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Whitemans Valley Fault and the earthquake-generating potential of Wellington's second order faults

A report on EQC Research Foundation Project 97/247

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Abstract

A NNE-SSW-trending linear scarp was trenched in Whitemans Valley, near Upper Hutt, and proved to be a fault scarp. Part of the c. 8-9 m high fault scarp trenched revealed twin reverse fault planes dipping at c. 45° to the west. Sediments displaced vertically by the fault planes include fan gravel and three loess/paleosol couplets. The fan gravel represents the youngest alluvial sedimentation at the site and at c. 80 thousand years (ka), it forms the oldest displaced unit seen in the trench. Chronology for the trench is based on coverbed stratigraphy, which consists of loess/paleosol couplets correlated with Porewa (c. 80-65 ka), Rata (c. 60-30 ka) and Ohakea (c. 24-14 ka) loesses. Possible dextral displacement of a stream channel suggests a dextral lateral component of slip along the fault, although there are no quantifiable data available.

With the exception of the topsoil, each unit in the trench has been vertically displaced by between 1.4 and 2.1 m (equivalent to dip-slip displacement of c. 2-3 m), which we interpret as evidence of a single rupture event. Younger units in the trench are apparently displaced more than older sediments, a fact best explained by assuming a strike-slip component (possibly with some SW dip on older sediments) and by variation in unit thickness. The rupture cuts and deforms a paleosol developed in the Ohakea Loess which is considered to be c. 10 ka or younger, but the topsoil is undeformed. Using the assumption that the c. 1.8 m vertical displacement is typical for a single rupture event, the c. 8-9 m high scarp represents 4 or 5 events. Rupture recurrence interval is estimated at 15-20 ka.

The fault can be mapped for a distance of c. 20 km between Witako Valley (SE Upper Hutt) and Wainuiomata. On the basis of the 2-3 m dip-slip displacement per event, rupture on the Whitemans Valley Fault is thought to result in a M=7.0±0.3 earthquake. This work outlines the rupture characteristics of a single "second order" fault in the Wellington region. It is conceivable that 10 similar "second order" faults in the Wellington region are active, suggesting that these faults may collectively contribute significantly to the region's seismic hazard.

INTRODUCTION

The occurrence of earthquakes in the Wellington region has been noted by those who have chosen to live here for at least 500 years. Elsdon Best (1923) documented some of the oral traditions of local Maori which indicate that not only had they experienced major earthquakes in pre-European times but also recognised that they could be accompanied by significant changes in the landscape. The 1848 Marlborough and 1855 Wairarapa earthquakes were an immediate initiation to the seismicity of the region for the early European settlers.

Understanding seismic hazard in the Wellington region is a continuing challenge for the earth science community with great relevance to the community at large. Such an understanding is dependent upon evaluation of return periods and magnitude estimates of nearby major earthquake sources. In Wellington, major surface-rupturing (shallow) earthquake sources have been identified and their characteristics estimated. These include, from west to east, the Shepherds Gully/Pukerua, Ohariu, Wellington and Wairarapa faults (Figure 1). The active nature of these major northeast-trending faults is now well-established, and progress has been made in characterising their earthquake potential in terms of magnitude, return period, and single event displacements (eg Van Dissen and Berryman 1996). Although no surficial features are conclusively attributable to deformation related to subduction interface earthquakes, it is likely that they also contribute significantly to the region's seismic hazard (eg Robinson 1986, 1988; Smith 1988).

A group of approximately north-south trending faults (here termed "second order" faults) has been identified in the region (eg Bell 1909, Stevens 1974). Most recently, during geological mapping of the region at a scale of 1:50 000, Begg and Mazengarb (1996) mapped them systematically. Examples of this family of faults occur close to, and within the Wellington urban area, but little is known about their earthquake-generating potential. At least some of them should be regarded as "active" (that is, with displacement within the last 125 ka). For example, the Baring Head Fault displaces a marine bench considered to be 125 ka in age (Ota et al. 1981), and subsurface and geophysical evidence suggests that the Evans Bay Fault has also been active in the last 125 ka (Lewis and Carter 1976; N.D. Perrin pers. comm.). Excavations on construction sites in the central city have revealed fault displacement of Quaternary sediments, although little is known of the ages of the sediments displaced (Perrin pers. comm.; Berryman pers. comm.).

Within Wellington City itself, landscape modification and urbanisation mostly precludes the possibility of establishing earthquake histories for these "second order" faults. However, the discovery of a linear scarp in Whitemans Valley with the characteristics of a fault trace presented an opportunity to evaluate the earthquake history of one of these north-south trending faults. The site was considered suitable for

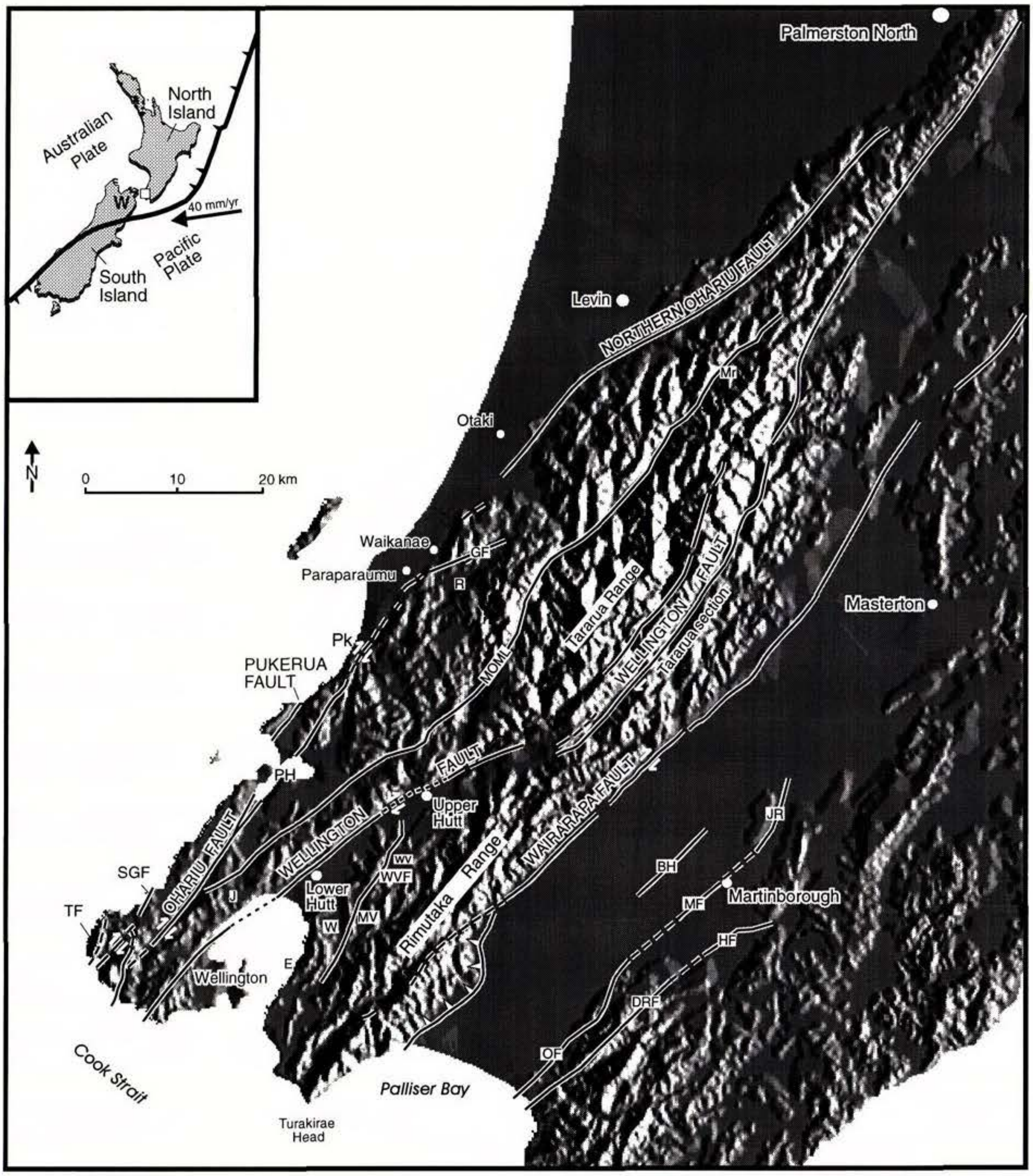

Figure 1: Location of the principal NE-SW-trending active faults in the Wellington region, with some additional (probably active) faults added. Note the location of the Whitemans Valley Fault to the east of the Lower Hutt Valley. Activity of these faults, particularly the principal faults, is directly related to the broader tectonic setting of the region, summarised on the inset map. The Pacific Plate is converging obliquely with the Australian Plate in the Wellington (W) region at a rate of about 40 mm/yr. TF = Terawhiti Fault; SGF = Shepherds Gully Fault; PH = Porirua Harbour; Pk = Paekakariki; R = Reikorangi valley; GF = Gibbs Fault; MOML = Moonshine-Otaki-Mangahao lineation; W = Wainuiomata; MV = MooresValley; WVF = Whitemans Valley Fault; wv = Whitemans Valley; BH = Bidwill Hill; OF = Otaraia Fault; MF = Martinborough Fault; JR = Jury Ridge; DRF = Dry River Fault; HF = Huangarua Fault.

paleoseismic study because it is in a rural setting and has not suffered the degree of modification common in an urban setting leaving important field relationships and fine surface and subsurface features critical in establishing fault activity and earthquake history intact. Also the scarp appears to displace Quaternary sediments providing an opportunity to date earthquake events using radiocarbon dating, volcanic ashes and/or loess stratigraphy.

STATEMENT OF OBJECTIVES

The intentions of the research project are to:

1. Determine whether or not the landform in Whitemans Valley is a fault trace by trenching across it;
2. Determine whether the structure displaces late Quaternary sediments and should therefore be regarded as an active fault;
3. If active, attempt to place constraints on the timing and size of events identified;
4. Estimate the likely earthquake magnitude represented by surface rupture on this fault;
5. Present a map showing the locations and extent of other possibly active "second order" faults in the Wellington region.

Fault trace in Whitemans Valley

Air photo lineations occur along a trend from the Witako Valley area, through Whitemans Valley, across a low saddle to Moores Valley and then over a spur towards Wainuiomata (Figure 2). In Whitemans Valley, a Quaternary surface is apparently displaced across the lineation, downthrown to the east. A trench was excavated across this lineation to assess whether its origin was fault-related (Figure 3 & 4). Results from trenching are discussed in the next section. The trend of the lineation is approximately NNE-SSW, distinguishing it from the principal active fault systems of the Wellington area which are orientated approximately NE-SW. The scarp at the trench site is about 8-9 m in height and is characterised by a low, oversteepened scarplet near its lower third. A profile across the scarp is presented in Figure 5.

Trench stratigraphy and correlations

A trench orientated 103° and approximately perpendicular to the scarp was excavated to a depth of about 4.5 m across the oversteepened scarplet in the lower third of the 8-9 m high scarp (see Figure 5). The exposed sequence consisted of alluvial fan gravel overlain by loess and paleosol couplets displaced by a pair of reverse fault planes trending c. 010 ° and dipping 45°W (Figure 4 and 5). Vertical displacement across the fault planes totals about 1.4 - 2.1 m (Table 1) and rupture is almost to the ground surface, with only the topsoil (Unit 12) not displaced.

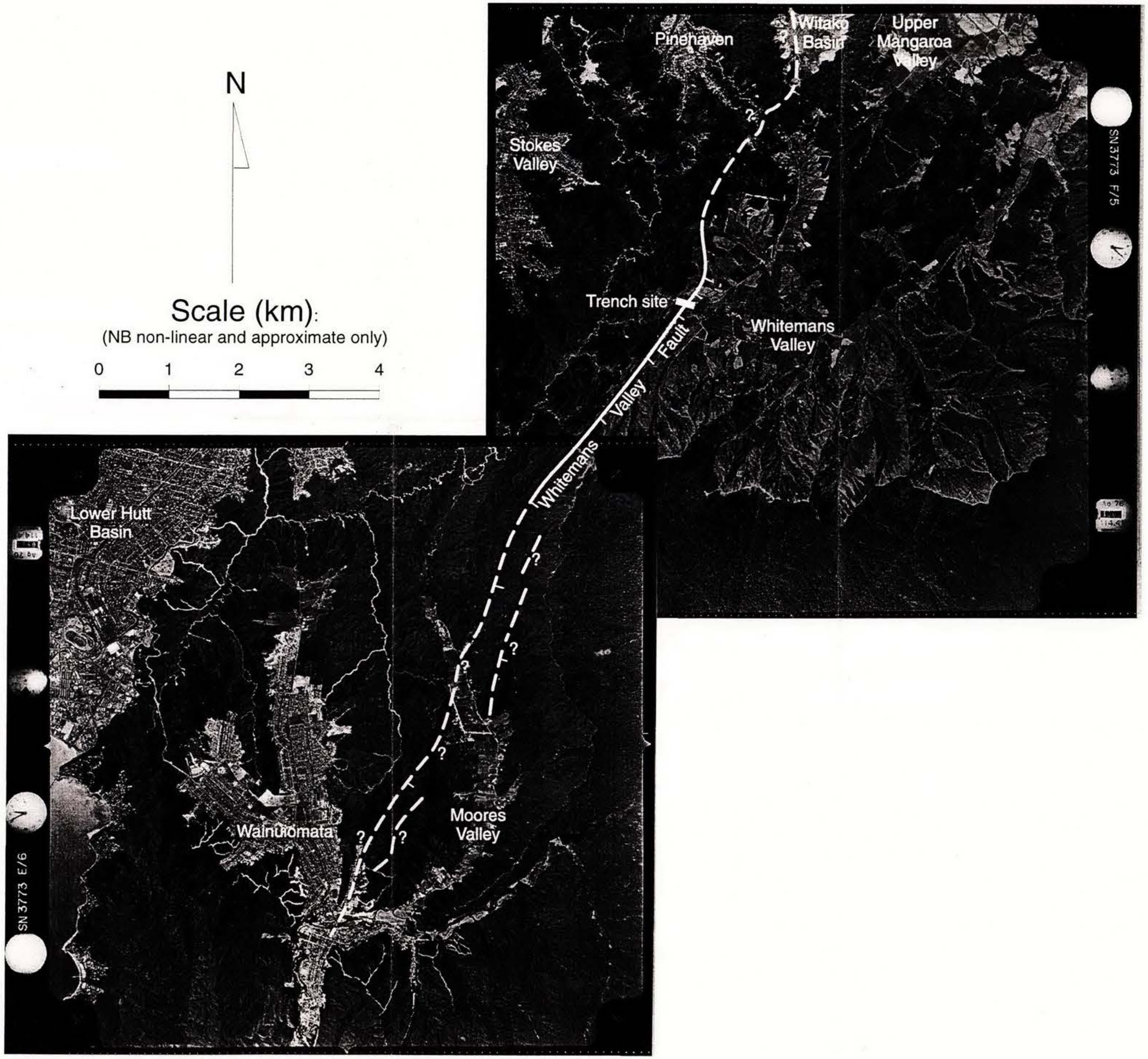

Figure 2: Aerial photographs showing the extent of the lineation interpreted as the trace of the Whitemans Valley Fault. A solid white line marks the extent of the fault where the location is known with confidence. Dashed lines marked the approximate location of the fault, determined only using aerial photographs and ticks on the line indicate downthrow on its eastern side. The fault may intersect the Wellington Fault in the Trentham area, and may extend southwards down the Wainuiomata River beyond the southern extremity indicated here.

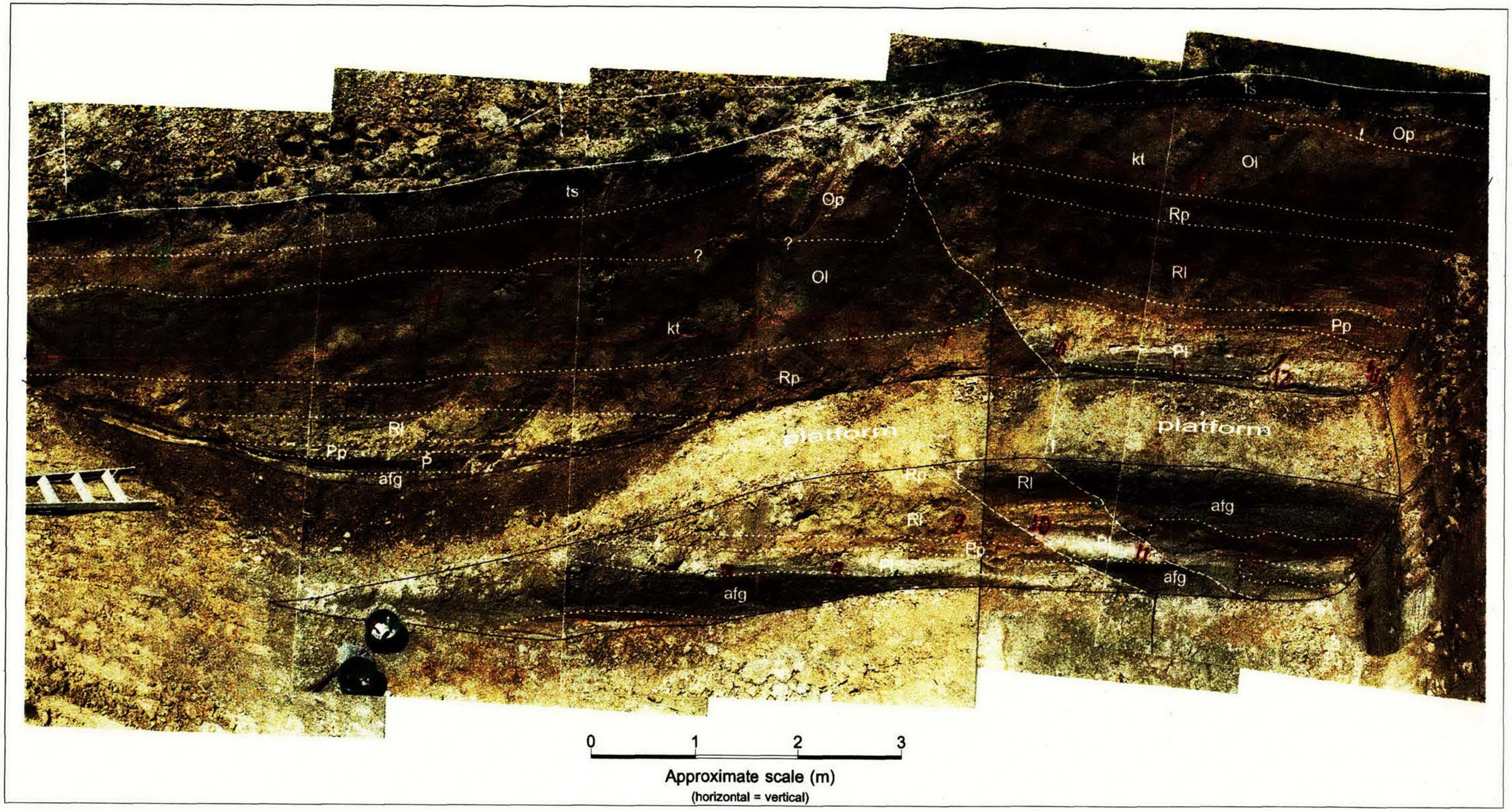

Figure 3: Composite photograph of the south wall of the Whitemans Valley Fault trench. Numbers written on the wall refer to the 1 m grid established as a drawing aid. Note the two clearly visible reverse faults (labelled "f"), the western (right hand) of which penetrates to near the top of the trench; the dark textured horizon at the lower right hand end of the trench is the alluvial fan gravel (afg); the same unit can be seen to the left of the right hand fault, then again at the very base of the trench to the left of the left hand fault; note also the c. 1 m wide platform (a trench safety feature). Pl = Porewa Loess; Pp = Porewa paleosol; Rl = Rata Loess; Rp = Rata paleosol; Ol = Ohakea Loess; kt = Kawakawa Tephra; Op = Ohakea paleosol; ts = topsoil.

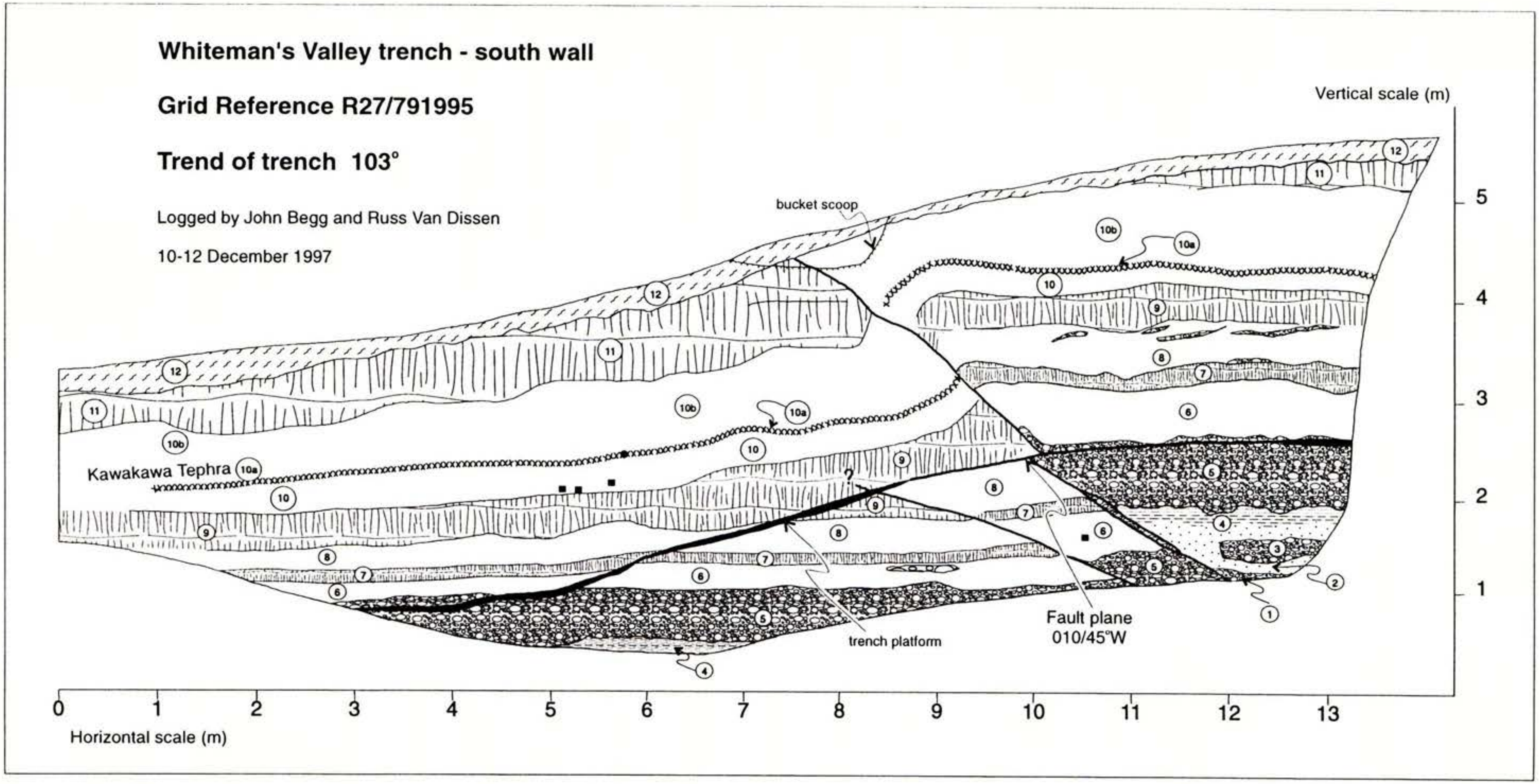

Figure 4: Log of the south wall of the Whitemans Valley Fault trench. Units 1 to 5 are alluvial (with a possible minor aolian signature) and consist of gravel (Units 1, 3 and 5), sand and silt (Units 2 and 4). Unit 5 is the youngest record of alluvial sedimentation in the sequence and its upper surface represents the abandoned surface of an alluvial fan. All subsequent sedimentation is essentially aolian, with perhaps a minor slopewash contribution. Unit 6 is a heavily gleyed, silty clay which is probably loessic in origin; it is correlated with the Porewa Loess. Unit 7 is a yellow brown silty clay paleosol, interpreted as a soil developed on the Porewa Loess. Unit 8 consists of a yellow brown clayey silt with stone lines that is correlated with Rata Loess. It is overlain by a silty clay paleosol (Unit 9) interpreted as a paleosol developed in Rata Loess. Unit 10 consists of a further loess unit with a re-worked tephra horizon (Unit 10 a) near its lower third. This loess is correlated with Ohakea Loess and the tephra with Kawakawa Tephra. Unit 11 is a paleosol developed in the Ohakea Loess and is the youngest horizon disrupted by faulting. Unit 12 is a thin topsoil. The small black squares are locations of samples taken for radiocarbon dating and the black circle is the location of a tephra sample for geochemical analysis.

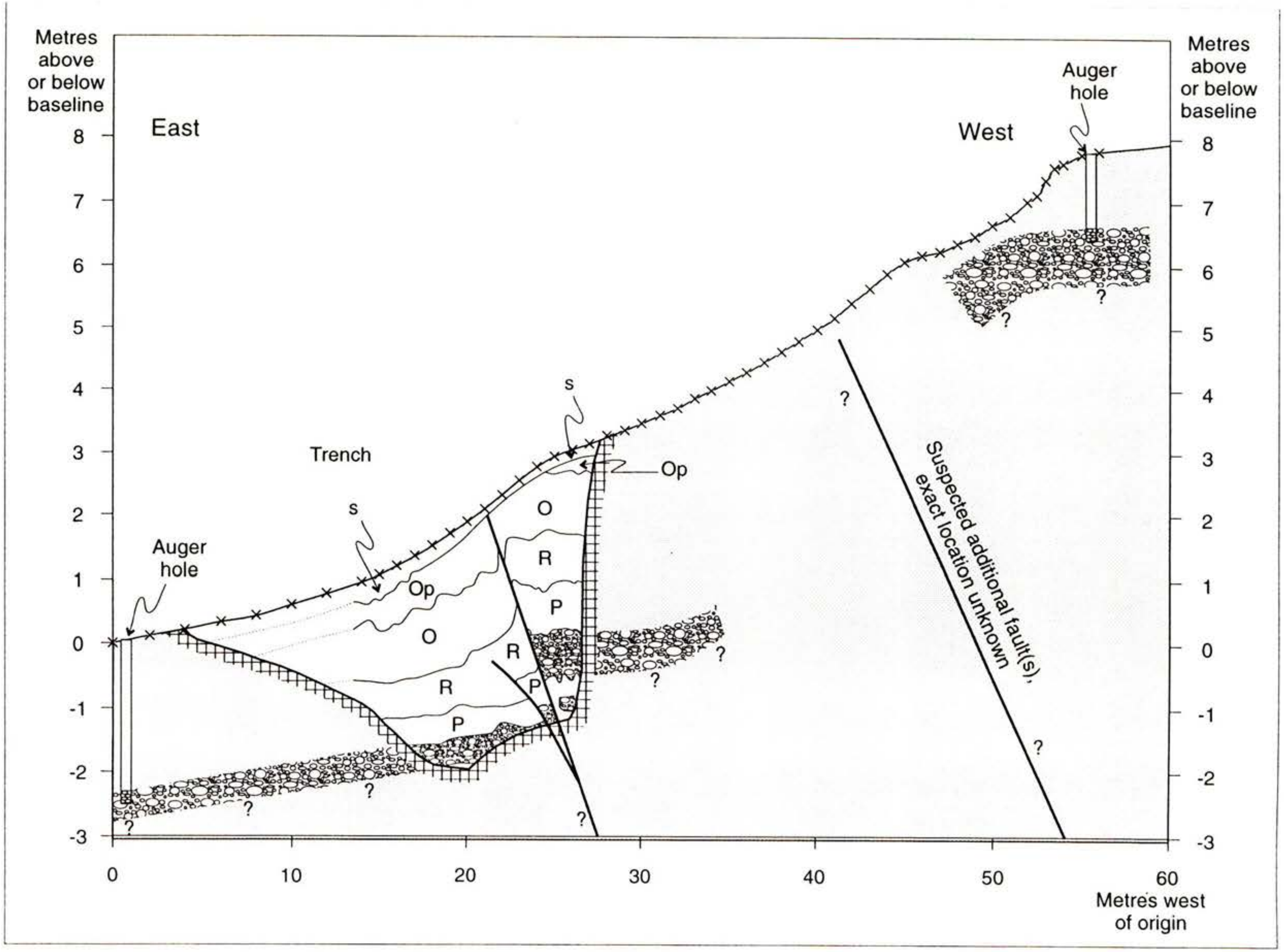

Figure 5: A levelled profile across the Whitemans Valley Fault scarp between two gently east-dipping fan surfaces. The eastern end of the profile is located c. 5 m north of the eastern end of the trench. Note two slightly steepened surface scarplets, the position of the trench, faults seen in the trench, and trench wall stratigraphy. Auger holes at either end of the profile provide information on the subsurface location of the buried alluvial fan surface. Note the vertical exaggeration of the diagram of c. 3.7 times. P = Porewa Loess and paleosol; R = Rata Loess and paleosol; O = Ohakea Loess; Op = Ohakea paleosol; s = topsoil.

A fan gravel unit (Unit 5) near the base of the trench provides a useful reference horizon, representing the youngest alluvial influence recorded in site sediments. The fan gravel surface represents the pre-existing extent of the fan which issued into the upper Mangaroa Stream (the Whitemans Valley basin) from a small tributary behind the trench site. Fan gravels can reasonably be assumed to have been continuous across the fault. Overlying coverbeds consist of aolian loess/paleosol couplets, a reworked tephra and topsoil.

Coverbeds on the alluvial gravel in ascending order consist of a heavily gleyed silty clay (Unit 6; probably loessic in origin) and a yellow brown silty clay paleosol (Unit 7). These units are correlated with the Porewa Loess and its paleosol, on the basis of stratigraphic sequence. A second loess/paleosol couplet, consisting of yellow brown clayey silt with occasional stone lines (Unit 8) and silty clay (Unit 9) overlies the gleyed loess and paleosol; these are correlated with the Rata Loess and paleosol, again on the basis of stratigraphic succession. A further overlying loess (Unit 10, 10a and 10b) and paleosol (Unit 11) is characterised by a thin (c. 10 cm thick) horizon of re-worked rhyolitic tephra (Unit 10a). The loess (units 10 and 10b) is correlated with Ohakea Loess, the paleosol (Unit 11) with Ohakea Paleosol and the tephra (Unit 10a) represents the 22.6 ka Kawakawa Tephra. Unit 11 is overlain by topsoil (Unit 12) up to 30 cm thick.

The age of the Porewa Loess (Unit 6) has been established elsewhere (eg Milne 1973; Milne and Smalley 1979; Berger et al 1992; Palmer and Pillans 1996) at c. 80-65 ka and the age of the paleosol (Unit 7) is assumed to represent the period from c. 65-60 ka. Palmer and Pillans (1996) estimated the age of Rata Loess (Unit 8) to be c. 60-30 ka, and the overlying paleosol (Unit 9) is assumed to represent the period c. 30-24 ka. The age of the Ohakea Loess (Unit 10, 10b) is estimated at c. 24-14 ka, and the Kawakawa Tephra (Unit 10a) is dated at 22.6 ka (Wilson et al 1988). The Ohakea Paleosol represents the period from about 14-10 ka.

The youngest unit displaced by the fault is the Ohakea paleosol (Unit 11) which developed between c. 14 and c. 10 ka after the principal phase of Ohakea Loess deposition (Pillans 1994). Close to the fault on the upthrown (west) side, the paleosol is eroded. In addition, it is dragged up along the fault in the trench wall. Assuming that the paleosol developed over at least several thousand years, faulting must post-date c. 10 ka. The consistency of horizon displacements, between the upper surface of the gravel and the Ohakea paleosol (Table 1) indicates that the identified faults are attributable to a single rupture event. This inference is supported by the observation that depositional thicknesses of the Porewa and Rata loesses are the same on each side of the fault and they show no erosional truncation near the fault, suggesting that there was no surface scarp or rupture at that time.

The age of the gravel fan (Unit 5), as inferred from the coverbed sequence, must predate the end of the depositional phase of Porewa Loess (ie > 65 ka). A maximum age for the fan surface is placed at about 110 ka, because a loess found elsewhere (albeit locally eg Wilde 1979; L4 of Palmer and Pillans 1996) was not found in the Whitemans Valley site. For the purposes of the rest of this report, the assumption is made that the fan gravel surface dates from c. 80 ka.

Auger holes at each end of the scarp profile provide some control on the total vertical displacement of the fan gravel surface. The c. 8-9 m height of the fault scarp, the location of the gravel surface beneath the profile (c. 9 m vertical displacement) and the fact that loess/paleosol couplets are flatter lying than the ground surface suggest there are one or more fault traces in the upper part of the scarp not exposed in the trench (Figure 4, 5).

In the trench, the fault is a moderately shallow (c. 45°), west-dipping reverse fault. A single displacement event is recorded on the faults in the trench, although one or more additional faults are interpreted to underlie the scarp to the west (upslope) of the trench site (Figure 5).

There are some data to suggest that the fault may carry a component of dextral strike-slip displacement. There is a slight dextral inflection in the course of the stream across the fault and on the downthrown side of the fault, there are some shallow blind-headed channels (about the same depth as the present bed of the stream) containing springs suggesting long term dextral displacement across the fault (Figure 6).

Another indication of dextral displacement is that apparent vertical displacements increase with decreasing age of the offset horizon (Table 1). If the lateral displacement is right lateral (as is likely in the regional setting), older units (represented by the 4-5 and 5-6 contacts) would have a steeper dip to the SW than younger units. It is also likely that at least some of the units (eg Units 5 and 6) vary in thickness along and across the trend of the trench, further accounting for the increase in apparent displacement.

Rupture recurrence interval can be estimated from single event dip slip values, the height of the scarp and the age of the displaced horizons. An assumption must be made that the single event displacement recorded in the trench (c. 2.8 m of dip-slip, with vertical displacement to c. 2 m) is typical for the fault. If so, the c. 9 m displacement of the fan gravel surface suggests a rupture history of 4 or 5 events. Previous rupture must have occurred on fault strands upscarp from the trench, as the trench faults only record a single rupture. The age of the alluvial gravel surface providing the foundation for the displaced landform and overlying coverbeds is c. 80 ka, suggesting a recurrence interval of about 15-20 ka, and a slip rate of about 0.1 mm/yr, one or two orders of magnitude less than the major strike-slip faults in the Wellington region.

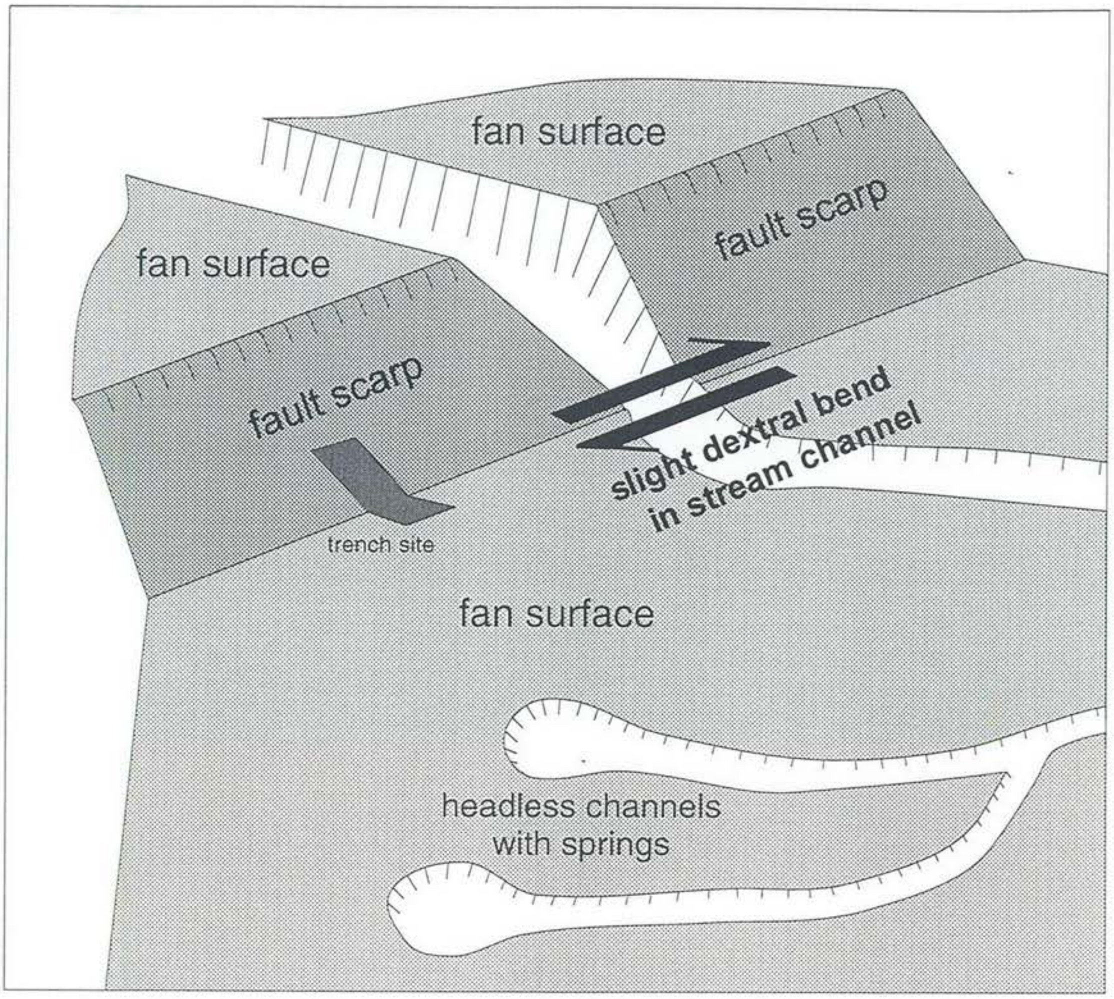

Figure 6: Sketch illustrating geomorphological features near the scarp that suggest the possibility of a strike-slip component for slip on Whitemans Valley Fault. The stream on the hanging wall is deeply incised into the upthrown and back-tilted sediments, and has clearly been confined to a single course for a significant period of time. There are fewer constraints on the position of the stream channel on the downthrown side of the fault, and the stream lies close to the old fan surface. Three (two shown here) small, unoccupied headless channels lie on the old fan surface and may represent old abandoned channels of the stream. Some doubt exists about this interpretation because the channel heads lie some 100 m east of the scarp and perhaps 75 m south of the piercing point of the stream across the scarp. The scale of the displacement exceeds expectations for this fault in the 80 ka available.

Table 1: Displacements of horizons within the Whitemans Valley trench.
Notes: (1) Accounts for displacement on the fault as well as drag/folding immediately adjacent to the fault (within 1 m).
(2) Horizons in the footwall are not in the same plane as horizons in the hanging wall because the trench was benched for safety reasons.

Displaced feature	**Apparent vertical displacement**			**Relative age**
	Preferred	Maximum	Minimum[1]	
				Oldest
4-5 contact	1.4 m	1.6 m	1.3 m	> 80 ka
5-6 contact[2]	1.5 m	1.8 m	1.4 m	c. 80 ka
6-7 contact[2]	1.9 m	2.0 m	1.7 m	c. 80-65 ka
7-8 contact[2]	1.9 m	2.0 m	1.7 m	c. 60 ka
8-9 contact[2]	2.0 m	2.4 m	1.9 m	c. 30 ka
9-10 contact	2.1 m	2.4 m	1.4 m	c. 24 ka
Kawakawa	2.0 m	2.4 m	1.5 m	22.6 ka
10-11 contact	2.0 m	2.5 m	1.6 m	c. 14 ka
top of 11	n/a	n/a	n/a	c. 10 ka
				Youngest

Seismic hazard and discussion

The Whitemans Valley Fault scarp can be mapped with certainty for a length of 8 km, but probably extends along a similar trend for up to 20 km (Begg and Mazengarb 1996). The fault dips beneath the hills on the western side of Whitemans Valley, and presumably occurs at depth beneath Wainuiomata, Taita and the Trentham-Heretaunga area.

Earthquake magnitude associated with single event surface rupture can be assessed by comparing the known physical characteristics of this fault with those of similar faults internationally and their known historical earthquakes (Wells and Coppersmith 1994).

The assumptions made here are that a characteristic rupture for this fault involves a net slip of 2.8 m, that the surface rupture length is 20 km and that earthquakes generated in a Whitemans Valley Fault earthquake are similar in magnitude to overseas historical fault rupture events with similar characteristics. If so, the Whitemans Valley Fault is considered capable of generating earthquakes in the range of c. M=7±0.3 (ie M=6.7-7.3). With a recurrence interval of 15-20 ka, the hazard represented by the fault is clearly much less than the major strike-slip faults in the Wellington region.

The relationship of the Whitemans Valley Fault to the Wellington Fault and their timing of rupture events is uncertain. Assuming the Wellington Fault is subvertical and/or exceeds the dip of the Whitemans Valley Fault the two faults may intersect at a depth. If the Wellington Fault is near vertical and the Whitemans Valley Fault dips consistently at 45° to the west, they would intersect at a depth of 5.5 km beneath the Taita Gorge. If this is the case, the fault is unlikely to be capable of producing a M=7 earthquake and a M=6.7 is considered more likely. Such an intersection may suggest transfer of stress between the two faults with rupture on Whitemans Valley Fault triggered by rupture on the Wellington Fault (eg Heaton 1982; Stein et al. 1994). Certainly, the size of the single event displacement on the Whitemans Valley Fault and the c. 80 ka age of the c. 8 m scarp height indicates that rupture does not happen with each Wellington Fault earthquake (c. 600 year recurrence interval; Van Dissen and Berryman 1996). There is very little evidence to suggest whether either assumption made here is right or wrong.

Land use in the vicinity of the Whitemans Valley Fault is mainly rural, with limited and low density population and development. The principal hazard is likely to be ground shaking in the Hutt Valley/Wellington area. The main contribution of this work to the seismic hazard of the Wellington region is recognition and initial quantification of the earthquake-generating potential of one of the second order faults of the area.

There are a significant number of faults in the Wellington area that can be included within the grouping of "second order faults". In the past they have been regarded as largely inactive (eg Stevens 1974). Two of them, Baring Head and the Evans Bay faults have been shown to be active (Ota et al. 1981; Lewis and Carter 1976; and Perrin pers. comm.). Seismic profiles show that the faults bounding the Somes Island horst and other faults in the east harbour area penetrate young sediments (Wood and Davey 1992) and may be active as well. This work shows that at least one more is still active and raises the possibility that others may be active. Other faults may have had traces that are now unrecognisable due to long recurrence intervals, scarp erosion and/or modification during development (eg the Terrace Fault and Lambton faults); some may be active but show no definitive Late Quaternary trace because their location has no Quaternary marker deposits. Figure 7 shows the locations of Wellington's principal faults and some second order faults that may be active.

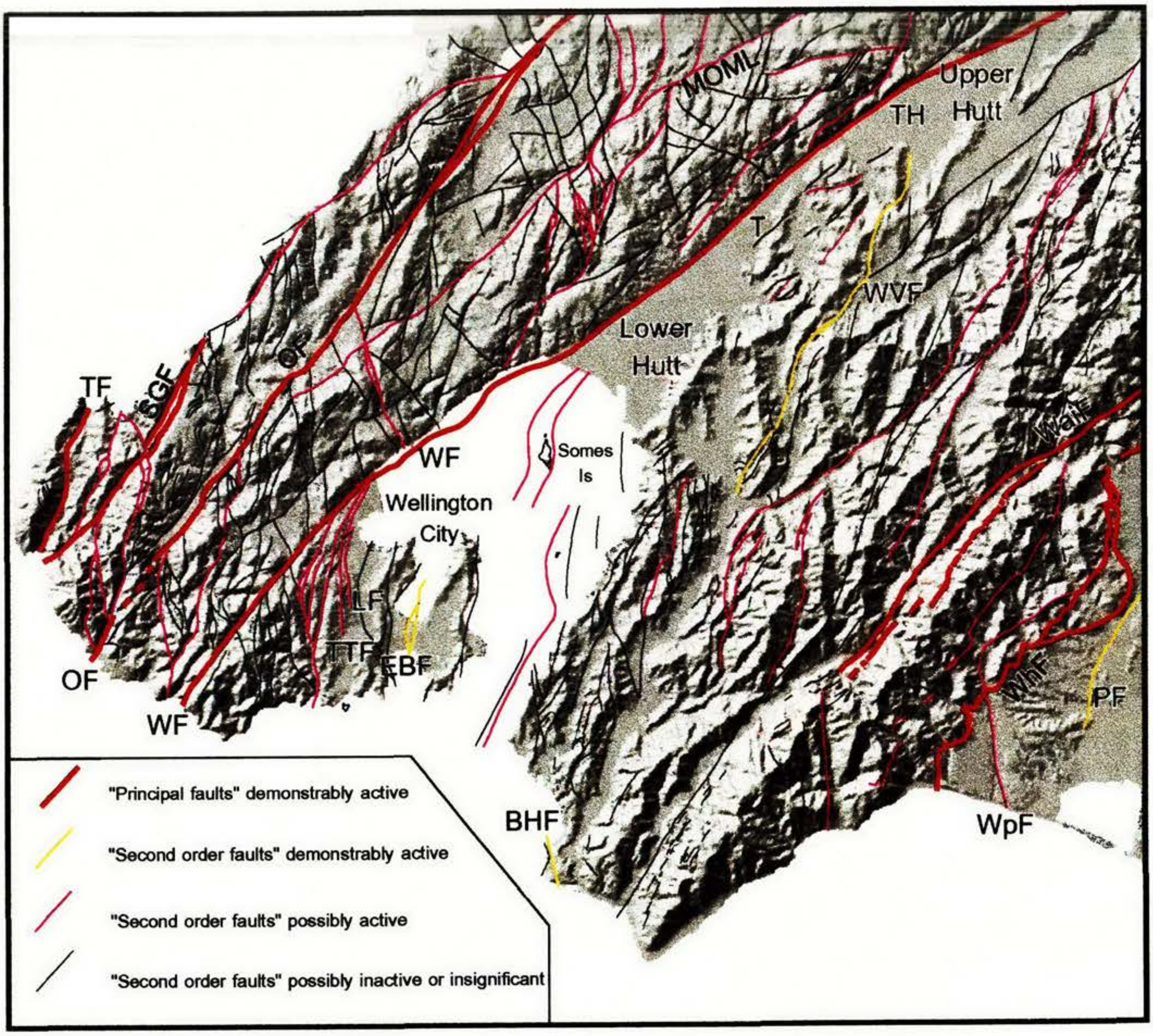

Figure 7: A representation of the second order faults in the greater Wellington area (after Begg and Mazengarb 1996). Here, these have been superimposed on a digital terrane model to indicate their impact on the landscape. Some of these faults can be shown to have limited displacement and/or mature morphology, suggesting they are minor features and/or are no longer active. Others clearly disrupt the landscape and significantly displace topography. In this diagram, faults in the region have been split into four categories on the basis of existing information, scarp morphology (as judged from air photo reconnaissance) and apparent displacement of late Cenozoic or Quaternary features and landscape dislocation:

a) Principal faults demonstrably active;
b) Second order faults demonstrably active;
c) Second order faults possibly active;
d) Second order faults possibly inactive or insignificant.

Some information is available on seismic hazard for types a) and b). Type c) faults present an additional hazard potential, while reconnaissance shows type d) faults are less likely to have an impact on seismic hazard. The subduction interface is also likely to contribute substantially to the regions seismic hazard, but quantification of these earthquakes presents a more difficult problem.

TF = Terawhiti Fault; SGF = Shepherds Gully Fault; OF = Ohariu Fault; MOML = Moonshine/ Otaki/ Mangaroa lineation; WF = Wellington Fault; TTF = The Terrace Fault; LF = Lambton Fault; EBF = Evans Bay Fault; BHF = Baring Head Fault; WVF = Whitemans Valley Fault; WaiF = Wairarapa Fault; WhF = Wharekauhau Fault; WpF = Wharepapa Fault; PF = Papatahi Fault; T = Taita; TH = Trentham-Heretaunga

The long return period deduced for the Whitemans Valley Fault suggests that seismic hazard related to any one of these faults is small compared with that of the principal strike-slip faults, but the hazard component may change significantly if the number of second order faults contributing to the overall hazard is great. If the number of active second order faults in the region (assuming each has a similar recurrence interval to the Whitemans Valley Fault) approaches ten, the attributable seismic hazard could represent a significant portion of the region's overall seismic hazard, although this would not be the case if they rupture in association with the "principal faults".

Conclusion

A linear geomorphic feature in Whitemans Valley recognised from aerial photographs and on the ground is an active, west-dipping fault trace with a reverse component and an unknown component of strike-slip displacement. It truncates late Quaternary sediments which provide a record of dip-slip displacement. The total scarp height is c. 8-9 m, and trenching of the lower part of the scarp revealed two fault planes dipping at c. 45° to the west, and that sediments ranging in age from c. 80 ka to c. 10 ka have been displaced by a single event with a dip-slip of c. 2.8 m that occurred prior to deposition of the topsoil. The last rupture occurred within the last c. 10 ka.

The scarp postdates development of the primary geomorphic feature, which is an alluvial gravel fan deposited from a small tributary stream issues from its steep-walled catchment onto an old, low-lying alluvial flat. Hand auguring at the top and bottom of the scarp indicates that the c. 2 m vertical displacement of the gravel fan surface recorded in the trench makes up only a part of the total displacement (c. 8-9 m). Assuming that the displacement seen in the trench is typical of that produced by rupture, 4-5 events are deduced to have occurred since the gravel fan was deposited. Coverbed stratigraphy indicates the age of the gravel fan is c. 80 ka (maximum 110 ka). The rupture recurrence interval for the fault is within the range 15-20 ka and the fault's vertical slip rate is c. 0.1 mm/year.

The Whitemans Valley Fault can be mapped from Witako Valley (SE Upper Hutt) through Whitemans Valley, Moores Valley and into Wainuiomata, a distance of c. 20 km. Regressions based on the magnitudes of historical earthquakes indicate that Whitemans Valley Fault rupture is probably accompanied by an earthquake of $M=7.0\pm0.3$.

While Whitemans Valley Fault poses a small contribution to the overall seismic hazard, the possibility exists that several other similar faults in the region are active, each contributing to the seismic hazard of the region.

Acknowledgments

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