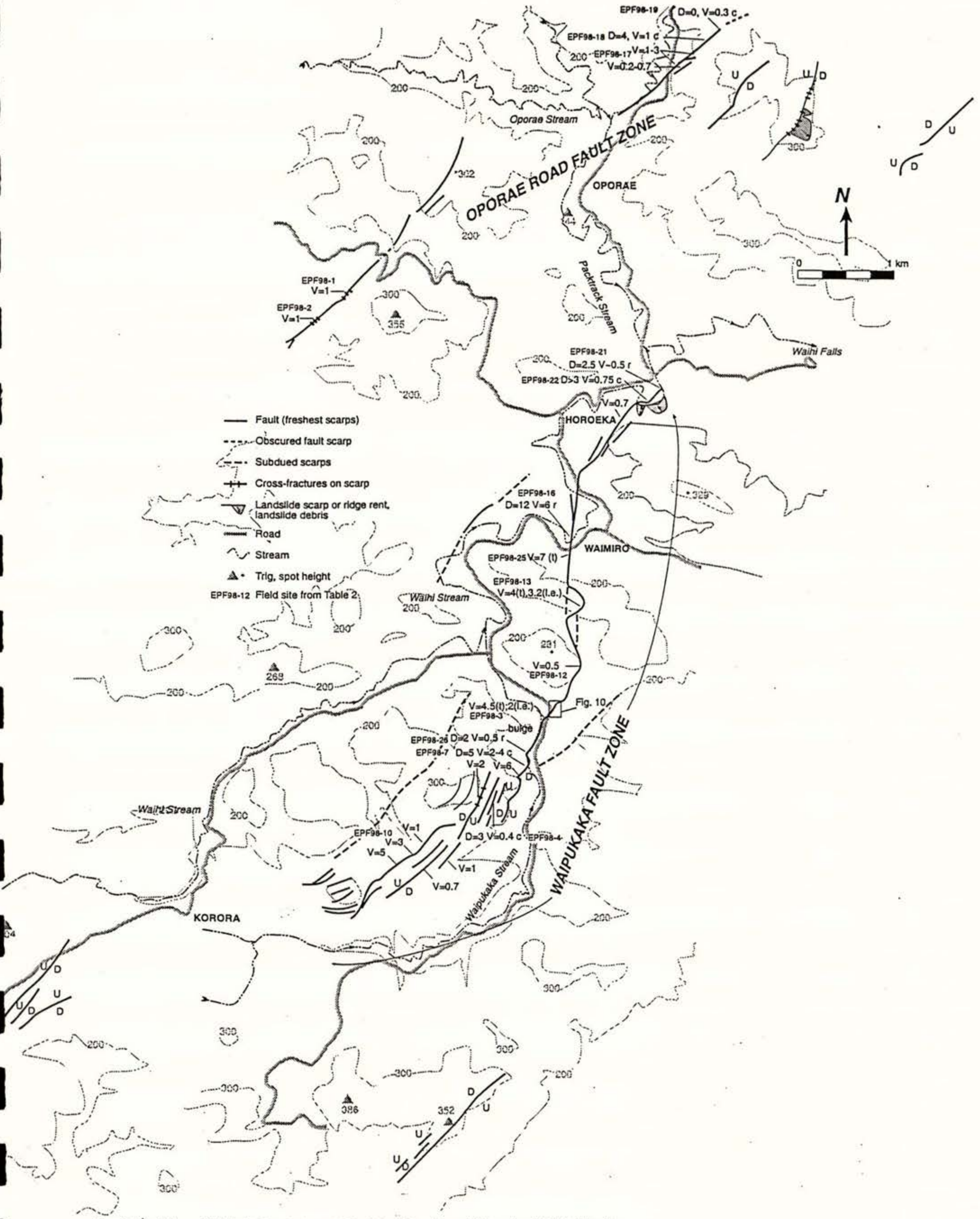

Figure 9. Detailed map of Waipukaka fault and other nearby East Puketoi faults. Measured offsets are keyed to Table 2. Location of trenches shown in Figure 10 (box).

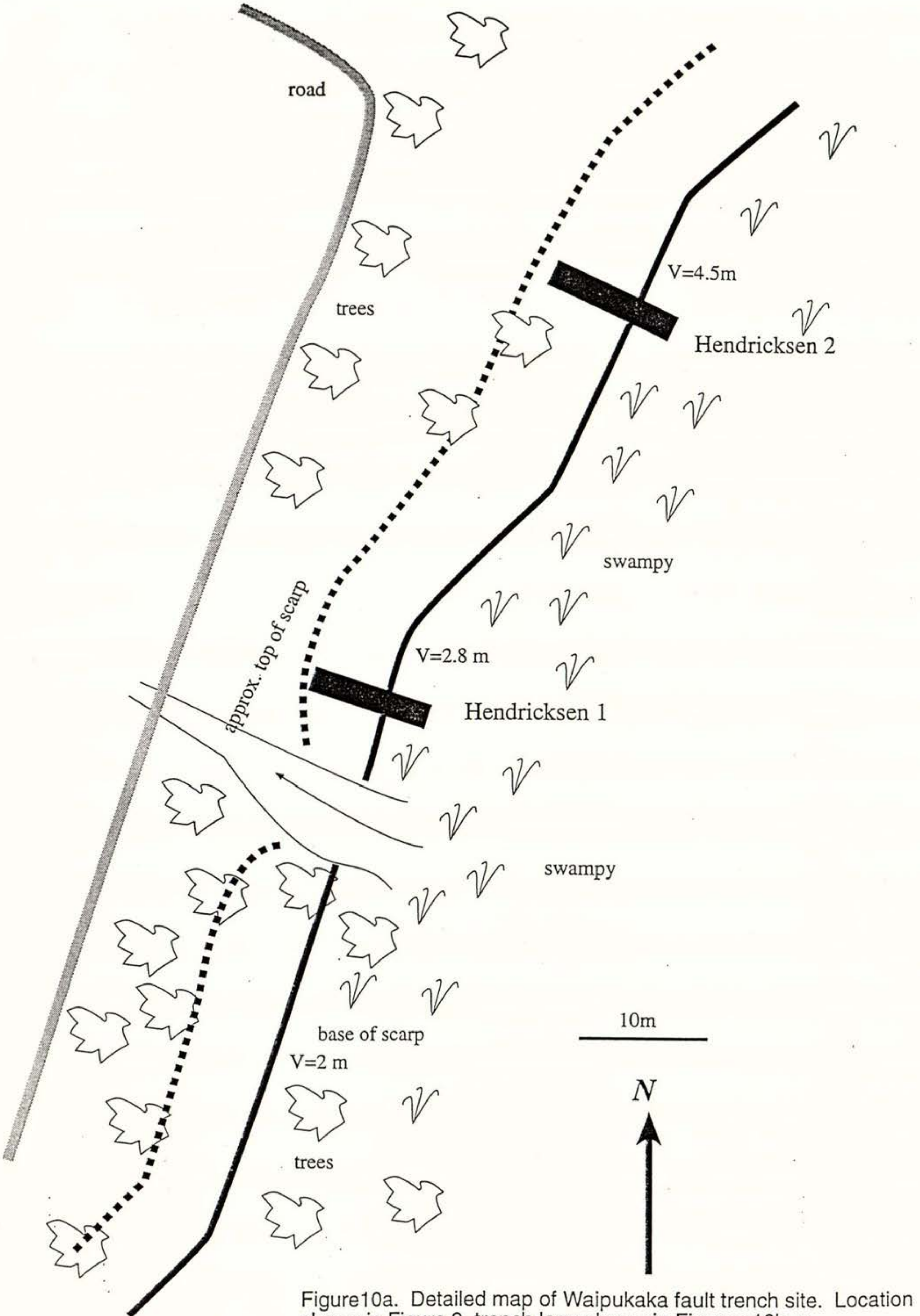

Figure10a. Detailed map of Waipukaka fault trench site. Location shown in Figure 9, trench logs shown in Figures 10b, c.

Hendricksen 1 trench
Waipukaka fault

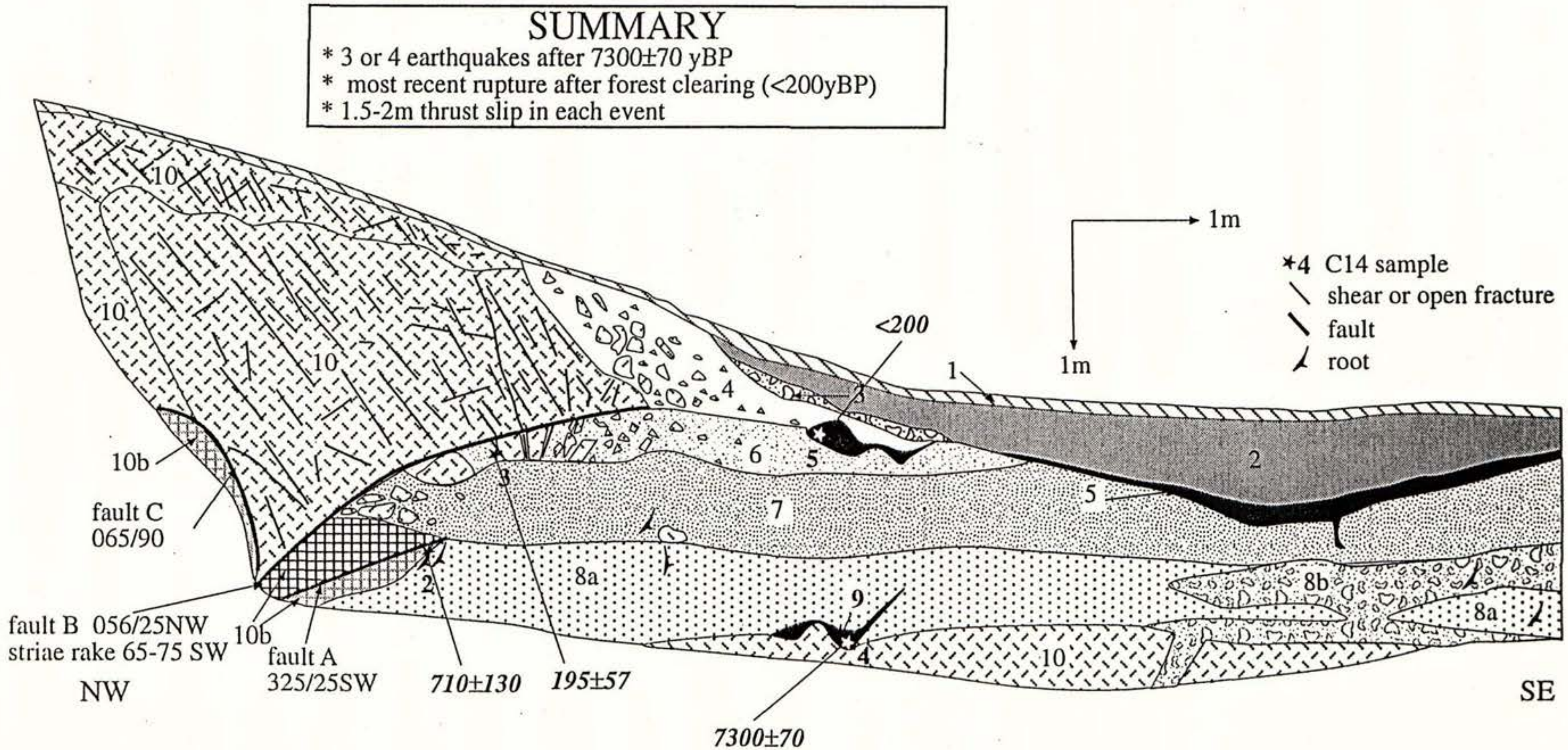

Figure 10b. Log of trench Hendricksen 1. Sample ages shown are conventional radiocarbon ages with 1s errors. See Table 3 for calibrated ages and following page for explanation of symbols.

Figure 10b (continued)

	DESCRIPTION	INTERPRETATION
1	Soft yellowish brown silt mottled with reddish yellow to strong brown colors; abundant modern grass roots	topsoil
2	Moderately loose greyish brown clayey silt with disseminated charcoal, roots wood fragments and peaty material, and rare angular cobbles and pebbles of bedrock	alluvial and/or sediment ponded at scarp
3	Moderately loose greyish brown silty gravel to gravelly silt with 35-65% angular bedrock clasts averaging 1-3cm but rarely up to 6cm. Contains abundant fine roots, including grass. Less dense than underlying unit	Reworked material from colluvial wedge
4	Moderately loose greyish brown gravelly silt with strong brown mottling. Clasts are angular, boulder to pebble size of bedrock shale, grade from ~50% clasts, mostly 15-20cm in west to ~15% clasts, average 2-3cm (rarely to 8cm) in east.	Colluvial wedge formed in most recent rupture; postdates charcoal/burn horizon, <200yBP
5	Upper organic horizon: Very dark grey to black clayey silt with abundant charcoal (>30%) including roots, fragments of wood, and peaty material.	Interpreted as forest clearing horizon formed during land settlement sample 1/5 ("modern"= <200yBP).
6	In west, coarse angular clast supported boulder brecccia with relatively fresh bedrock clasts from <1 to 40 cm in a matrix of dark greyish brown silt, clasts fining to east. Grades eastward to to matrix supported, greyish brown gravelly silt with relatively fresh angular bedrock clasts ~5 to ~1cm.	Colluvial wedge formed in penultimate rupture; predates charcoal/burn horizon, sample 1/5; sample 1/3 (195±57 yBP interpreted as a root younger than wedge.
7	Dense light olive grey clayey silt in east grades westward into gravelly silt, which coarsens westward. Contains highly weathered angular clasts of bedrock up to 4 cm with Mn-staining. Strong brown to yellowish red mottling throughout but more intense at western end.	Colluvial wedge from ante-penultimate event. No dateable material.
8a	Dense light greenish grey slightly clayey silt with strong brown mottling and sparse (<5%) angular bedrock clasts to 1cm. Mn staining pervasive but most intense at top and western part of unit.	Alluvial silt, possibly ponded against fault scarp
8b	Light olive grey gravelly silt with yellowish red angular pebbles to cobbles of very weathered bedrock. Matrix supported, with clasts up to 30%, clasts from <2mm to 3cm; average ~1cm.	Alluvial gravel
9	Lower organic horizon: Very dark brown to black wood and peaty material encased in silty clay; includes roots, branches, twigs	Wood deposited during inital stages of ponding of alluvial material by fault scarp? Dated by sample 1/4 (7300±70 yBP)
10	Light grey to grey massive siltstone. Ranges from relatively unbroken rock to fractured but intact, to intensely fractured and disrupted, shown schematically by density of fractures	Cretaceous bedrock (Whangai formation).
10b	Mixed zone, fault breccia: dark olive grey pebbly silt with angular fragments of bedrock ranging from clay size to 1cm, intensely sheared. Clay gouge in lighter pattern.	Faulted bedrock

Hendricksen 2 trench
Waipukaka fault

SUMMARY

At least 3 earthquakes, possibly 4; 3 event since sample 2/2 (2762±57 yBP):

* Most recent rupture appears to be historic, as colluvial wedge overlaps/interfingers with charcoal and historical artifacts layer .

* Penultimate rupture predates forest clearing.

*Minimum displacement in each event is 0.7-1 m thrust slip.

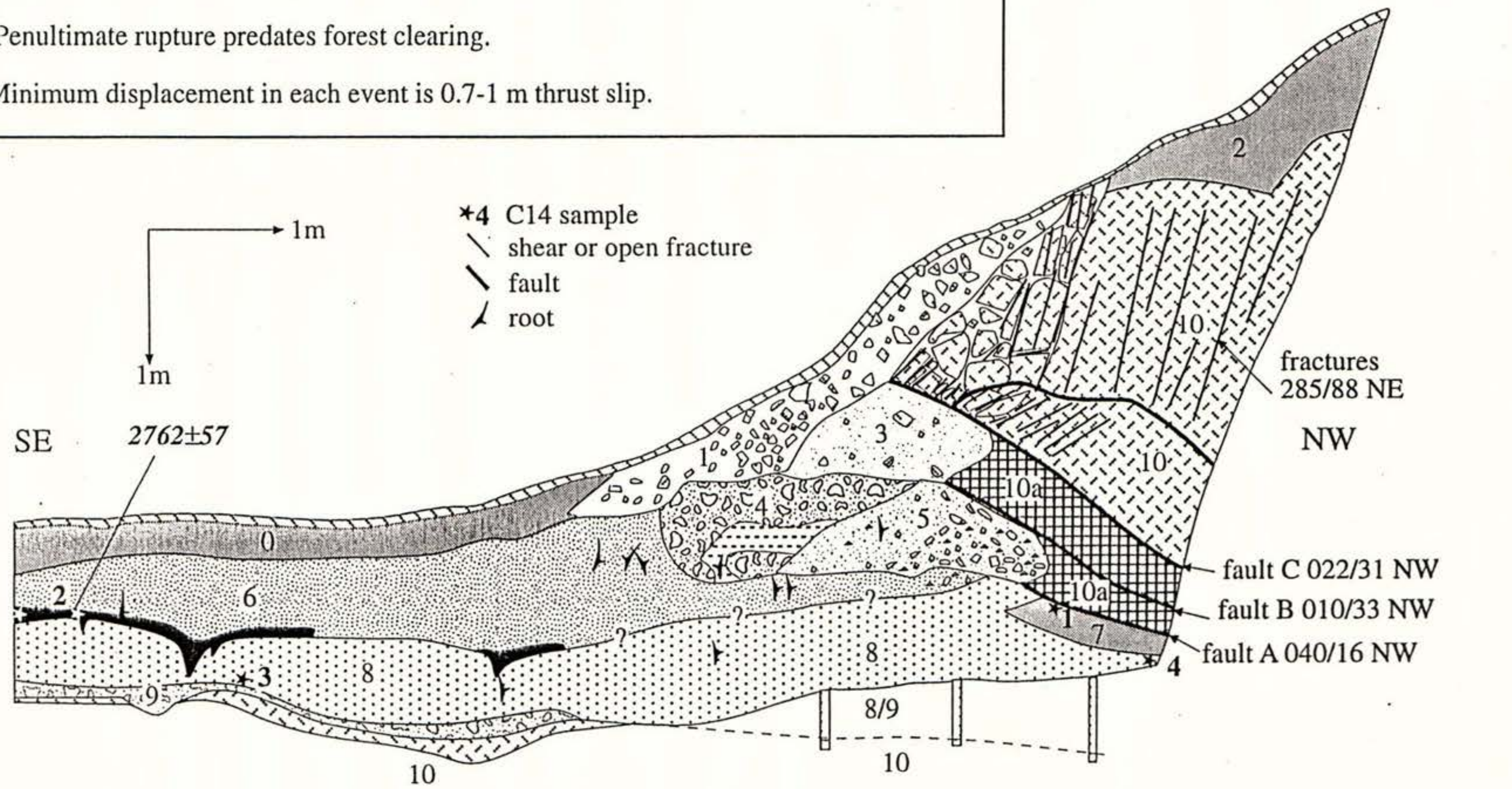

Figure 10c. Log of trench Hendricksen 2. Sample ages shown are conventional radiocarbon ages with 1s errors. See Table 3 for calibrated ages and following page for explanation of units.

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Unit	DESCRIPTION	INTERPRETATION
	Soft yellowish brown silt mottled with reddish yellow to strong brown colors; abundant modern grass roots	topsoil
0	Loose greyish brown to dark greyish brown silt with disseminated charcoal, peaty material, and a concentrated layer of charcoal and artifacts at the base, including glass bottles, pottery, shoes.	Alluvial and/or sediment ponded at scarp; post European settlement and forest clearing
1	Loose light yellowish brown gravel breccia to gravelly silt, with angular clasts of moderately weathered bedrock to 40cm, fining to east, with clast abundance decreasing from >50% in west to <10% in east.	Colluvial wedge formed in most recent rupture; in part postdates charcoal/burn horizon.
2	Loose brownish yellow gravely silt with angular clasts of moderately weathered bedrock averaging 0.5-1cm, max 3 cm	Finer hillslope colluvium on bedrock scarp. No dateable material.
3	Moderately dense light yellowish brown gravelly silt with 25-30% angular clasts of bedrock ranging 1-6 cm, average 2-3cm.	Colluvial wedge formed during penultimate event. No dateable material.
4	Dense mottled greyish brown to light brownish grey gravely silt with areas of clayey silt with rare pebbles. Clasts up to 30%, range 1-5 cm, average 2-4 cm composed entirely of angular weathered bedrock.	It is uncertain if this represents colluvial wedge or alluvial sedimentation, however geometry suggests a channel in and possible reworking of underlying unit (5).
5	Dense mottled light olive grey gravelly clayey silt with highly weathered angular clasts of bedrock from 0.5-5cm, fining and decreasing in abundance from west to east, and from bottom to top of unit, from ~25% clasts in west to ~10% in east. Contains carbonized and degraded roots and other organic material. Strong brown mottling is more intense to east.	Colluvial wedge from ante-penultimate event (or earlier event if unit 4 is a colluvial wedge). Post dates 2762±57 yBP.
6	Light brownish grey clayey silt with intense strong brown mottling, abundant root material, and sparse highly weathered bedrock clasts.	Alluvial silt, possibly ponded against fault scarp. Post dates 2762±57 yBP.
6a	Dark greyish brown clayey silt with abundant disseminated organic material; unit pinches out to west but contact below can be followed as a contrast between siltier material above and clayier below.	Ponded horizon between alluvial units 6 and 8, possibly during or after an event which dammed the stream. 2762±57 yBP.
7	Dark greyish brown silty fine sand with sparse gravel at base composed of angular bedrock clasts up to 3-4cm. Grades to light grey sandy silt at top and to east.	Alluvial sediment. Contains root sample 1 sheared off by fault A.
8	Greenish grey silty clay with strong brown mottling except at western end of unit, where it contains peaty material.	Oldest unit ponded above bedrock, possibly the earliest event preserved in trench. Samples 3,4 near base of unit.
9	Grey fine sand with sparse moderately fresh angular bedrock clasts to up to 3 cm in sharp contact with moderately fresh but fractured bedrock.	Oldest alluvial unit or ?weathered top of bedrock? Predates sample 3
10	Light grey (weathered) to grey (fresh) massive siltstonebedrock. Ranges from relatively unbroken rock to fractured but intact, to intensely fractured and disrupted, shown schematically by density of fractures	Cretaceous bedrock (Whangai formation).
10a	Mixed zone, fault breccia: dark olive grey pebbly silt with angular fragments of bedrock ranging from clay size to 1cm, intensely sheared. Clay gouge	Faulted bedrock. Mixed with unit 5 along fault B

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