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AN INVESTIGATION OF LATEST DISPLACEMENT EVENTS ON THE WELLINGTON FAULT IN THE LOWER HUTT AREA

Earthquake Commission
Research Project 93/128

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ABSTRACT

Five trenches were excavated across the Wellington Fault in Lower Hutt, in an attempt to refine the ages and magnitudes of last displacement events of the fault. Trenches 1a and 1b, near Belmont School, did not expose the fault trace, although fissures in silt horizons below 2 m depth suggested its proximity.

Trench 2, south of Melling Railway Station, exposed the fault trace, and provided a minimum age for the last event of 282-446 calendar years BP (cal BP). There is possible evidence for a previous movement at less than 643-783 cal BP. Sand dykes up to 40 mm wide and 1.5 m long propagated upwards from a sandy gravel unit through silt and fine sand beds, probably during the 1855 AD Wairarapa Fault displacement, and show that liquefaction is possible in this material.

Trench 3, across a 1.3 m high scarp beneath Normandale Bridge, exposed 2 subtle fault traces, but the only dateable material was older than 2000 years.

Trench 4, across a 2 m high scarp at Parliament Street, exposed disrupted clay lenses within a gravel deposit, and provided a maximum age for the last event of 293-427 cal BP. The disrupted lens and enclosing gravels were dated at 3152-3626 cal BP, suggesting that they had been uplifted along the fault scarp by subsequent fault events.

Trenches 5a-5c, at Laery Street, exposed a degraded fault scarp onlapped by historic (post-1840 AD) back-swamp and levee deposits. Material suitable for dating recent fault events was not exposed.

The two ages bracketing the last fault event in Lower Hutt (282-446 cal BP) are similar to previously published ages for the Wellington Fault displacement at Long Gully and Kaitoke (300-450 cal BP Van Dissen et al (1992)). Older material from Trench 2 (643-783 cal BP) coincides with Van Dissen et al.'s (1992) penultimate event of 670-830 cal BP. Material in Trench 4 dates a fault event at 3467-3626 cal BP, which coincides with Van Dissen et al.'s (1992) oldest dated event at 3380-3540 cal BP.

INTRODUCTION

The Wellington Fault is one of the more significant active faults in New Zealand, on account of both its length, and its location through the cities of Wellington, Lower Hutt and Upper Hutt. From its ill-defined termination in Cook Strait (Carter et al. 1988), it extends along or within the axial North Island ranges to the Bay of Plenty, a distance of some 450 km (Figure1). Recent mapping by C. Mazengarb (IGNS, pers. comm.) indicates that in the Upper Hutt - Kaitoke area, the fault has laterally offset the Late Jurassic Esk Head Melange by no more than 10-12 km.

Within the Wellington Region, the section of the Wellington Fault between Cook Strait and the southern Tararua Range is regarded as a single segment, the 75 km Wellington-Hutt Valley Segment of Berryman (1990). The single segment model was interpreted from the fault geometry, and corroborated by similar dates of last displacements at Long Gully and Kaitoke (van Dissen et al. 1992). Earlier workers (for example, Cotton 1960; Grant-Taylor et al. 1974) suggested 3 or more segments, based on geomorphologic evidence.

Van Dissen et al. made only brief mention of the interval of the fault within the lower Hutt valley (Figure1), where a scarp up to 3 m high is preserved over 2.8 km. This scarp was first recognised by Grant-Taylor (1967), and further documented by Stevens (1974) and Ota et al. (1981). Beanland (1988) identified the fault at Richmond Street, Petone from two trenches and associated seismic and ground radar surveys. Stirling (1992) inferred 20 m lateral displacement of a <4000 yr BP beach ridge across the fault in the Petone area.

Van Dissen et al. (1992) considered that the most recent rupture occurred 300-450 calendar years BP (cal BP), with a previous event at 670-830 cal BP. They judged the average recurrence interval for the last 140 000 years to be 420-780 years. These results show that the present time is within the envelope for the next fault rupture, but the wide error limits on the ages significantly limit the predictive ability of the results.

The aims of the present study were to refine the ages and magnitudes of last displacement events of the Wellington Fault by trenching in a hitherto little-studied part of the fault. Given the high density of commercial and residential buildings on or close to the fault scarp, a further aim was to examine how the sediments, in particular gravels, had responded to strong earthquake shaking, and to predict how they might behave in future events.

Study Method

We identified a number of potential trench sites (Figure1) in vacant properties either across the fault scarp, or where the fault was inferred to reach the surface. Five trenches (1a, 1b, 3, 4 and 5) were excavated by Eric Dodds Contractors Ltd using a Hitachi EX 120 backhoe, in September 1994. The walls of the trenches were logged and photographed, and samples of organic material were collected for age determinations. Logging and site restoration were completed on the day of excavation. The ground surfaces at trench sites 3, 4 and 5 were levelled using a Dumpy Level and tape. Logs and samples from an earlier investigation at 92 Pharazyn Street (trench 2) were also incorporated in this study.

Radiocarbon dating of selected samples (Table 1) was undertaken by the Nuclear Sciences Group, Institute of Geological and Nuclear Sciences Ltd. Detailed documentation supplied by IGNS is presented in the Appendix.

Interpretation of the geomorphology of the study area was aided by the earliest air photographs available, flown in February 1941 (SN 163 runs 180-181, at 1:16090 scale). These predated the extensive stopbank construction and gravel extraction that subsequently modified the course of the Hutt River. Detailed topographic data were obtained from 1:500 scale aerial plan series 1634 "Petone - Melling Motorway" and 2142 "Melling - K.G. Bridge - Haywards", produced by the Department of Survey and Land Information.

TABLE 1. SUMMARY OF RADIOCARBON SAMPLES.

Location	Lab number	Sample	Radiocarbon age (yr BP)	Calibrated age (cal BP)	δ13C ‰	Sample material
Belmont School	NZ 8275	1A	1384 ± 43	1237-1296	-28.6	wood
92 Pharazyn St	NZ 8276	2A	810 ± 91	643-783	-29.1	humics
92 Pharazyn St	NZA4628	2C	329 ± 63	282-446	-25.75	charcoal
Normandale Br	NZ 8277	3A	2264 ± 47	2150-2312	-25.8	wood
12 Parliament	NZ 8278	4A	334 ± 32	293-427	-27.9	wood
12 Parliament	NZ 8279	4F	3364 ± 73	3467-3626	-26.0	wood
12 Parliament	NZ 8280	4G	3080 ± 67	3152-3341	-24.0	wood
2 Laery St	NZ 8281	5A	1169 ± 42	978-1061	-25.7	wood

GEOMORPHOLOGY

The lower Hutt valley is an asymmetric fault-angle depression formed by transpression on the Wellington Fault. The northwest side of the valley is characterised by a steep line of bluffs broken only by deeply incised streams draining relatively small catchments. The southeast side of the valley comprises relatively gently sloping spurs and wide valleys filled with alluvium (Stevens 1957).

At present, the Hutt River maintains a slightly sinuous course within 200 m of the northwest side of the valley. In the lower 3 km of the valley, the river is forced across the valley by a series of beach ridges (Stevens 1973, Stirling 1992) to the southeast side of the valley before entering Wellington Harbour. Reconstructions of the valley prior to 1855 (Stevens 1973 figure 16A) show the river occupying a much broader and more sinuous meander-belt up to 1 km wide (Figure 1). After the Wairarapa Fault event of 1855, and prior to extensive gravel extraction and stopbank construction, the river occupied a floodplain up to 300 m wide, of gravel and sand bars. Thus the valley asymmetry is not just due to the Wellington Fault, but also to regional tilting caused by Wairarapa Fault displacement (Stirling 1992).

As the river runs close to the northwest edge of the valley, preservation of older sedimentary deposits on that side of the valley is extremely limited. From the Taita Gorge southwards, a 3 km interval of terraces on the northwest side of the valley is up to 500 m wide. Trench exposures and drillhole data seen by the authors in this area revealed coarse gravel-dominated deposits, interpreted as Hutt river floodplain deposits, interspersed with angular gravel-clay debris flows from steep, adjacent gullies. In the Belmont area, terraces up to 250 m wide flank either side of the confluence of Speedy's Stream, one of the larger northwest tributaries. A small terrace remnant occurs at the former shingle plant site, and then from Melling southwestwards, wide areas of older sediment are preserved as the river changes course southward.

No surface traces of the fault (in the Lower Hutt area) have been found north of central Pharazyn Street, presumably because of erosion and/or deposition by the Hutt River since the last displacement.

RESULTS

Trenches 1a and 1b

These trenches were excavated in a triangular shaped parcel of land owned by Mr R MacGaffin, immediately south of Belmont School (Figure 2; R27/716998). There was no geomorphic expression of a fault scarp in this area, but extrapolation from the Pharazyn Street area further south suggested that the fault trace is between 80 to 150 m out from the foot of the hills, and therefore could pass through the property. The 1941 air photos show that the site is on a terrace surface traversed by Speedy's Stream, a tributary of the Hutt River that exits from a gorge 250 m upvalley of the site. The Hutt River floodplain, in 1941, cut across the southeastern half of the property, and the margin of this corresponds to a 0.5-1.5 m high terrace riser visible today.

Trench 1a

Trench 1a was excavated southeastwards from the northwest boundary. The trench was 39 m long and up to 4.5 m deep (Figure 3), interrupted at 17-22 m by a shallow section across a 1 m diameter sewer pipe. Progress beyond 39 m was curtailed by very loose gravel of the recent channel deposits.

As the sewer was thought to conceal a possible fault intercept, a second parallel trench was excavated 40 m southwest of Trench 1a. Trench 1b (Figure 4) progressed for 11 m before loose running gravel prevented further excavation to the southeast. A side trench 6 m long was then dug to test a possible disturbance.

Stratigraphy: Both trenches revealed a series of lenticular gravel-filled channels within a dominantly silt-clay sediment. The gravels were reddish brown or brownish grey (bluish grey where unoxidised), crudely bedded to massive pebble-cobble gravels with variable silt and/or sand matrix, ranging from loose, permeable units with negligible sand matrix, to tightly packed, clast-supported gravel with appreciable silt-clay matrix. Less common units of coarse sandy pebbly gravel exhibited well-defined foreset bedding.

In addition to the above sandy gravels, a few fine to coarse sand units occurred. The northwest 14 m of Trench 1a were blanketed by a fine sand horizon, interpreted as a crevasse splay or channel-abandonment facies.

Dimensions of the sand and gravel lenses were 0.2-0.8 m thick and from 3.5 m laterally. The base of the trench followed a single gravel unit at least 17 m wide. Many of the gravel lenses in the trenches may have been deposited by channels of Speedy's Stream.

At the southeast end of both trenches, the mixed silt-gravel sedimentation was replaced by a full trench depth of loose, uniformly coarse gravel horizons. The margins of this correspond to the surface terrace riser which marked the historic Hutt River channel edge. The same facies is exposed over several metres thickness in the former gravel plant site 800-900 m to the south. Silt-clay units within the sequence were typically light brown, (greyish blue below the oxidation horizon) and massive, with variable mottling. Some unoxidised horizons were rich in fine vertical stems interpreted as rush vegetation. Rare wood remains, as roots and branches or logs, occurred below the oxidation horizon, but the few examples above the oxidation horizon were highly decomposed. Some silt intervals had a loose, earthy texture, and it is not known if this was due to original depositional state, or to soil processes. At least one silt unit was a channel-plug deposit with rounded base and steep margins.

In both trenches, vertical fissuring occurred in silt horizons below 2 m depth; the strongly iron-stained fissures were up to 0.3 m long and variously striking 120-150° (normal to the fault trend) or 235° (parallel to the fault trend).

Evidence of faulting: In Trench 1a, the 5 m interval left to support the sewer pipe at 17-22 m concealed an apparently abrupt change in depth to the lowest exposed gravel horizon. On the northwest side of the interval, the top of the gravel was consistently at 3.3 m depth, but on the southeast side, it was at 4.3 m. Fissuring in the firm silt above the gravel was limited to 3-10 m southeast of the concealed interval. A wood root in the top of the silt (NZ 8275) was dated at 1237-1296 cal BP, so that the silt horizon should have experienced at least two Wellington Fault events, based on the interpretation of Van Dissen et al. (1992).

Trench 1b was located 40 m southwest of Trench 1a, in an attempt to intercept the fault while avoiding the sewer. A zone of steeply dipping beds and apparently disrupted sandy gravel lenses at 5.5 m (Figure 4) suggested a fault intercept, but the side trench which opened this up along trend did not expose consistently disrupted horizons. As in Trench 1a, vertical fissures occurred below 3 m depth, striking 130°. At the southeast end, the sides of a silt channel-plug may have been over-steepened by fault-induced liquefaction.

The sediments in Trench 1b showed abrupt and complex lateral changes, but it is unclear whether this complexity is typical of the silt-gravel association, or whether it reflects channelisation along surface fissures. No convincing evidence for a buried fault-scarp was found in either trench.

In summary, neither Trench 1a nor 1b provided clear evidence of the Wellington Fault trace. It is possible that the fault was obscured in Trench 1a by the sewer pipe, and on a trend of 055°, the fault may have passed immediately southeast of Trench 1b.

Trench 2

Trench 2 was excavated in January 1993 at 92 Pharazyn Street (Figure 5; R27/696984), the property of Crosshills Development Ltd. There was no geomorphic expression of a fault scarp in the vicinity, but extrapolation from the scarp further southwest on Pharazyn Street indicated the fault could cross the property. The trench was commenced at the southeast corner of the property and extended 44 m westwards as far as the old house on the property. The trench depth was generally 2.0 m, extended in places to 2.9 m.

Stratigraphy: The oldest sediment (Unit 1 in Figure 6a, 6b), exposed only in the western half of the trench, consisted of thinly interbedded, grey gravel and bluish grey sand. The gravel comprised unweathered, well rounded sandstone pebbles and cobbles with minor coarse sand-granule matrix. Iron-staining was locally intense at the water-table near the base of the trench. Sand beds comprised moderately sorted medium-coarse sand with granule-pebble laminae and rare wood fragments.

This was sharply overlain by Unit 2 clay-silt, which formed the basal unit (up to 1.2 m exposed) in the eastern half of the trench. The lower part of the unit consisted of light purplish grey clay-silt with iron-oxide mottling around fossil root channels. In the eastern half of the trench, the upper 0.3-0.8 m was weathered, with weak soil development shown by an incipient nutty texture and slight fissuring. Sand-filled root channels were common.

Unit 2 was irregularly overlain by Unit 3, comprising brownish grey, fine-coarse sand up to 1.6 m thick. The contact between the two units was typically indistinct, with cm-scale irregularity, and may have been modified by liquefaction. In other respects, the irregular basal contact of Unit 3 and overlying cross-bedding suggested a scoured surface overlain by crevasse-splay or channel sediments. Unit 3 was in turn overlain by topsoil or pit infillings.

Evidence of faulting: The interface between the Units 1 and 2 was a steeply dipping (down to the SE) contact, with deformed coarse sand bedding and irregular clasts of carbonaceous coarse sand. The orientation of the sand laminae and elongate clasts does not support a channel-margin slump feature, but does support a fault displacement.

Humic debris in the coarse sand clasts gave an age of 643-783 cal BP (NZ 8276). These clasts were incorporated within the disturbed zone, and are inferred to have originally been a continuous horizon, forming in a poorly drained area. We postulate that it formed in a depression adjacent to a low scarplet. Humic material is generally regarded as unreliable for dating, because it is readily mobilised by groundwater (W H Melhuish, IGNS, pers.comm.). This date coincides with Van Dissen et al.'s (1992) penultimate fault event of 670-830 cal BP, and may provide a minimum age for that event.

Following deposition of the carbonaceous horizon, clay-silt levee/floodplain sediments were deposited, with subaerial weathering and plant colonisation. The latest Wellington Fault rupture disrupted the sand and clay-silt sediments, though it seems unlikely that any vertical offset took place at this site. Subsequently, perhaps soon after the event, the site was blanketed by Unit 3 sand as one or more crevasse splays. Charcoal fragments near the base of Unit 3, 16 m southeast of the faulted zone, date the unit as younger than 282-446 cal BP (NZA 4628, by accelerated mass spectrometry). This provides a minimum age of the last fault displacement, and coincides with Van Dissen et al.'s (1992) date of 300-450 cal BP; unfortunately it does not reduce the error limit on the event.

Eight metres northwest of the fault zone, a number of sand dykes up to 40 mm wide have propagated from Unit 1 sandy gravel through Unit 2 silt and into Unit 3, up to 1.5 m above the top of the gravel. Material within the dykes ranges from fine sand up to 10 mm diameter pebbles. These unusual features indicate that liquefaction can occur in a gravel horizon with high sand content. This extrusion took place after the last Wellington Fault event and probably during the 1855 AD Wairarapa Fault rupture.

Trench 3

Trench 3 was excavated on the Hutt City Council property beneath the Normandale Bridge off Pharazyn Street, adjacent to the water pumping station (Figure 7; R27/688979). In this area, a semi-circular alluvial fan of about 100 m radius is centred on a small valley draining the Normandale hill country. A step up to 1.3 m high oriented SW-NE across the fan surface is considered to be the degraded scarp of the Wellington Fault.

Trenching commenced 31.8 m from the edge of Pharazyn Street, and proceeded along the southwest boundary of the property, initially for 19.0 m. Some days later, after the first trench had been filled in, an extension was excavated a further 14 m. The trench depth varied between 3.0 and 4.1 m (Figure 8).

Stratigraphy: The oldest sediment exposed (Unit 1) was a bed of dark bluish grey sandy pebble-cobble gravel, horizontal-bedded, with tightly packed, subangular to well rounded, slightly weathered sandstone clasts. Towards the northwest end of the trench, this was conformably overlain by 1.0 m of uniformly bedded, grey silt, clay and fine sand beds. This is interpreted as a floodplain (channel/barform) deposit, probably of the Hutt River, overlain by levee sediments.

Unit 2 was a greyish blue gravelly silt-clay bed 0.4-0.6 m thick, with distinctive clasts of highly weathered green sandstone and slightly weathered black argillite matrix-supported by a firm, plastic silt-clay. The combination of the two clast types, with very few other clasts, contrasted with the moderately weathered sandstone clasts which predominated in other gravel beds. We considered the possibility that this represents a fault pug material injected from some depth below, but the mobilisation of such material through sediments with much lower shear strength seems unlikely. An identical material was encountered in close proximity to the fault in Trench 4, 160 m away, suggesting that it represents a widespread debris flow. The highly weathered clasts may have been derived from a terrace of ancient gravels on the hillside.

Unit 3 was a bluish grey or strongly iron-stained sandy pebble gravel bed similar to Unit 1, present only in the southeast part of the trench.

Unit 4 comprised laterally continuous, 0.2-0.4 m thick horizons of grey to brown silty gravel to gravelly silt beds, variably clast or matrix supported, with clasts of subrounded to angular, pebble to cobble sized sandstone and argillite. Laterally persistent thin grey silt beds formed valuable marker horizons along much of the trench. Discontinuous, iron-stained, vertical fissures in these horizons were oriented at 090-105°. Age control was provided by a tree root at the top of a silt bed at 2.6 m depth, which yielded an age of 2150-2312 cal BP. This unit is interpreted as a series of debris flow deposits on the flanks of the alluvial fan at the foot of the Normandale gully, a small but steep catchment.

Unit 5 comprised variably packed, greyish brown pebble-cobble gravels which overlay a steep scoured surface on Unit 1 sediments at the northwest end of the trench. It is interpreted as a south-trending channel-fill deposit, but the relation to Units 3 and 4 is unclear.

Unit 6, the youngest sedimentary unit, comprised loosely packed, brownish grey sandy gravels and light brown fine sand beds. Gravel clasts were well rounded, moderately weathered sandstone granules to pebbles with rare cobbles. Towards the northwest end of the trench, a 12 cm thick, iron-stained silt bed formed a persistent marker horizon. The unit was overlain by sandy loam soil, some fill material and concrete foundation structures.

Evidence of faulting: Two subtle and discontinuous dislocations occurred at 9.5-10.4 m and 11.5-12.5 m, respectively 3 and 5 m northwest of the midpoint of the apparent scarp. Both dislocations dipped 60-70° northwest, but the 9.5 m feature was apparently downthrown 0.6 m to the southeast, whereas the 11.5 m feature was downthrown 0.3 m to the northwest.

The 9.5 m feature was identified by offset of the Unit 1 cobble gravel bed against Unit 2 gravelly silt-clay at 3.5-4.1 m depth, and a tilted granule-pebble gravel lens within Unit 4 at 2.5 m depth. Unit 5 gravels at 1.8 m truncated the feature with no apparent offset.

The 11.5 m feature was identified by offset of Unit 1 sandy gravel against Unit 2 sandy silt at 3.7-4.1 m depth, with a 0.1 m thick silt horizon disrupted along the fault plane. At 2.7-2.9 m depth, a 0.2 m thick silty sand bed within Unit 4 was warped downwards across the fault plane. At 1.7 m depth, a loosely packed gravel bed was juxtaposed against a tightly packed sandy gravel, indicating 0.2 m displacement. This was overlain at 1.3 m by a Unit 5 sand bed which crossed the feature with no apparent disturbance.

The sand and gravel beds of Unit 6 form a series of low-angle foresets prograding across a degraded scarp (Figure 8). As a scarp is still present, it is likely that further displacements have taken place since Unit 6 deposition. The scarp is, however, more degraded than in a second alluvial fan in the pensioner flats area to the northeast, and the intervening interfan area, perhaps due to property development and bridge construction.

Drillholes along the Normandale Bridge alignment demonstrate the deeper subsurface stratigraphy of this area (Figure 9; after M. W. Stirling, unpublished). Within the Taita Alluvium on the northwest side of the fault, debris flow units can be identified overlying fluvial gravels; on the southeast side of the fault, peaty sediments and sands appear to replace the debris flows, and correlation across the fault is difficult, if not impossible. At depth, the top and base of the Petone Marine Beds are vertically offset 2 and 6 m respectively, while the difference in thickness across the fault suggests several metres lateral displacement.

Trench 4

Trench 4 was excavated at 12 Parliament Street, the property of Mr N. Ravji (Figure 10; R27/687978). There was a clear geomorphic expression of a 1.0-1.5 m high scarp at the southeast end of the property. Trenching commenced at the southeast boundary, and progressed 11 m at up to 2.9 m depth (Figure 11).

Stratigraphy: Beneath the ground surface, highly variable thicknesses of fill to 1.3 m depth included reworked soil, field drain cobbles and brick fragments. Below this, a brown clay to gravelly clay unit pinched out to the northwest, locally underlain by the gravelly clay-silt with distinctive clasts (described as Unit 2 in Trench 3). Most of the excavated succession comprised greenish grey (greyish brown where oxidised), coarse sandy pebbly gravel composed of subangular to subrounded sandstone clasts.

Evidence of faulting: A subvertical funnel-shaped clay deposit within the gravel sequence was encountered in the first metre of the excavation, bound by loose, faintly vertical-laminated sandy gravel. After the trench was widened to 3 m, two elongate clay wedges were traced across the floor, oriented 065°. The larger wedge exhibited subvertical banding, variously olive sand, medium brown clay, light blue clay, light greenish grey gravelly clay and brown clayey gravel over 90 cm width. These deposits are interpreted as infillings of large fissures which opened during a fault event.

Samples for radiocarbon dating were taken from wood fragments within the larger clay fissure-fill (NZ 8279), and from the gravel adjacent to the fissure-fill (NZ 8280). These yielded ages of 3467-3626 and 3152-3341 cal BP respectively. The age of the materials, considering their position at the scarp and closeness to the surface, is considerably older than expected, and it is surprising that the gravel sample was younger than the clay sample. The ages do, however, correlate with a fault event dated in a Long Gully trench at 3380-3540 cal BP (Van Dissen et al. 1992).

The clay deposits were unconformably overlain by an original soil material containing a tree-fern log. This is considered to have fallen from a growth position on the face of the scarp. Radiocarbon dating of a sample of this log, NZ 8278, yielded an age of 293-427 cal BP. This age is very similar to Van Dissen et al.'s (1992) last fault event of 300-450 cal BP; it is possible that the tree-fern fell at the time of the earthquake.

It is possible that more recent displacements on the fault in this area occurred a short distance downslope, and that the sediments exposed in the trench were uplifted and exhumed. The position of the trench against the boundary of a developed property did not allow us to explore this possibility.

Trenches 5a, 5b and 5c

These trenches were excavated in close proximity in the grounds of Dux Engineers Ltd, at 2 Laery Street and the adjoining vacant lot on the corner of Parliament and Laery Streets (Figure 12; R27/ 686977). A degraded fault scarp is traceable on both sides of this property, but is obscured by buildings and wall construction on the property itself. Trenching through the area was constrained by a stormwater drain aligned parallel to the projected fault trace, and by the high water table at the foot of the scarp area. A concrete driveway and wall were partially removed to facilitate trench access; a number of separate trenches was required due to interruption by heavy rain-falls.

Two composite sections are presented (Figure 13a), as shown on the plan view (Figure 13b).

Stratigraphy: The oldest materials exposed were granule-pebble gravels in 10-60 cm beds distinguished by variable matrix and packing (Unit 1 in Figure 13a). At the NW end of the trench, this unit extended up to RL 6.3 m. Bark at RL 0.9 m (NZ 8281) yielded a radiocarbon date of 978-1061 cal BP. The difference in levels of the top of gravels at either end of the trenched area indicates that vertical displacement has taken place within the area.

Unit 1 was sharply overlain by Unit 2, comprising up to 0.65 m of yellowish brown silt with abundant wood fragments, including horizontal logs up to 300 mm diameter. At least two logs had been clearly cut by axe, and these, together with a piece of pottery, dated the unit as post-1840 (European settlement). The silt was overlain by 0.25 m of interbedded soft clay, fine sand and peaty silt with rootlets at the top.

Unit 3 conformably overlay Unit 2, but overlapped onto Unit 1 in Trench 5c. It consisted of greyish green, medium dense, fine sand with abundant root and plant fragments. At 9.4 m along Trench 5c, a light greyish green silt-gravel deposit, probably a channel-plug, abutted Unit 1 gravel with a steep, abrupt contact. The material was highly variable, grading from clast-supported silty gravel to gravelly silt, laterally grading to Unit 3 fine sand.

Overlying materials were considered to be man-emplaced fills. Unit 4, a tongue of brownish grey granule-pebble gravel overlying Unit 3, was considered reworked Unit 1 gravel. Unit 5 comprised basal pebble gravel grading up to brown matrix-supported gravelly silt with pottery shards. Unit 6 comprised yellowish brown, poorly sorted medium sand, and Unit 7 was undifferentiated topsoil and gravelly fill.

Evidence of faulting: Correlation of the fault scarps crossing Railway Avenue to the southwest, and the Trench 4 site to the northeast, suggested that the fault lay in the Trench 5a-5b area. The difference in elevation of Unit 1 and Unit 2 top surfaces between the two trenches is approximately 1.0 m (over 7.5 m distance), and indicates that Unit 2 (post 1840 AD) is significantly higher in Trench 5b than in Trench 5a. The difference in elevation of Unit 1 can be explained by erosion and/or fault displacement; the difference in Unit 2 is not easy to explain and may relate to lateral facies changes.

In both Trench 5a and the southeast end of 5c, extensive groundwater inflows occurred during excavation, and these suggest relatively high-permeability zones within fault-disrupted gravel. Apart from the dip in the top surface of Unit 1 gravel in Trench 5c, there is no evidence of displacement.

The trenches reveal a degraded fault scarp which has been onlapped by back-swamp (Unit 2) and levee (Unit 3) deposits. The step at the northwest end of Trench 5c is considered to mark the edge of a gravel borrow pit. The area was subsequently used as a spoil dump, and a platform of fill was built out over the natural sediments. Finally, a concrete wall was built, and a concrete pad laid down 2 m below ground level.

CONCLUSIONS

The trenching work in Lower Hutt has not provided any new information on the amount of displacement during a Wellington Fault rupture event. It has confirmed the complexity of deformation when fault rupture extends through young alluvial materials. It has also confirmed our location of the Wellington Fault from surface mapping.

Data from two trenches confirm the Van Dissen et al (1992) age of 300-450 cal BP for the most recent fault rupture, but can not narrow down the wide error limits of this date. A single date from trench 2 possibly supports the Van Dissen et al age for the penultimate fault rupture of 670-830 cal BP. Two dates from Trench 4 support a fault rupture identified by Van Dissen et al at 3380-3540 cal BP.

The apparent synchroneity of fault events in Lower Hutt with Van Dissen et al's data from Long Gully and Kaitoke tends to support the model of a single fault segment between Cook Strait and Kaitoke. However, in all cases, the error limits of 150-160 years are so wide that they do not contradict alternative concepts. For example, the fault may be subdivided into smaller segments, and a rupture on one may have triggered rupture on others. The long interval between fault events at c. 700 cal BP and c. 3500 cal BP is attributed to the incompleteness of the geologic record, but it is also possible that there was a long period without seismic activity on the fault.

Sediments exposed along the fault trace showed a wide variation of age and texture. Dominant lithologies were pebble gravels and clayey silts, interbedded or intermixed.

Evidence of liquefaction was limited to Trench 2 in which a number of sand dykes propagated upwards from a sandy gravel bed. The assessment of liquefaction in these materials is very difficult using conventional approaches to liquefaction investigation and analysis. It is likely that similar materials underlie much of the Hutt City commercial area, with the possibility of widespread liquefaction during strong shaking.

RECOMMENDATIONS

Gathering information on the nature of the Wellington Fault in the Hutt City area is made difficult by the limited access to suitable trench sites. Sites do become available from time to time due to development activities, and it is important that funding is available to carry out small short-term projects to examine and sample trench exposures on temporarily vacant land. However there is no agency that would clearly be responsible (and hence fund) such work, although research that enables a better estimate of seismic hazard has benefits to a wide community.

It is also important that fault displacement data be made publicly available so that they can be used for ongoing seismic hazard studies. At present there is no organisation that has the role of collecting these data and making them freely available. In this report we have been able to present some important data gathered during investigations carried out for a property developer, which until now was only available in an unpublished report.

In a similar way, data related to liquifaction should be made freely available. Given the difficulty of assessing liquifaction potential of gravels, documentation of past liquefaction based on logs from trenches and foundation excavations can provide valuable insights into the distribution of liquefiable soils in the Hutt Valley.

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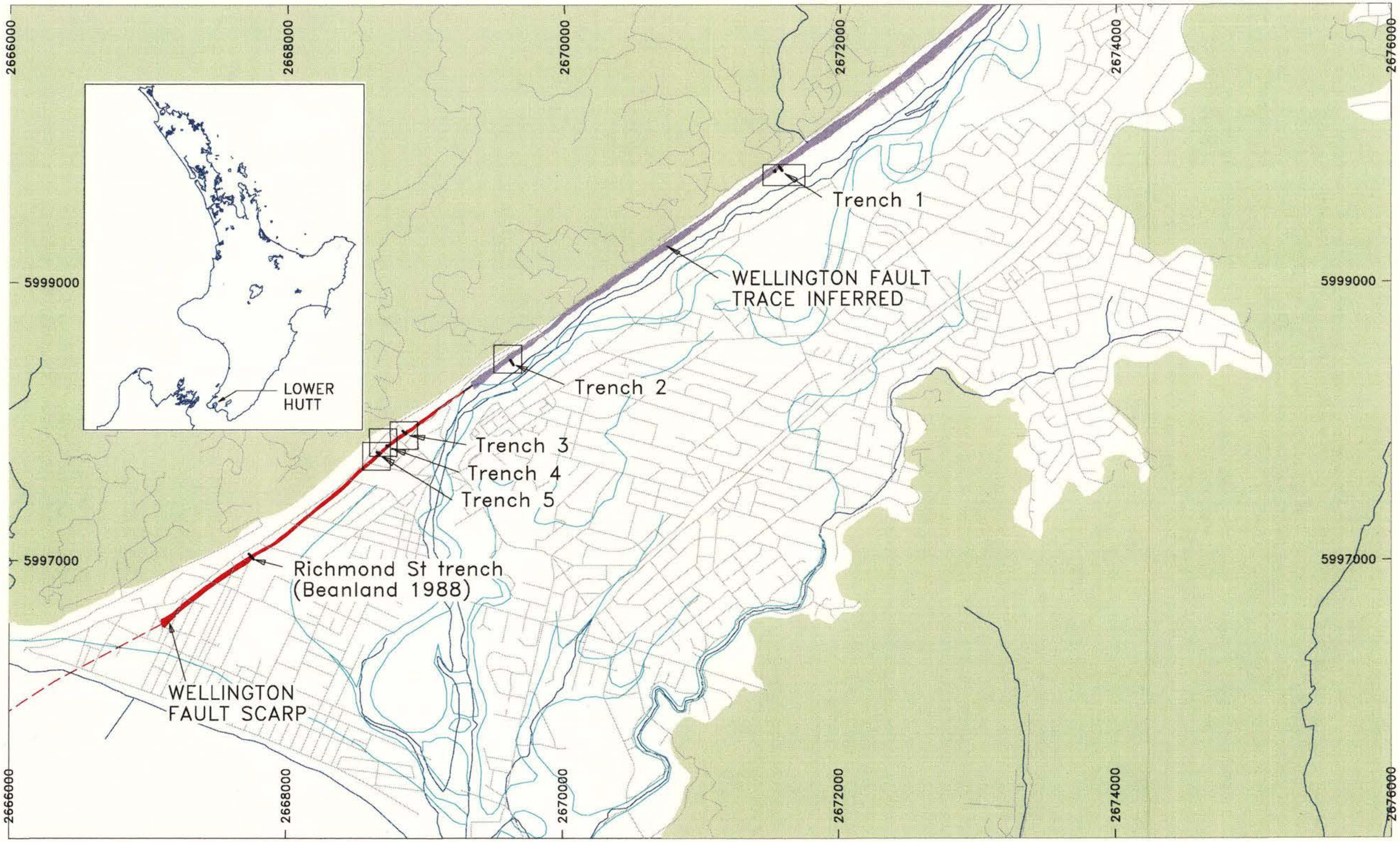
FIGURES



GRAPHIC SCALE 0 0.5 1.0 1.5 km

EXPLANATION

- Roads
- Rivers
- Rivers before 1855 earthquake (from Stevens 1973 fig.16A)
- Basement
- Outline of detailed 1:1000 scale plan
- Wellington Fault identified by scarp trace
- Wellington Fault position poorly constrained (IRBA 1991)

ORIGINAL SCALE 1:30000

GRID: NZ Map Grid

DWG NO: 359_25

Ian R Brown Associates Ltd
Geological Engineering Consultants

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Tel (04) 3858603 Fax (04) 3843306

EARTHQUAKE COMMISSION

WELLINGTON FAULT RESEARCH STUDY

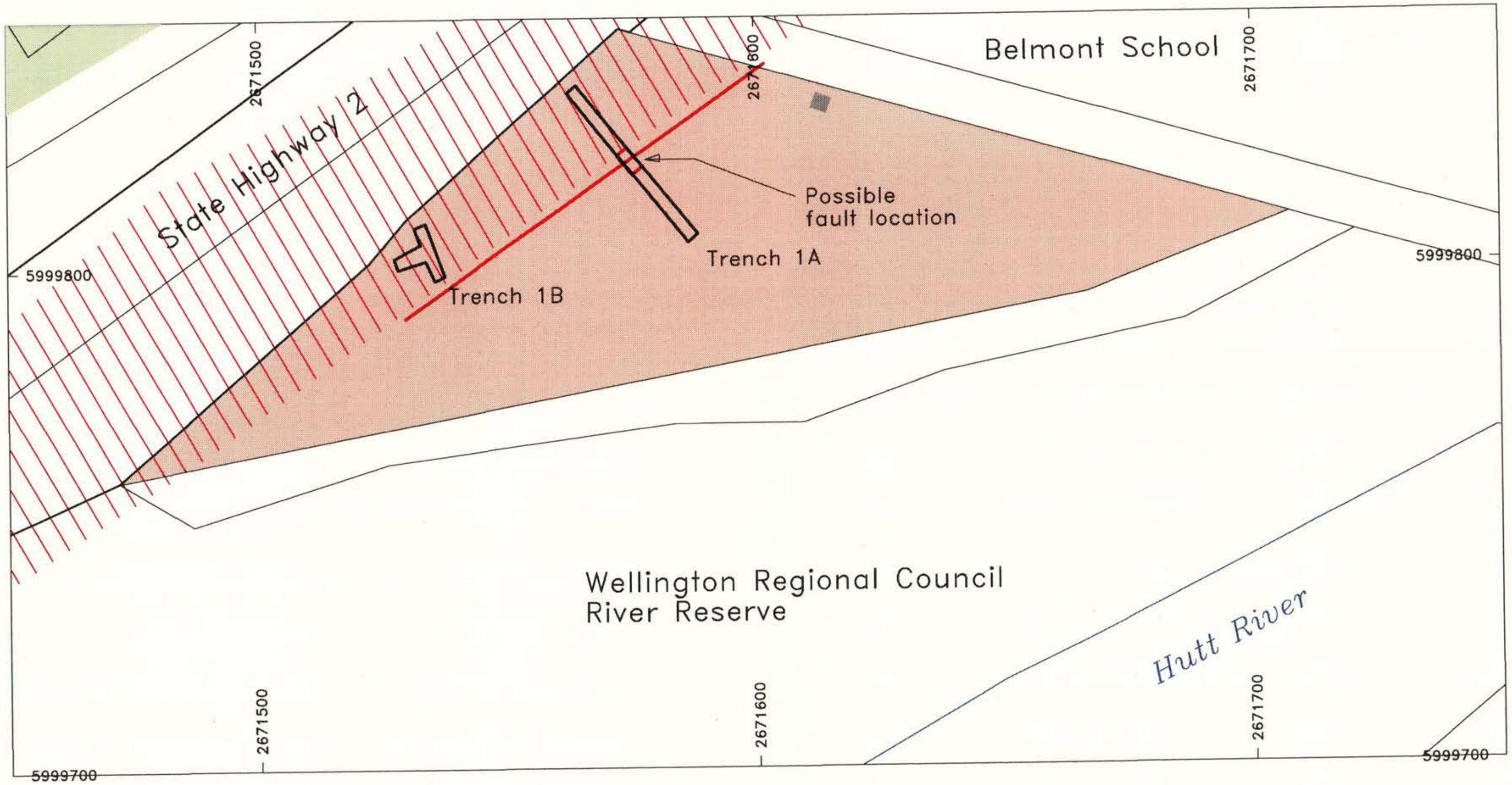
Location of Wellington Fault, Lower Hutt

FIGURE 1

Drawn W Leask

Approved

Date 18-4-1995



GRAPHIC SCALE 0 10 20 30 40 50 m

EXPLANATION

McGaffin property
Buildings
Basement
Wellington Fault zone estimated prior to trenching (IRBA 1991)
Alluvial fan
Trenches 1A,1B

ORIGINAL SCALE 1:1000
GRID: NZ Map Grid
DWG NO: 359_8

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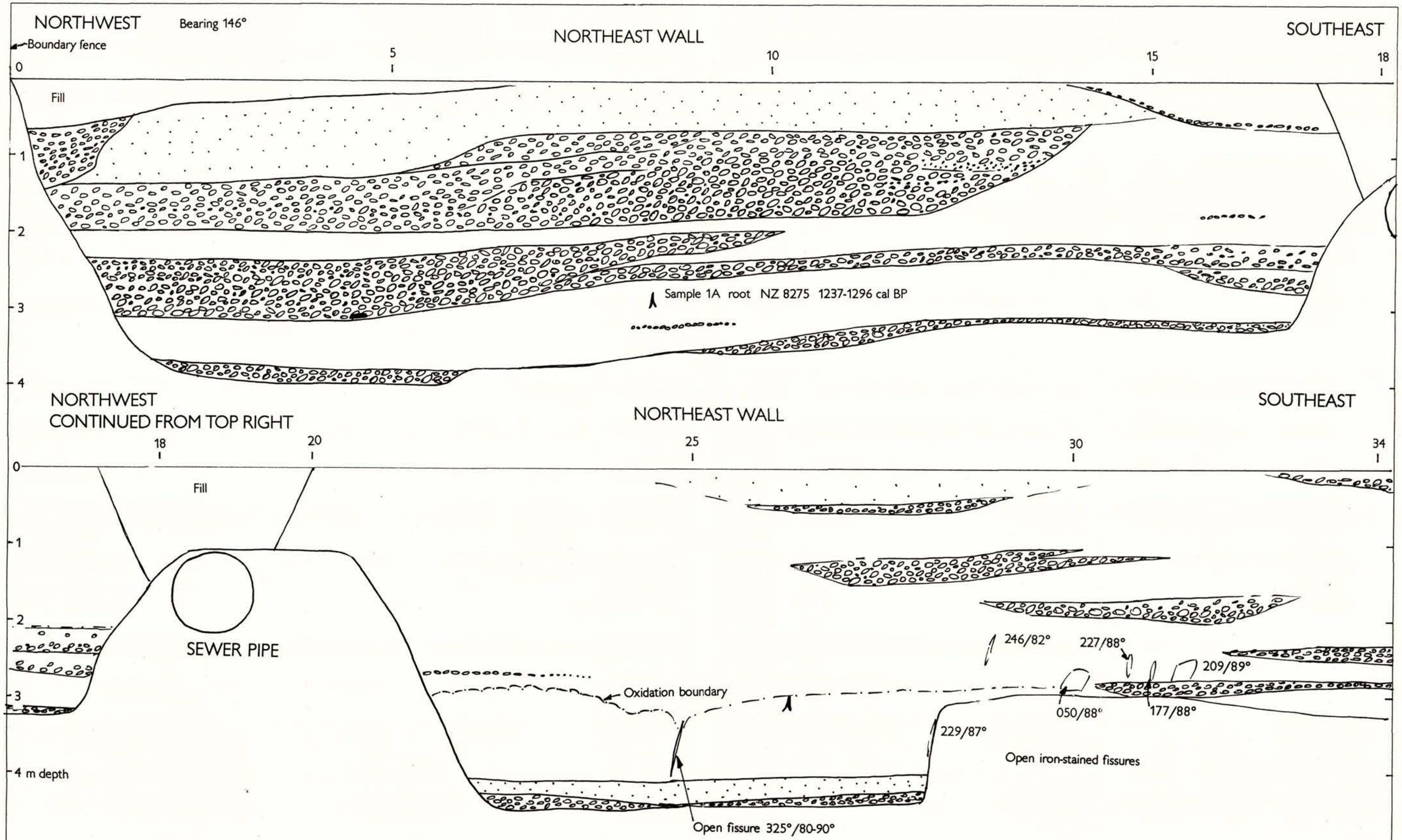
Trench 1 site plan, McGaffin property

FIGURE 2
Drawn W Leask
Approved
Date 18-4-1995



GRAPHIC SCALE

EXPLANATION

Wood, roots

Clay

Silt

Sand

Gravel

325°/80° Dip direction/dip

ORIGINAL SCALE 1:50

GRID:

DWG NO: 359_9

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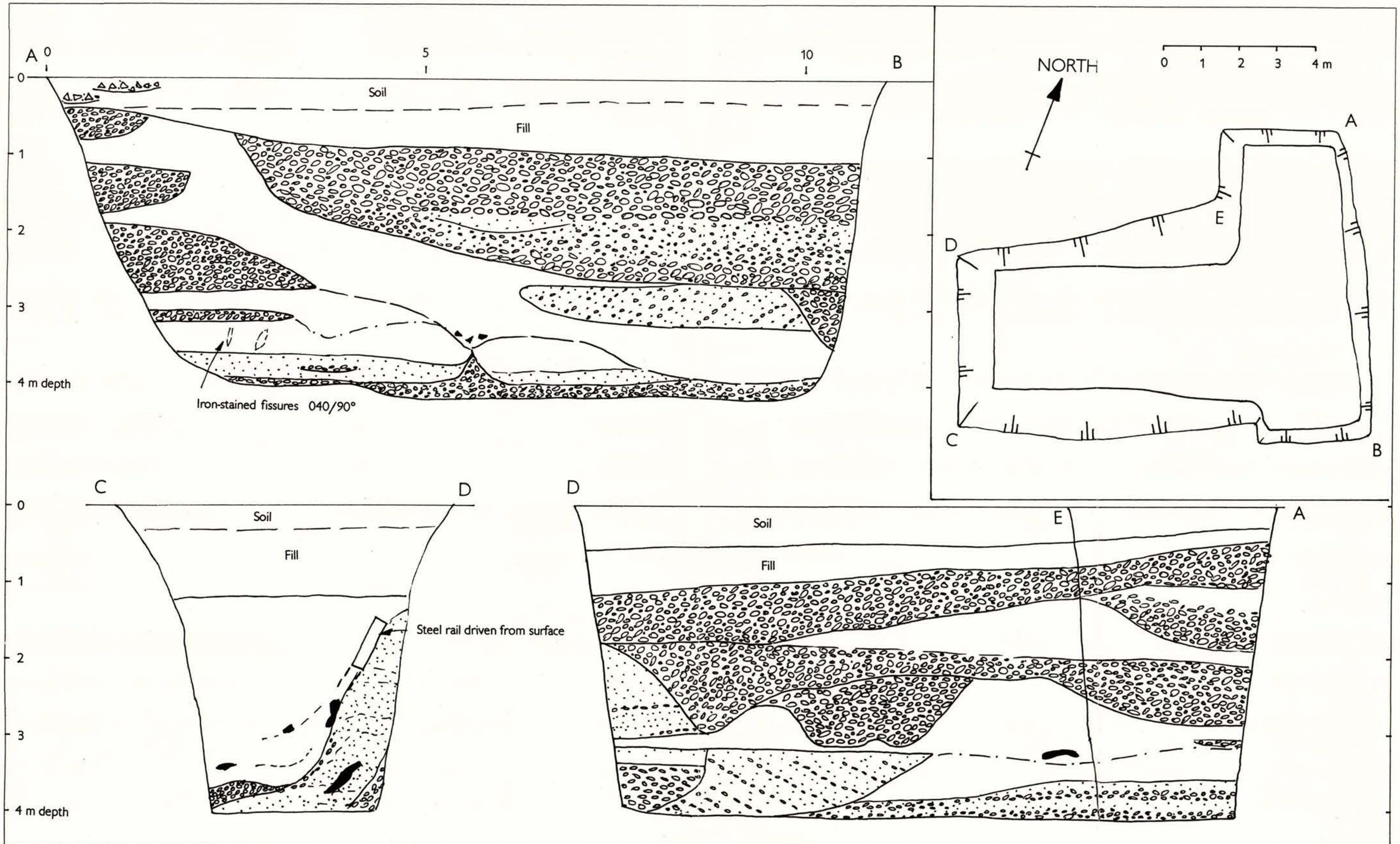
Trench 1a: McGaffin property, Belmont

FIGURE 3

Drawn W Leask

Approved

Date 14-12-1994



GRAPHIC SCALE

EXPLANATION

Wood, roots
Clay
Silt
Sand
Gravel
oxidation boundary

ORIGINAL SCALE 1:50

GRID:

DWG NO: 359_10

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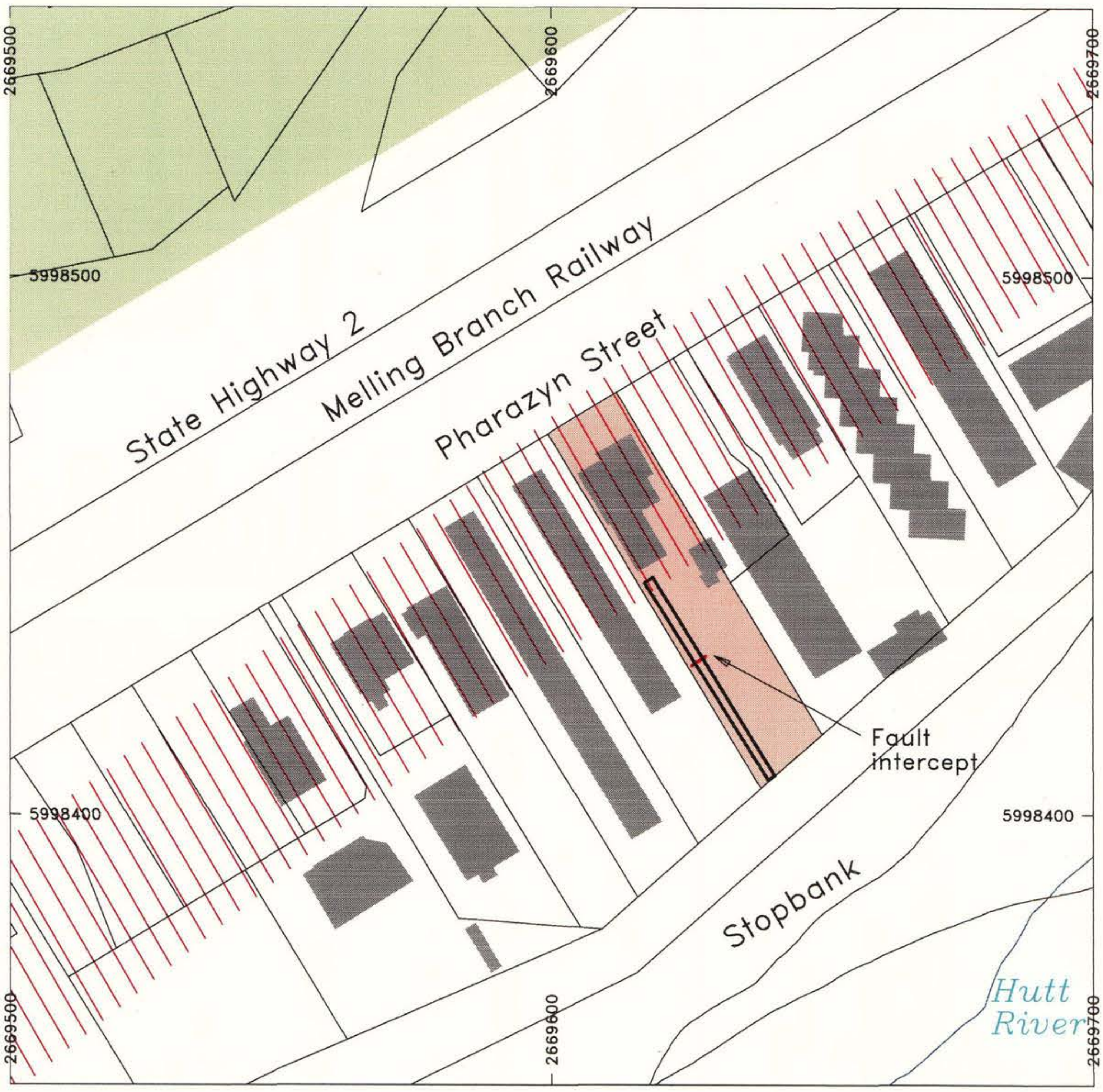
Trench 1b: McGaffin property, Belmont.

FIGURE 4

Drawn W Leask

Approved

Date 20-1-1995



GRAPHIC SCALE 1:1000

0 10 20 30 40 50 m

EXPLANATION

- 92 Pharazyn Street
- Buildings
- Cadastral boundaries
- Basement
- Wellington Fault zone estimated prior to trenching (IRBA 1991)
- Alluvial fan
- Trench 2 (Jan 1993)

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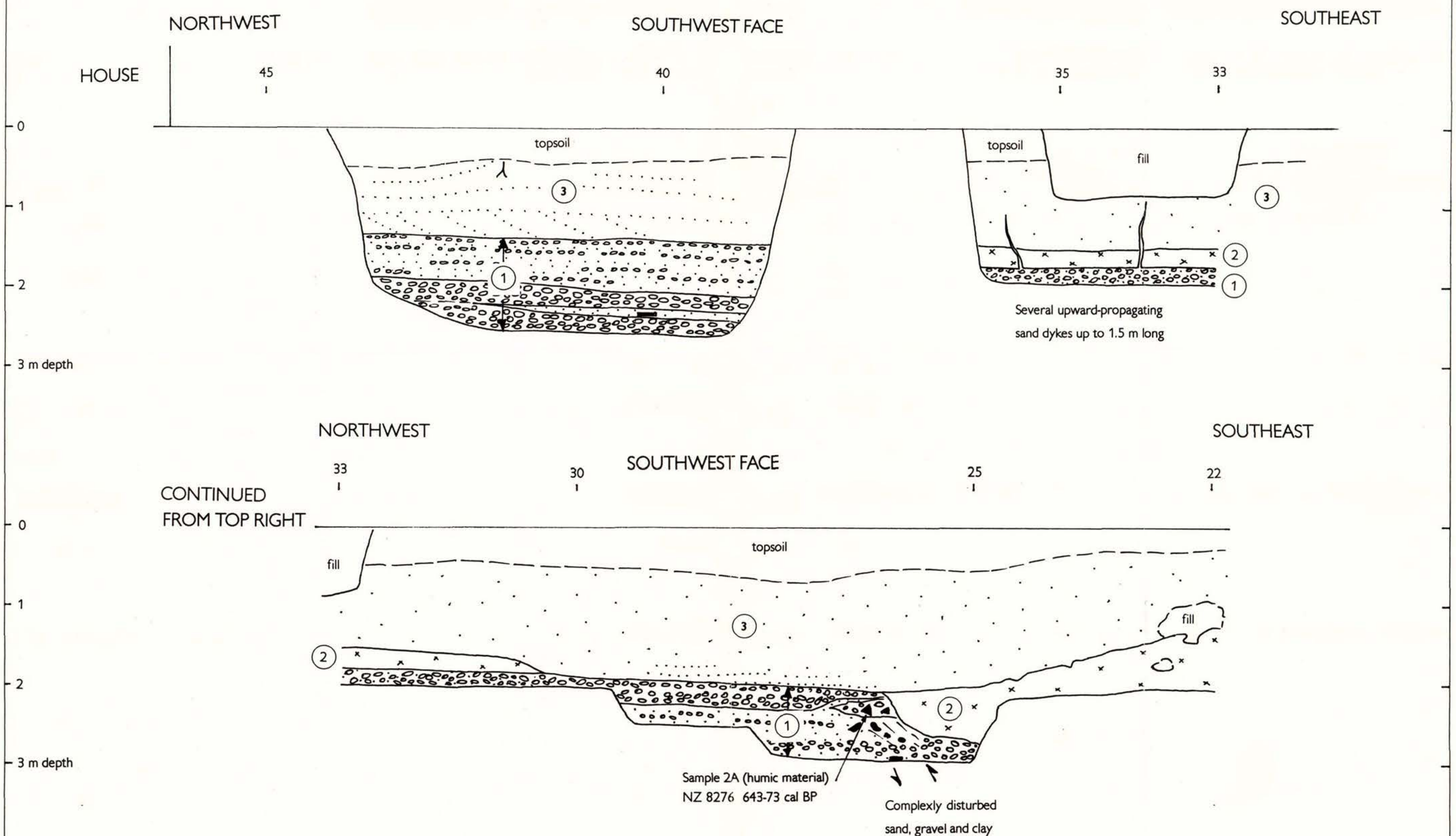
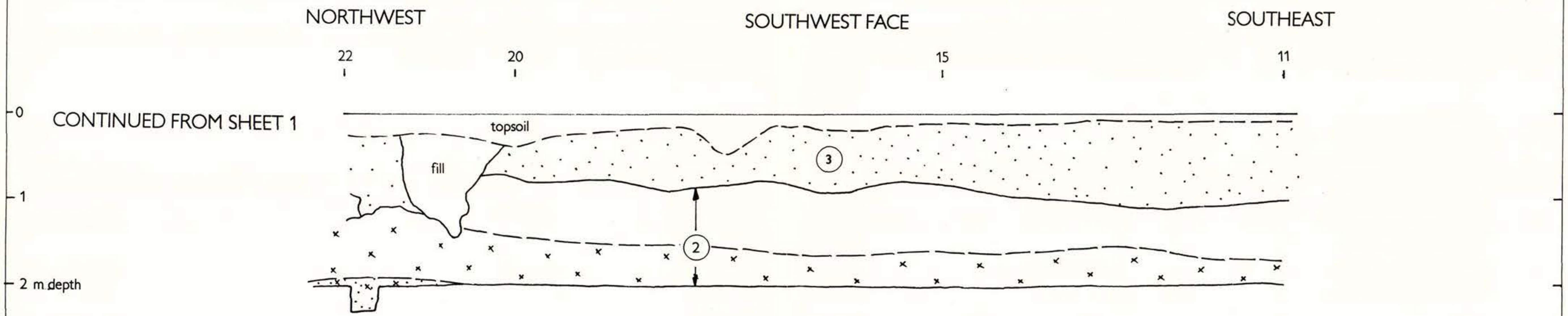
WELLINGTON FAULT RESEARCH STUDY

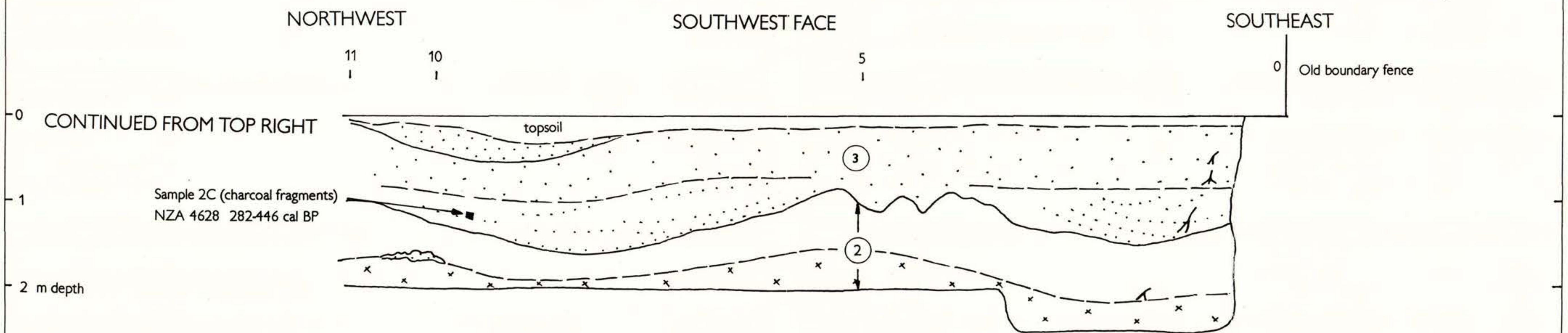
Trench 2 site plan, 92 Pharazyn Street

DWG NO 359_11	DATE 18-4-1995	FIGURE 5

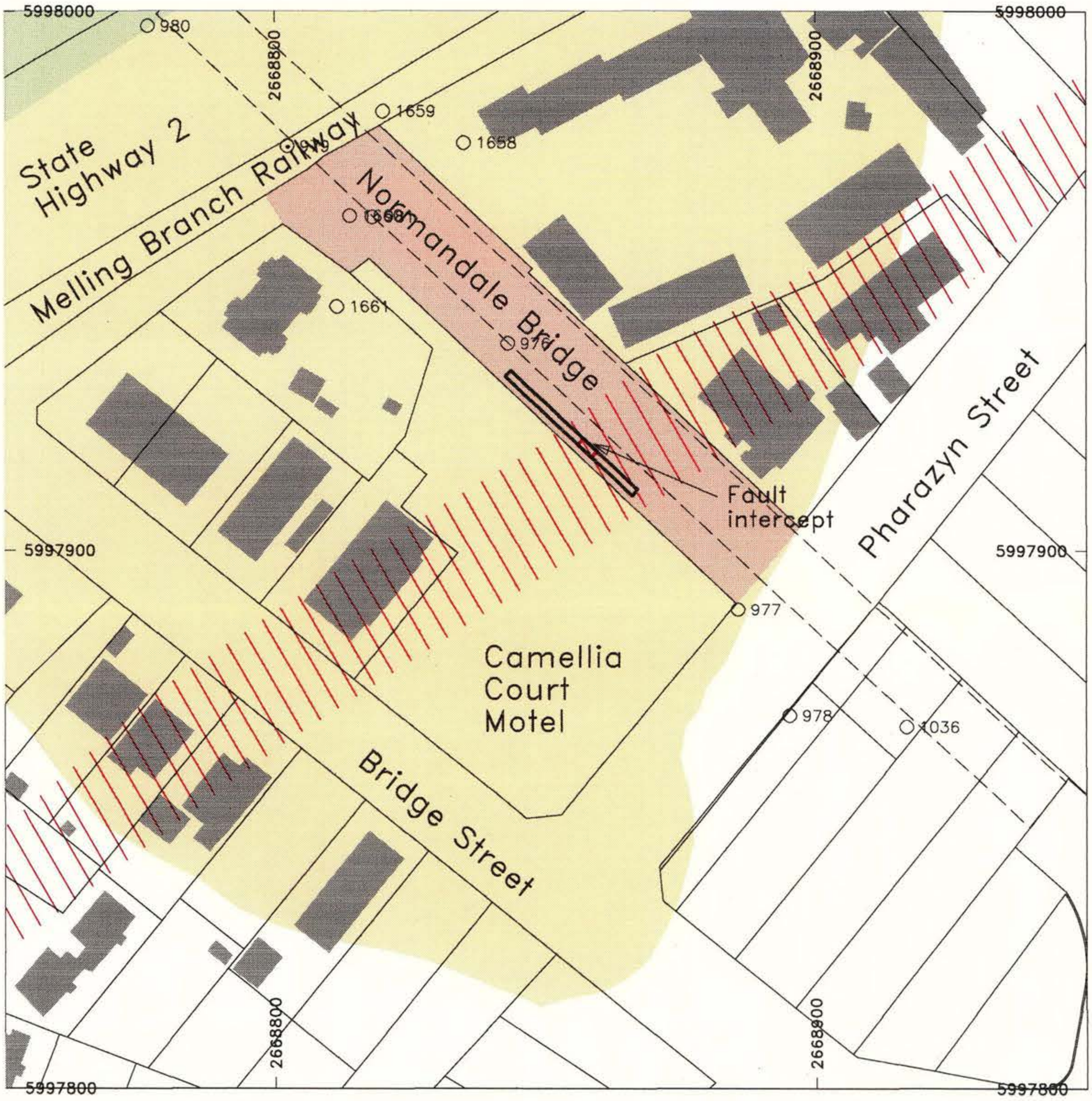


GRAPHIC SCALE	ORIGINAL SCALE 1:50	Ian R Brown Associates Ltd *Geological Engineering Consultants*	EARTHQUAKE COMMISSION	FIGURE 6a
EXPLANATION Wood, roots Clay Silt Sand Gravel	GRID:		WELLINGTON FAULT RESEARCH STUDY	Drawn W Leask
		PO Box 9043 Wellington New Zealand Tel (04) 3858603 Fax (04) 3843306	Trench 2: 92 Pharazyn Street (sheet 1)	Approved
	DWG NO: 359_12			Date 18-1-1995





GRAPHIC SCALE	ORIGINAL SCALE 1:50	Ian R Brown Associates Ltd *Geological Engineering Consultants*	EARTHQUAKE COMMISSION	FIGURE 6b
EXPLANATION: Wood, roots; Clay; Silt; Sand; Gravel	GRID:		WELLINGTON FAULT RESEARCH STUDY	Drawn W Leask
		PO Box 9043 Wellington New Zealand	Trench 2: 92 Pharazyn Street (sheet 2)	Approved
	DWG NO: 359_13	Tel (04) 3858603 Fax (04) 3843306		Date 18-1-1995



GRAPHIC SCALE 1:1000

0 10 20 30 40 50 m

EXPLANATION

- The Hutt City Council property
- Buildings
- Cadastral boundaries
- Basement
- Wellington Fault scarp
- Alluvial fan
- Trench 3
- ○ 977 Drillhole (IRBA (1991) identifier)

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EARTHQUAKE COMMISSION

WELLINGTON FAULT RESEARCH STUDY

Trench 3 site plan, Normandale Bridge

DWG NO 359_14	DATE 18-4-1995	FIGURE 7

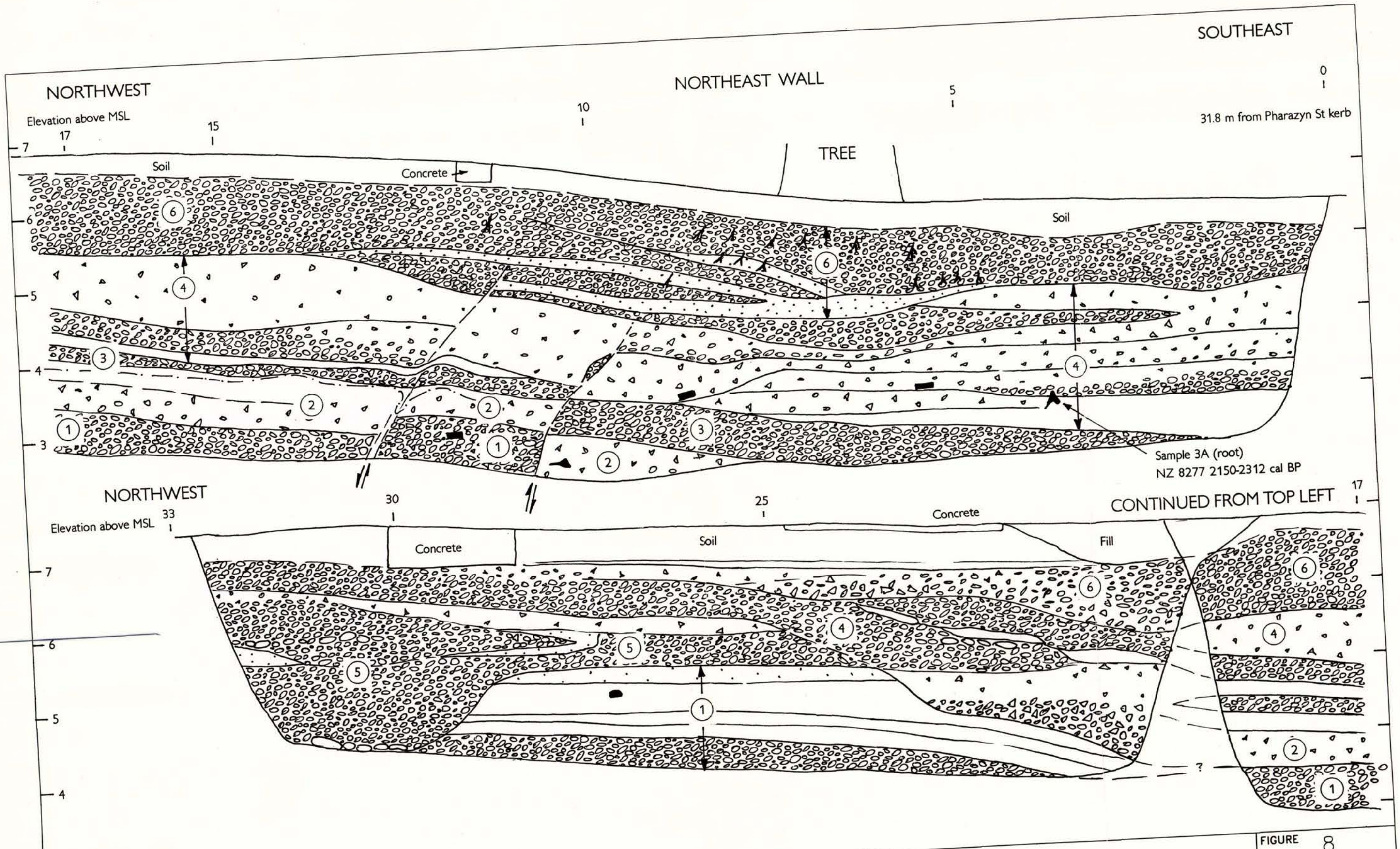

FIGURE 8

ORIGINAL SCALE 1:50

GRAPHIC SCALE

GRID:

EXPLANATION

Wood, roots

Clay

Silt

Sand

Gravel

oxidation boundary

DWG NO: 359_15

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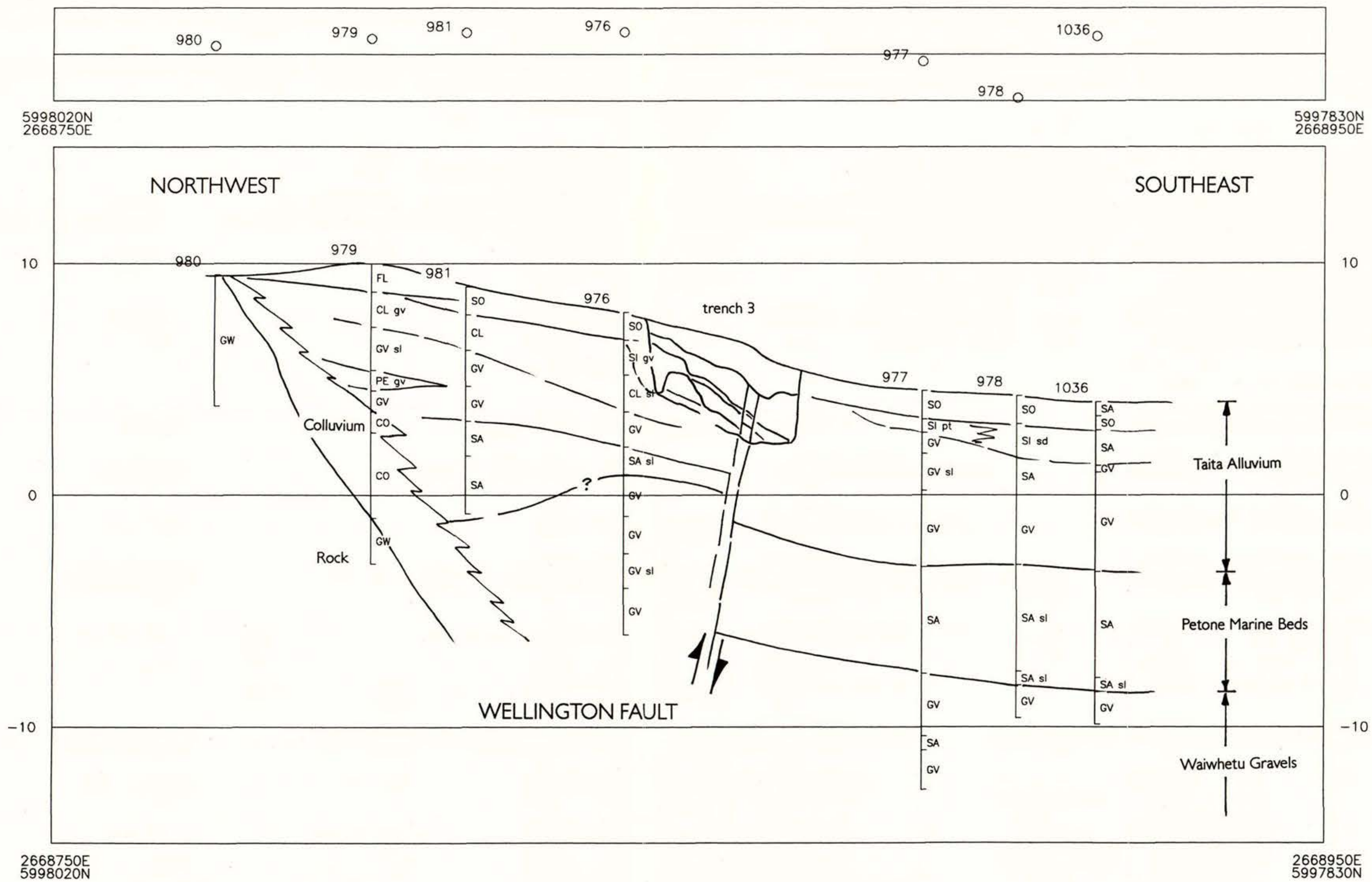
WELLINGTON FAULT RESEARCH STUDY

Trench 3: Beside Normandale Overbridge

Drawn W Leask

Approved

Date 14-12-1994



GRAPHIC SCALE 0 10 20 30 40 50 m

Horizontal Scale 1:1000
Vertical Scale 1:200

ORIGINAL SCALE 1:1000

GRID: NZ Map Grid

DWG NO: 359_22

EXPLANATION

PRIMARY LITHOLOGIES

- CL Clay
- CO Colluvium
- FL Fill
- GV Gravel
- GW Greywacke
- PE Peat
- SA Sand
- SI Silt
- SO Soil

SUBORDINATE MATERIALS

- gv gravelly
- pt peaty
- sd sandy
- sl silty

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WELLINGTON FAULT RESEARCH STUDY

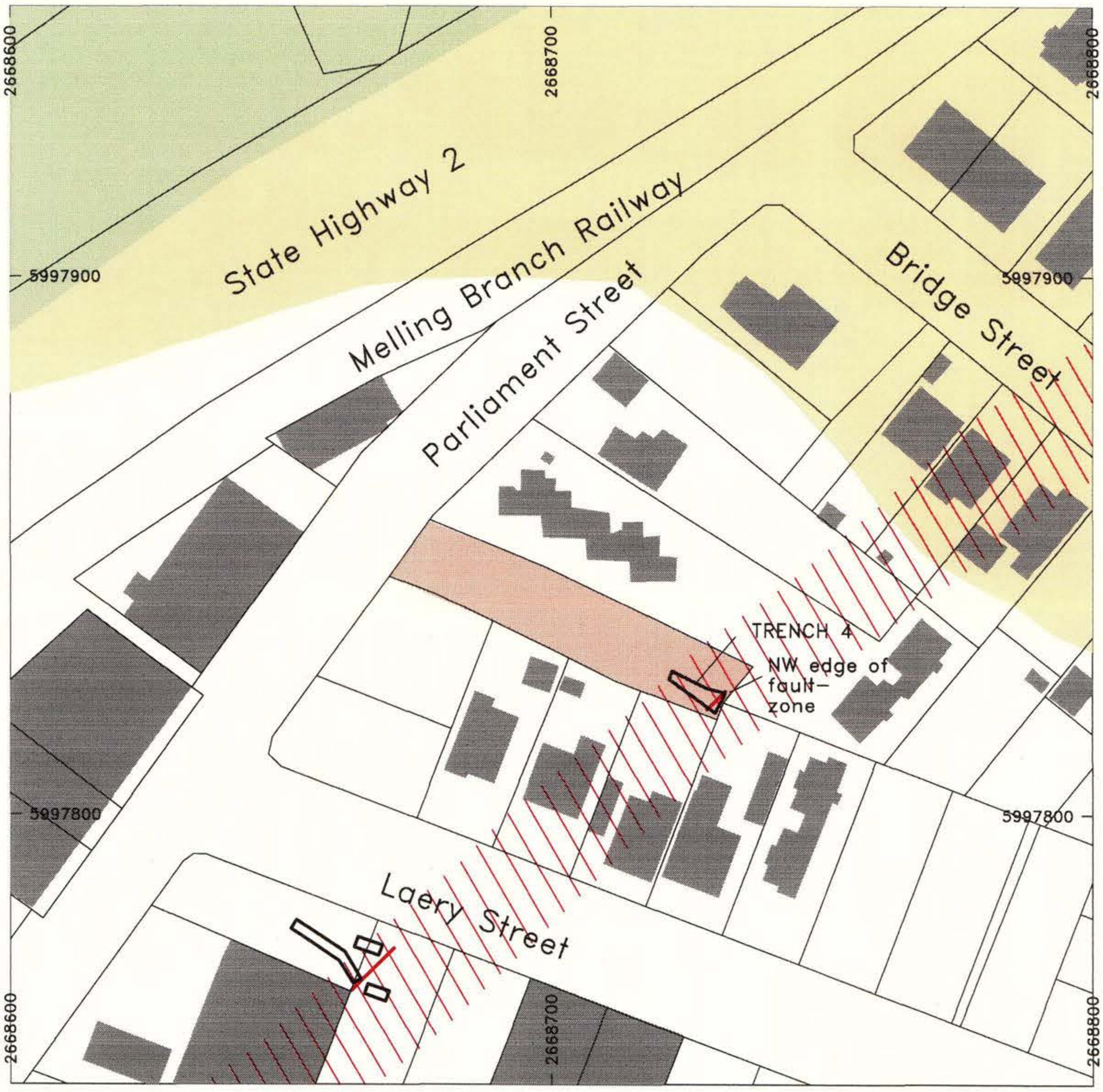
Cross Section along Normandale Bridge

FIGURE 9

Drawn W Leask

Approved

Date 5-4-1995



GRAPHIC SCALE 1:1000

0 10 20 30 40 50 m

EXPLANATION

12 Parliament St

Buildings

Cadastral boundaries

Basement

Wellington Fault scarp

Alluvial fan

Trenches

Ian R Brown Associates Ltd

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EARTHQUAKE COMMISSION

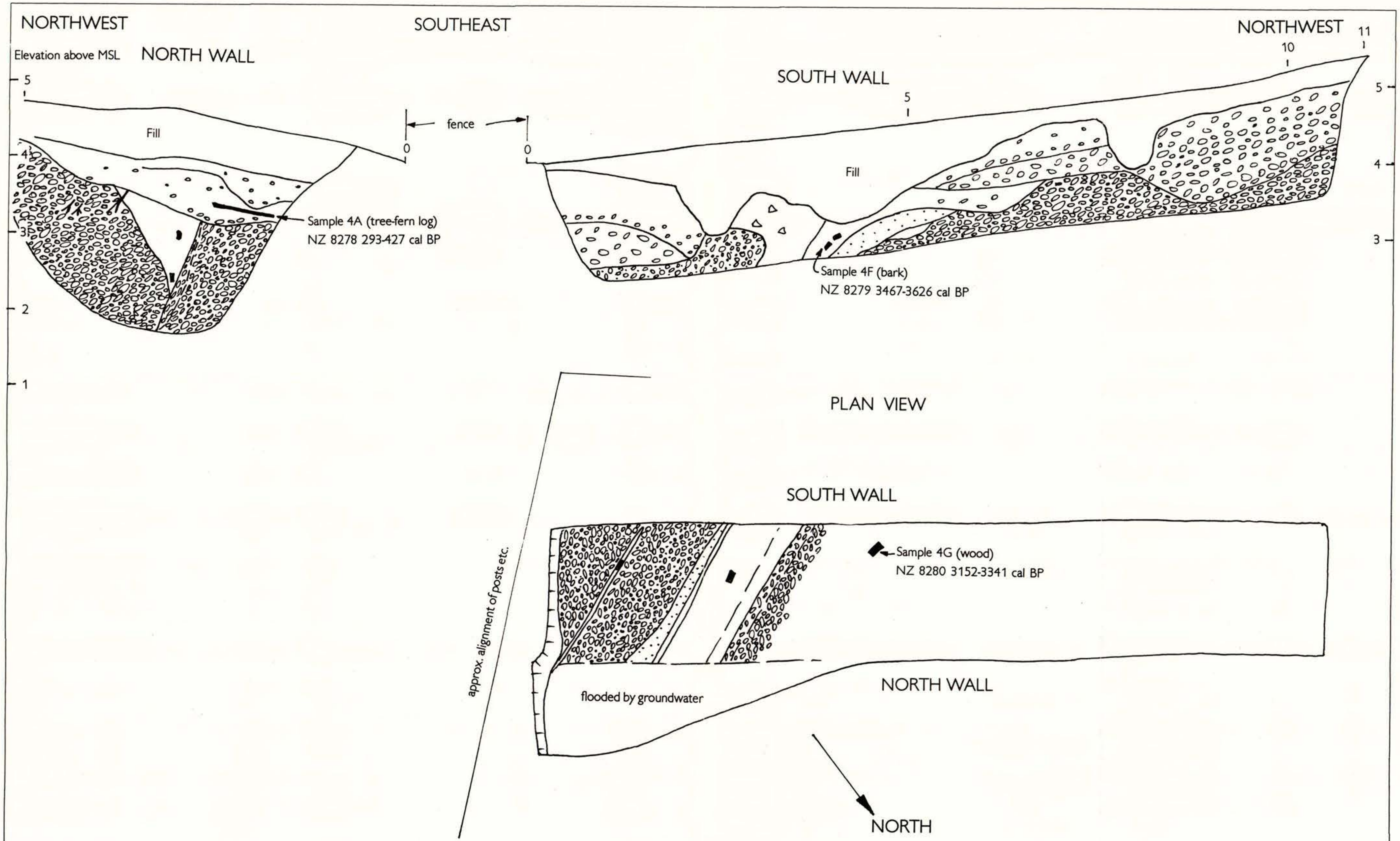
WELLINGTON FAULT RESEARCH STUDY

Trench 4 site plan, 12 Parliament Street

DWG NO 359_16

DATE 18-4-1995

FIGURE 10



GRAPHIC SCALE	ORIGINAL SCALE 1:50	Ian R Brown Associates Ltd *Geological Engineering Consultants*	EARTHQUAKE COMMISSION	FIGURE 11
EXPLANATION: Wood, roots; Clay; Silt; Sand; Gravel	GRID:	PO Box 9043 Wellington New Zealand Tel (04) 3858603 Fax (04) 3843306	WELLINGTON FAULT RESEARCH STUDY Trench 4: 12 Parliament Street	Drawn W Leask
	DWG NO: 359_17			Approved
				Date 21-12-1994

GRAPHIC SCALE 1:1000

0 10 20 30 40 50 m

EXPLANATION

- Dux Engineering property
- Buildings
- Cadastral boundaries
- Basement
- Wellington Fault scarp
- Alluvial fan
- Trenches 5A, 5B, 5C (see Fig 13b for details)

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Geological Engineering Consultants

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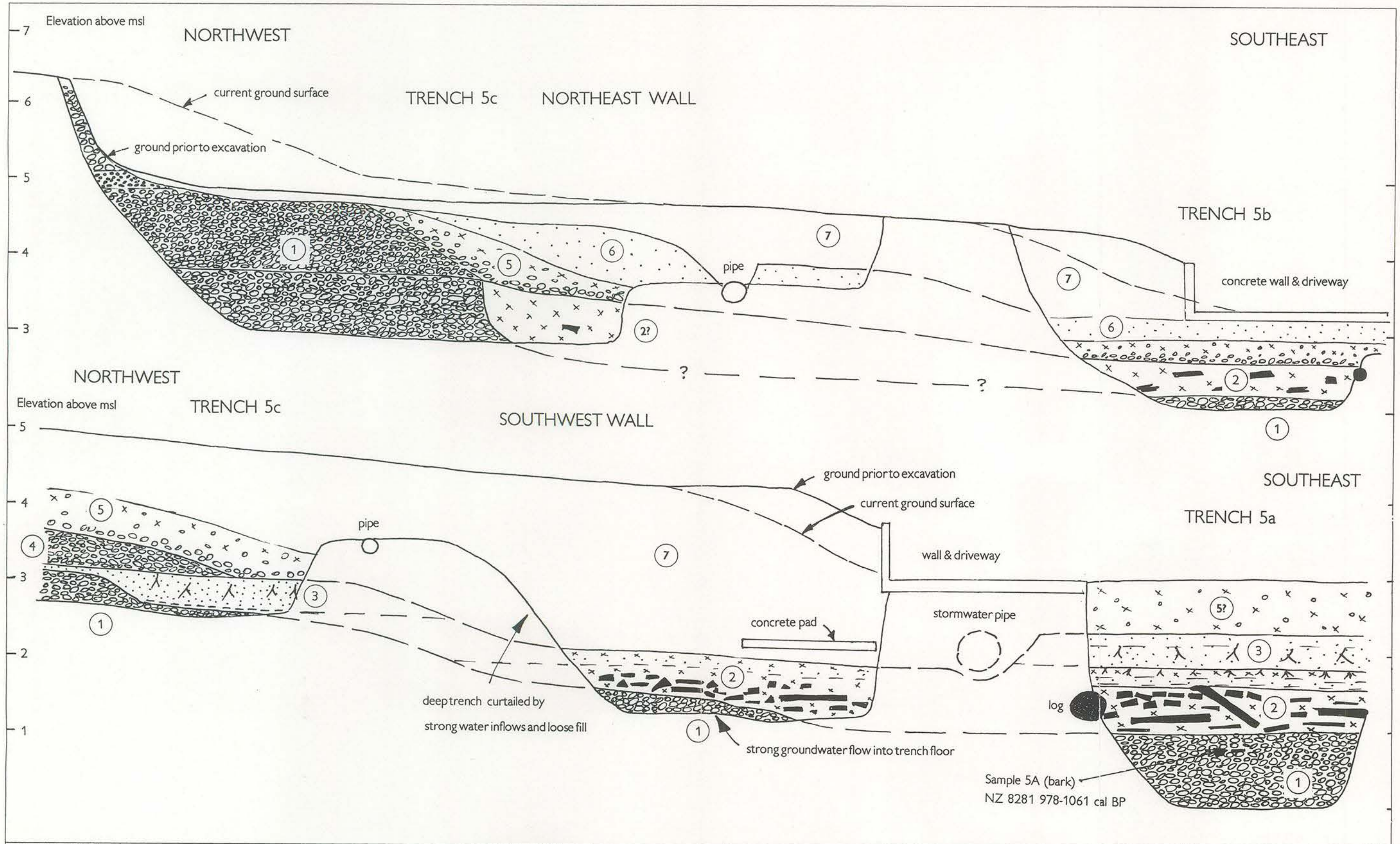
EARTHQUAKE COMMISSION

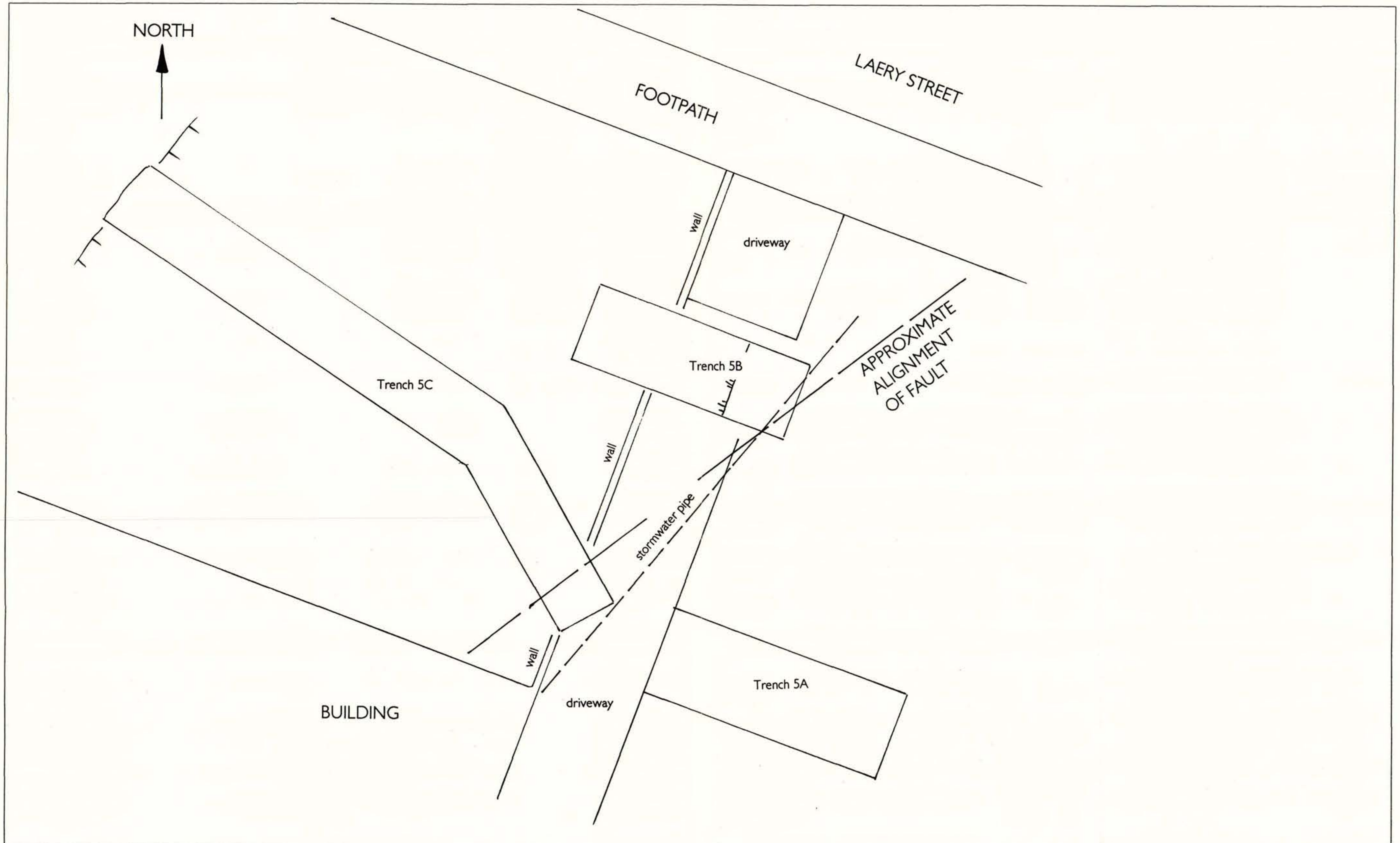
WELLINGTON FAULT RESEARCH STUDY

Trench 5 site plan, 2 Laery Street

DWG NO 359_18 | DATE 18-4-1995 | FIGURE 12



GRAPHIC SCALE	ORIGINAL SCALE 1:50	Ian R Brown Associates Ltd *Geological Engineering Consultants*	EARTHQUAKE COMMISSION	FIGURE 13a
EXPLANATION Wood, roots Clay Silt Sand Gravel	GRID:	PO Box 9043 Wellington New Zealand Tel (04) 3858603 Fax (04) 3843306	WELLINGTON FAULT RESEARCH STUDY Trench 5: Dux Engineering, 2 Laery St.	Drawn W Leask Approved Date 18-1-1995
	DWG NO: 359_19			



GRAPHIC SCALE 0 2 4 6 8 m

ORIGINAL SCALE 1:100

EXPLANATION

GRID:

DWG NO: 359_20

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EARTHQUAKE COMMISSION

WELLINGTON FAULT RESEARCH STUDY

Trench 5a,b,c locations, Laery St.

FIGURE 13b

Drawn W Leask

Approved

Date 13-4-1995

APPENDIX

Radiocarbon laboratory measurement reports by Nuclear Sciences Group, Institute of Geological & Nuclear Sciences Ltd

Institute of
GEOLOGICAL
& NUCLEAR
SCIENCES
Limited

29 NOV 1994

NS-CA/4/1-WHM

9 November 1994

Dr W Leask
Ian R Brown Associates Ltd.
PO Box 9043
WELLINGTON

Dear Dr Leask

RADIOCARBON DATING BY GAS COUNTING
SAMPLES R18789/1-2, 4-8

The results for your samples are enclosed.

All of the samples were needed for gas counting so there is no residual material left to be returned.

The peat sample was, in fact, organic matter soluble in NaOH plus coarse sand. Following the procedure used at Oxford University, the organics were re-precipitated with acid and burned to carbon dioxide for counting. The small size of this sample meant the accuracy was not high and I have kept the gas in case you might need an AMS date.

Cellulose was prepared from the other samples and processed by our standard procedures.

The $\delta^{13}C$ value for R18789/6 was lost and I have had to estimate the value. Allowance has been made for the resulting date.

Yours sincerely

Hugh Melhuish

W H Melhuish

30 Gracefield Road, PO Box 31312, Lower Hutt, New Zealand, Telephone: 0-4-570 4637, Facsimile: 0-4-570 4657

A Crown Research Institute

Institute of Geological & Nuclear Sciences

Nuclear Sciences Group
PO Box 31-312
Lower Hutt
New Zealand

Telephone (04)5704616
FAX (04) 569 0657

RAFTER RADIOCARBON LABORATORY
Radiocarbon Laboratory Measurement Report

R Number	: 18789/1	NZ 8275
Sample ID	: 359-1A	
Description	: wood, Belmont school, Lower Hutt	
Submitter	: W Leask, I R Brown Associates Wellington	

Date measured	: November 2, 1994	Counting time : 2700 minutes
δ13C	: -28.6 per mille	Counter : C 7347
Radiocarbon age	: 1384 ± 43 years BP	
D14C	: -158.2 ± 4.6 per mille	
Per cent modern	: 83.7 ± 0.5 per cent	

Measurement standard is NBS I oxalic acid. Background standard is Kapuni well CO2

'Per cent modern' is the absolute per cent modern, corrected for the age of the oxalic acid standard

'Radiocarbon age' is the Conventional Radiocarbon Age

Radiocarbon age, D14C and per cent modern are as defined in Stuiver and Polach, Radiocarbon (1977), 19 353-363

file CA/4/1
R18789/1

INSTITUTE OF GEOLOGICAL AND NUCLEAR SCIENCES LTD.
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RADIOCARBON CALIBRATION REPORT

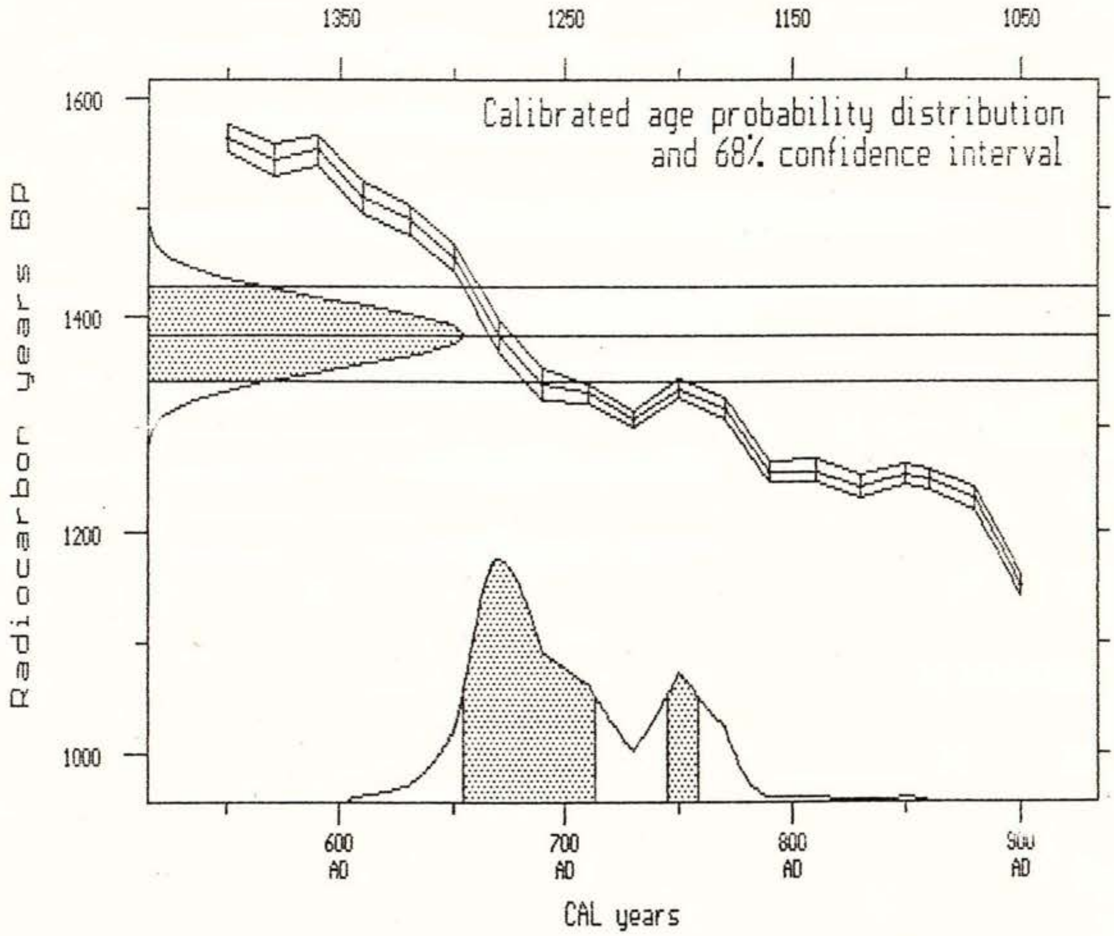
NZ 8275 CONVENTIONAL RADIOCARBON AGE 1384 ± 43 years BP

Bi-decadal radiocarbon calibration from:
Bard E, Arnold M, Fairbanks RG, and Hamelin B, 1993, Radiocarbon 35(1):191
Kromer B, and Becker B, 1993, Radiocarbon 35(1):125
Linick TW, Long A, Damon PE, and Ferguson CW, 1986, Radiocarbon 28(1):943
Pearson GW and Stuiver M, 1993, Radiocarbon 35(1):25
Stuiver M and Pearson GW, 1993, Radiocarbon 35(1):1

With 40 year southern hemisphere offset as recommended by Vogel, Fuls & Visser, 1993, Radiocarbon 35(1):73

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0)
95% confidence interval is 638 AD to 778 AD 1312 CAL BP to 1172 CAL BP

68% confidence interval is 654 AD to 713 AD 1296 CAL BP to 1237 CAL BP (58%)
plus 745 AD to 758 AD 1205 CAL BP to 1192 CAL BP (9%)



file CA/4/1
R18789/2

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RADIOCARBON CALIBRATION REPORT

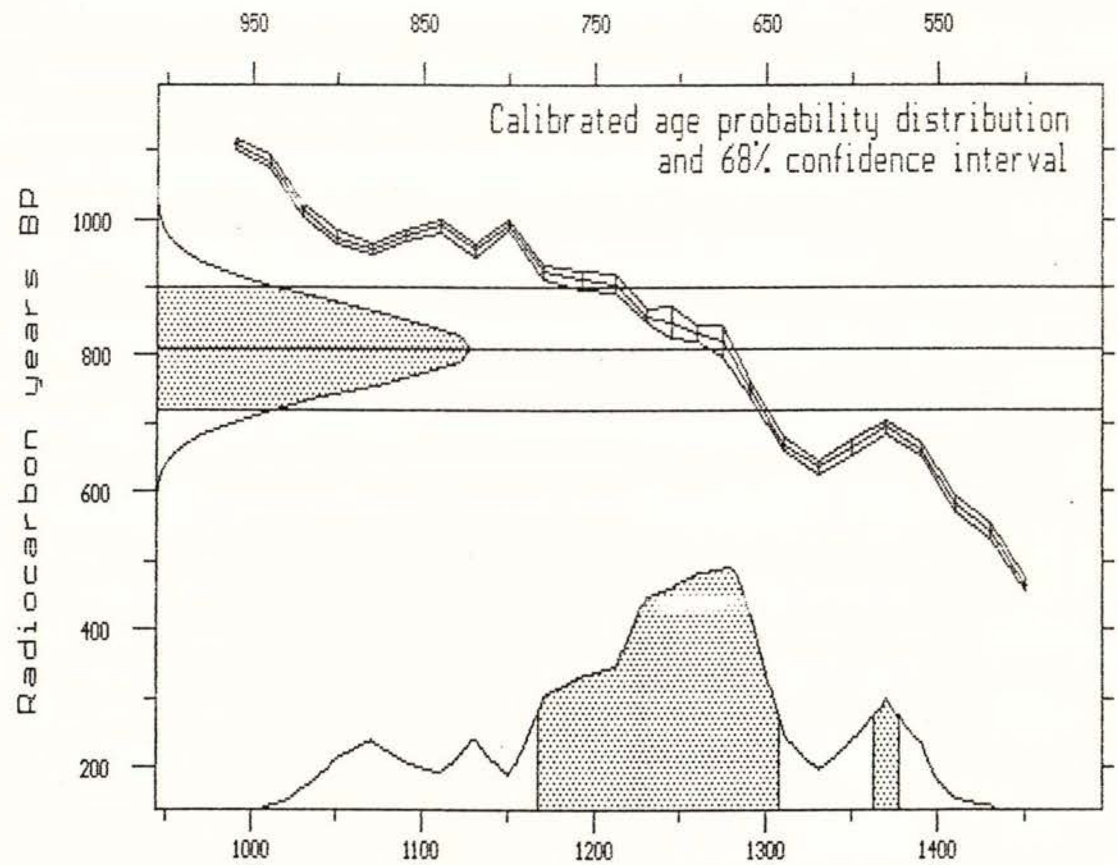
NZ 8276 CONVENTIONAL RADIOCARBON AGE 810 ± 91 years BP

Bi-decadal radiocarbon calibration from:
Bard E, Arnold M, Fairbanks RG, and Hamelin B, 1993, Radiocarbon 35(1):191
Kromer B, and Becker B, 1993, Radiocarbon 35(1):125
Linick TW, Long A, Damon PE, and Ferguson CW, 1986, Radiocarbon 28(1):943
Pearson GW and Stuiver M, 1993, Radiocarbon 35(1):25
Stuiver M and Pearson GW, 1993, Radiocarbon 35(1):1

With 40 year southern hemisphere offset as recommended by Vogel, Fuls & Visser, 1993, Radiocarbon 35(1):73

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0)

95% confidence interval is	1045 AD to 1101 AD	905 CAL BP to	849 CAL BP	(8%)
plus	1114 AD to 1397 AD	836 CAL BP to	553 CAL BP	(87%)
68% confidence interval is	**1167 AD to 1307 AD**	**783 CAL BP to**	**643 CAL BP**	**(64%)**
plus	**1363 AD to 1377 AD**	**587 CAL BP to**	**573 CAL BP**	**(4%)**



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New Zealand

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FAX (04) 569 0657

RAFTER RADIOCARBON LABORATORY
Radiocarbon Laboratory Measurement Report

R Number	: 18789/2	NZ 8276
Sample ID	: 359-2A	
Description	: peat, Pharazyn St. Lower Hutt R27/69639843	
Submitter	: W Leask, I R Brown Associates Wellington	

Date measured	: November 2, 1994	Counting time : 5200 minutes
δ13C	: -29.1 per mille	Counter : AA 447
Radiocarbon age	: 810 ± 91 years BP	
D14C	: -95.9 + 10.2 per mille	
Per cent modern	: 89.9 ± 1.0 per cent	

Measurement standard is NBS I oxalic acid. Background standard is Kapuni well CO2

'Per cent modern' is the absolute per cent modern, corrected for the age of the oxalic acid standard

'Radiocarbon age' is the Conventional Radiocarbon Age

Radiocarbon age, D14C and per cent modern are as defined in Stuiver and Polach, Radiocarbon (1977), 19 353-363

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RAFTER RADIOCARBON LABORATORY
Radiocarbon Laboratory Measurement Report

R Number	: 18789/4	NZ 8277
Sample ID	: 359-3A	
Description	: wood, Normandale o'bridge Lower Hutt R27/68879791	
Submitter	: W Leask, I R Brown Associates Wellington	

Date measured	: November 1, 1994	Counting time	: 2600 minutes
δ13C	: -25.8 per mille	Counter	: C 7346
Radiocarbon age	: 2264 ± 47 years BP		
D14C	: -245.6 ± 4.4 per mille		
Per cent modern	: 75.0 ± 0.4 per cent		

Measurement standard is NBS I oxalic acid. Background standard is Kapuni well CO2

'Per cent modern' is the absolute per cent modern, corrected for the age of the oxalic acid standard

'Radiocarbon age' is the Conventional Radiocarbon Age

Radiocarbon age, D14C and per cent modern are as defined in Stuiver and Polach, Radiocarbon (1977), 19 353-363

file CA/4/1
R18789/4

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RADIOCARBON CALIBRATION REPORT

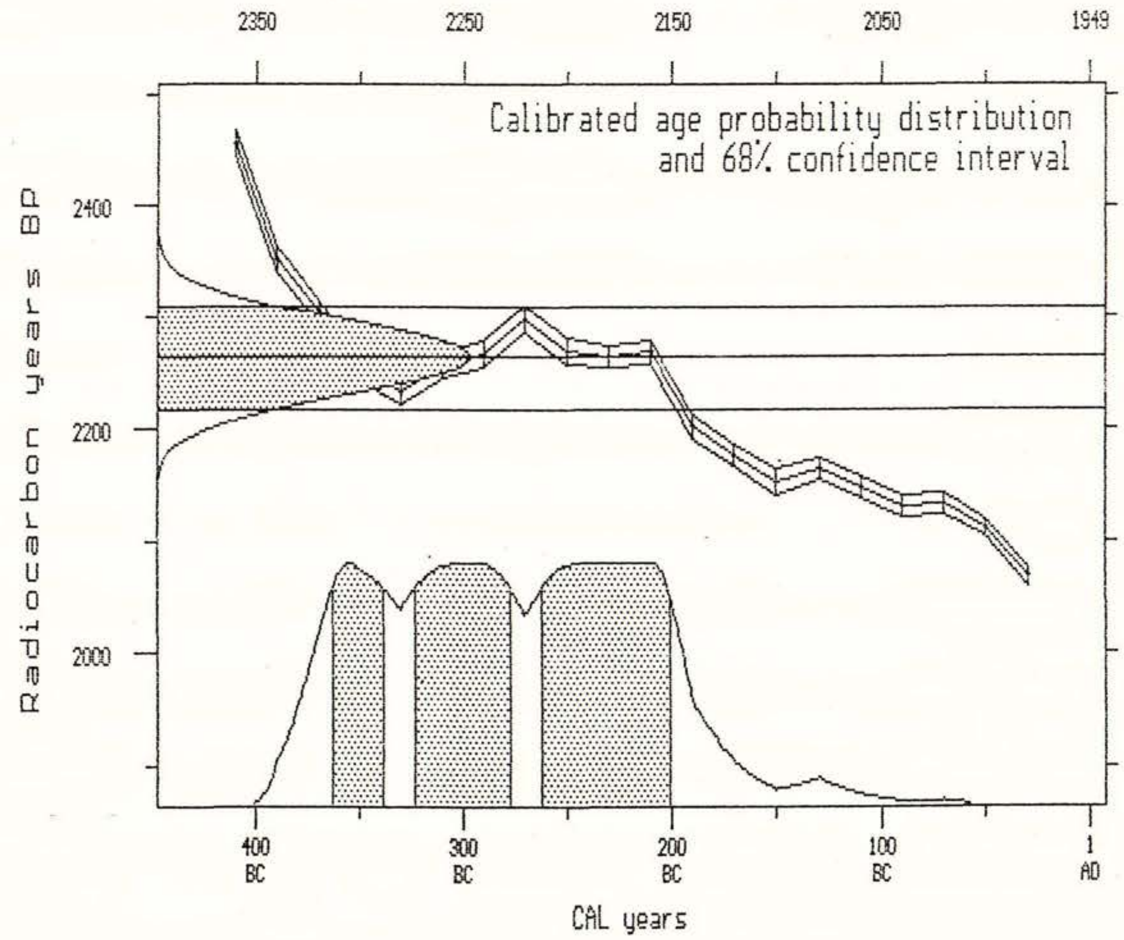
NZ 8277 CONVENTIONAL RADIOCARBON AGE 2264 ± 47 years BP

Bi-decadal radiocarbon calibration from:
Bard E, Arnold M, Fairbanks RG, and Hamelin B, 1993, Radiocarbon 35(1):191
Kromer B, and Becker B, 1993, Radiocarbon 35(1):125
Linick TW, Long A, Damon PE, and Ferguson CW, 1986, Radiocarbon 28(1):943
Pearson GW and Stuiver M, 1993, Radiocarbon 35(1):25
Stuiver M and Pearson GW, 1993, Radiocarbon 35(1):1

With 40 year southern hemisphere offset as recommended by Vogel, Fuls & Visser, [illegible]:73

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0)
95% confidence interval is 387 BC to 174 BC 2336 CAL BP to 2123 CAL BP (95%)

68% confidence interval is	**363 BC**	**to**	**338 BC**	**2312 CAL BP**	**to**	**2287 CAL BP**	**(13%)**
plus	**323 BC**	**to**	**277 BC**	**2272 CAL BP**	**to**	**2226 CAL BP**	**(24%)**
plus	**262 BC**	**to**	**201 BC**	**2211 CAL BP**	**to**	**2150 CAL BP**	**(32%)**



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RAFTER RADIOCARBON LABORATORY
Radiocarbon Laboratory Measurement Report

R Number	: 18789/5	NZ 8278
Sample ID	: 359-4A	
Description	: wood, 12 Parliament St. Lower Hutt R27/68739782	
Submitter	: W Leask, I R Brown Associates Wellington	

Date measured	: October 21, 1994	Counting time : 4400 minutes
δ13C	: -27.9 per mille	Counter : C 7342
Radiocarbon age	: 334 ± 32 years BP	
D14C	: -40.7 ± 3.8 per mille	
Per cent modern	: 95.4 ± 0.4 per cent	

Measurement standard is NBS I oxalic acid. Background standard is Kapuni well CO_2

'Per cent modern' is the absolute per cent modern, corrected for the age of the oxalic acid standard

'Radiocarbon age' is the Conventional Radiocarbon Age

Radiocarbon age, D14C and per cent modern are as defined in Stuiver and Polach, Radiocarbon (1977), 19 353-363

file CA/4/1
R18789/5

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PO Box 31312, Lower Hutt, New Zealand
Phone (04) 569 0637, Fax (04) 569 0657

RADIOCARBON CALIBRATION REPORT

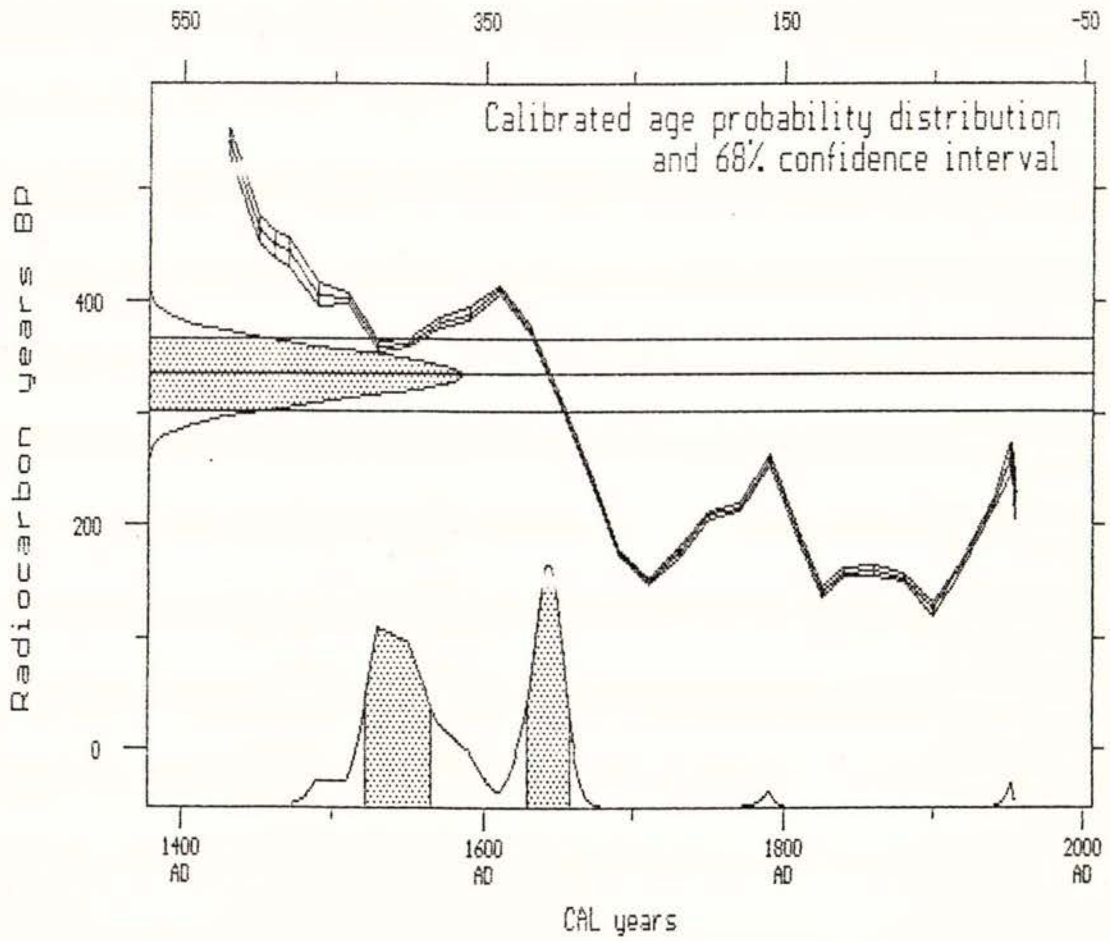
NZ 8278 CONVENTIONAL RADIOCARBON AGE 334 ± 32 years BP

Bi-decadal radiocarbon calibration from:
Bard E, Arnold M, Fairbanks RG, and Hamelin B, 1993, Radiocarbon 35(1):191
Kromer B, and Becker B, 1993, Radiocarbon 35(1):125
Linick TW, Long A, Damon PE, and Ferguson CW, 1986, Radiocarbon 28(1):943
Pearson GW and Stuiver M, 1993, Radiocarbon 35(1):25
Stuiver M and Pearson GW, 1993, Radiocarbon 35(1):1

With 40 year southern hemisphere offset as recommended by Vogel, Fuls & Visser, 1993, Radiocarbon 35(1):73

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0)

95% confidence interval is	1511 AD to 1602 AD	439 CAL BP to	348 CAL BP (55%)
plus	1616 AD to 1665 AD	334 CAL BP to	285 CAL BP (37%)
68% confidence interval is	**1523 AD to 1566 AD**	**427 CAL BP to**	**384 CAL BP (38%)**
plus	**1629 AD to 1657 AD**	**321 CAL BP to**	**293 CAL BP (30%)**



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RAFTER RADIOCARBON LABORATORY
Radiocarbon Laboratory Measurement Report

R Number	: 18789/6	NZ 8279
Sample ID	: 359-4F	
Description	: wood, 121 Parliament St. Lower Hutt R27/68739782	
Submitter	: W Leask, I R Brown Associates Wellington	

Date measured	: October 28, 1994	Counting time	: 4000 minutes
δ13C	: -26.0 per mille	Counter	: AA 445
Radiocarbon age	: 3364 ± 73 years BP		
D14C	: -342.1 ± 6.0 per mille		
Per cent modern	: 65.4 ± 0.6 per cent		

Measurement standard is NBS I oxalic acid. Background standard is Kapuni well CO_2

'Per cent modern' is the absolute per cent modern, corrected for the age of the oxalic acid standard

'Radiocarbon age' is the Conventional Radiocarbon Age

Radiocarbon age, D14C and per cent modern are as defined in Stuiver and Polach, Radiocarbon (1977), 19 353-363

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RADIOCARBON CALIBRATION REPORT

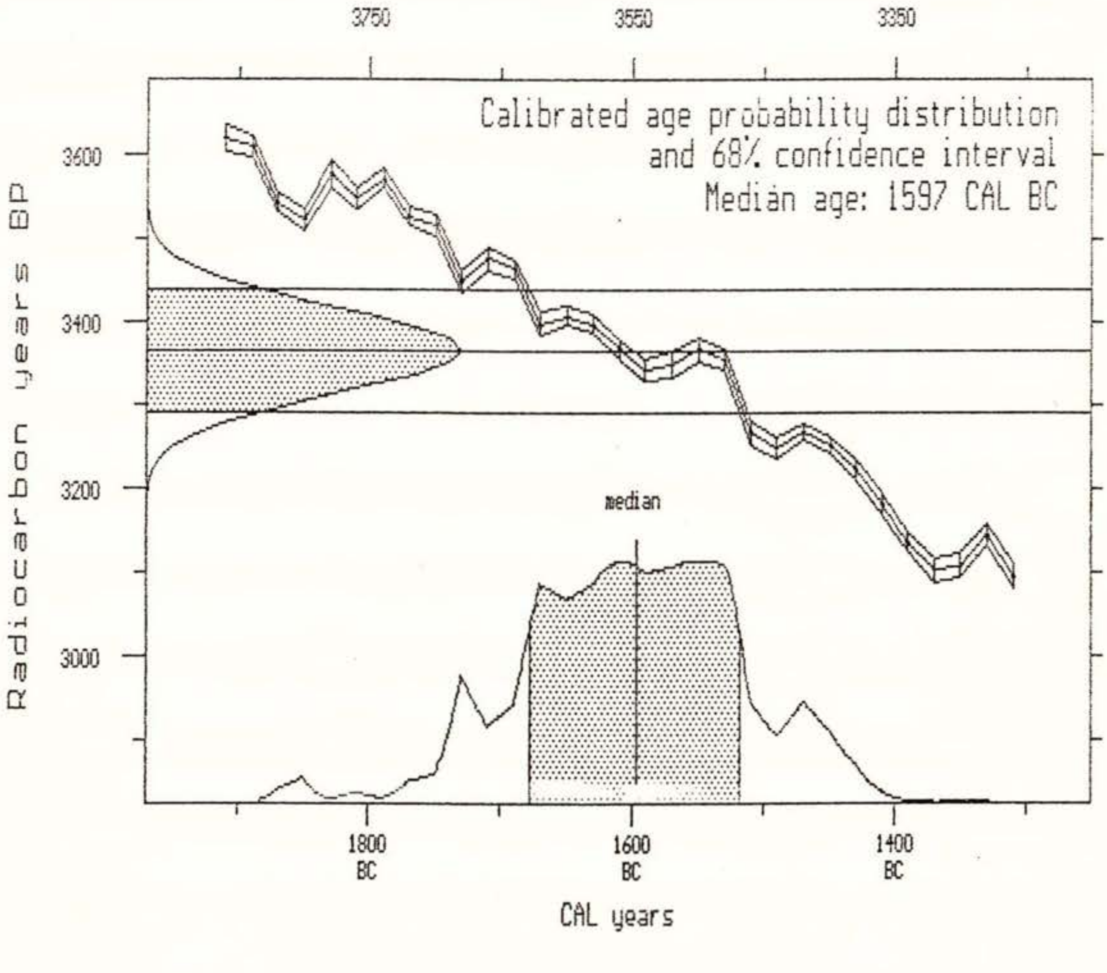
NZ 8279 CONVENTIONAL RADIOCARBON AGE 3364 ± 73 years BP

Bi-decadal radiocarbon calibration from:
Bard E, Arnold M, Fairbanks RG, and Hamelin B, 1993, Radiocarbon 35(1):191
Kromer B, and Becker B, 1993, Radiocarbon 35(1):125
Linick TW, Long A, Damon PE, and Ferguson CW, 1986, Radiocarbon 28(1):943
Pearson GW and Stuiver M, 1993, Radiocarbon 35(1):25
Stuiver M and Pearson GW, 1993, Radiocarbon 35(1):1

With 40 year southern hemisphere offset as recommended by Vogel, Fuls & Visser, 1993, Radiocarbon 35(1):73

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0)
95% confidence interval is 1746 BC to 1431 BC 3695 CAL BP to 3380 CAL BP (95%)

68% confidence interval is 1677 BC to 1518 BC 3626 CAL BP to 3467 CAL BP (68%)



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RAFTER RADIOCARBON LABORATORY
Radiocarbon Laboratory Measurement Report

R Number : 18789/7 NZ 8280

Sample ID : 359-4g

Description : wood, 12 Parliament ST> Lower Hutt R27/68739782

Submitter : W Leask. I R Brown Associates Wellington

Date measured : November 1, 1994 Counting time : 2840 minutes

δ13C : -24.0 per mille Counter : AA 446

Radiocarbon age : 3080 ± 67 years BP

D14C : -318.5 ± 5.7 per mille

Per cent modern : 67.8 ± 0.6 per cent

Measurement standard is NBS I oxalic acid. Background standard is Kapuni well CO2

'Per cent modern' is the absolute per cent modern, corrected for the age of the oxalic acid standard

'Radiocarbon age' is the Conventional Radiocarbon Age

Radiocarbon age, D14C and per cent modern are as defined in Stuiver and Polach, Radiocarbon (1977), 19 353-363

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RADIOCARBON CALIBRATION REPORT

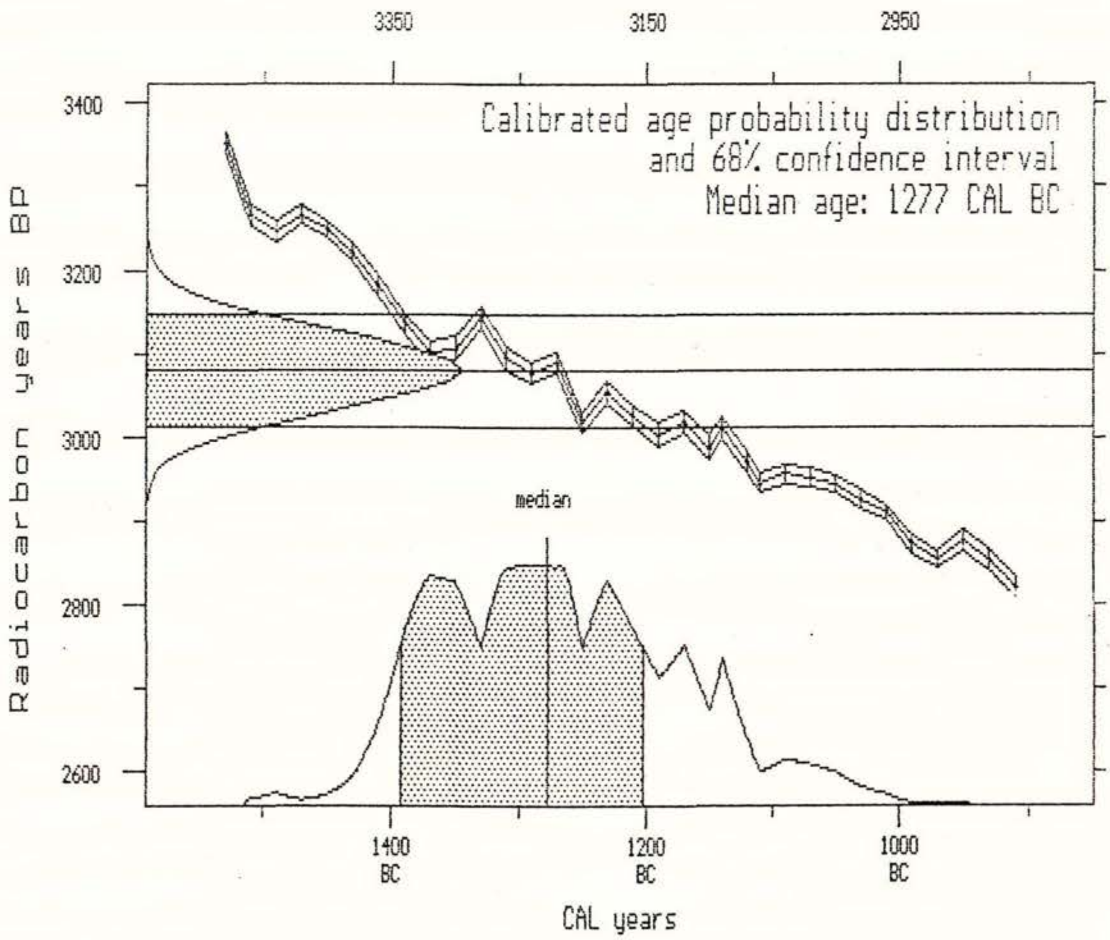
NZ 8280 CONVENTIONAL RADIOCARBON AGE 3080 ± 67 years BP

Bi-decadal radiocarbon calibration from:
Bard E, Arnold M, Fairbanks RG, and Hamelin B, 1993, Radiocarbon 35(1):191
Kromer B, and Becker B, 1993, Radiocarbon 35(1):125
Linick TW, Long A, Damon PE, and Ferguson CW, 1986, Radiocarbon 28(1):943
Pearson GW and Stuiver M, 1993, Radiocarbon 35(1):25
Stuiver M and Pearson GW, 1993, Radiocarbon 35(1):1

With 40 year southern hemisphere offset as recommended by Vogel, Fuls & Visser, 1993, Radiocarbon 35(1):73

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0)
95% confidence interval is 1424 BC to 1063 BC 3373 CAL BP to 3012 CAL BP (95%)

68% confidence interval is 1392 BC to 1203 BC 3341 CAL BP to 3152 CAL BP (68%)



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RAFTER RADIOCARBON LABORATORY
Radiocarbon Laboratory Measurement Report

R Number : 18789/8 NZ 8281

Sample ID : 359-5A

Description : wood, 2 Laery St. Lower Hutt R27/68679777

Submitter : W Leask, I R Brown Associates Wellington

Date measured : October 25, 1994 Counting time : 1580 minutes

δ13C : -25.7 per mille Counter : C 7343

Radiocarbon age : 1169 ± 42 years BP

D14C : -135.5 ± 4.5 per mille

Per cent modern : 86.0 ± 0.5 per cent

Measurement standard is NBS I oxalic acid. Background standard is Kapuni well CO2

'Per cent modern' is the absolute per cent modern, corrected for the age of the oxalic acid standard

'Radiocarbon age' is the Conventional Radiocarbon Age

Radiocarbon age, D14C and per cent modern are as defined in Stuiver and Polach, Radiocarbon (1977), 19 353-363

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RADIOCARBON CALIBRATION REPORT

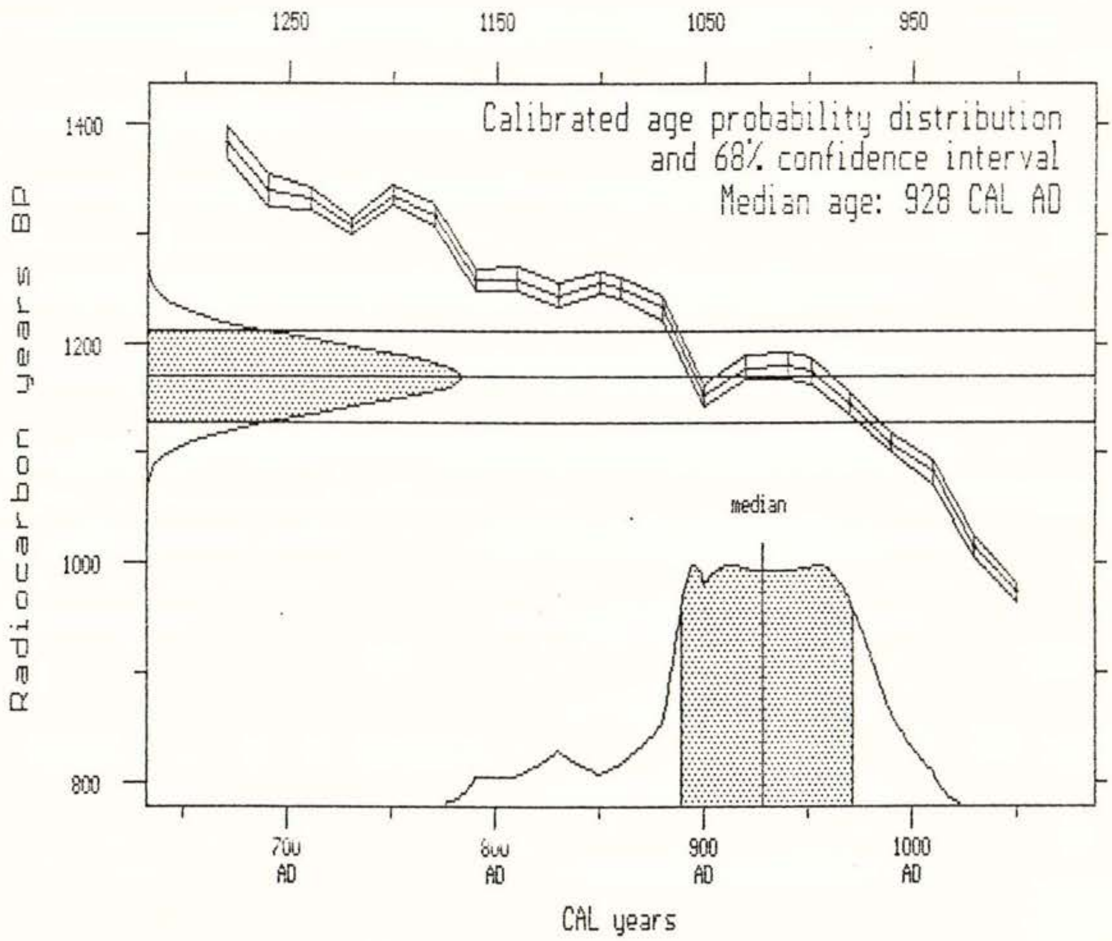
NZ 8281 CONVENTIONAL RADIOCARBON AGE 1169 ± 42 years BP

Bi-decadal radiocarbon calibration from:
Bard E, Arnold M, Fairbanks RG, and Hamelin B, 1993, Radiocarbon 35(1):191
Kromer B, and Becker B, 1993, Radiocarbon 35(1):125
Linick TW, Long A, Damon PE, and Ferguson CW, 1986, Radiocarbon 28(1):943
Pearson GW and Stuiver M, 1993, Radiocarbon 35(1):25
Stuiver M and Pearson GW, 1993, Radiocarbon 35(1):1

With 40 year southern hemisphere offset as recommended by Vogel, Fuls & Visser, 1993, Radiocarbon 35(1):73

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0)
95% confidence interval is 816 AD to 1010 AD 1134 CAL BP to 940 CAL BP (95%)

68% confidence interval is 889 AD to 972 AD 1061 CAL BP to 978 CAL BP (68%)



29 NOV 1994

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NS-CA/6/1-JC

28 November 1994

Dr W Leask
Ian R Brown Associates Ltd
P O Box 9043
WELLINGTON

Dear Dr Leask

Enclosed is the result of one charcoal sample - 359-2C (R18789/3). Also enclosed is the invoice number 14186 covering the cost of this sample.

I have also enclosed the remainder of the charcoal sample as you requested on the submission form.

Best wishes

Jannine Cooper

Encl: Pretreatment and result reports, and invoice.

30 Gracefield Road, PO Box 31312, Lower Hutt, New Zealand, Telephone: 0-4-570 4637, Facsimile: 0-4-570 4657

A Crown Research Institute

Sample Pre-treatment

R: 18789/3 **Surname:** Leask **Operator:** Jannine

Description: Charcoal

Details: Examined microscopically and cleaned in a cold, mild acid wash. The sample was then ground and treated consecutively with hot solutions of acid, alkali, and acid.

Comments:

Fraction dated: Treated charcoal.

Stored: Untreated and treated charcoal, soil, and humic acids.

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Rafter Radiocarbon Laboratory

Accelerator Mass Spectrometry Result

R 18789/3

Description	Charcoal
Sample ID	359-2C
Submitter	W. Leask
	Ian R Brown Associates Ltd

Radiocarbon Laboratory Reference	NZA 4628
Date measured	16-Nov-94
$\delta^{13}C$	-25.75 ‰
* **Age**	329 ± 63 BP
$\Delta^{14}C$	-45.2 ± 7.5 ‰
** **Per cent modern**	95.48 ± .75

Issued 16/11/94

* Reported age is the conventional radiocarbon age before present (BP)

** Per cent modern means absolute per cent modern relative to the NBS I oxalic acid standard.

Age, $\Delta^{14}C$ and per cent modern are as defined by Stuiver and Polach, Radiocarbon 19:353-363 (1977)

The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error component that is based on the analysis of an ongoing series of measurements on ANU sucrose secondary standard. For the present result the system error component is conservatively estimated as .6% (= ± 48 radiocarbon years).

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RADIOCARBON CALIBRATION REPORT

NZA 4628 CONVENTIONAL RADIOCARBON AGE 329 ± 63 years BP

Bi-decadal radiocarbon calibration from:
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Stuiver M and Pearson GW, 1993, Radiocarbon 35(1):1

With 40 year southern hemisphere offset as recommended by Vogel, Fuls & Visser, 1993, Radiocarbon 35(1):73

CALIBRATED AGE in terms of confidence intervals (Smoothing parameter: 0)

95% confidence interval is	1456 AD to	1683 AD	494 CAL BP to	267 CAL BP (82%)
plus	1746 AD to	1806 AD	204 CAL BP to	144 CAL BP (10%)
plus	1934 AD to	1954 AD	16 CAL BP to	-4 CAL BP (4%)
68% confidence interval is	**1504 AD to**	**1603 AD**	**446 CAL BP to**	**347 CAL BP (42%)**
plus	**1615 AD to**	**1668 AD**	**335 CAL BP to**	**282 CAL BP (25%)**
plus	**1789 AD to**	**1792 AD**	**161 CAL BP to**	**158 CAL BP (1%)**
plus	**1950 AD to**	**1953 AD**	**0 CAL BP to**	**-3 CAL BP (1%)**