

# DISTRIBUTION OF GEOLOGICAL MATERIALS IN LOWER HUTT AND PORIRUA, NEW ZEALAND A COMPONENT OF A GROUND SHAKING HAZARD ASSESSMENT

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## ABSTRACT

Geological materials in the Lower Hutt, Eastbourne, Wainuiomata, and Porirua urban areas are mapped and described as part of a multi-disciplinary assessment of seismic ground shaking hazards. Emphasis is mainly on the flat-lying parts of these areas which are underlain by variable Quaternary-age sediments that overlie Permian-Mesozoic age 'greywacke' bedrock. Within the Quaternary-age sediments, the two material types recognised on strength characteristics are:

- 1) Soft sediments, typically composed of normally consolidated, fine-grained materials (sand, silt and clay), with typical standard penetration values (SPT) of <20 blows/300 mm; and
- 2) Loose to compact coarser-grained materials (sand, gravel), with SPT values of >20 blows/300 mm.

The total thickness and nature of Quaternary-age sediments in the study areas is described, with particular emphasis on the thickness and geotechnical properties of near-surface sediments. Such sediments are considered likely to have a significant influence on the amplification and attenuation of ground shaking intensity during earthquakes.

In the Lower Hutt valley, near-surface soft sediments greater than 10 m thick have an areal extent of ~16 km<sup>2</sup>. Such soft sediments underlie much of Petone and the Lower Hutt urban and city centres, and have a maximum known thickness of 27 m near the western end of the Petone foreshore. In the Wainuiomata area, near-surface soft sediments greater than 10 m thick have an areal extent of ~3 km<sup>2</sup>, and attain a maximum thickness of 32 m. In Porirua, near-surface soft sediments have a maximum thickness of 14 m, cover an area of ~2 km<sup>2</sup>, and underlie much of the city centre. In the Lower Hutt valley the total known thickness of Quaternary-age sediments, including near-surface soft sediments is 300 m. Quaternary-age sediments are very much thinner in other areas, with thicknesses of 60 m recorded in Wainuiomata, 10 m in Eastbourne, and 90 m in the Porirua area.

## INTRODUCTION

A multi-disciplinary study of the ground surface response to earthquakes in the Lower Hutt and Porirua areas was undertaken during 1991-92 by the Institute of Geological and Nuclear Sciences Limited (IGNS), formerly DSIR Geology and Geophysics, for the Wellington Regional Council. The study has involved component studies of surface and sub-surface geological mapping [this paper], penetrometer probing [18], weak motion earthquake records [21], and strong motion accelerograph records [17]. The overall assessment of ground shaking hazard incorporates information from all these studies, and is presented in Van Dissen et al. [23], of this volume.

Local geological conditions are known to influence the character of earthquake ground motions [3,22]. Many workers have studied geological information to improve the quantification of the variations in the ground shaking hazard as a result of geology. The geological materials that have been identified as having most effect on shaking intensities are deep, soft soils [16]; thick alluvial or diluvial layers [13]; and 'soft' (soil) sites [15].

The primary aim of this paper is to identify areas of thick and/or low strength soil that are most likely to influence and modify ground shaking during earthquakes affecting the Lower Hutt and Porirua areas. The soils are mapped according to their geotechnical properties, including broad strength characteristics and grain size as well as their thickness. For the purposes of this study, the mapping units selected as important for the definition of ground shaking hazard zones were based on the following parameters:

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- 1) distribution, thickness and properties of soft sediments<sup>1</sup>, within 30 metres of the ground surface; and
- 2) distribution and thickness of all normally-consolidated Quaternary-age sediments<sup>2</sup> overlying bedrock (i.e. the total depth to bedrock).

The geology and geomorphology of the Wellington region is briefly discussed. The surface geology of the Lower Hutt and Porirua study areas is described using geological map units common to both areas. The geological maps have been compiled from the examination of aerial photographs, supplemented by field checking, a review of published literature (e.g. [1,6,8,9,10,14,19]) and unpublished reports and data held in IGNS files.

The sub-surface geology of the Lower Hutt and Porirua study areas is assessed using data from drillholes, together with information on the geotechnical properties of the Quaternary sediments. Sub-surface geological data in the Lower Hutt valley was initially collated by Fry [7] from Wellington Regional Council and local borough records, and compiled on to a computer database, which was later expanded to include geotechnical testing data [4]. Following the addition of new sub-surface data from the Wainuiomata and Eastbourne areas this "expanded" database was used for the present study. For the Porirua area, sub-surface geological information has been compiled mainly from existing site data contained in IGNS and Porirua City Council records.

## GEOLOGICAL SETTING

During the Quaternary (last 2 million years), the topography of the Wellington region has evolved in response to climatic, sea-level and tectonic changes. The major elements of the landscape have been formed as a result of crustal deformation (uplift and subsidence) associated with strike-slip movements along major north-east trending faults (e.g. Wellington Fault, Ohariu Fault). Hills with steep to moderately steep slopes and rounded to flat tops rise to heights of 400 m, and large rivers (e.g. Hutt, Wainuiomata) and several small streams drain both local and regional catchments of variable size. Port Nicholson (Wellington Harbour) and Porirua Harbour form major coastal inlets (Fig. 1).

Bedrock in the region is Torlesse Supergroup rocks of Upper Paleozoic (Permian) to Mesozoic age (280 - 65 million years ago), comprising interbedded indurated sandstone and mudstone, generally referred to in New Zealand as 'greywacke and argillite', or 'greywacke'. As a result of many phases of tectonic deformation these rocks are complexly folded and faulted, and are also closely jointed [14,20,24]. The general trend of bedrock structures (bedding, major faults) is north to northeast [14,24]. The unweathered, intact bedrock is generally strong to very strong, although the rock mass is somewhat weaker because of closely spaced (0.1 - 0.5 m) joints and the presence of many sheared zones. At the ground surface, the bedrock is typically moderately to highly weathered, but on steeper slopes (e.g. coastal and inland cliffs) exposures are

generally only slightly to moderately weathered because erosion has removed the more weathered materials.

Modification of the landscape by erosion has been accompanied by the deposition of coarse grained slope and colluvial deposits at the base of steep slopes (e.g. Wellington Fault scarp). Most of the soft, fine grained sediments in the region are alluvial, estuarine or marine in origin, and have been deposited mainly in the larger stream and river valleys of the region (e.g. Hutt, Wainuiomata and the Porirua Basin - Fig. 1).

## STUDY AREAS

The distribution of geological materials in the Lower Hutt and Porirua study areas is shown on the geological map (Fig. 1). In addition to bedrock and man-made fill, five units of Quaternary sediment are recognised at the ground surface. Descriptions of the soft sediment units, bedrock and fill materials are summarised in Table 1. In the geological maps (Fig. 1) differentiation of the units is based mainly on surface morphology, depositional environment, and material type. Coarse-grained alluvial sediments are present along the larger rivers and streams, whereas fine-grained marine, beach and estuarine deposits are more typical of land areas adjacent to the Wellington and Porirua harbours. Almost all of the flat-lying areas underlain by Quaternary sediments have been utilised for city, urban and industrial developments, while the surrounding 'greywacke' hills are only partly utilised for housing development; the remainder being mostly farmland.

The Lower Hutt study area includes three flat-lying sub-areas (Lower Hutt, Wainuiomata and Eastbourne - Fig. 1), which are described separately. The Porirua study area is dominated by the two arms of Porirua Harbour (Porirua Arm and Pauatahanui Arm), but is discussed here as one area. Details of the geology of each area (Lower Hutt, Wainuiomata, Eastbourne and Porirua) are discussed below. The thickness of soft sediments in each area is shown by 10 m (isopach) contours in Fig. 2, and the total thickness of Quaternary sediments is shown by 50 m contours in Fig. 3. It should be noted that in the latter figure, the total thickness of Quaternary sediments includes all near surface soft sediments. However, for the purpose of this study thin (<10 m) Quaternary sediments (such as colluvium and slope deposits) are included with the underlying bedrock.

The 10 m isopach (sub-surface sediment thickness) contours on near-surface soft sediments shown in Fig. 2 are generalised because of scale limitations. Generalised contours are considered appropriate for this regional assessment because they delineate the maximum extent of thick soft sediments. Detailed appraisals of smaller areas (e.g. Lower Hutt City centre, where there are more closely spaced drillholes) show rapid vertical and horizontal variations in sediment types and thickness that cannot be represented at a regional scale. The 50 m contour interval for the total thickness of Quaternary sediments (ie depth to bedrock) in Fig. 3 reflects the wider distribution and greater thickness of these sediments within each study area.

## LOWER HUTT

The wedge-shaped Lower Hutt valley is a result of down-warping of the Port Nicholson area in association with strike-slip movement along the Wellington Fault [19]. The pronounced, north-east striking fault line scarp of up-faulted 'greywacke' bedrock forms the north-western side of the valley, while the south-eastern side is bounded by another steep bedrock ridge. The valley has been infilled with variable fine to coarse-

<sup>1</sup> In this paper, the term soft sediments is used to refer collectively to a number of normally-consolidated fine-grained engineering soils (comprising sand, silt and clay) with SPT values that are generally <20 blows/300 mm.

<sup>2</sup> Quaternary-age sediments are referred to hereafter as Quaternary sediments.

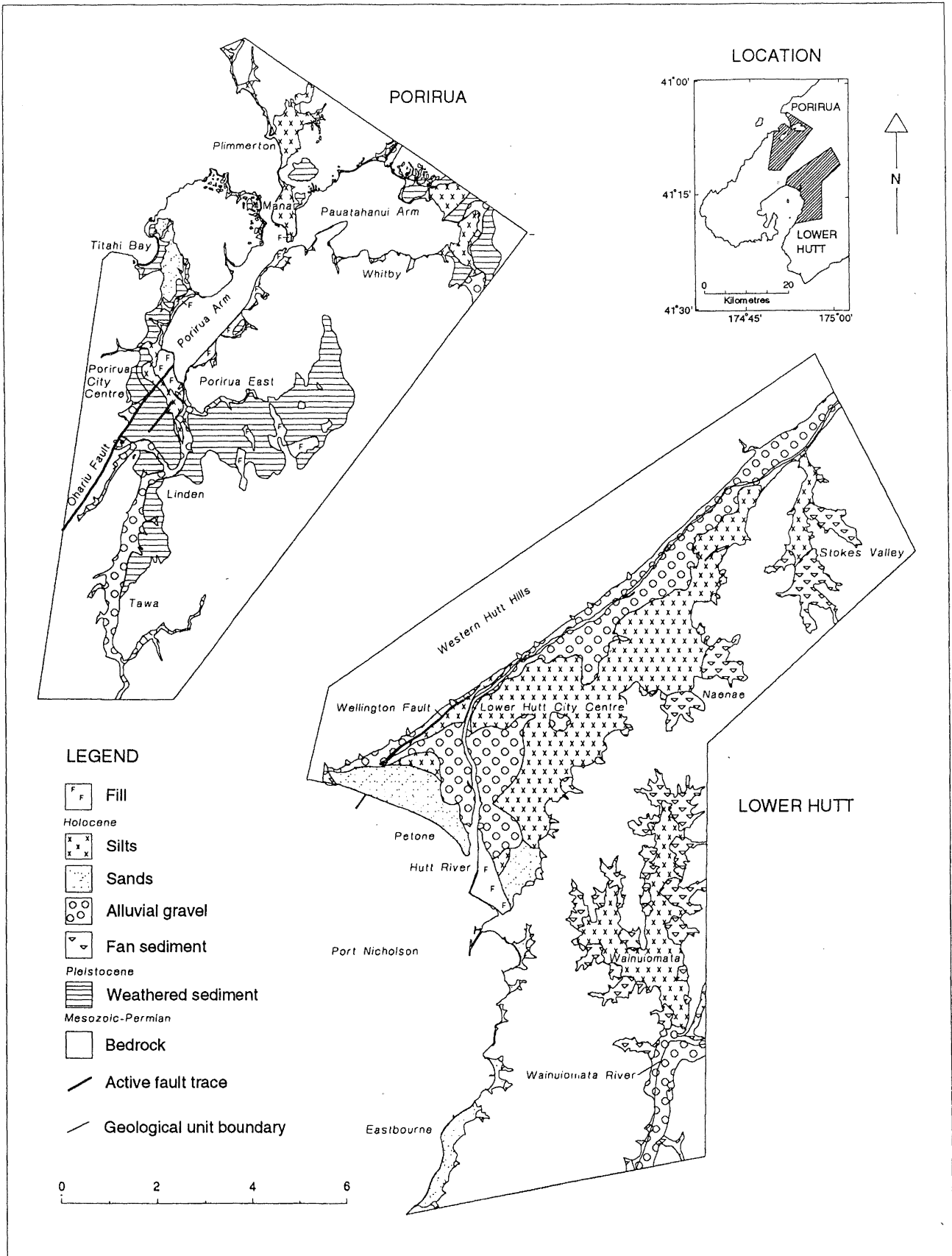


Figure 1: Surface geological map

Table 1: Descriptions of geological units to accompany surface geological map on Figure 1

Geological unit	Surface type and location
Fill	Land surface reclaimed from harbour edge (underlain by marine sediments). Cut and fill operations during subdivision development on the hills of Porirua East (underlain by weathered sediment and bedrock).
HOLOCENE	
Silt	Alluvial surfaces or swamps, sometimes organic and may include peat (backwater reaches of the Hutt River, Wainuiomata and the Taupo Swamp at Plimmerton). Areas of recent accumulation of marine and estuarine silt near harbour edge. Surfaces underlain by silt and sandy silt.
Sand	Beach and dune surfaces (at Petone and Titahi Bay respectively). May contain shells or thin peat layers. Surfaces underlain by sand or gravelly sand.
Alluvial gravel	Alluvial surfaces close to present day stream and river courses (eg. Hutt River, Wainuiomata River). Surfaces underlain by sandy gravel.
Fan sediment	Fan surfaces along valley sides. Surfaces underlain by gravelly silty sand and sandy gravel.
PLEISTOCENE	
Weathered sediment	Older marine and alluvial surfaces preserved in the Porirua area. These surfaces have not been areas of active sedimentation during the Holocene. Surfaces are underlain by silt, sand and gravel (including an extremely weak sandstone at Titahi Bay).
UPPER PALAEOZOIC - MESOZOIC	
Bedrock (Torlesse Supergroup 'greywacke')	At the ground surface, moderately to highly weathered except on steeper slopes where it may be slightly weathered. The depth of weathering is up to 30 metres. Colluvial deposits are commonly preserved in former valleys.

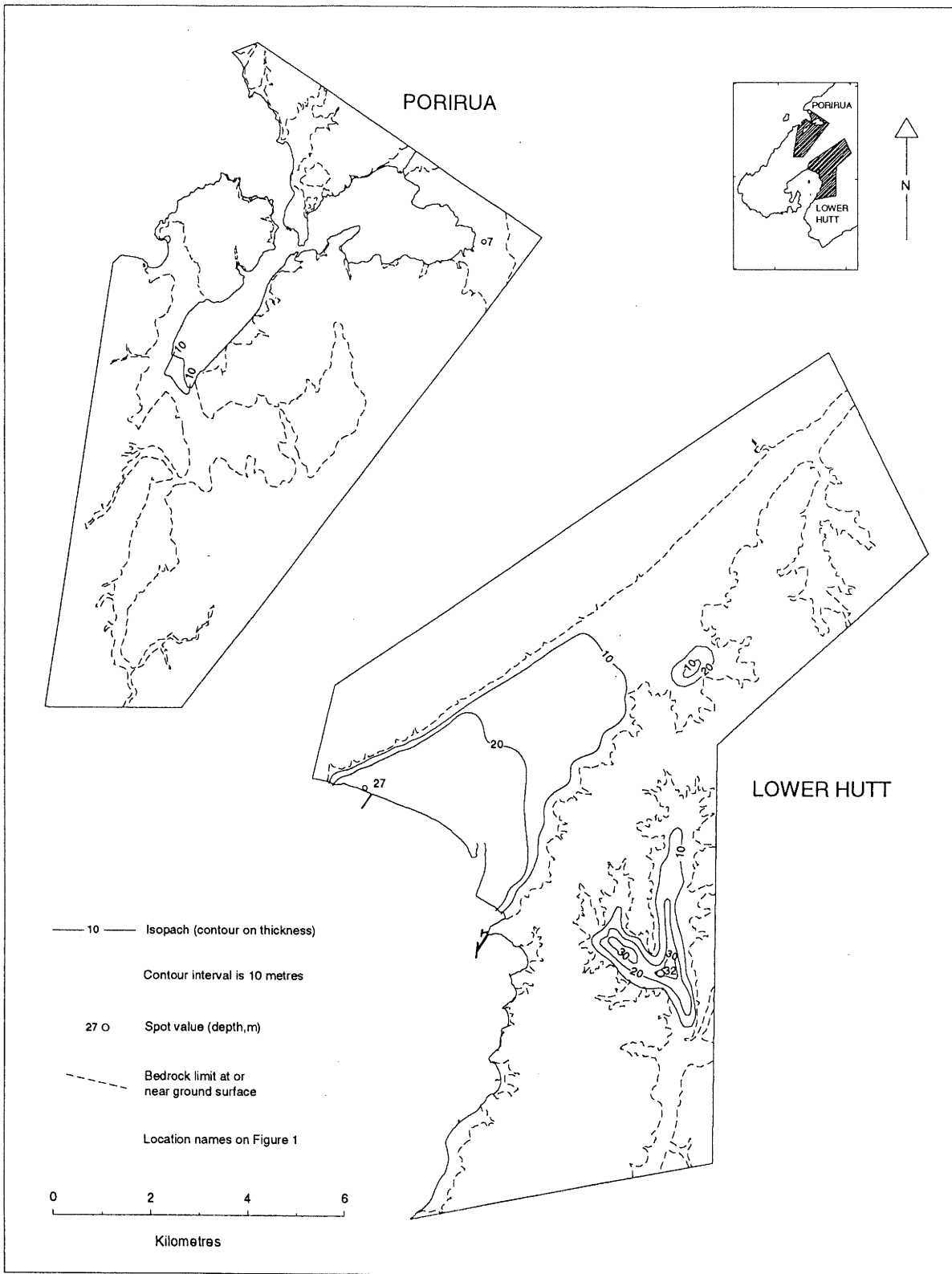


Figure 2: Contours on thickness of soft sediments

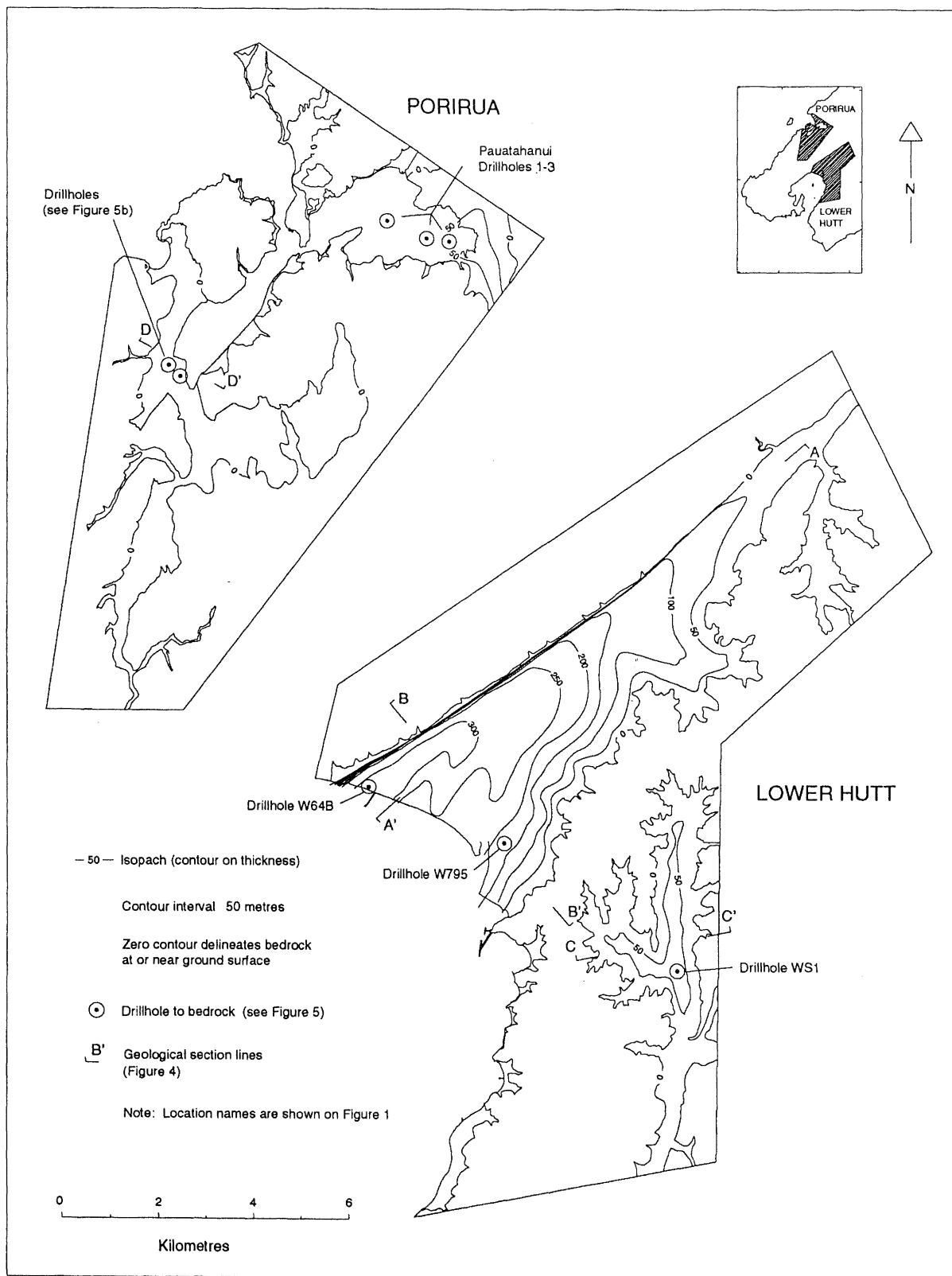


Figure 3: Contours of total thickness of Quaternary sediments

grained alluvial materials (gravel, sand, silt) deposited along the course of the Hutt River. Fan alluvium derived from the valley sides, is present in some areas, together with silt and sand deposited by smaller streams on the valley floor. At the southern (Petone) end of the valley these terrestrial deposits merge with the coastal (marine) beach deposits and estuarine silt and sand [8,19]. In most areas 'greywacke' bedrock is covered with a thin veneer (normally <5 m thick) of loess, colluvium and slope-wash deposits. In places on the western hills of the Hutt valley old gravel deposits are preserved [19].

Information on subsurface geology in the Hutt Valley comes essentially from drillholes drilled for groundwater and foundation investigations over the past 40 years. The drillhole database contains records of 850 holes, of which 370 holes are deeper than 5 m, 20 are deeper than 50 m, and the remainder are less than 5 m deep. The holes have been drilled using a variety of techniques, and the quality of drillhole logs varies widely. The coverage is not uniform over the valley area, with the greatest density of holes in the Petone and Lower Hutt City centre areas.

In the Hutt Valley floor, geological materials within 30 m of the ground surface range from coarse gravel to fine-grained silt and clayey silt. The units present include parts of the Taita Alluvium, Melling Peat, Petone Marine Beds and the Waiwhetu Artesian Gravel [19]. Where the top of the Waiwhetu Artesian Gravel is 10 to 30 m below the ground surface, it acts as the principal aquifer for the Hutt valley groundwater resource [6]. This 'compact' sandy gravel is present under the whole valley, and is estimated to be 30 to 50 m thick. The materials below the aquifer are mainly gravels, and include units such as the Wilford Shell Bed and the Moera Basal Gravel [19]. The total thickness of coarse-grained alluvial sediments in the Hutt Valley is illustrated by the long section and cross section (A-A' and B-B') in Fig. 4. Detailed stratigraphy of these deposits is shown by two drillhole logs (Fig. 5a).

A sequence of interbedded terrestrial, estuarine, and marine deposits overlie the gravel aquifer. In these overlying deposits the lateral and vertical sedimentary relationships are complex, with channelling and overlap resulting in lensing and inter-fingering of materials. Many of the materials are fine-grained, have high water contents (firm silt, soft silt, firm silty clay and 'loose' fine to medium sand), and low SPT values (<10 blows/300 mm, Table 2). They may also include organic layers in former areas of poor drainage away from the Hutt River channel, such as at Naenae. Although the fine-grained sediments generally act as an aquiclude for the artesian system, the water table may be close to the ground surface in places where the overlying materials contain lenses of more permeable sediments. Coarser grained beds and lenses (e.g. gravelly sand) may form up to 40% of the total thickness of the near-surface sediments at specific points within the area delineated by the soft sediment contours. Shear wave velocities of 175 m/s have been measured in some soft sediment areas [18].

In Fig. 2, contours showing the thickness of soft sediments under Petone are drawn at the base of the Petone Marine Beds. The maximum thickness of soft sediments in the area is 27 m, at a point close to the western side of the valley (Fig. 2). Further up valley the soft sediments gradually thin and grade laterally into the Taita Alluvium under the Lower Hutt City centre and towards Naenae (Figs. 2 and 4). The area underlain by soft sediments greater than 10 m thick includes the lower half of the Hutt Valley and covers an area of approximately 16 km<sup>2</sup>. The northern end of the Hutt valley, and also Stokes Valley, is

thought to be predominantly infilled with coarse river gravel and fan alluvium, and which contains little soft sediment.

In Fig. 3, contours showing the total thickness of Quaternary sediments (i.e. depth to bedrock) in the Lower Hutt valley are based on gravity measurements [5] with control provided by two deep (>150 m) drillholes (logs in Fig. 5a). On the western and eastern sides of the valley, the bedrock surface has been projected down from the surrounding hills to tie into drillhole control points. As shown in Figs. 3 and 4, much of the valley has more than 150 m of Quaternary sediments overlying bedrock, with a maximum depth of about 300 m in the south-west corner of the valley close to the Port Nicholson foreshore at Petone. In Stokes Valley, the shape of the bedrock surface has been estimated by downward projection of the surrounding hills, giving a maximum sediment thickness (depth to bedrock) of 25 m.

### WAINUIOMATA

The Wainuiomata area is located in two western tributary valleys of the Wainuiomata River, and has a general elevation of about 90 m above sea level. Tectonic down-warping, along with aggradation by the Wainuiomata River, has effectively dammed the courses of these tributary streams, and the valleys have been infilled, initially with fan alluvium derived from the valley walls, and more recently with fine-grained alluvial and lacustrine sediments (fine sand, silt and clay) [2,8]. By contrast, sediments transported and deposited by the Wainuiomata River are mainly coarse-grained gravels.

Prior to the cone penetrometer test (CPT) probing by Stephenson and Barker [18], there were few drillholes to provide subsurface information on the extent and properties of geological materials underlying the Wainuiomata area. Seven CPT probes delineated up to 32 m of low-resistance materials in the centre of the valley [18]. Existing SPT data indicate N values of between 3 and 10 for silt, and 10 to 30 for more gravelly materials, as shown in Table 2. The higher SPT values are likely to be associated with fan alluvium deposited closer to sides and heads of valleys, as suggested by the shape of the soft sediment contours (Fig. 2). Data currently available for the Wainuiomata area indicate that the areal extent of soft sediments with a thickness >10 m is about 3 km<sup>2</sup>, with a maximum depth of about 32 m (Fig. 2). The top 19 m of the soft sediment materials have a shear wave velocity of 90 m/s, whereas the velocity of the underlying materials (19-32 m) is 150 m/s [18]. The CPT probing indicates the stiffness of the materials increases with depth [18].

In Fig. 3, the contours indicating depth to bedrock are based on one drillhole in the centre of the valley (Fig. 5b) and the inferred continuation of the surrounding hill slopes beneath the valley floor (Fig. 4). This gives a maximum sediment depth of >60 m in the tributary valley. In the Wainuiomata River valley a maximum depth to bedrock of 35 m was obtained from shallow seismic refraction surveys [11, 12]. However, the seismic refraction surveys were sited 3 to 4 km upstream of the confluence of the western tributary valleys and the Wainuiomata River, and at the Wainuiomata River mouth. Further work is needed to resolve this apparent discrepancy in the depth to bedrock values for the Wainuiomata River and the western tributary valleys.

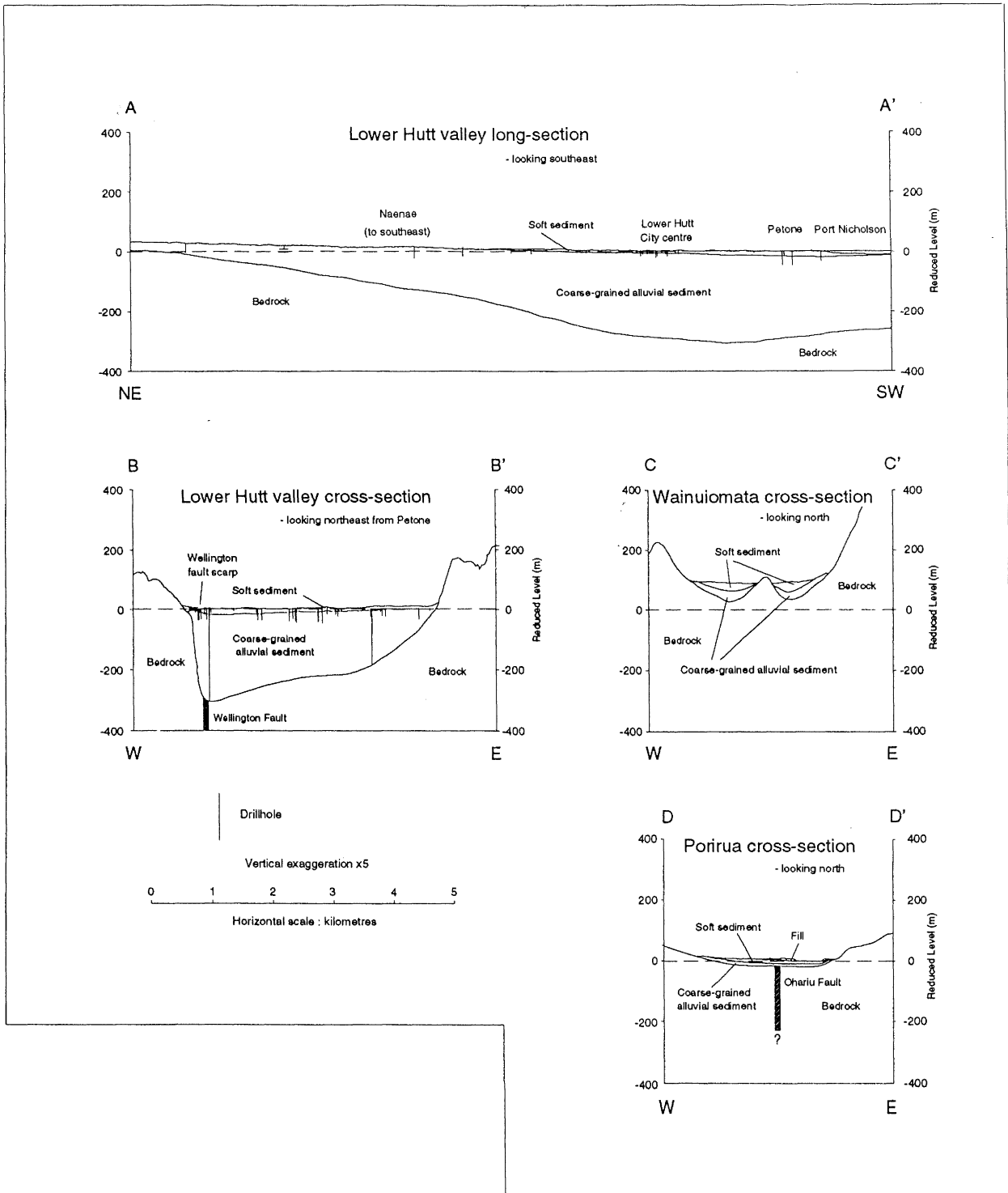


Figure 4: Geological sections

Drillhole #: W 64B  
 Location : THE ESPLANADE  
 Grid reference : R27/6697 9610  
 Reduced level : 2.4 m a.s.l.

Drillhole #: W 795  
 Location : PARKSIDE ROAD  
 Grid reference : R27/6974 9503  
 Reduced level : 1.8 m a.s.l.

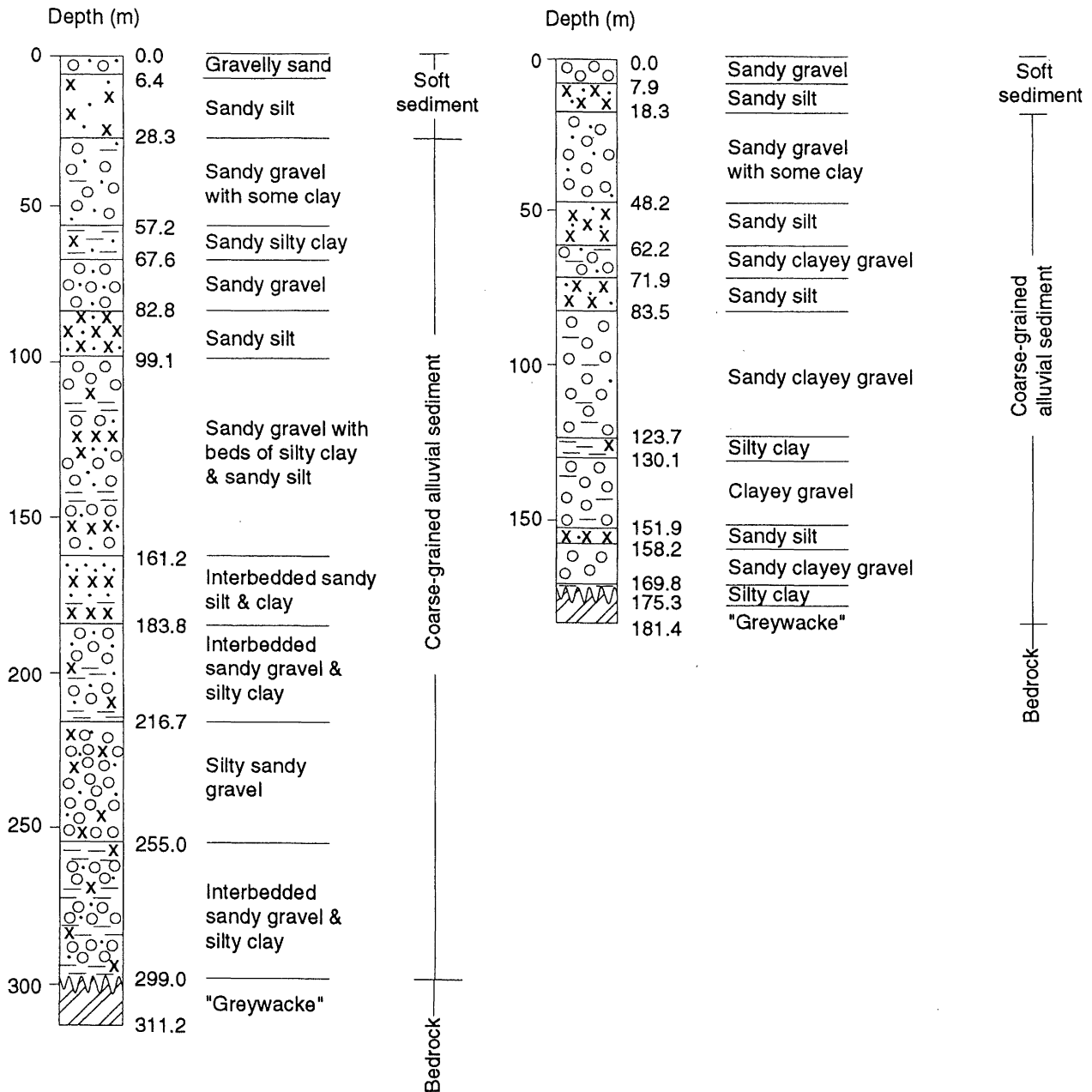


Figure 5a: Lower Hutt drillholes to bedrock

Table 2: Summary of typical geotechnical properties for Quaternary sediments.

MATERIAL DESCRIPTION	USBR <sup>1</sup> CLASS	ENGINEERING PROPERTIES				
		Shear <sup>2</sup> wave velocity (m/s)	Drilling/probing		Laboratory testing <sup>3</sup>	
			SPT (blows/ 300mm) <sup>3</sup>	CPT Cone resistance (MPa) <sup>2</sup>	Water content (%)	Void ratio
<b>LOWER HUTT</b>						
Soft sediments (up to 27 metres thick)						
1) alluvial silt (soft to firm silt, sometimes organic)	ML-OL	175	1-10	1-2	50-100	0.8-1.5
2) alluvial silt (firm silty clay)	CL		10-15	1-3	30-60	0.7-1.0
3) beach sand ('loose' sand or gravelly sand)	SW		5-20	5-10	40-60	0.6-1.1
4) alluvial gravel ('loose' sandy gravel)	GW		10-40	>20		
Coarse-grained alluvial sediments						
1) alluvial gravel ('compact' sandy gravel)	GW		30->60			
2) fan alluvium (silty gravelly sand)	SM		15-30	>20		
<b>WAINUIOMATA</b>						
Soft sediments (up to 32 metres thick)						
1) alluvial silt (soft to firm silt)	ML	90 & 150	3-10	1-2		
2) fan alluvium (silty sandy gravel)	GM		10-30	10-15		
Coarse-grained alluvial sediments						
1) alluvial gravel ('compact' sandy gravel)	GW		30->60			
<b>EASTBOURNE</b>						
Soft sediments						
1) beach sand ('loose' sand or gravelly sand)	SW			5-20		
<b>PORIRUA</b>						
Soft sediments (up to 14 metres thick)						
1) marine silt (silt and sandy silt)	ML-OL	110	1-10	1-5	20-40	1.0-1.5
2) alluvial sediment (sand and gravelly sand)	SW		10-20	5-10	40-60	0.6-1.0
Coarse grained alluvial sediments						
1) weathered gravel (silty gravel)	GC		30-100	>30		
2) alluvial gravel (silty sandy gravel)	GM		15-30	>30		

1. Determined by the authors

2. Stephenson and Barker [16]

3. Local Borough records and other sources

Drillhole #: WS1  
 Location: Wainuiomata Fire Station  
 Grid reference: R27/7327 9259  
 Reduced level : ~ 86 m a.s.l.

PORIRUA STRATIGRAPHIC SECTION

Location: see ① below  
 Grid reference: see ① below  
 Reduced level: ~ 3 m a.s.l.

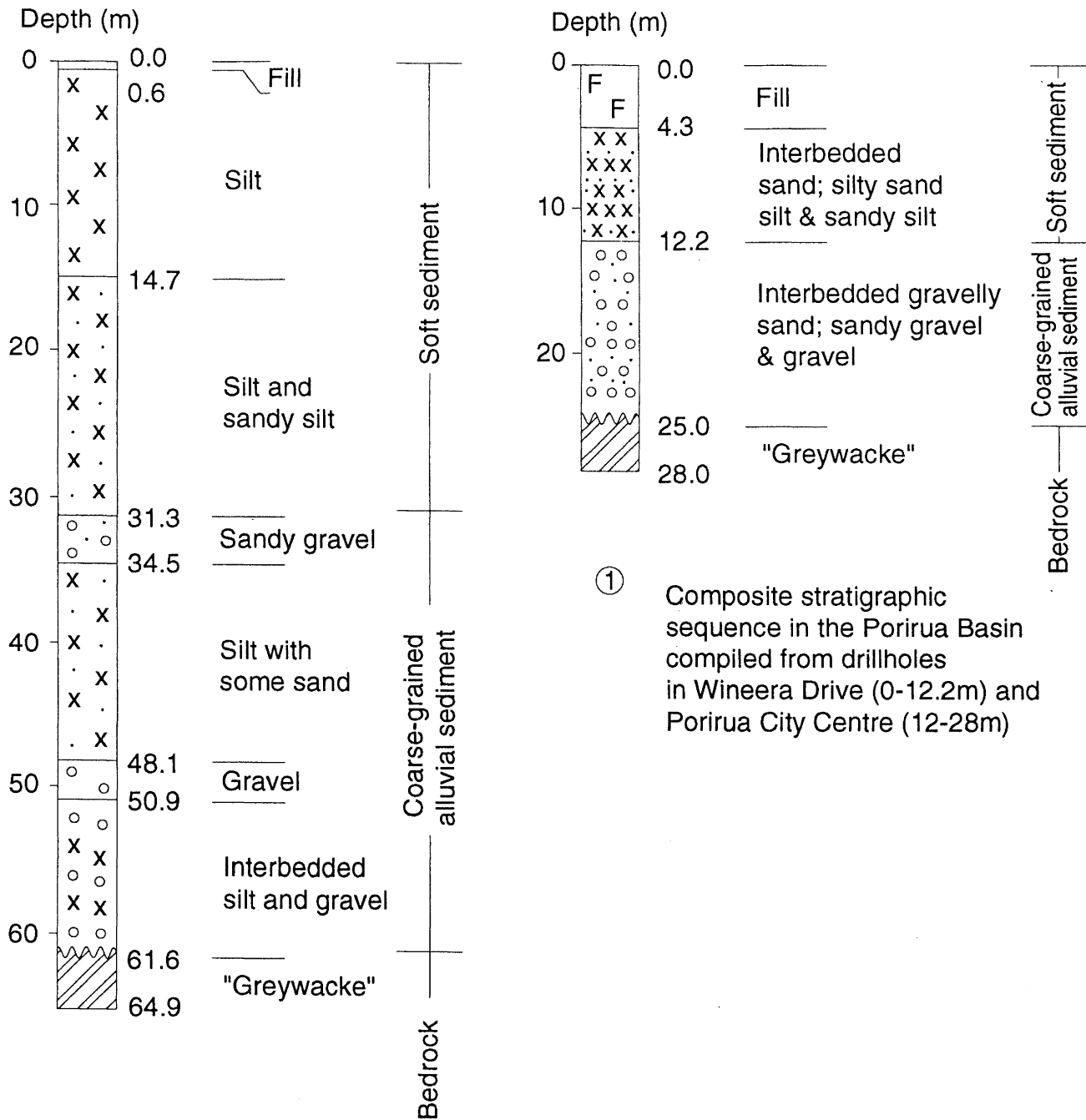


Figure 5b: Wainuiomata drillhole and a stratigraphic column for Porirua based on drillhole data

## EASTBOURNE

The Eastbourne area, and other smaller urban areas in bays on the east side of Wellington Harbour, are part of a narrow, flat-lying coastal strip located at the base of steep bedrock slopes. The dominant materials underlying these areas appear to be mainly loose to medium dense beach sand, and gravel, probably with inter-fingered locally-derived fan alluvium (medium dense gravelly silty sand and silty gravels) close to the base of the steep coastal slopes.

Little data is available on sub-surface materials in these eastern bay areas. Apart from the six CPT probes reported by Stephenson and Barker [18], no drilling records are known. CPT probe data indicates less than 3 m of unconsolidated soft sediments in the Eastbourne area, which cannot be shown in Fig. 2. However, Stevens [19] refers to "a swamp" at Lowry Bay between Eastbourne and Petone which may contain more than 3 m of soft sediments, but no sub-surface data is available. Bedrock is assumed to be close to the ground surface in the Eastbourne area, probably less than 10 m below the ground surface.

## PORIRUA

Porirua Harbour is considered to be a drowned river valley system [1]. Relative sea level changes have resulted in the deposition of inter-collated marine and fluvial sediments along both the Porirua and Pauatahanui arms of the harbour and extending into adjoining streams. As shown in Fig. 5b, drillholes in the Porirua City area indicate a maximum depth to bedrock of about 25 m. However, this is probably a minimum value as the depth relates to a tributary channel, rather than to the centre of the drainage channel into Porirua Arm, where the depth to bedrock is probably somewhat greater. The Quaternary sediments sampled by the drillholes indicate a gradual change from coarse-grained alluvial sediments (sand and gravel) at the base of the sequence (12-25 m), to fine-grained, estuarine and shallow marine sediments (sand, sandy silt, silt) in the top 12 m.

Stephenson and Barker [18] carried out CPT and seismic cone penetrometer test (SCPT) probes at several sites in and around the Porirua Arm, and at Tawa (Fig. 1), recording a maximum soft sediment thicknesses of 10-14 m at the Porirua City centre on land reclaimed from Porirua Harbour. Soft sediments greater than 10 m thick cover an area of about 2 km<sup>2</sup>, and are limited to the present day shoreline close to the Porirua City centre area, and extending to the western side of the Porirua Arm (Fig. 2). As shown in Fig. 5b the soft sediments generally overlie coarse-grained alluvial sand and gravel up to 10-15 m thick.

Drillhole data from the eastern end of Pauatahanui Inlet (Fig. 2) [9] indicate the presence of 13 m of soft sediments (marine silt) overlying alluvial gravel. A nearby seismic line (near Pauatahanui Bridge) is interpreted to show a thin (2-5 m) soft soil layer overlying 30 m of gravel, below which is 60 m of either dense gravel or weathered greywacke bedrock [9]. If the deeper layer is gravel, then the depth to bedrock is much greater than is recognised in the Porirua Arm (this is not unlikely since the Porirua depth is a minimum value as it is not in the centre of the channel).

The limited geotechnical information available in the Porirua area is summarised on Table 2. The lowest SPT values (2-7 blows per 300 mm) were recorded in the fine grained sediments (silt and sandy silt), becoming greater with increasing grain size.

A shear wave velocity of about 110 m/s for soft sediments has been determined by Stephenson and Barker [18]. CPT probes from Mana, Whitby, Linden and Tawa encountered soft sediments with a thickness < 6 m [18].

## DISCUSSION

This paper describes the distribution and properties of soft, unconsolidated sediments that are likely to influence ground shaking hazards in the area. Knowledge of the properties of geological materials and their distribution enables the differences between the effects measured at different weak and strong motion instrument sites to be incorporated into regional ground shaking hazard studies.

The soft sediment materials (delineated on Fig. 2) are more variable in Lower Hutt than in Wainuiomata or Porirua (Figs. 5a & 5b). This is because the Hutt River is a much larger river system, and has a more complex sedimentation regime than smaller fluvial systems such as those in the Porirua and Wainuiomata areas. Whether there are other localised soft sediment areas in the Lower Hutt valley, such as at Naenae is uncertain, and extensive drilling and/or probing investigations would be needed to accurately determine the presence and extent of such areas. Normal site specific investigations that are required for many urban developments should detect thick, soft sediments, allowing appropriate design and construction actions to be taken.

The total thickness of Quaternary sediments delineated by the structure contours on Fig. 3 is reasonably well constrained in the Lower Hutt valley by drillhole records and a gravity survey [5]. However, in the Wainuiomata and Stokes Valley areas the total depth of sediments have had to be estimated by projection of bedrock valley slopes beneath the valleys. This provides reasonable but poorly constrained estimates. In Porirua the total thickness of Quaternary sediments is only well constrained in the City centre area where there are drillholes to bedrock. The more subdued topography of the Porirua area (part of a drowned stream valley system) is reflected in the thinner, but more generally widespread distribution of Quaternary sediments (Fig. 1).

## CONCLUSIONS

The flat-lying parts of the Lower Hutt and Porirua areas are underlain by variable thicknesses of Quaternary, alluvial and marine sediments overlying Torlesse Supergroup 'greywacke' bedrock. On steeper slopes, where there is less urban development, the thicknesses of Quaternary sediments overlying bedrock are normally much less than 10 m.

In the Lower Hutt valley, the Quaternary sediments attain a maximum thickness of 300 m beneath the Petone foreshore and progressively thin up valley towards the north. Over an area of ~ 16 km<sup>2</sup> from the foreshore at Petone to central Lower Hutt there are up to 27 m of near-surface soft sediments, including soft silt, soft silty clay and 'loose' sand. At Naenae a local area of soft sediments up to 20 m deep was found beneath the site of a former swamp.

In Wainuiomata, Quaternary sediments reach a maximum thickness of 60 m in the western valleys tributary to the Wainuiomata River. The top 30 m are soft sediments, and include fine-grained alluvial and lacustrine silt over an area of about 3 km<sup>2</sup>.

In Eastbourne, the Quaternary sediments are less than 10 m thick and significant thicknesses of soft sediments were not encountered.

In Porirua, Quaternary sediments have a maximum thickness of 25 m, except for a local thickening to 90 m at the eastern end of Pauatahanui Inlet. The top 10-15 m of a ~2 km<sup>2</sup> area around the margins of Porirua Arm of the harbour are soft sediments comprising marine silt, beach sand and estuarine sandy silt.

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