Client Report 1999/116

CONFIDENTIAL

Earthquake Hazards of the Bay of Plenty Region – Update to 1999

N D Perrin

1999

Institute of
GEOLOGICAL
& NUCLEAR
SCIENCES
Limited

Institute of
GEOLOGICAL
& NUCLEAR
SCIENCES
Limited

Earthquake Hazards of the Bay of Plenty Region - Update to 1999

by

N D Perrin

Prepared for

ENVIRONMENT BAY OF PLENTY

CONFIDENTIAL

Institute of Geological & Nuclear Sciences Client Report 1999/116

October 1999

Gracefield Research Centre, 69 Gracefield Road, PO Box 30368, Lower Hutt, New Zealand, Telephone: +64-4-570 1444, Facsimile: +64-4-570 4600

A Crown Research Institute

COMMERCIAL-IN-CONFIDENCE

This report has been prepared by the Institute of Geological & Nuclear Sciences Limited exclusively for and under contract to Environment Bay of Plenty. Unless otherwise agreed in writing, all liability of the Institute to any other party other than Environment Bay of Plenty, in respect of the report is expressly excluded.

CONTENTS

Figures:

SUMMARY

Progress in re-defining the hazard and risk of earthquakes in the Bay of Plenty Region has been substantial in the last five years. New felt intensity and peak ground acceleration attenuation models have been developed for both the whole of New Zealand and the special case of the Taupo Volcanic Zone. These new models enable more accurate estimates of future earthquake ground-shaking.

Detailed mapping of active faults and determination of their potential as earthquake sources, particularly in the Bay of Plenty Region, has also been carried out in the last five years. Several maps of predicted isoseismals from representative scenario earthquakes have been derived using data from recent detailed assessments of seismic sources in the region. These source data have also been used to derive a preliminary national probabilistic seismic hazard model, which indicates that the central part of the Bay of Plenty Region has a seismic hazard that may be comparable to that of Wellington.

Continuing analysis of the effects of the 1987 Edgecumbe Earthquake has been used for improved damage ratio determinations, and also to improve the understanding of liquefaction and landsliding resulting from earthquakes. Studies of earthquake-induced landsliding, liquefaction and damage ratios from other notable earthquakes, such as 1929 Murchison, and 1931 Hawkes Bay, have also been undertaken, and the results compared with those from the Edgecumbe earthquake.

Systematic landslide mapping has revealed information on past landslides on Motuhora and White Islands which indicate there is a potential for locally-generated tsunami resulting from future failures, especially during earthquakes.

Recommendations are made on mitigating the hazard of fault rupture, and the need for further work on delineating other aspects of the earthquake hazard in the Bay of Plenty Region is discussed.

1.0 INTRODUCTION

This report summarises data that has become available since the last report to Environment Bay of Plenty (Hull et al, 1994), and is to enable an assessment of the need to undertake further work on the basis of the presently-known level of risk presented by damaging earthquakes in the region.

Active faults in the region have been mapped at a scale of 1:50,000 and are presented here at a scale of 1:250,000. A digital copy at higher resolution than the paper copy has been made available for Environment Bay of Plenty to use for zoning purposes.

To illustrate the earthquake hazard of the Region, representative scenario earthquakes generated by the mapped active faults and other seismogenic structures have been modelled, and isoseismal maps have been produced for each scenario. An extract from the preliminary national probabilistic seismic hazard model of Stirling et al (1998) is also presented, covering the Bay of Plenty Region. An extract from a national model for liquefaction susceptibility is also included, together with a map of liquefaction and landsliding caused by the 1987 Edgecumbe earthquake.

2.0 PROBABILISTIC SEISMIC HAZARD ANALYSIS

Preliminary probabilistic seismic hazard maps have been constructed for New Zealand (Stirling et al, 1998), based on the distribution and long-term seismic behaviour of known active faults and the spatial distribution of historical earthquakes. Subduction zone earthquake sources are also included in the model, along with magnitudes and rupture lengths of large New Zealand earthquakes since 1843, and the instrumental record of seismicity since 1964.

These data are used to predict future ground motions that will occur across the country. Figure 1 is that part of the derived map covering the Bay of Plenty Region, showing peak ground accelerations with a 10% probability of excedence in 50 years. The results of the model for the main towns and cities of the Bay of Plenty Region are shown in Table 1. This model indicates that the central part of the Bay of Plenty Region has a similar seismic hazard to Wellington, and is considerably different from the model of Smith and Berryman (1986), because of the explicit incorporation of active faults into the Stirling et al (1998) model. Smith and Berryman (1986), indicated lower peak ground accelerations of 0.25 to 0.3 g at 10% probability in 50 years for the Bay of Plenty Region (equivalent to MM 8).

It should be noted that the probabilistic seismic hazard of the Region is illustrated by an extract from a national model, and is therefore generalised and at too low a resolution for detailed assessment. The methodology described in Stirling et al (1998), should be applied to a more detailed study specific to Bay of Plenty Region. Furthermore, the ground motions estimated for locations in and west of the Taupo Volcanic Belt (Figure 2) may be overestimated in Figure 1 and Table 1, since recent studies have shown that the ground motions tend to be strongly attenuated in this region (Dowrick and Rhoades, 1999). This effect has not yet been incorporated into the seismic hazard model because of the complexities involved.

TABLE 1: Peak Ground Accelerations with 10% probability of excedance in 50 years from Model of Stirling et al, 1998.

Location	pga (in g) at 10% probability in 50 years	Approx. equivalent Modified Mercalli intensity
Tauranga	0.4	8 – 9
Te Puke	0.45	8 – 9
Rotorua	0.45	8 – 9
Kawerau	0.5	9
Edgecumbe	0.55	9
Whakatane	0.5	9
Opotiki	0.3	8

3.0 SEISMIC SOURCES

3.1 Active Faults

Faults are a prime source of earthquakes. When sufficient stress builds up to overcome the friction on a fault plane, displacement occurs, generating earthquake shaking. These displacements may be either vertical (dip-slip, normal or reverse, depending on the dip of the fault plane and which side moves relatively upward), or horizontal (transcurrent or strike-slip).

The Bay of Plenty Region straddles the boundary between the Taupo Fault Belt (Figure 2), with its associated belt of predominantly normal faults, and the North Island Shear Belt, a zone of predominantly transcurrent faults (Figure 2). Whakatane is in the area where these two different systems of faulting meet (Figure 3).

The active faults that have been identified in the region are shown in Figures 1 and 2. Along with the subducting Pacific tectonic plate and the subduction interface, these are the sources of past and future earthquakes in the region. Data on the estimated seismic potential of these various faults are given in Table 2/

3.2 Subduction Interface and Subducting Slab

The Bay of Plenty Region is also underlain by the subducting Pacific tectonic plate (Figures 2 and 4), which is also capable of generating earthquakes. The main source of large earthquakes by this plate tectonics mechanism is caused by sudden slippage in the subduction interface zone, which is the plane of contact between the top of the subducting (underthrusting) Pacific Plate and the Australian Plate. Most of the interface zone, however, may be uncoupled, (Beavan & Haines, 1997) but at those parts at depths of around 18 km in the Raukumara Sector, and 23 km in the Hawkes Bay Sector (Figure 5 and Woodward Clyde/IGNS, 1997), the plates appear to be coupled and potentially the source of very large earthquakes of up to M_w 8.0.

TABLE 2: SEISMIC SOURCES

Fault	Fault /Seg Length (km)	Average Displ. (Metres) (1)	Slip Rate (mm/year)	Seismogenic Depth (Km) (2)	Estimated Earthquake (M_w) (3)	Average Recurrence (years) (4)	Fault Type (5)	References
Kerepehi North	46	1.8	0.5	15	7.0	3600	N	
Kerepehi South	23	1.8	0.5	15	6.7	3600	N	
Matata	22	2.0	2.0	8	6.3	1000	N	1
Braemar	20	2.0	1.0	8	6.3	2000	N	2
Rotoitipakau	6	1.0	0.6	8	5.8	1650	N	2, 3
Onepu	5	1.0	1.5	8	5.7	650	N	2, 4
Edgecumbe								
---1987 seg	13	1.4	2.5	8	6.5	550	N	4
---coastal seg	9	1.4	2.5	8	6.0	550	N	5
---multi-seg	18	2.0	2.5	8	6.2	800	N	5
Te Teko	8	1.0	1.0	8	5.9	1000	N	4
Awakeri	12	2.0	1.0	12	6.2	2000	N	5
Waiohau								
---Matahina	22	1.0?	1.4	12	6.4	?	Dn	2, 5
---Galatea	58	3.0	1.4	15	7.0	?	Dn	2, 5
---multi-seg	80	3.0	1.4	15	7.1	3000	Dn	5
Whakatane								
---Whakatane	21	1.0	1.0	15	6.5	1000	Dn	2
---Ruatoki	40	3.0	1.0	15	6.8	3000	Dn	2
---multi-seg	61	3.0	1.0	15	7.0	3000	Dn	2
Waimana	50	2.0	0.7	15	6.9	2850	Dn	2
Waikaremoana	24	2.0	0.5	15	6.6	4000	Dn	2
Ngapouri	18	1.0	0.3	8	6.2	3300	N	6
Paeroa	28	2.0	2.0	8	6.4	1000	N	7

Fault	Fault /Seg Length (km)	Average Displ. (Metres) (1)	Slip Rate (mm/year)	Seismogenic Depth (Km) (2)	Estimated Earthquake (M_w) (3)	Average Recurrence (years) (4)	Fault Type (5)	References
Whirinaki	19	1.0	0.3	8	6.3	3300	N	6
White Island								
---Seg A	11	1.5	1.0	8	6.0	1500	N	5
---Seg B	19	2.0	1.0	8	6.3	2000	N	5
---Seg C	21	2.0	1.0	8	6.3	2000	N	5
Rurima								
---seg A	18	2.0	0.6	8	6.2	3300	N	5
---seg B	25	2.0	0.6	8	6.4	3300	N	5
Rangitaiki	19	2.0	2.3	8	6.3	870	N	5
Nukuhou	8	1.0	2.4	8	5.9	400	N	5
Ohiwa	16	2.0	0.7	8	6.2	2850	N	5
Subduction Interface, Raukumara	-	7.8-8.0	-	18	8.0	1300	Thrust	5
Subduction Interface, Hawkes Bay	-	7.8-8.0	-	23	8.0	700	Thrust	5
Subducted Lower Plate	-	-	-	40-200	<8.0	?	Thrust	5

References:
1. Ota et al, 1988 2. Beanland, 1989 3. Beanland et al, unpublished 4. Beanland et al, 1989 5. Woodward Clyde/IGNS, 1997 6. Lloyd et al, unpublished 7.Hull and Nairn, 1988 (unpubllished)

Notes:
1. This value is is assumed to be an acceptable estimate of average slip on the whole fault surface for the purposes of estimating seismic moment.
2. All normal faults assumed to dip at 60°, and strike-slip faults at 80°. These fault dips are accepted in calculating fault areas for seismic moment.
3. Moment magnitude calculated from Wells & Coppersmith, (1994) using a median value of the rupture area versus moment magnitude relationship developed from World-wide empirical data base.
4. This estimate assumes the fault behaves truly in a characteristic fashion with all of the slip accomodated in only the maximum event. In probabilistic estimates of hazard it is accepted that there will be a range of earthquakes on the fault which will accomodate the observed surface fault slip rate.
5. N represents normal faults, and Dn represents dominantly dextral strike-slip with subordinate normal movement.

The subduction interface may be capable of producing earthquakes up to magnitude 8, but only from the locked portion at a depth of around 18 km for the Raukumara section, and 23 km for the Hawkes Bay section (Refer Figure 5). The slip is interpreted to be more aseismic at depths greater than this. Epicentres of earthquakes generated by the subduction interface are therefore at least 100 km from Whakatane, and at least 50 km from the Opotiki District's eastern boundary. A magnitude 8 event on the interface in the Raukumara subduction sector would probably cause strong shaking throughout the Region, but local sources result in higher intensities there.

The subducting crustal slab beneath the Bay of Plenty Region is capable of producing earthquakes up to magnitude 8, but very rarely. Smaller earthquakes with sources within the subducting slab are very common (refer Figure 4), but even large ones are not likely to result in damaging intensities of shaking in the Region. This is because of their distance (including the depth dimension), and because the seismic energy travels up the subducting slab, resulting in the strongest shaking being offset to the east of the epicentre. Seismic waves generated by a large earthquake at 100 km depth could be directly beneath Whakatane, but their path is over 200km long, first up the subducting crustal slab, then through over 100km of more highly-attenuating crust of the Australian Plate which includes the exceptionally highly-attenuating Taupo Volcanic Zone westwards from Whakatane.

4.0 SCENARIO EARTHQUAKES

Six representative scenario events have been modelled from the source data in Table 2, using the new attenuation models (Dowrick & Rhoades, 1999). These have been modelled for particular faults using the new 1:50,000 scale active fault database (refer Figure 6, which is a reduced copy). The scenarios have been selected to give a reasonable geographic distribution, while selected those most likely to be damaging to property in the Region.

A magnitude 7.0 event on the Kerepehi fault Kerepehi (Northern) segment is shown in Figure 7. It is notable that Tauranga is in the MM 7 intensity zone for this event, and MM8 would be experienced on the west side of Tauranga Harbour. The average return period for such an event is 3,600 years. The southern segment scenario has not been modelled because its effects on Tauranga would be less significant than a northern segment event.

The scenario earthquake for the Matata fault is shown in Figure 8. Whakatane and Edgecumbe are both inside the MM 7 zone. This is a smaller event (M 6.3) than the Edgecumbe earthquake (M 6.6) of 1987 (refer Fig 14). Although not modelled, a similar scenario is appropriate for the Braemar fault with slightly changed postions of epicentre and isoseismals. Smaller events would result from rupture on the Rotoitipakau and Onepu faults, which are almost in the same area, and Edgecumbe is also very close and very similar.

Figures 9 and 10 show the fault rupture and isoseismal scenarios for two segements of the Waiohau fault, and Figures 11 and 12 are for Whakatane fault scenarios. It should be noted that for the Whakatane segment of the Whakatane fault, (Figure 11) the standard New Zealand attenuation model (Dowrick and Rhoades, 1999) has been used, while the Taupo Volcanic Zone model would be appropriate for the western half of the isoseismal ellipses. The Whakatane segment of the Whakatane fault is on the boundary between the North Island shear belt (standard attenuation model) and the Taupo Volcanic Zone (more highly-attenuating model). The effect of this would be to reduce the radius of the isoseismals on the western side to a small extent.

Subduction zone earthquakes have not been modelled because it is considered that damaging intensities of shaking are unlikely to occur in the main towns of the region because of their distance from the hypocentres of any such events.

5.0 DAMAGE RATIOS and CASUALTY ESTIMATES

The severity of damage to buildings and their contents as a result of earthquake effects was not addressed in the 1994 report. Studies undertaken by Dowrick and Rhoades (1993, 1995) have provided useful data to enable prediction of the cost of future damaging earthquakes by assessing the cost of claims on commercial plant, equipment and stock, resulting from the 1997 Edgecumbe earthquake. Earlier work was undertake to determine damage ratios for domestic property (Dowrick & Rhoades, 1990), as has been undertaken for other historic earthquakes (Napier 1931-Dowrick et al, 1995), and work is continuing to correlate damage ratios with MM intensities.

A damage ratio is defined as the cost of damage to an item divided by the replacement value of that item. Mean damage ratios can be derived for each Modified Mercalli intensity, and for each type of building.

For domestic and commercial buildings affected by the Edgecumbe earthquake, the mean damage ratios (Dowrick & Rhoades, 1990, 1993) were:

MM Intensity Zone	Mean Damage ratio, houses	Mean Damage ratio, commercial buildings
MM6 Zone	1.0 X 10^{-4}	< 0.001
MM7 Zone	0.0063	0.0026
MM8 Zone	0.021	c. 0.018
MM9 Zone	c. 0.080	0.054

For plant, equipment and stock, the mean damage ratios (approximated from Dowrick & Rhoades 1995) were:

MM Intensity Zone	Mean damage ratio, stock	Mean damage ratio, equipment
MM7 Zone	0.021	0.003
MM9 Zone	0.11	0..049

These mean damage ratios are a summary from much more detailed analysis, which includes the type of construction and age and the robustness of stock. They allow in broad terms the calculation of the likely losses resulting from an earthquake, and the degree of damage expected in various types of buildings.

New Zealand has few deaths recorded as being caused by building damage during earthquakes (with the notable exception of the 1931 Hawkes Bay earthquake), but Dowrick, 1998, made a study of the incidence of deaths in New Zealand earthquakes as a function of building type, damage state and intensity. Most casualties have been in or near unreinforced masonry buildings, and timber buildings have caused no deaths. Other conclusions of this study are that most deaths have been caused by buildings, and over 90% of building-related deaths have occurred at MM10 intensities, and the risk of death in unreinforced masonry buildings in a high-hazard region (e.g. Wellington) are two to three orders of magnitude higher than in a low-hazard region (e.g. Auckland). It should be noted that the central part of the Bay of Plenty Region is a high-hazard area with a seismic hazard comparable to that of Wellington.

6.0 EARTHQUAKE EFFECTS AND MITIGATION

6.1 Fault Rupture

Besides their potential for being the sources of damaging earthquakes, the faults also constitute a ground rupture hazard. Even where a building survives the shaking effects of an earthquake, if it straddles the fault rupture, destruction is almost certain. It is therefore recommended that buildings should not be allowed to straddle a fault.

Damage to buildings from fault rupture is easily avoidable, provided the fault location and the width of associated deformation and secondary rupturing can be established with precision.

The faults on Figure 6 have been located at a resolution of 1:50,000. It should be noted that at this scale, the thickness of a 0.5 mm line represents a width of 25 m, so this level of resolution is not sufficient for site-specific purposes.

To mitigate the hazard of fault rupture, it is recommended that structures intended for habitation or any other critical structures should not be built within 20 m of an active fault trace, which means the precise location of a fault needs to be established at a site, including any indications of secondary rupture or deformation. Therefore it is recommended that District Schemes should include a provision for investigations where the proposed development is within 50 m of the mapped fault location, and the developer should be required to show the proposed development takes the fault into account, either by avoidance, or by an acceptable engineering solution.

There is no nation-wide policy on active faults, but various local authorities have there own rules, which generally follow the recommendation of the former NZ Geological Survey, DSIR (now part of GNS) that buildings should not be built within 20 m of an active fault. A good example is the City of Lower Hutt District Plan which has rules concerning the Wellington fault which include "*Subdivision and development will be managed to ensure that no building is constructed within 20 metres of the fault line, and that no subdivision results in an allotment being created which is unusable for development purposes*". This policy applies to a 150 metre wide "Wellington Fault Special Study Area" (i.e. it extends 75 m either side of the known or inferred location of the fault. The rules further state that, within the special study area, "*An engineering report will be required prior to any development, to ensure that any buildings proposed are not within 20 m of the fault line.....This will ensure that buildings are constructed in a safe manner and at a safe distance from the area susceptible to permanent ground deformations*". Exceptions to this rule are covered by the statement "*The conditions of compliance shall not apply to utilities or accessory buildings which are not for habitable or working purposes.*"

6.2 Earthquake-Induced Landslides and Liquefaction

A liquefaction hazard map for the Bay of Plenty Region (Figure 13) has been generated from a national model developed by Hancox et al (1999), using geological mapping and the inferred susceptibility of certain mapped geological units to liquefaction during earthquakes.
Liquefaction usually takes the form of sound boils, or sand eruptions from fissures when saturated sands are mobilised by earthquake shaking (i.e. sands flow like liquid, with complete loss of strength). Ground subsidence can result from liquefaction, but the potentially more serious problem is lateral spread, where large areas of beach or river bank can slide on very low gradients because of liquefaction of underlying layers.

The experience of the 1987 Edgecumbe earthquake proved that the liquefaction susceptibility of lowland areas in the Bay of Plenty Region is high, and could be a very significant hazard in the event of other large earthquakes. It is therefore important to delineate areas of susceptibility so that future development could take the hazard into account.

The liquefaction susceptibility map in Figure 13 is an extract from a nation-wide model, using estimated physical properties of materials geologically mapped at 1:1,000,000 scale. Further refinement of this model would need to take into account the topography and depth of the water table, because susceptible materials have to be saturated to liquefy, and would need to be compiled at a scale of 1:50,000. However, Figure 13 generally provides a good outline of liquefaction susceptibly in low-lying areas, but is probably an over-estimate around Lake Rotorua because topography and depth to groundwater has not been taken into account.

Liquefaction susceptibility mapping can be carried out by geological mapping and correlation of the estimated susceptibility of mapped geological units with recorded historical instances of liquefaction (as in Figure 14). Further investigations would include compilation of all available subsurface data from drilling (especially where penetration data is recorded), followed by selection of suspect sites for cone-penetration testing.

Liquefaction susceptibility determinations from cone-penetrometry are now very reliable as a result of improved recording and analysis developments in recent years. The technique was well-established in the 1980s (e.g. Sugawara, 1989), and is now widely used.

6.2.1 Ground Damage Resulting from the Edgecumbe Earthquake

Hancox et al, 1997, compiled landslide and liquefaction data resulting from the Edgecumbe earthquake in 1987 (Figure 14). All of these ground-damage effects occurred within the MM7 isoseismal, and the majority are enclosed by the MM9 isoseismal. The results form this work indicated that MM10 intensities might have been experienced at Edgecumbe.

Landslides resulting from the Edgecumbe earthquake were mainly small and shallow, and affected mainly slopes steeper than 40 degrees. Failures of cut slopes steeper than 50 degrees comprised more than 50% of those recorded. In these cases it was mainly pumice and tephra that failed.

Such an earthquake would have generated more landslides if it had been centred in hilly terrain, rather than on the plains, and if the ground had been saturated, failures would have been much more prevalent (the earthquake occurred in early autumn when the ground was relatively dry).

Liquefaction was widespread on the plains, comprising mainly sand boils which had little effect in the rural environment. This effect can be damaging to services, as liquefied sand can fill ducts and pipes, or result in loss of bearing strength causing structures to sink or float. Subsidence of the ground surface can occur as a result of liquefaction, resulting in damage to buildings and inundation by flooding, but it is mainly the related effect known as lateral spread of embankments that caused problems in the Edgecumbe earthquake, where it was mainly bridge abutments and stopbanks that were affected.

6.3 Landslides and Tsunami

The hazard presented by tsunami in the Bay of Plenty has been reported elsewhere (Johnston et al, 1998). One of the mechanisms by which tsunamis occur is large landslides into the sea. In this region, the steep-sided volcanic islands in the Bay of Plenty are particularly susceptible to earthquake-induced landsliding. In particular, Motuhora (Whale) Island, 7.5 km from the coast near Whakatane appears to be particularly hazardous, based on eye-witness accounts of landsliding as a result of an earthquake in 1944 (published in the Bay of Plenty "Beacon" on 7 July 1944).

A shallow earthquake of Magnitude 4.9 occurred just before midday on Sunday 2 July 1944, followed by a Magnitude 4.2 aftershock 6 minutes later. The observers were half a mile offshore from Motuhora when they felt the water under the boat shudder, and then heard a roaring sound as boulders hurtled down the slopes of the island which appeared to be shaking like jelly. They reported slips continuing for a quarter of an hour, sending up clouds of dust "which rose many hundreds of feet above the island". They observed that a large mass of rock fell from the cliffs on the north side of the island. Similar dust clouds were observed from the island and the coastal cliffs between Ohope and Whakatane during the 1987 earthquake.

From this description, the earthquake epicentre must have been very close to the island. Although the records indicate the main shock epicentre was about 9 km to the WNW of Motuhora, the accuracy of the determination of the epicentre is such that it does not preclude the possibility that Motuhora was at the epicentre, which would appear to be the case from the published description.

Aerial photograph studies for landslide mapping reveal signs of extensive landslides from the west and north sides of Motuhora. These coasts seem to be more susceptible to landsliding as a result of greater wave action causing undercutting of the slopes. Only superficial slide scars are recognisable on the south side of the island.

Although no wave was observed from this event, landsliding was ubiquitous on the island, and there is the potential for larger earthquakes to result in major collapse of the island, possibly generating a wave that could be damaging to the coast near Whakatane. Failures with volumes in the order of 1,000,000 m^3 are possible. Since the water depth is only 25 to 50m around the island, these landslides are not likely to have a significantly larger underwater portion, which to some degree restricts their tsunami potential.

White Island may be capable of producing tsunami from sector collapse of the volcano. Landslide scars are apparent on the southwest (Poroporo) and northwest (flank of Ngatoro Peak) sides of the island, with volumes estimated to be in the order of millions of cubic metres. Water depth surrounding the island is about 300 m, and the landslides may have underwater portions larger than their visible portions, increasing their potential to produce tsunami.

It is recommended that further investigation of the tsunamigenic potential of coastal and island landslides be carried out.

6.4 Ground shaking hazard

Areas underlain by deep, soft sediments are often subjected to greater shaking than nearby sites on bedrock due to amplification effects. Deep, soft sediments have lower shear wave velocities than rock, and seismic wave amplitude increases as the velocity decreases. Where there is a marked shear wave velocity contrast between the rock and the soil, resonance effects may also be present.

The possibility of amplification of shaking is generally more significant for large, distant earthquakes. In these cases, damaging intensities can be experienced in areas of deep, soft sediments while damage may be slight or even absent on stiff soils and rock. For nearby earthquakes, amplification effects are usually minimal, partly because the intensity of shaking is already high, and partly because attenuation in soft sediments can even reduce the shaking intensities below that experienced on rock.

The effect of soft sediments is to increase the risk of damaging earthquake shaking in areas where they are present. This is because there are many more earthquake sources involved than just the nearby ones, and consequently a greater frequency of damaging intensities will be experienced in these areas.

Seismic microzoning addresses this hazard by identifying these areas so that appropriate seismic loading codes can be applied for structures. Methodology for microzoning includes geological mapping, compilation of existing subsurface information, and analysis of the effects of past earthquakes (instrumental records and felt reports). New information is then acquired by deploying an array of seismographs, and conducting drilling and seismic cone penetrometry in critical areas. The maps produced show zones of relative shaking hazard so that future development can take account of the ground shaking hazard.

7.0 LIMITATIONS IN THIS STUDY

The New Zealand seismic hazard model is currently being refined and significant changes are expected from the current to the final versions. In particular, the high level of attenuation in the Taupo Volcanic Zone has not yet been incorporated into the model because of the computational difficulties of doing so. Seismic hazard estimates for the Taupo Volcanic Zone (TVZ) and areas west of it are expected to be significantly reduced once the effect of the TVZ can be properly modelled.

8.0 CONCLUSIONS AND RECOMMENDATIONS

1. Preliminary probabilistic seismic hazard modelling shows that the seismic hazard in the central part of the Bay of Plenty Region, including Whakatane District and part of Rotorua District, may be comparable to that in Wellington and therefore significantly higher than previously estimated.

2. A probabilistic seismic hazard model should be constructed for the Bay of Plenty Region with more detailed information, and at higher resolution than the preliminary national model of Stirling et al (1998).

3. To complete stage 1 of the recommendations of Hull et al, 1994, further investigations are required into the active faults and other earthquake-generating structures affecting the region, particularly in relation to return periods and magnitudes. This will require further trenching investigations of active faults, and more detailed mapping of them. The data obtained will be used for more detailed earthquake scenarios, and isoseismal maps should be derived for all possible sources.

4. Ground shaking hazard (microzoning), and liquefaction potential determinations (Stages 2 and 3 of Hull et al, 1994) are justified on the basis of the seismic hazard in the Region.

5. Earthquake hazard synthesis and policy development (Stage 4 of Hull et al, 1994) should then be undertaken to quantify the hazard, and develop avoidance or mitigation measures.

6. A policy on development on or near active faults should be developed along the lines of that adopted by Hutt City.

ACKNOWLEDGEMENTS

The author wishes to acknowledge Mark Stirling and Jim Cousins for valuable discussions, undertaking internal review and suggesting improvements to this report and Mark Rattenbury and Michelle Park for map production.

REFERENCES

Beanland, S., Berryman, K.R., and Blick, G.H., 1989: Geological investigations of the 1987 Edgecumbe earthquake, New Zealand. *NZ Journal of Geology and Geophysics 32: 73-92*

Beanland, S., 1989: Seismotectonic gazard assessment of Matahina Dam. *NZ Geological Survey Client Report 89/9.*

Beavan, J., and Haines, J., 1997: Geodetic coupling of the Hikurangi subduction margin , New Zealand, imaged from GPS data. *EOS Transactions, American Geophysical Union 78 (46):166.*

Dowrick, D.J., 1998: Earthquake risk for property and people in New Zealand. *NZ Nat Soc for Earthquake Engineering Conference Proceedings, March 1998, pp 43-50.*

Dowrick, D.J., and Rhoades, D.A., 1990: Damage ratios for domestic buildings in the 1987 Edgecumbe earthquake. *Bull. NZ Nat Soc. for Earthquake Engineering 23 (2): 137-149*

Dowrick, D.J., and Rhoades, D.A., 1993: Damage costs for commercial and industrial property as a function of intensity in the 1987 Edgecumbe earthquake. *Earthquake Engineering and Structural Dynamics 22: 869-884.*

Dowrick, D.J., and Rhoades, D.A., 1995: Damage ratios for plant, equipment and stock in the 1987 Edgecumbe earthquake, New Zealand. *Bull. NZ Nat Soc. for Earthquake Engineering 28 (4): 265-278*

Dowrick, D.J., and Rhoades, D.A., 1999: Attenuation of Modified Mercalli intensity in New Zealand earthquakes. *Bull. NZ Nat Soc. for Earthquake Engineering 32 (2): 55-89*

Dowrick, D.J., Rhoades, D.A., Babor, J. and Beetham, R.D., 1995: Damage ratios for houses and microzoning effects in Napier in the magnitude 7.8 Hawkes Bay, New Zealand earthquake of 1931. *Bull. NZ Nat. Soc for Earthquake Engineering 28 (2): 134-145.*

Hancox, G.T., Heron, D., and Johnston, D., 1999: ASB Bank disaster contingency project: geological hazard maps and hazard assessment of locations in the North Isalnd, New Zealand. *Inst. Geological & Nuclear Sciences Client Report 1999//16*

Hancox, G.T., Perrin, N.D., and Dellow, G.D., 1997: Earthquake-induced landsliding in New Zealand and implications for MM intensity and seismic hazard assessment. *Inst. Geological & Nuclear Sciences Client Report 43601B*

Hull, A., Downes, G., and Van Dissen, R., 1994: Earthquake hazards of the Bay of Plenty Region. *Inst. Geological & Nuclear Sciences Ltd Client report 333910.12*

Johnston, D.M., Manville, V., Berryman, K., Beetham, D., Chague-Goff, C., Goff, J., 1998: "Hazardscape" Boundaries for the Bay of Plenty Region. *Environment Bay of Plenty Planning Publication* 98/5, 51 p.

Ota, Y., Beanland, S., Berryman, K.R. and Nairn, I.A., 1988: The Matata fault: active faulting at the northwestern margin of the Whakatane graben, eastern Bay of Plenty, New Zealand. *NZ Geological Survey Record 35: pp 6-13.*

Smith, W.D., and Berryman, K.R., 1986: Earthquake hazard in New Zealand: inferences from seismology and geology. *Royal Society of NZ bulletin 24: 223-243*

Stirling, M.W., Wesnousky, S.G., and Berryman, K.R., 1998: Probabilistic seismic hazard analysis of New Zealand. *NZ Journal of Geology & Geophysics Vol 41: 355-375.*

Sugawara, N., 1989: Empirical correlation of liquefaction potential using CPT. *Int. Conference on Soil Mechanics and Foundation Engineering, Vol 12, No 1 pp 335-338*

Woodward Clyde/IGNS, 1997: Matahina power station seismic hazard assessment. *Contract No. NH 95/80. (Unpublished report).*

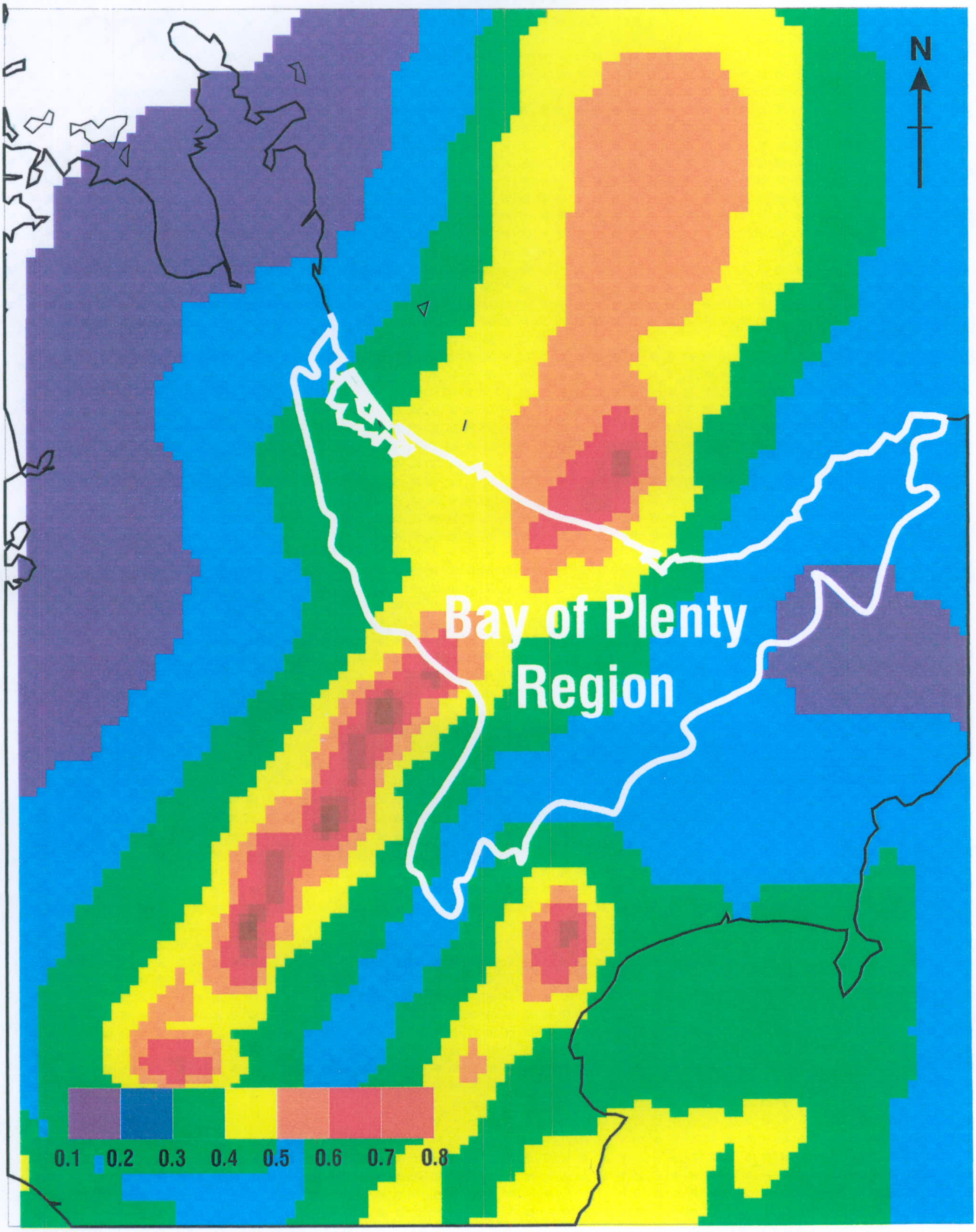

Figure 1: Map of peak ground accelerations (in g) expected at 10% probability in 50 years on rock.

(From Stirling et al, 1998, Figure 7b)

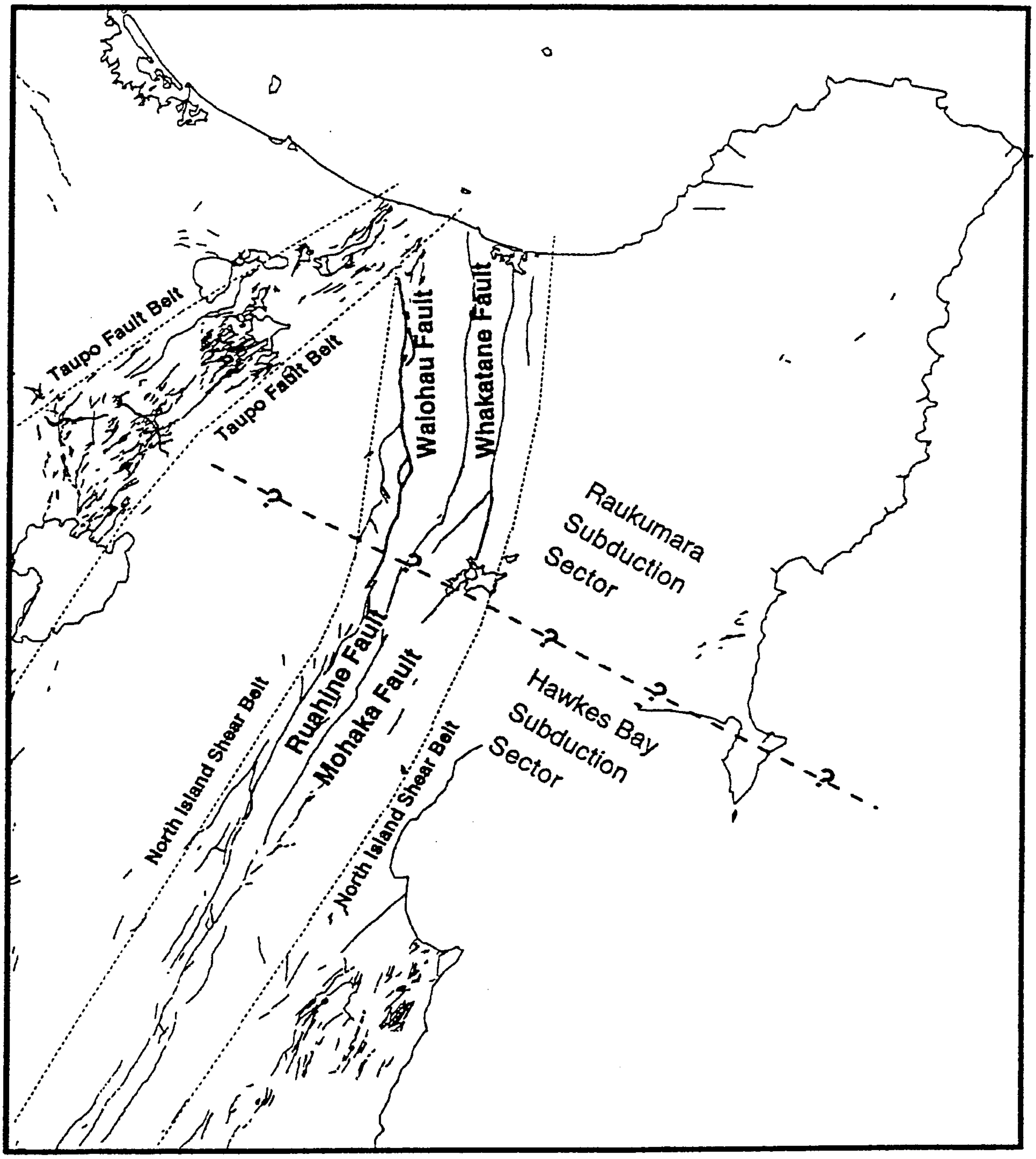

Figure 2 Regional fault setting, and sectors of Hikurangi Subduction Zone.

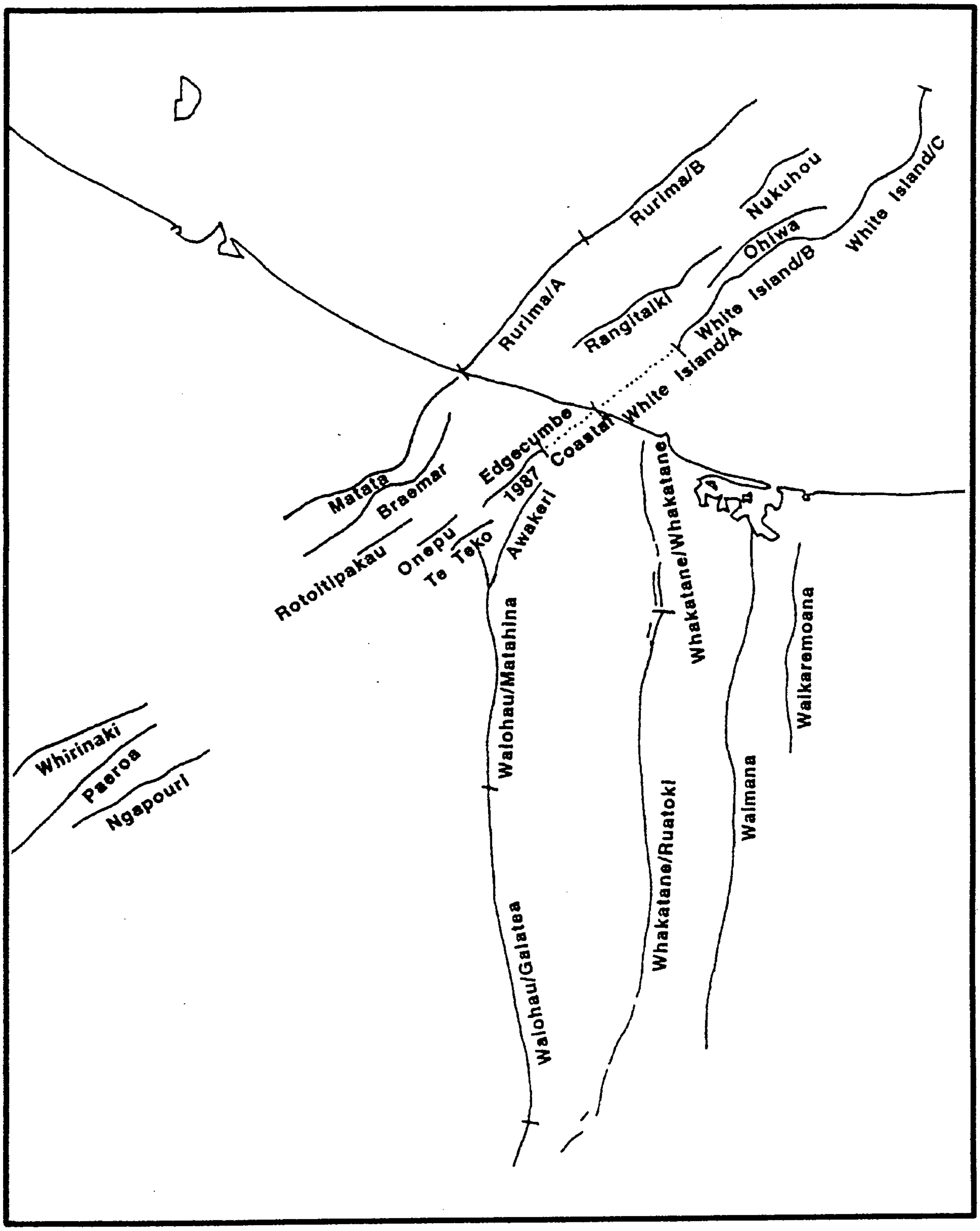

Figure 3 Seismogenic faults in the vicinity of Whakatane, including off-shore faults

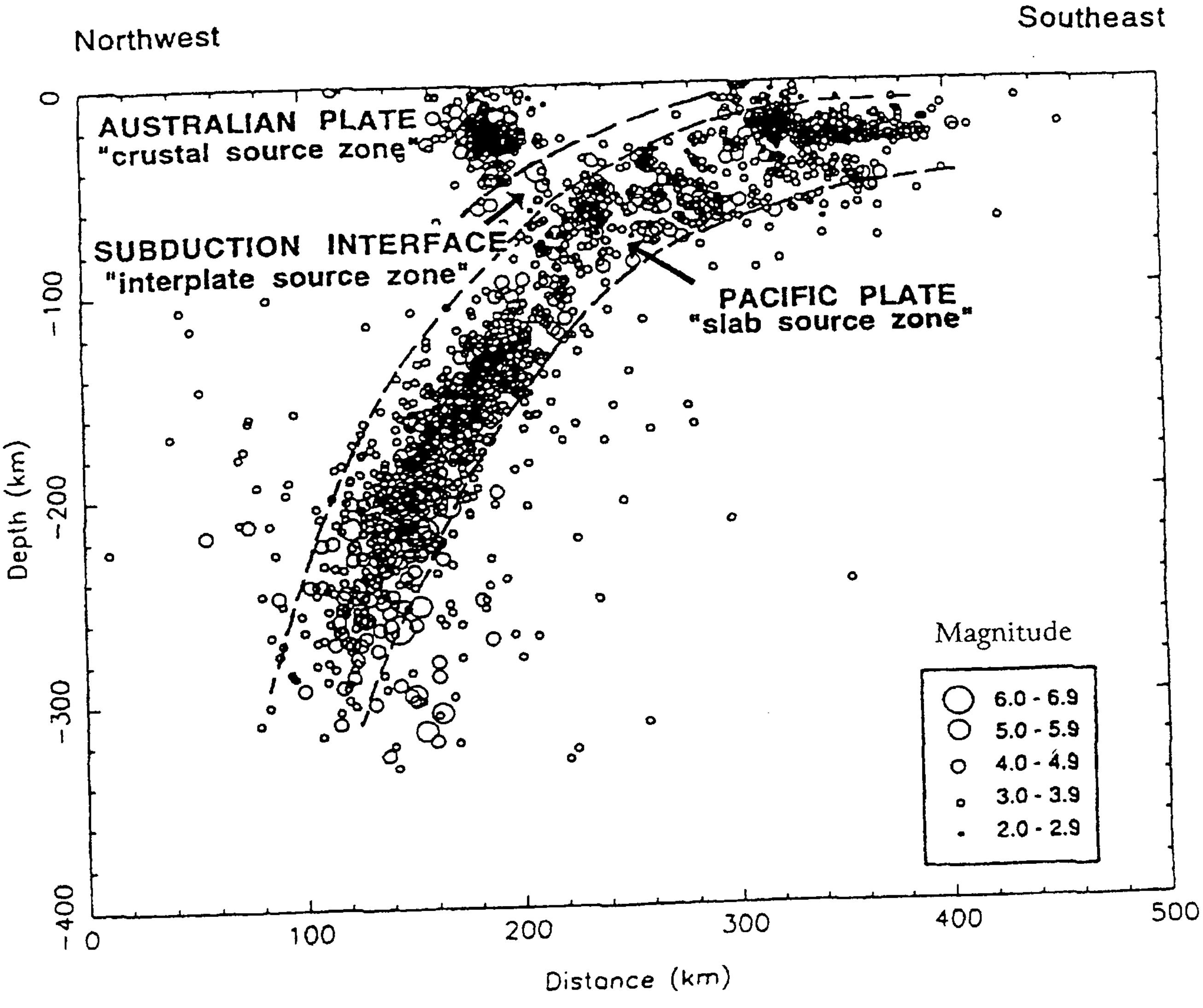

Figure 4 Subduction zone structure in a northwest-southeast section

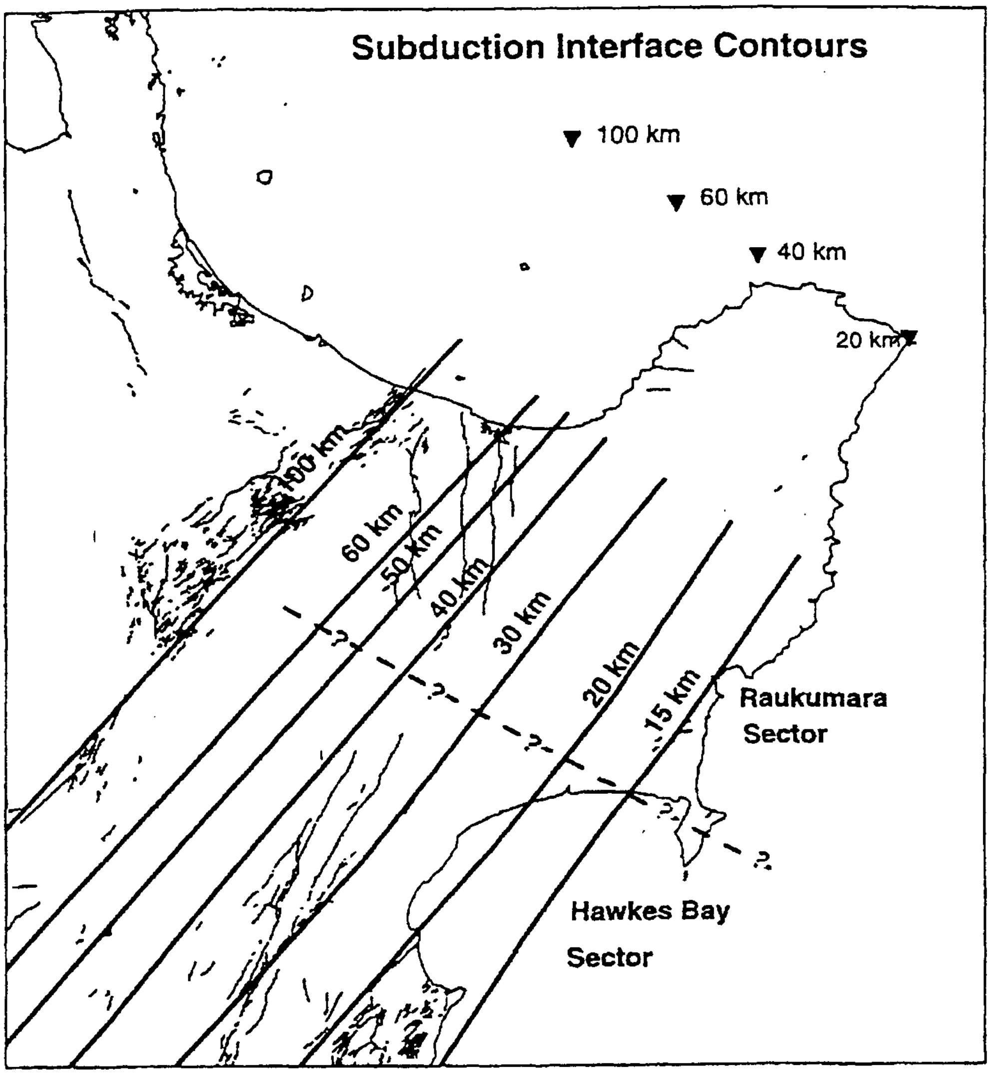

FIGURE 5: Contours on the subduction zone interface (from Woodward Clyde/IGNS, 1997)

APPENDIX 1

MODIFIED MERCALLI INTENSITY SCALE - 1996 *(after Dowrick, 1996**)*

MM1 *People*
Not felt except by a very few people under exceptionally favourable circumstances.

MM2 *People*
Felt by persons at rest, on upper floors or favourably placed.

MM3 *People*
Felt indoors; hanging objects may swing, vibration similar to passing of light trucks, duration may be estimated, may not be recognised as an earthquake.

MM4 *People*
Generally noticed indoors but not outside. Light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building.

Fittings
Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock.

Structures
Walls and frame of buildings, and partitions and suspended ceilings in commercial buildings, may be heard to creak.

MM5 *People*
Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people alarmed.

Fittings
Small unstable objects are displaced or upset. Some glassware and crockery may be broken.
Hanging pictures knock against the wall.
Open doors may swing.
Cupboard doors secured by magnetic catches may open.
Pendulum clocks stop, start, or change rate (H*).

Structures
Some windows Type I* cracked.
A few earthenware toilet fixtures cracked (H).

MM6 *People*
Felt by all.
People and animals alarmed.
Many run outside.*
Difficult experienced in walking steadily.

Fittings
Objects fall from shelves.
Pictures fall from walls (H*).
Some furniture moved on smooth floors, some unsecured free-standing fireplaces moved.
Glassware and crockery broken.
Very unstable furniture overturned.
Small church and school bells ring (H).
Appliances move on bench or table tops.
Filing cabinets or "easy glide" drawers may open (or shut).

Structures
Slight damage to Buildings Type I*.
Some stucco or cement plaster falls.
Windows Type I* broken.
Damage to a few weak domestic chimneys, some may fall.

Environment
Trees and bushes shake, or are heard to rustle.
Loose material may be dislodged from sloping ground, e.g. existing slides, talus slopes, shingle slides.

MM7 *People*
General alarm.
Difficulty experienced in standing.
Noticed by motorcar drivers who may stop.

Fittings
Large bells ring.
Furniture moves on smooth floors, may move on carpeted floors.
Substantial damage to fragile* contents of buildings.

Structures
Unreinforced stone and brick walls cracked.
Buildings Type I cracked some with minor masonry falls.
A few instances of damage to Buildings Type II.
Unbraced parapets, unbraced brick gables, and architectural ornaments fall.
Roofing tiles, especially ridge tiles may be dislodged.
Many unreinforced domestic chimneys damaged, often falling from roof-line.
Water tanks Type I* burst.
A few instances of damage to brick veneers and plaster or cement-based linings. Unrestrained water cylinders (Water Tanks Type II*) may move and leak.
Some windows Type II* cracked. Suspended ceilings damaged.

Environment
Water made turbid by stirred up mud.
Small slides such as falls of sand and gravel banks, and small rock-falls from steep slopes and cuttings.
Instances of settlement of unconsolidated or wet, or weak soils.
Some fine cracks appear in sloping ground. A few instances of liquefaction (ie small water and sand ejections).

MM8 *People*
Alarm may approach panic.
Steering of motorcars greatly affected.

Structures
Building Type I, heavily damaged, some collapse*.
Buildings Type II damaged, some with partial collapse*.

Buildings Type III damaged in some cases.
A few instances of damage to Structures Type IV.
Monuments and pre-1976 elevated tanks and factory stacks twisted or brought down.
Some pre-1965 infill masonry panels damaged.
A few post-1980 brick veneers damaged.
Decayed timber piles of houses damaged.
Houses not secured to foundations may move.
Most unreinforced domestic chimneys damaged, some below roof-line, many brought down.

Environment
Cracks appear on steep slopes and in wet ground.
Small to moderate slides in roadside cuttings and unsupported excavations.
Small water and sand ejections and localised lateral spreading adjacent to streams, canals, lakes, etc.

* Items marked * in the scale are defined in the following note.

** Dowrick, D. J. 1996: The Modified Mercalli Earthquake Intensity Scale - Revisions Arising from Recent Studies of New Zealand Earthquakes. *Bul. N Z Nat. Soc. Earthquake Eng. 29 (2): 92-106.*

MM9 *Structures*
Many Buildings Type I destroyed*.
Buildings Type II heavily damaged, some collapse*.
Buildings Type III damaged, some with partial collapse*.
Structures Type IV damaged in some cases, some with flexible frames seriously damaged.
Damage or permanent distortion to some Structures Type V.
Houses not secured to foundations shifted off.
Brick veneers fall and expose frames.

Environment
Cracking of ground conspicuous.
Landsliding general on steep slopes.
Liquefaction effects intensified and more widespread, with large lateral spreading and flow sliding adjacent to streams, canals, lakes, etc.

MM10 *Structures*
Most Buildings Type I destroyed*.
Many Buildings Type II destroyed*.
Buildings Type III▽ heavily damaged, some collapse*.
Structures Type IV▽ damaged, some with partial collapse*.
Structures Type V▽ moderately damaged, but few partial collapses.
A few instances of damage to Structures Type VI.
Some well-built* timber buildings moderately damaged (excluding damage from falling chimneys).

Environment
Landsliding very widespread in susceptible terrain, with very large rock masses displaced on steep slopes.
Landslide dams may be formed.
Liquefaction effects widespread and severe.

MM11 *Structures*
Most Buildings Type II▽ destroyed*.
Many Buildings Type III▽ destroyed*.
Structures Type IV▽ heavily damaged, some collapse*.
Structures Type V▽ damaged, some with partial collapse.
Structures Type VI suffer minor damage, a few moderately damaged.

MM12 *Structures*
Most Buildings Type III▽ destroyed.
Many Structures Type IV▽ destroyed.
Structures Type V heavily damaged, some with partial collapse.
Structures Type VI moderately damaged.

NOTE TO 1996 NZ MM SCALE

Items marked * in the scale are defined below.

Construction Types:

Buildings Type I (Masonry D in the NZ 1965 MM scale)

Buildings with low standard of workmanship, poor mortar, or constructed of weak materials like mud brick or rammed earth. Soft storey structures (e.g. shops) made of masonry, weak reinforced concrete, or composite materials (e.g. some walls timber, some brick) not well tied together. Masonry buildings otherwise conforming to Buildings Types I - III, but also having heavy unreinforced masonry towers. (Buildings constructed entirely of timber must be of extremely low quality to be Type I).

Buildings Type II (Masonry C in the NZ 1966 MM scale)

Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces. Such buildings not having heavy unreinforced masonry towers.

Buildings Type III (Masonry B in the NZ 1966 MM scale)

Reinforced masonry or concrete buildings of good workmanship and with sound mortar, but not formally designed to resist earthquake forces.

Structures Type IV (Masonry A in the NZ 1966 MM scale)

Buildings and bridges designed and built to resist earthquakes to normal use standards, i.e. no special collapse or damage limiting measures taken (mid-1930's to c. 1970 for concrete and to c. 1980 for other materials).

Structures Type V

Buildings and bridges, designed and built to normal use standards, i.e. no special damage limiting measures taken, other than code requirements, dating from since c. 1970 for concrete and c. 1980 for other materials.

Structures Type VI

Structures, dating from c. 1980, with well-defined foundation behaviour, which have been specially designed for minimal damage, e.g. seismically isolated emergency facilities, some structures with dangerous or high contents, or new generation low damage structures.

Windows

Type I - Large display windows, especially shop windows.
Type II - Ordinary sash or casement windows.

Water Tanks

Type I - External, stand mounted, corrugated iron water tanks.
Type II - Domestic hot-water cylinders unrestrained except by supply and delivery pipes.

H - (Historical) More likely to be used for historical events.

Other Comments

"Some" or "a few" indicates that the threshold of a particular effect has just been reached at that intensity.
"Many run outside" (MM6) variable depending on mass behaviour, or conditioning by occurrence or absence of previous quakes, i.e. may occur at MM5 or not till MM7.
"Fragile Contents of Buildings". Fragile contents include weak, brittle, unstable, unrestrained objects in any kind of building.
"Well-built timber buildings" have: wall openings not too large; robust piles or reinforced concrete strip foundations; superstructure tied to foundations.
▽ Buildings Type III - V at MM10 and greater intensities are more likely to exhibit the damage levels indicated for low-rise buildings on firm or stiff ground and for high-rise buildings on soft ground. By inference lesser damage to low-rise buildings on soft ground and high-rise buildings on firm or stiff ground may indicate the same intensity. These effects are due to attenuation of short period vibrations and amplification of longer period vibrations in soft soils.