A PRELIMINARY SEISMIC MICROZONATION OF VICTORIA, BRITISH COLUMBIA

by

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ABSTRACT

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Earthquakes represent the most serious catastrophic natural hazard in the Victoria area. The city is in Zone 3, the highest Canadian risk category, and an earthquake capable of generating intensity VIII on the Modified Mercalli Scale is postulated with a return period of one hundred years. However, because of differences in local ground conditions, the actual intensity of shaking during an earthquake may be expected to vary considerably. A seismic microzonation map showing this anticipated spatial variation in intensity is obviously required to enable decision makers to evaluate possible alternatives in reducing the harmful effects of future earthquakes.

This study aims to provide such a microzonation of the city of Victoria. It is based on a geomorphological investigation of local bedrock topography and Quaternary stratigraphy, and includes an intensity survey of the last earthquake, occurring in 1946, which caused extensive damage in the city. From a study of borehole data, city engineering reports, pre-development maps, and fieldwork, a three dimensional overview of the city's geomorphology was obtained and mapped. By interviewing persons who had been in Victoria during the 1946 earthquake, over two hundred intensity ratings for that event, ranging from

III to VII, were obtained. An attempt was then made to explain the spatial variations in intensity by correlation with possible causal variables.

A strong correlation was found to occur between intensity experienced and ground conditions, so providing the basis for the development of a three-zone microzonation map of Victoria. On this model, intensities lower than average can be expected in areas where bedrock appears within ten feet of the surface, while in contrast higher than average intensities are anticipated in areas underlain by thick Victoria clay. Over one-half of Victoria falls into the first category, while only small areas of unfavourable ground have been identified.

At present, the only human adjustments to the seismic hazard in Victoria appear to be the application of earthquake-resistant building regulations to major structures and individual insurance policies. It is hoped that the microzonation map included in this study may serve to heighten the perception of risk and so stimulate a greater range of social adjustments.

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Over three hundred Victoria residents contributed their time to discuss the 1946 earthquake. Without their co-operation, the study would not have been possible. Mr. Ainslie Helmcken, City Archivist, provided directories and maps which enabled the author to identify and locate potential respondents. The borehole data was made available through the auspices of the Capital Regional District Planning Board. Mr. Charles Goldie of the City Engineer's Department permitted access to data which added greatly to the geological information.

Thanks are extended to Mr. John Bryant and Mr. Ian Norie for their help in the preparation of illustrative materials. Finally, the author would acknowledge the understanding and support of his wife, Vel, throughout this endeavour.

Therefore, whosoever heareth these sayings of mine, and doeth them, I will liken him unto a wise man, which built his house upon a rock:

And the rain descended, and the floods came, and the winds blew, and beat upon that house; and it fell not: for it was founded upon a rock.

And every one that heareth these sayings of mine, and doeth them not, shall be likened unto a foolish man, which built his house upon the sand.

Matt 7: 24-26

CHAPTER 1

INTRODUCTION

Interest in natural disasters has grown rapidly in the past few decades. Clifford S. Russell has suggested several reasons for this expanded interest.[1] More people have vicariously experienced natural disasters through the medium of television. Concern about nuclear attack has led to a comparison of its effects with those of natural disasters. A feeling has grown that advancing technology will soon give man control over nature. Finally, the public has demanded improvements in the criteria on which expenditure decisions, including those associated with protective measures against natural disasters, are taken.

The natural events which underlie disasters have long been the subject of various disciplines, such as meteorology, hydrology, and seismology. The subject becomes an area of specific interest to geographers when natural hazards are defined in terms of their actual or potential impact on society and viewed as a joint product of the events occurring in nature and the existing human adjustments to those events.[2]

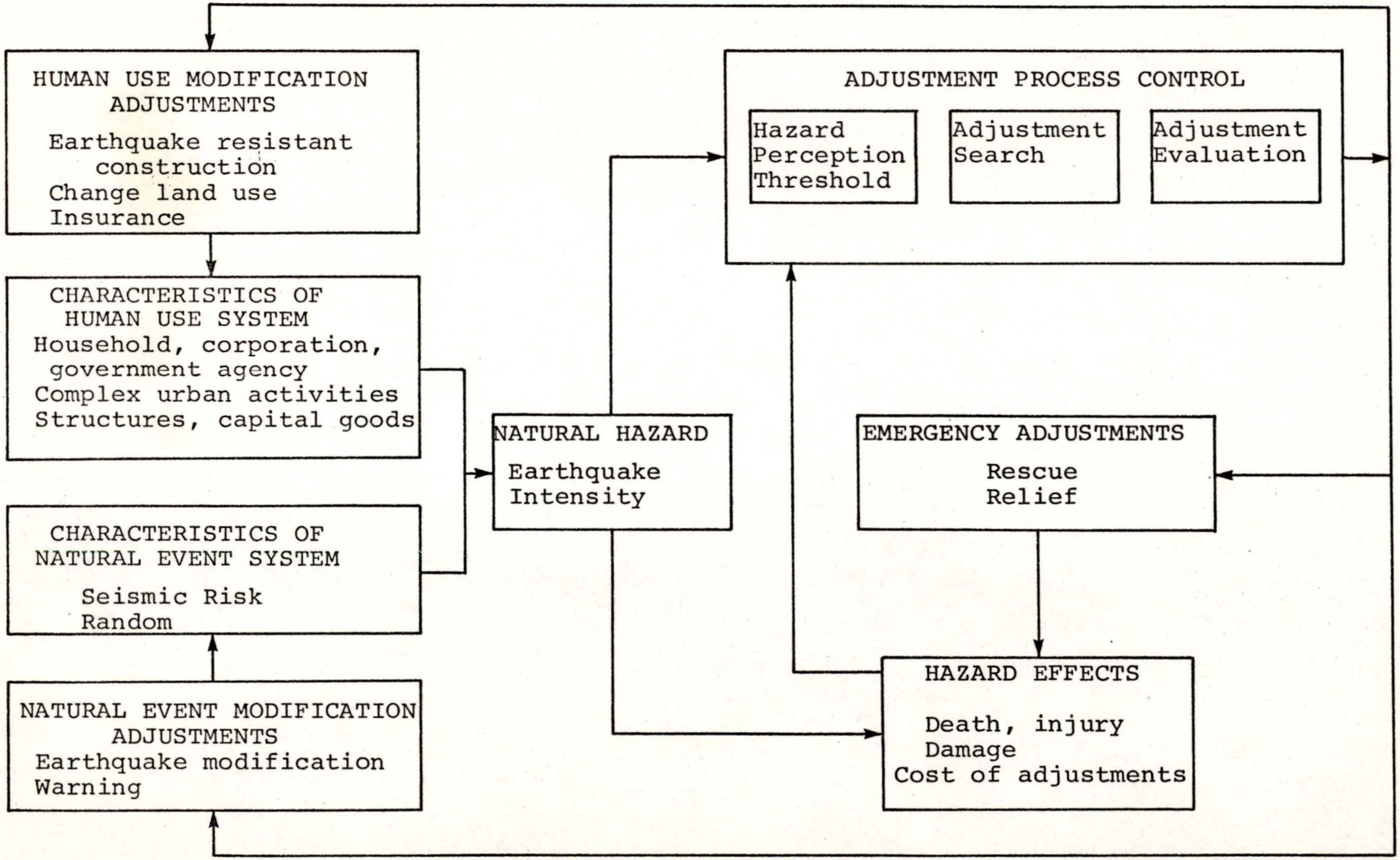
Despite an improving technology and man's increasing ability to buffer himself against the harmful effects of nature, losses from natural disasters continue to rise as both occupancy of hazardous areas and material wealth grow. Dacy and Kunreuther have estimated that the average annual rate of increase in damage from hurricanes, floods, tornadoes, and earthquakes in the United States for the period 1925-1965 was 2.5 percent per year.[3] No equivalent figures are available for Canada, but based on a comparable standard of living and a faster rate of population growth, the same conditions probably obtain in this country.

In North America, damaging earthquakes occur less frequently than floods, hurricanes, or tornadoes, but the damage from earthquakes has grown at a faster rate. In the United States, the rate of increase was 5.8 percent per year for the period 1925-1965, more than double the average increase for the leading four disasters.[4] Of the natural hazards which might pose a catastrophic threat to Victoria, the city is considered to be most vulnerable to earthquakes.

Human Adjustment to Natural Hazards

The general systems model of human adjustment to natural hazards developed by Kates represents an area where the risk from a single hazard does not vary spatially during a time period appropriate to the character of the natural event and the related human activity.[5] In terms of the natural hazard and area discussed in this study, earthquakes in Victoria, the expectation of a tremor is the same in all parts of the city during any hundred year period.[6] The basic elements of the model are a human use system and a natural event system which interact to pose a

FIGURE 1 - HUMAN ADJUSTMENT TO EARTHQUAKE



After R.W. Kates

natural hazard. Specific hazard effects are generated, bringing an adjustment process control into play to govern the adoption of various possible modifications. Either the human use system or the natural event system may be modified, or emergency adjustments may be initiated to modify the hazard effects directly. Any combination of adjustments may, of course, be used to modify one or all of these elements. Figure 1 illustrates the linkage between the various elements.[7]

The human use system is described in terms of adjustment capability and hazard effects. The smallest unit of human occupance considered is the household, while larger independent decision making units are corporations and government agencies at various levels. The activities of the inhabitants must be taken into account in the description of human use, but in the case of a city, these are too complex to detail in a model. The damageable material wealth would include all structures and capital goods.

The characteristics of the natural event system are the subject of entire disciplines, but for the purposes of the model, four characteristics are of major importance - magnitude, frequency, duration, and temporal spacing. For earthquakes, magnitude and frequency may be conveniently displayed simultaneously on a seismic zoning map which portrays an estimate of the risk of earthquake

*

occurrence over a wide area. The duration of an earthquake is usually measured in seconds, and is ultimately reflected in intensity, as discussed below.

The natural hazard must be viewed as an interaction of the two preceding elements, and will therefore vary with the natural event, the human use of the area, and any adjustments man has made to either of these elements. This interaction is described in detail for any given earthquake by the Modified Mercalli Intensity Scale (see Appendix A), which indicates the degree of damage sustained.

If the natural event is large enough to overcome whatever adjustments were made to counteract it, other effects beyond the cost of adjustments must be considered. In this case, we are concerned primarily with loss of life, injuries, and damage.

The adjustment process control, representing decision making theory, is the most complicated element in the model. For each decision maker, there is a perception threshold based on his individual perception, hazard experience, and personality, below which he takes no action. If action is deemed necessary, he seeks a suitable adjustment by evaluating known alternatives. It appears that the frequency of adoption of adjustments is a function of hazard frequency, so it might be expected that few adjustments for earthquakes are adopted, since damaging earthquakes are so infrequent.

Modifications to the human use system may involve attempts to raise the damage threshold, as provided by earthquake resistant construction. The distribution of damage potential may be altered by changes in land use. The effects may be externalized through insurance.

Adjustments to modify the natural event system none for earthquakes. are feasible for some events, such as water storage to modify droughts. Research has been conducted in earthquake modification and warning and practical results in this area are conceivable in the future.

Emergency adjustments are designed to reduce the harmful effects of a hazard after the event. Rescue units can keep the casualty toll from mounting, and relief operations can ameliorate the effects of damaged homes and belongings.

Need for Microzoning

In man's quest to reduce the harmful effects of natural hazards, he must use all the means at his disposal. Seismic zoning maps and microzoning maps provide him with * aids in making rational decisions about adjustments to the earthquake hazard. The basic distinction between seismic zoning maps and microzoning maps is that the former portray an estimate of the risk of earthquake occurrence over a wide area while the latter show the local variation in earthquake intensity over a small area.

The earliest seismic zoning maps were published in the USSR in 1937.[8] A seismic probability map of the United States was prepared in 1948 but withdrawn from official use in 1952.[9] Both maps were criticized because they were based on the distribution of known damaging earthquakes which occurred in the last two centuries, and it was felt that geological factors were little considered. On the other hand, a 1965 zoning map for New Zealand, based on an attempt to relate earthquake risk to the relative age of crustal deformation, has been criticized by seismologists.[10] Despite shortcomings stemming from a short period of recorded earthquake history, these maps are officially accepted in several countries, including Canada and the USSR.

The first seismic zoning map for Canada was prepared in 1952 by Hodgson in cooperation with the Division of Building Research National Research Council, and incorporated into the 1953 edition of the National Building Code.[11] Using a concept originally established in the United States, it divided the country into four zones of potential damage: Zone 3 indicated major damage, Zone 2 moderate damage, Zone 1 minor damage, and Zone 0 no damage. This map was based on a knowledge of the distribution of the larger earthquakes experienced in Canada in recorded times, as well as on general geological and geophysical considerations such as major fault zones.[12]

Deficiencies were evident, for example in areas where a Zone 3 abutted directly on a Zone 0, as in Northern

Ontario and Quebec, the assessment of risk was uncertain. Many users of the map claimed that the inclusion of large metropolitan centres such as Montreal and Ottawa in Zone 3 was not warranted, since no serious damage had occurred in these cities in this century.[13] Recognizing these defects, Hodgson initiated efforts to produce a more sophisticated map.

In 1970, a new seismic zoning map was published, based on a computer analysis of all earthquakes recorded since 1899.[14] The risk at any given site was based on the effects of all known earthquakes at that site determined by calculating the maximum peak horizontal ground acceleration of each earthquake. For each site, the acceleration amplitude with a probability of annual exceedance of 1 in 100 was determined by statistical methods. The four zones are defined in Table I and delimited in Figure 2. The areas where maximum accelerations may be expected in Southern Canada are the lower St. Lawrence River area and western British Columbia, including the whole of Vancouver Island.

Since the acceleration data were obtained by an averaging process, the map is applicable only to average ground conditions. It only depicts the projected average areal distribution of peak horizontal ground acceleration due to earthquakes based on statistics for a period of less than seventy years. Despite these limitations, the map is the best scientific estimate of seismic risk available in

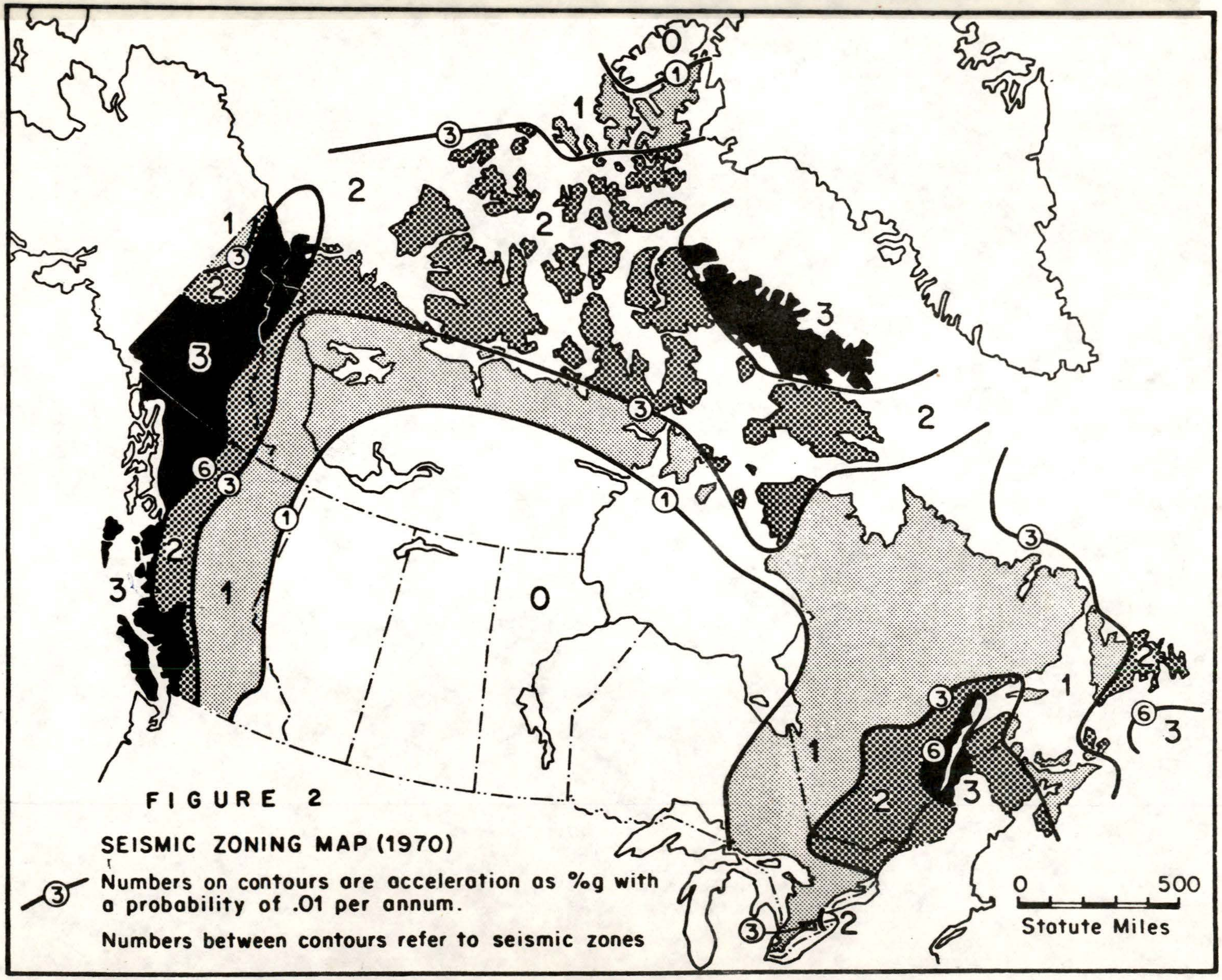


FIGURE 2

SEISMIC ZONING MAP (1970)

③ Numbers on contours are acceleration as %g with a probability of .01 per annum.

Numbers between contours refer to seismic zones

SOURCE: Whitham, Milne, and Smith, "New Seismic Zoning Map", p. 7.

Canada at present, and it was adopted into the National Building Code in 1970.

TABLE I

DEFINITION OF SEISMIC ZONES

Zone	Acceleration with annual probability of exceedance of 1 in 100 (A100)
3	$A100 \geqslant 6$
2	$6 > A100 \geqslant 3$
1	$3 > A100 \geqslant 1$
0	$1 > A100$

SOURCE: Associate Committee on the National Building Code. Canadian Structural Design Manual, 1970: Supplement No.4 to the National Building Code of Canada (Ottawa: National Research Council, 1970), p. 595.

An empirical relationship between acceleration and intensity is expressed by

$$\log_{10} a = \frac{I}{3} - 1.5$$

where a is the acceleration in percent of gravity and I is the earthquake intensity as defined by the Modified Mercalli Scale.[15] Since Victoria is situated in a Zone 3, an acceleration of 6 percent gravity or greater has an annual probability of exceedance of 1 in 100. Converted to intensity, this approximates an intensity VII earthquake.

Specific studies allow greater precision in assessing the seismic risk of a particular site. The most definitive work on earthquake risk in Canada was published by Milne and Davenport in 1969.[16] For Western Canada, this study was based on a statistical computation of 1479 earthquakes which occurred between 1899 and 1960. A peak horizontal ground acceleration of 10.7 percent gravity for a hundred year return period was calculated for Victoria in this study.[17] Using the conversion equation noted above, an intensity VIII earthquake may be derived for the city. Since intensities in the study referred to firm soil conditions, even higher intensities may be postulated for less stable areas.

While seismic zoning maps indicate risk in terms of natural event characteristics in the natural hazard model, microzoning maps are important tools in considering possible adjustments to earthquakes. The mere existence of such a map will tend to lower the hazard perception threshold of the decision maker. His search for an adjustment and its evaluation may now be conducted with greater precision. All the suggested human use modification adjustments can be applied spatially as dictated by the expected variation in intensity. Decisions on the amount of earthquake resistant design required in building, the advisability and cost of insurance, and land use zoning must take into consideration the relative potential for earthquake damage as shown on microzoning maps. If earthquake modification became practical, it might be in the form of strain release by controlled earthquakes. The ceiling suggested for the intensities to be generated by these triggered earthquakes could be based on the maximum intensity considered tolerable on the worst type of ground as determined from microzoning. Even decisions about emergency adjustments would benefit from microzonation maps in that rescue and relief facilities could be established in the safest areas.

The production of such maps has been advocated in recent years by many agencies in the United States. The National Academy of Sciences Committee on the Alaska Earthquake, in recommending that earthquake-hazard maps be prepared for all densely populated seismic areas, explained:

> At any specific site, earthquake hazard depends on seismic probability, foundation conditions, topography, local and regional geology, proximity to surface-water bodies, occupance, and structural design. All these variables except the time-dependent ones (occupance and structural design) can readily be shown on maps. Such maps, indicating comparative hazard at each point on the ground surface, are of great help in determining appropriate land-use patterns.
>
> Cities should be encouraged to prepare maps of this sort as guides to land-use decisions. The relocation of Valdez following the Alaska earthquake is an excellent example of a decision based on the use of comparative-hazard information.[18]

The National Academy of Sciences Committee on Seismology stated:

> Another important subject that involves many interactions between geology, seismology, and earthquake engineering is the preparation of seismic risk or zoning maps. The recognition that certain areas of the world are more subject to earthquake hazard than others immediately creates the desire for a

> seismic risk map that would indicate for any given locality the relative danger from earthquakes. Such maps must reflect local geological and soil conditions, which are known to have important influences on earthquake-resistant design, as well as considerations of the number of earthquakes of various sizes likely to occur in a given region in a prescribed time period.
>
> At present, attempts are being made to base such seismic risk maps on measurements of small, frequent earthquakes, both to indicate relative seismicity of a region and to compare relative ground motions under different conditions of local geology. As indicated above, extrapolations of any kind from small earthquakes to large destructive earthquakes must be treated with the utmost caution, particularly from the viewpoint of earthquake-resistant design. If good modern maps are not available, the engineer's work is seriously hampered.[19]

In 1971, the President's Task Force on Earthquake Hazard Reduction recommended that the Federal government should proceed with several priority projects, including:

> 4. Greatly improved mapping of earthquake geologic hazards in metropolitan regions is essential for adequate evaluation of seismic risk in built up areas. More sophisticated risk evaluation is, in turn, the key to well-informed decisions on planning, zoning and code requirements.[20]

While not expressing it in such specific terms, Canadian scientists have indicated interest in microzonation problems. The Department of Energy, Mines and Resources formed a Committee on Recent Crustal Movements and Seismic Regionalization to suggest suitable new projects or modifications to existing ones to aid in eventual "seismic regionalization", a study combining earthquake data with geophysical and geological data.[21] The Solid-Earth Sciences Study Group, in arguing for expanded geotechnical research, states:

> While the evaluation of the intensity and probability of earthquakes on a regional basis is an important task of the seismologist, the influences of dynamic loadings, such as produced by earthquake shock on the behaviour of various soil types is of concern to the soil mechanics and foundation engineer. Earthquake provisions of the present National Building Code with respect to soft compressible soils, for example, specify that buildings be designed to resist 1.5 times the loads due to earthquakes. The multiplication factor is arbitrarily applied regardless of building height, soil depth or topographic location of the building because more precise knowledge of the reaction of the soil to earthquake conditions does not exist. It is estimated that the cost of the use of the earthquake loading factor is $500,000 per year for the City of Ottawa alone, and that substantial reductions in this cost could be attained through an adequate knowledge of the behaviour of soils under dynamic loading.[22]

One of the first steps in reducing losses from natural hazards must be the spatial determination of the hazard. In case of earthquakes, this involves the production of microzoning maps for all urban areas in high risk zones. Despite this need, as far as the author is aware, this study represents the first attempt to microzone a Canadian city. Hopefully, such a map will stimulate decision makers into adopting the appropriate modifications to the human use system, thereby reducing the hazard and disaster potential in Victoria.

FOOTNOTES

[1] Clifford S. Russell, "Losses from Natural Hazards", Journal of Land Economics 46 (1970): 383.

[2] Ibid., p. 385.

[3] Douglas C. Dacy and Howard Kunreuther, The Economics of Natural Disasters: Implications for Federal Policy (New York: The Free Press, 1969), p. 17.

[4] Ibid.

[5] Robert W. Kates, "Natural Hazard in Human Ecological Perspective: Hypotheses and Models", Economic Geography 47 (July 1971): 443.

[6] A hundred year period is considered appropriate since this is the return period on which the Canadian seismic zoning is based, and it is a reasonable expected lifetime of major structures.

[7] This description of the model of human adjustments to natural hazards follows very closely that presented by Kates in "Natural Hazard: Models", pp. 443-48.

[8] S.V. Medvedev, Engineering Seismology, trans. Israel Program for Scientific Translations staff (Jerusalem: Israel Program for Scientific Translations, 1965), p.1.

[9] C.F. Richter, "Seismic Regionalization", Bulletin of the Seismological Society of America 49 (April 1959): 125.

[10] R.H. Clark et al., "Tectonic and Earthquake Risk Zoning in New Zealand", in Proceedings of the Third World Conference on Earthquake Engineering, ed. J.H. Van Roekel (Wellington, New Zealand: Government Printer, 1966), pp. I-125 to I-128.

[11] K. Whitham, W.G. Milne, and W.E.T. Smith, "The New Seismic Zoning Map for Canada: 1970 Edition", The Canadian Underwriter (June 1970): 2.

[12] John H. Hodgson, "There are Earthquake Risks in Canada", EMO National Digest 5 (December 1965): 6.

[13] Whitham, Milne, and Smith, "New Seismic Zoning Map", p.2.

[14] Ibid., p.4.

[15] W.G. Milne and A.G. Davenport, "Distribution of Earthquake Risk in Canada", Bulletin of the Seismological Society of America 59 49?, (April, 1969): 739.

[16] Ibid., pp. 729-54.

[17] Ibid., p. 746

[18] Committee on the Alaska Earthquake, Toward Reduction of Losses from Earthquakes (Washington: National Academy of Sciences, 1969), p.8.

[19] Committee on Seismology, Seismology: Responsibilities and Requirements of a Growing Science, Part II: Problems and Prospects (Washington: National Academy of Sciences, 1969), p. 34.

[20] Task Force on Earthquake Hazard Reduction, In the Interest of Earthquake Safety (Berkeley: University of California Printing Department, 1971), p. 10.

[21] Whitham, Milne, and Smith, "New Seismic Zoning Map", p. 5.

[22] Solid-Earth Sciences Study Group, Earth Sciences Serving the Nation (Ottawa: Information Canada, 1971), p. 225.

CHAPTER 2

EARTHQUAKE HISTORY OF VICTORIA

The recorded earthquake history of British Columbia covers a very short time span geologically speaking, because of the relatively recent European settlement of the province. An earthquake noted in the diary of a Victoria resident in 1853 represents the earliest written record from Vancouver Island.[1]

The first seismograph on the West Coast began operation in Victoria in 1899, only the second such instrument in Canada. It was initially located in the basement of the Customs Building at Government and Humboldt Streets. In 1916, the three Victoria seismographs then in use were moved to the Gonzales observatory and in 1939 were moved to their present location at the Dominion Astrophysical Observatory on Little Saanich Mountain. In 1951, seismographs were installed at Alberni and Horseshoe Bay, permitting triangulation of epicentres of local earthquakes.

During the first fifty-eight years of seismograph operation in Victoria, twenty-five times as many earthquakes were recorded than in the preceding fifty-eight year period. This indicates the lack of complete early records, but Milne notes that for earthquakes of intensity V or greater, the record since 1841 is reasonably complete for the Victoria area.[2]

West Coast Earthquakes

Since 1841, the West Coast of British Columbia has experienced one great earthquake and five major earthquakes.[3] Intensity VI has been reached in Victoria on at least twelve occasions, and over one hundred earthquakes have been felt.

Before 1918, seven tremors generated intensities of VI in the city. Of these, the 14 December 1872 earthquake centred east of Hope is considered the most severe, being estimated at 7.5 on the Richter magnitude scale. The shaking was felt over a half million square mile area and precipitated a spectacular landslide on Mount Cheam, near Chilliwack. In Victoria, bells were rung and crockery was knocked off shelves.

The magnitude 7.0 earthquake of 6 December 1918, centred near Estevan Point lighthouse on the west coast of Vancouver Island, is the first for which intensities in specific areas of the city are available.[4] Two incidents in the Fairfield area of the city indicate that intensity VII was reached locally. A house on Chapman Street (Map 1 grid reference 151/86) was damaged to the extent that all the doors and windows had to be repaired, and the tremor was felt inside a streetcar on May Street in the vicinity of Linden Avenue (151/86).

On 12 November 1939, an earthquake with its epicentre near Olympia, Washington shook the Victoria area.

Bricks fell from an old building on Store Street (157/89), while a milk bottle was reported knocked over and broken in the Fairfield district.[5] An interesting sidelight is that phesants and quail in Beacon Hill Park (151/88) started screaming before the first shock was felt, as if they had sensed what was about to happen.[6]

A magnitude 7.3 earthquake occurred on 23 June 1946, with the epicentre in the Strait of Georgia, twelve miles north of Courtenay. In the epicentral area, cracks up to eighteen inches wide appeared on sand spits, beaches disappeared, and coastal waters deepened by almost one hundred feet in some locations. A twelve acre field on Read Island dropped down twenty to thirty feet. One man was drowned when his boat was swamped by the local tsunami generated by the tremor. Damage in adjacent towns and villages was widespread, but mainly restricted to breakage of chimneys, windows, and crockery.[7] The effects of this earthquake in Victoria are discussed in the next section.

The largest earthquake recorded in British Columbia took place on 20 August 1949 with an epicentre near the Queen Charlotte Islands. Although the magnitude reached 8.0, little damage resulted as the area is sparsely settled.

The 29 April 1965 earthquake, magnitude 6.5, left two persons dead from falling debris in Seattle. In Victoria, the intensity varied considerably from area to area, with the Empress Hotel (154/89) being the site of the highest reported intensity. Plaster fell from the ceiling in parts of the old wing.[8]

To the date of writing (March 1974), the last severe shaking in Victoria occurred on 14 February 1969. The comparatively low magnitude tremor (4.0 to 4.2) had its epicentre only forty miles to the east of the city, explaining the relatively high intensity reached. Many people were awakened and jars were broken when knocked off shelves in a grocery store on Foul Bay Road (160/78), indicating an intensity of V.[9]

23 June 1946 Earthquake

Although no figures are available on the dollar losses incurred as a result of the 23 June 1946 earthquake, the damage was the most extensive recorded in the city's history. A maximum intensity of VII was reached with a distinct areal pattern discernible in the intensities observed. Map 1 (see back pocket) illustrates the intensities determined for 202 sites in this study. A serial number identifies each location and a brief remark on the intensity at the point can be found in Appendix B.

Areas where the highest intensities were reached included the area north of Burnside Road and Frances Street (163/91), around the intersection of Hillside Avenue and Quadra Street (160/87), the Fairfield district east from Cook Street along Chapman Street (151/85), and around the intersection of Haultain Street and Belmont Avenue (159/82).

In these areas walls cracked and many chimneys were broken. In other areas, such as central West Victoria (157/93), or along eastern Finlayson Street (163/86), the earthquake was felt only as a slight vibration.

According to eyewitness reports, Victoria was a scene of wild disarray for a few moments on that day. Buildings swayed and plate glass windows bulged in and out as the tremor rocked the city. Telephone poles nodded to each other, the wires whipping about like skipping ropes. Chimneys and steeples appeared ready to topple as they swayed, while hedges and sidewalks undulated in snake-like motion.

Occurring at 10:15 A.M., on Sunday, the earthquake caught most residents either at home or at church. A woman fainted in St. Andrew's Cathedral (serial 69), but only a few people left the church.[10] There were no reports of any physical injuries.

Chimney breakage was the major damage most readily evident. Figure 3 (serial 25) shows one type of breakage, where part of the chimney rotated clockwise without toppling. Other chimneys broke at the roofline and fell to the ground. The Fire Department was kept busy all day pulling down damaged chimneys and found it prudent to warn all citizens against the use of chimneys which might have been cracked unnoticeably inside the house. They recommended immediate inspection of all flues to prevent serious fires from resulting.[11]

FIGURE 3

1946 EARTHQUAKE DAMAGE, VICTORIA

Photograph by Clifford Banks

Only two public or commercial buildings were slightly damaged. The old fire hall (serial 89), which used to stand at the top of Broad Street in an area which is now part of Centennial Square, was cracked along one wall to such an extent that girders had to be placed against it for support. A new fire hall was constructed shortly after in a new location, the move being hastened by the damage to the original building. Cracks appeared in several places in the Empress Hotel (serial 64), tiles were torn from bathroom walls, and plaster fell in many parts of the old wing. The most serious crack developed where the main building (completed in 1908) and the south wing (completed in 1912) are joined.

An interesting phenomenon was the noise accompanying the earthquake. Approximately twenty percent of respondents reported sounds, variously described as a crunching or cracking sound, a lion's roar, rough thunder, a truck, a truck dumping coal, and tanks coming down the road. In locations where the highest intensities were reached, little sound other than nails pulling out of boards or articles crashing to the floor was reported. This apparent paradox is discussed further in Chapter 5.

Many people were frightened by the shaking, while others saw humour in the incidents connected with it. One man became slightly irritated because the weeds he was hoeing refused to stand still during the tremor. Another had difficulty changing his flat tire, as the spare was bouncing around on the pavement when he went to reach for it. Seeing all the damage around him, one little boy ran home to assure his mother, "I didn't do it".

FOOTNOTES

[1] All the information in the following section, unless otherwise specifically noted, comes from W.G. Milne, "Seismic Activity in Canada West of the 113th Meridian, 1841-1951", Publications of the Dominion Observatory, vol. 18, no. 7 (Ottawa: Queen's Printer, 1964).

[2] Ibid., p. 124.

[3] Great earthquakes are considered to be those which register 8.0 or higher on the Richter scale, while major earthquakes range from 7.0 to 7.9 on that scale. Damage may occur in the epicentral area with magnitudes of 5.0 or over.

[4] While being interviewed about the 1946 earthquake during this study, several respondents volunteered information on the 1918 earthquake.

[5] Victoria Daily Times, 13 November 1939, p. 1.

[6] Victoria Daily Colonist, 14 November 1939, p. 2.

[7] Ernest A. Hodgson, "Report on Field Trip, British Columbia Earthquake, June 23, 1945", Ottawa, 1946, pp. 38-39.

[8] Victoria Daily Times, 29 April 1965, p. 2.

[9] Victoria Daily Times, 14 February 1969, p. 19.

[10] Victoria Daily Times, 24 June 1946, p. 3.

[11] Ibid.

CHAPTER 3

GEOLOGY OF VICTORIA

As was pointed out earlier, geological and geomorphological conditions play an important part in the determination of earthquake hazard. As a result, all microzonation methods are based on these considerations, and therefore, before the method used in this study can be fully appreciated, the geology and geomorphology of the city must be described in some detail.

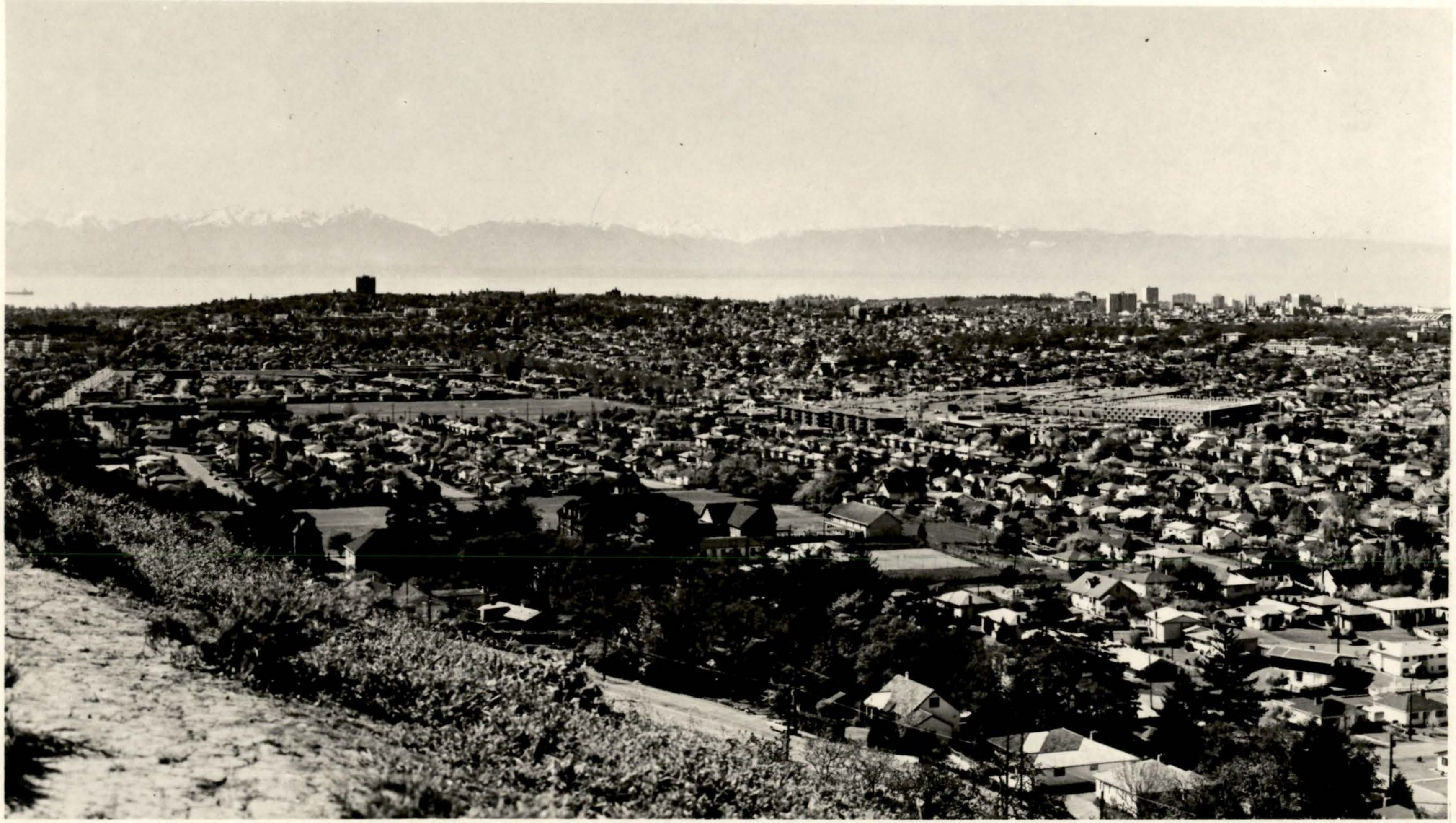
Victoria is situated in the extreme southeastern portion of Vancouver Island, British Columbia. It lies in a coastal trough which extends northwest from Puget Sound to the Alaskan border. In the Victoria area, the lowland is flanked by the Vancouver Island Ranges to the west and Haro Strait to the east.

The relief of the glaciated lowland is broken by many residual hills, three of which attain elevations slightly over two hundred feet above sea level. Figure 4, a view from one of the higher hills just outside the city limits, illustrates the rolling appearance of the topography. The extreme western portion of Victoria is cut off by a drowned valley known in various segments as the Inner Harbour, Upper Harbour, and Selkirk Water.

Basement rocks are exposed in many parts of the city. The oldest of these have been variously identified as being Devonian to Jurassic in age.[1] During the Coast Range Orogeny, believed to have occurred during the

FIGURE 4

GENERAL VIEW OF VICTORIA



Photograph by Ian Norie

Jurassic,[2] these rocks were greatly deformed, metamorphosed, and invaded by granitic plutons. Large folds, striking approximately northwest, are complicated by small folds and contortions. The rocks have been fractured, sheared, and faulted.[3]

Clapp has pointed out that the bedrock surface is very irregular in the city and the stratigraphy of the surficial deposits is very complex.[4] In the present study, examination of borehole records and visual inspection confirm both observations. Since the depth to bedrock and the type of surficial deposits are of particular interest in the prediction of seismic effects, both subjects are now considered more fully.

Bedrock Topography

Following the 1967 Caracas earthquake, Seed and others conducted a detailed study of the relationship between structural damage and the depth of the underlying surficial deposits.[5] Structural damage to buildings of 5 to 9 stories was highest where the unconsolidated sediments were 50 to 70 metres (165 to 230 feet) deep. Where the deposits exceeded 160 metres (525 feet) in depth, damage to buildings over 10 stories high was several hundred percent higher than where depths were below 140 metres (460 feet). They concluded that the severity of ground motions and the resulting damage to tall buildings was affected to a large degree by the depth and characteristics of the underlying deposits, even in the same city and for the same earthquake. If this is the case, the depth of surficial deposits is a factor which must be considered in microzoning any area.

Clapp has postulated that the bedrock surface in the coastal plain was eroded more or less into its present form during the early Pleistocene. Local depressions resulted from differential erosion along shear zones, joint planes and along the contacts between various rock formations. Modification of this surface by glaciation during the Pleistocene was probably limited to smoothing by the southward flowing ice.[6] This view is supported by the presence of unconsolidated sediments underlying drift at Cowichan Head, about ten miles north of the city.

The depth to bedrock is shown in some of the borehole records shown in Appendix C. Street plan profiles and visual examination of outcrops provided information on areas where bedrock appeared within ten feet of the surface.[7] These sources indicate the extreme irregularity of the bedrock surface in many places across the city, while the deepest borehole (152090/94695) penetrated 198 feet before probable bedrock was encountered. The steep slopes of the surface are exemplified by the bedrock topography near the corner of Douglas Street and Kings Road, where bedrock is found 5 feet under Kings Road while 25 feet away, borehole 159535/88435 extends to 61 feet without encountering bedrock. Figure 5, a section along a line paralleling Douglas Street, further illustrates the irregularity of the

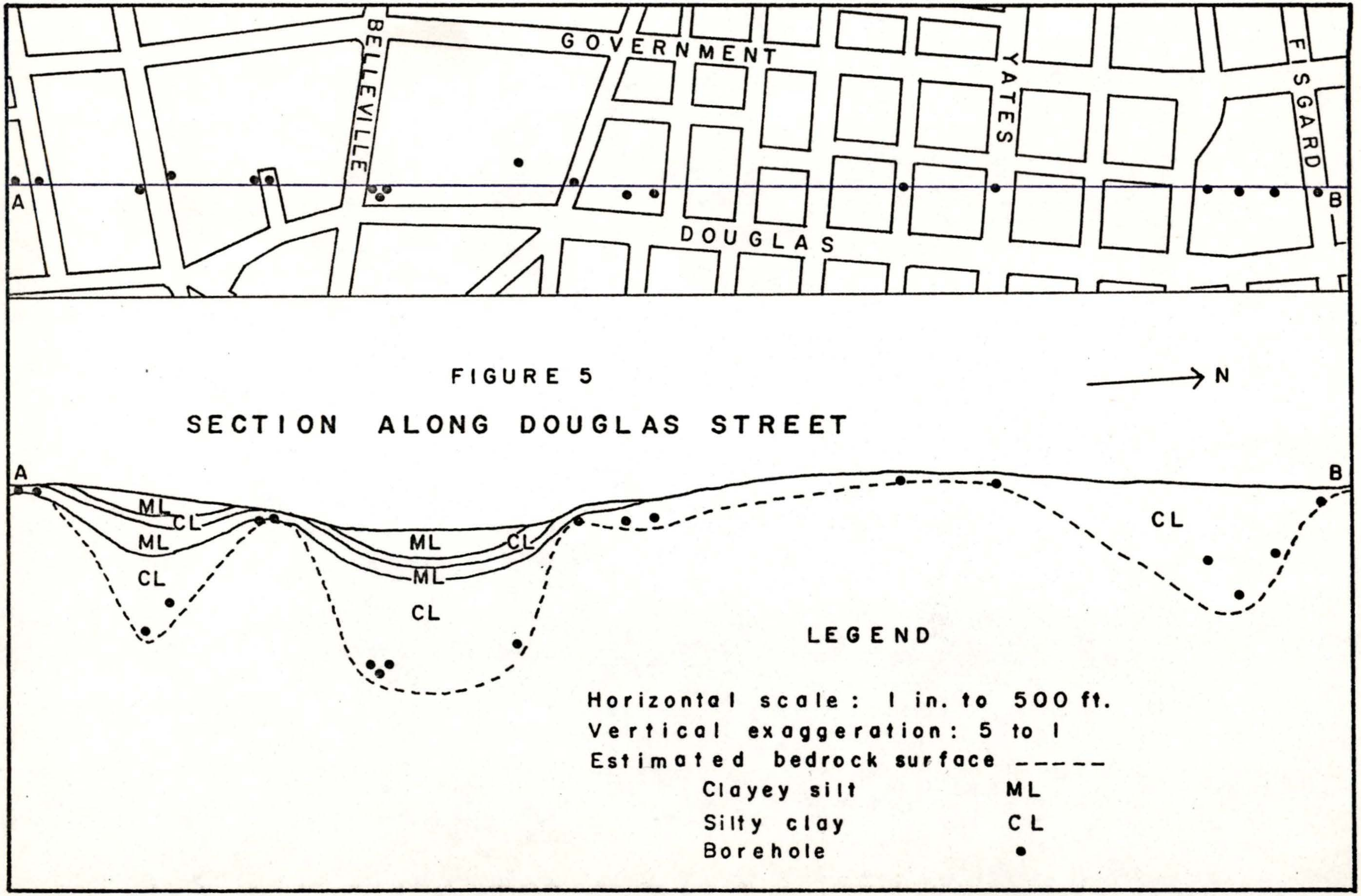


FIGURE 5

SECTION ALONG DOUGLAS STREET

bedrock surface.

Lacking seismic refraction profiles or sufficient borehole data to determine the depth to bedrock over the entire area, no attempt has been made to draw an isopach map. However, areas where bedrock is encountered in the top ten feet are quite accurately identified, and are shown on Map 2.

Surficial Deposits

One of the first to record the effect of ground conditions on damage to buildings during earthquakes was Macmurdo, who in commenting on the earthquake near the Runn of Cutch, India in 1819, stated "Buildings situated on rock were not so much affected by the earthquake as those whose foundations did not reach to the bottom of the soil."[8]

Ground conditions affect earthquake damage potential in several ways. Primary effects may be considered to be the actual shaking of structures by seismic ground motion while secondary effects are those phenomena only initiated by the ground vibrations, such as settlement or liquefaction of cohesionless sediments.

Analyses of data from microseisms,[9] small earthquakes, and to a lesser degree large seismic events, have established that ground surface motions during earthquakes vary with ground conditions in a reasonably predictable way. Seed and Idriss found that in the four earthquakes, for which sufficient data were available on accelerations both in underlying rock and ground surface, the amplification factor of the unconsolidated deposits varied from 0.8 to 4.0.[10] Although the relationship has been clearly demonstrated, the research has suffered from a paucity of strong-motion seismograph data. As a result, in most cases practical assessment of the amplification factor has been based on empirical studies which have related general surficial sediment conditions to actual damage observed after earthquakes.

This generalization can be seen in both the definitions of ground types and the range of the soil site as shown in Table II. The soil factor, used in building codes to vary the permitted minimum lateral strength of structures, ranges from a 50% increase in Canada to a 300% increase in Chile. Soil descriptions may be a short qualitative statement as in Canada, a comprehensive description of the ground as used in Japan, a quantitative measure of allowable soil pressure as defined in Argentina and India, or some combination of these as in Rumania.

It is significant that at least eleven countries have recognized the importance of local ground conditions to earthquake damage potential and have included a soil amplification factor in their national building code.

The ground vibration during an earthquake may compact loose sediments to such a degree that settlement is evident. During the 1964 Alaska earthquake, compaction of

2.5 feet in alluvium occurred at Homer.[11] Differential settlement of structures would be serious with this magnitude of compaction.

Liquefaction of saturated loose deposits has caused severe damage in many earthquakes. Seismic vibration compacts the surficial materials and increases the pore water pressure, causing the water in the voids to move upwards to the surface, as evidenced in mud spouts and sand boils. Structures may disappear into the resulting quicksand, while light underground structures such as septic tanks may be floated to the surface, as was the case in Niigata, Japan, in 1964.[12] Again, differential settlement can result in extensive damage.

If the backfill in waterfront bulkheads liquefies, the increased pressure in the backfill may be much higher than the extreme pressure which the bulkhead was designed to withstand. In the Chilean earthquake of 1960 in Puerto Montt, a quay wall made of sixteen foot reinforced concrete sections on thirty-five foot high earth-filled concrete caissons was completely overturned for almost a thousand feet.[13] In addition to the damage to the bulkheads themselves, the low-lying areas they are designed to protect would be inundated if they were breached.

Liquefaction in or under a sloping unconsolidated sediment mass can lead to flow slides. Even a thin layer of liquefied material under a surface of firm sediments

TABLE II

SOIL FACTOR IN SELECTED NATIONAL BUILDING CODES

Country	Soil Description	Soil Factor
Argentina	Allowable Soil Pressure (in KSF):	
	>8.2	1.00
	8.2-4.1	1.33
	4.1-2.05	1.67
	<2.05	2.00
Canada	Soil:	
	Not highly compressible	1.0
	Highly compressible	1.5
Chile	Soil:	Varies with period of structure
	Rock	1.6 - 1.0
	Conglomerate or very compact	2.4 - 2.0
	Loose (scarcely compact):	
	(1) mat or similar foundation	2.0 - 2.4
	(2) other foundations	2.4 - 3.0
France	Soil:	Varies with foundation type
	Rocky	1.0 - 0.80
	Medium	1.15- 0.90
	Loose soil possessing sufficient strength to hold together in water	1.0 - 1.30
	Mud, silt, slime, saturated	1.10- 1.30
Greece	Soil:	
	Little (hard, thick)	1.0
	Medium	1.5
	Big (weathered, marshy, silt)	2.0
	Great (slide potential)	2.0
India	Allowable Soil Pressure (in KSF):	Varies with Seismic Zone
	>9.225	0 - 0.12
	4.1-9.225	0 - 0.15
	2.05-4.1	0 - 0.18
Italy	Soil is not considered	
Mexico	Soil compressibility:	Varies with type of structure
	Low	1.0 - 2.5
	High	1.5 - 2.5

TABLE II - continued

Country	Soil Description	Soil Factor
Japan	Soil:	Varies with type of structure
	I. Rock, hard sandy gravel, Tertiary or older strata over considerable area	1.00 - 1.67
	II. Diluvia or gravelly alluvium (sandy, gravel, sandy hard clay, loam,etc.) 16' of thicker over a considerable area.	1.33 - 1.67
	III. Alluvium: soft delta deposits, topsoil, mud, etc., 98' or thicker	1.67
	IV. Reclaimed marsh, muddy sea bottom, etc., with depth of reclaimed ground 9.84' or more and less than 30 years since reclamation.	2.50 - 1.67
Rumania	Soil:	
	Allowable bearing >4.096 KSF	1.00
	Allowable bearing <4.096 KSF	1.25
	Silts, water saturated soils above foundation level	1.50
Turkey	Soil:	
	Hard and monolithic rock	1.0
	Sand, gravel strong and compact soils	1.33
	Other	1.67
USA	Soil is not considered.	
USSR	Soil factors are incorporated in microzone maps for individual areas.	
West Germany	Soil:	Varies with Seismic Zone
	Rock, gravel, coarse sand, and hard cohesive soil	0.05
	Medium and fine sand, half-hard cohesive soil	0.075 - 0.05
	Stiff cohesive soil and pile foundations	0.10 - 0.05

Source: J. Mendenhall, Building Code Analysis, quoted in John H. Wiggins, Jr., and Donald F. Moran, *Earthquake Safety in the City of Long Beach Based on the Concept of Balanced Risk* (N.p., 1971), pp. E-1 to E-7.

may cause a serious slide over a wide area, as at Turnagain Heights, Anchorage, during the 1964 Alaska earthquake. Here, approximately 130 acres moved up to 600 feet laterally, destroying 75 houses.[14] The points of most severe damage were at the toe of the slide and at the back where houses dropped into the graben left by the surficial material as it moved off.

Areas of loose deposits may fail without liquefaction occurring. Seismic vibration may cause lateral spreading at the base of fill, leading to cracking or collapse of structures built on it. The collapse of the Sheffield Dam during the 1926 Santa Barbara earthquake is attributed to such slumping of fill.[15]

Since various unconsolidated deposits react in different ways to seismic vibration, the characteristics and distribution of these surficial deposits should be considered in microzoning. The deposits of southern Vancouver Island have been described by Fyles[16] but have not been discussed in detail for the Victoria area.[17] An attempt has been made here to correlate the local stratigraphy with Fyles' nomenclature and to consider the seismic response of the various deposits by analogy to similar sediments elsewhere. The major stratigraphic units and their correlative local deposits are listed in Table III.

TABLE III

VANCOUVER ISLAND STRATIGRAPHY

Major Unit	Local Deposit
Salish sediments	Varied
Capilano sediments	Marine sand, silt, Victoria clay
Vashon drift	Vashon till
Quadra sediments	Cordova sands and gravels Quadra clay
Dashwood drift	?
Mapleguard sediments	?

After J.G. Fyles.

The oldest surficial materials found on Vancouver Island are the non-glacial deposits termed Mapleguard sediments by Fyles.[18] Although small pockets of these sediments may exist in deep hollows in the bedrock surface, they have not been identified locally.

Deposits of Dashwood drift can only be distinguished from the younger Vashon drift by their stratigraphic position below the Quadra sediments. Clapp referred to this drift layer as Admiralty till and described a three foot layer in southeastern Victoria.[19] Fyles considers these deposits as being equivalent to Vashon drift, but notes other tills in the Cordova Bay area, three miles north of the city, as possibly correlating with the Dashwood.[20] No evidence of this drift layer can be found in the borehole data.

NB

The basal unit of the Quadra sediments is a silty, clayey material which contains some sand, gravel, and occasional boulders.[21] A layer of this Quadra clay, over fifty feet thick, is exposed at Cowichan Head. It has not been identified in the borehole records, but it seems reasonable to assume that such deposits may be found in the deep depressions in the bedrock surface not reached during boring. Fyles notes that these clays are compact and stiff and able to support moderately large stresses without deformation.[22]

In the standard succession seen elsewhere on Vancouver Island, the Quadra clay is overlain by a well-sorted deposit of fine - to medium - grained sand, known locally as the Cordova (Quadra) sands and gravels. At higher elevations where younger deposits may have been removed by wave erosion, these sands may appear at the surface. This may be the case at borehole 156090/81420 where six feet of well-graded sand is the surface layer. Clapp suggested that thick deposits were protected from glacial erosion in the lee of the residual hills.[23] This seems to be borne out at borehole 158735/79040, south of Mount Tolmie, where a forty foot layer of sand is encountered as the surface layer. Throughout most of the city, however, the sand lies under Victoria clay, as at borehole 149840/84400 and at borehole 163800/82280. This deposit represents a seismic hazard in that it might liquefy when saturated,[24] with results as discussed earlier for Niigata or Anchorage.

The Vashon till consists of gravel and boulders set in a dense silty, sandy matrix.[25] Deposits up to forty feet thick can be seen on the sea cliffs to the south of the city. Although the terminology used in the borehole records makes it difficult to differentiate till from some other clay rich deposits, a thirty-eight foot layer is tentatively identified at borehole 148920/85800, where it overlies thirteen feet of Cordova sand and gravel. Other sites where till is identified as such in the records are 153985/91000 and 154574/91455. Vashon till is compact and hard, and will not consolidate under heavy loads. When saturated, however, its high silt and clay content make it susceptible to sliding.[26]

Post-glacial materials, deposited when the relative sea level was at least twenty feet higher than at present, are termed Capilano sediments on Vancouver Island.[27] Since few boreholes extend far beyond the rocks in the Vashon till, the records for the stratigraphy of the post-glacial deposits are more complete.

The lowest unit of the Capilano sediments is a silty clay, known locally as Victoria clay. By its stratigraphical position, this clay has been tentatively identified in 84.6 percent of the boreholes presented in Appendix C. The thickest deposit is eighty-four feet at borehold 158510/89150 (Rock Bay). A desicated upper layer is evident in many cases, as at site 149140/86570 where fourteen feet of clay of low to medium plasticity is underlain by thirty-two feet of soft clay. At site 157540/78155, a ten foot layer of clay of low to medium plasticity overlies seventy-one feet of clay of high plasticity. The oxidized upper layer is stable and not readily deformed under load. However, some of the unoxidixed clays below the water-table may be quick clays.[28] Formed under marine conditions similar to those prevailing in the Ottawa - St. Lawrence River valleys when the Leda clay was deposited, it is not unreasonable to suspect that these clays may become unstable during a major seismic event.

Silty and sandy marine deposits cover some parts of the city, as at site 152090/79610 where four feet of silty sand is the first layer encountered, or at 153370/88320 where ten feet of poorly-graded sand overlies clay. If such marine sands are saturated, they also might liquefy during seismic vibration.[29]

Salish sediments, related to present sea, river and lake levels, do not appear to be extensive locally. Eight feet of organic silt forms the surface layer at site 148245/84475. At 150480/85645, four feet of peat lies at the surface, while four feet of clay overlies two feet of peat at 151850/86330. Since fills are usually less consolidated than natural deposits and therefore pose a much greater seismic risk, their distribution is therefore of great interest in microzoning. As with glacial drift, the description of fill in the borehole records varies. At site 153720/88700, the eighteen foot layer of inorganic clay and clayey gravel is known to be fill from other data.[30] At some sites, as at 154945/89600, fill is identified as such in the records of boring.

Surficial Geology of Victoria

The complexity of the stratigraphy and the uneven distribution of the boreholes make it impossible to adequately map even the younger deposits of the Victoria area. However, several features which are of significance in seismic microzoning can be mapped with some accuracy and are shown on Map 2. Areas where bedrock occurs within the top ten feet are delineated.[31] The pre-settlement drainage pattern is influenced both by the bedrock surface and the surficial deposits. In turn, the streams and swamps have slightly modified both the surface topography and sediments. Areas where extensive fill has been used to alter the shoreline are indicated on Map 2.

Two major trends are obvious in the location of near-surface bedrock. An irregular ridge with minor interruptions stretches from Ross Bay (151/83) to Victoria West (159/94) in a northwesterly direction. Roughly parallel to this feature is another irregular ridge extending from the eastern boundary of the city to the northern boundary. Despite their irregularity, these ridges appear to follow the line of major lineaments on Vancouver Island, for which the northwest strike of folding

FIGURE 6

ROCKY TERRAIN IN VICTORIA

during the Coast Range Orogeny has been evoked as the cause. The second trend is the exposure of masses of bedrock on the residual hills, as might be expected. The largest of these hills is centered northwest of Government House (154/84), while Beacon Hill Park (152/88) is the centre of another. Smaller isolated pockets of bedrock occur throughout the city. Figure 5, a photograph of part of northeastern Victoria, illustrates the typical rocky terrain.

Extensive boggy areas existed before initial European settlement along Bowker Creek (160/81) and its tributaries in northeastern Victoria, in the Fairfield area centred on Chapman Street (151/86), and between Government House and Ross Bay (151/82). Smaller swamps were centred near the intersection of Vancouver Street and View Street (155/86), at the intersection of Vining Street and Stanley Street (157/83), around Steele Street (163/91), and at the intersection of Langford Street and Walker Street (159/95) in Victoria West. The point of land at the western end of the Johnson Street bridge (157/90) was separated from the mainland by mud flats and swampy ground before reclamation. Rithet's Bog (Figure 7), a present-day swamp about three miles north of Victoria, probably typifies the pre-settlement swamps of the city area.

As might be expected, peat and other highly organic soils and clays are found at or near the surface of

FIGURE 7

MARSHY GROUND NEAR VICTORIA

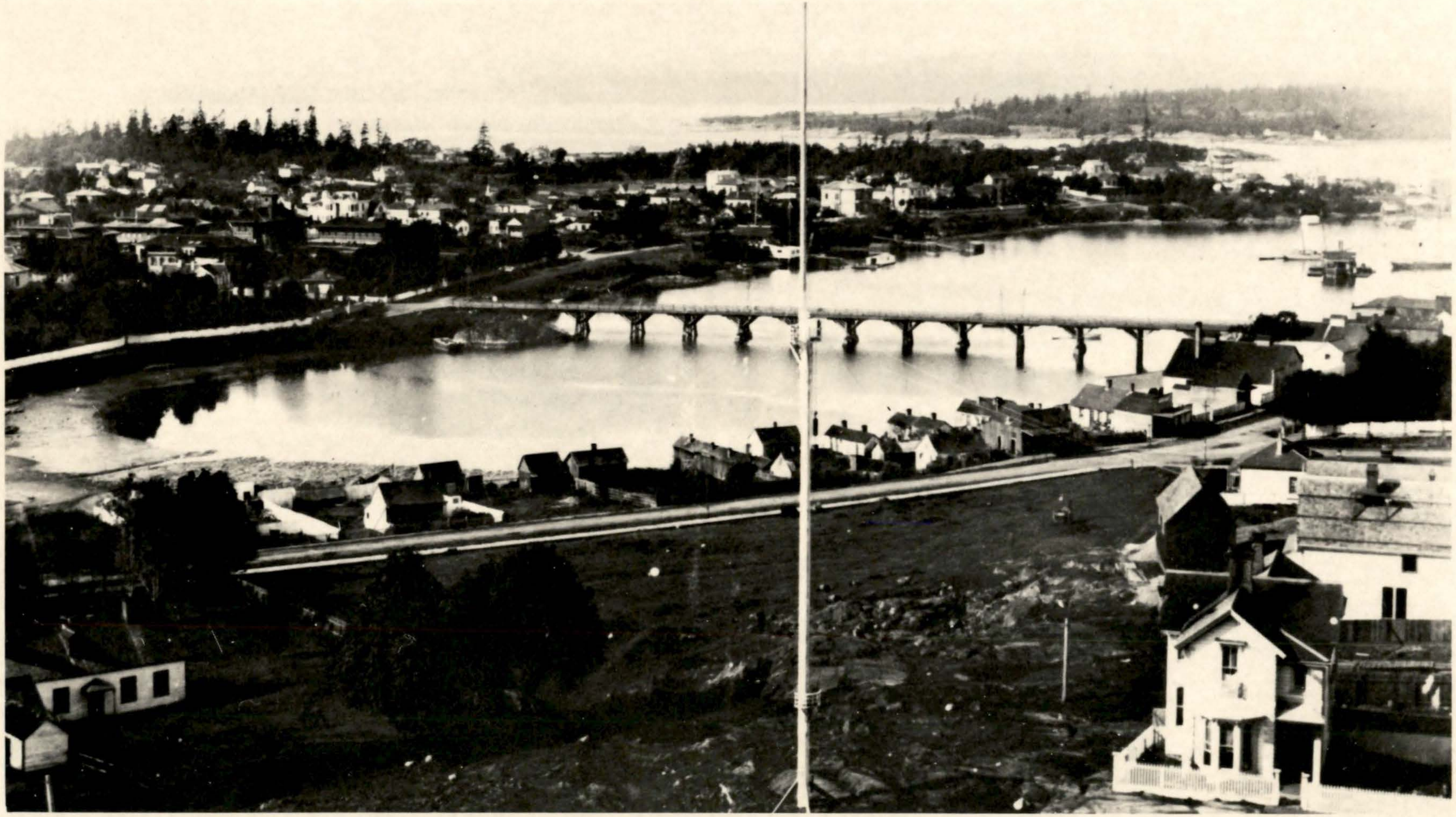
the former swamps, at at the corner of Topaz Avenue and Quadra Street (16135/86910) and near the intersection of Linden Avenue and May Street (150480/85645). All boreholes in the former swamps show a clay layer, identified tentatively as Victoria clay. Although the deepest borehole (161535/86910) penetrates seventy-six feet of sediment, no rock has been encountered in any hole bored in former swampy areas.

The head of James Bay (154/89) is the site of the most extensive land reclamation in Victoria. Figure 8 shows the area before the turn of the century. The present-day causeway is located slightly further out towards the harbour than the Government Street bridge visible in the illustration. Other areas of extensive fill appear to be at the heads of Lime Bay (157/92) and Rock Bay (158/89), and at the north end of the neck of land to the west of the Johnson Street bridge (157/91).

Boreholes in the reclaimed areas indicate deep deposits of clay under the fill. Near the Empress Hotel, at site 153665/88705, twenty feet of fill overlies eleven feet of recent alluvium, which in turn overlies sixty-nine feet of Victoria clay without bedrock being encountered at a depth of one hundred feet. At Rock Bay, the stratigraphic column of the borehole at 158510/89150 is simply described as clay to a depth of eight-four feet, with no bedrock encountered.

FIGURE 8

JAMES BAY BEFORE RECLAMATION



From the collection of the Provincial Archives, Victoria.

It is clear from the preceding description of the irregular bedrock surface and the wide range of surficial sediments in the Victoria area that the degree of threat from seismic hazards can vary greatly even in locations in close proximity. The lack of depth to bedrock information over much of the city and uncertainty as to how local deposits would respond during a large earthquake make the construction of a microzoning map difficult. However, since earthquakes represent the most serious natural hazard in the area, it is essential that such a map be attempted. It is with this task that the remainder of this thesis is concerned.

FOOTNOTES

[1] J.E. Muller dates it as Carboniferous to ? Devonian in his "Geological Reconnaissance Map of Vancouver Island and Gulf Islands" (open file map, 1971): C.H. Clapp places the age at lower Jurassic in Map 70A which is included in Geology of the Victoria and Saanich Map-Areas, Vancouver Island, B.C. (Ottawa: Government Printing Bureau, 1913).

[2] David J.T. Carson, The Plutonic Rocks of Vancouver Island, British Columbia: Their Petrography, Chemistry, Age and Emplacement (Ottawa: Information Canada, 1973), p.9.

[3] Clapp, Geology of Victoria and Saanich Map-Areas, p.5.

[4] Ibid., p. 25.

[5] H. Bolton Seed and Per B. Schnabel, "Soil and Geologic Effects on Site Response during Earthquakes", Proceedings of the International Conference on Microzonation for Safer Construction Research and Application (Seattle: n.p., 1972), p. 63 (hereafter cited as Proceedings).

[6] Clapp, Geology of Victoria, pp. 8-15.

[7] These sources of data are discussed in detail in chapter 4.

[8] J. MacMurdo, "Papers Relating to the Earthquake which Occurred in India in 1819", Philosophical Magazine, Vol. 63, pp. 105-177, quoted in Seed and Schnabel, "Soil and Geologic Effects", p. 62.

[9] Microseisms are not small earthquakes, but continuous disturbances recorded by seismographs. They are caused, inter alia, by machinery, traffic, wind, or breaking waves.

[10] H. Bolton Seed and Izzat M. Idriss, "Influence of Soil Conditions on Ground Motions During Earthquakes", Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers 95 (January 1969): 132.

[11] H. Bolton Seed, "Soil Problems and Soil Behavior", in Earthquake Engineering, ed. Robert L. Wiegel (Englewood Cliffs, N.J.: Prentice-Hall, 1970), p. 228.

[12] Ibid., p. 230.

[13] Ibid., p. 235.

[14] Ibid., p. 239.

[15] Ibid., p. 243.

[16] J.G. Fyles, Surficial Geology of Horne Lake and Parksville Map-Areas, Vancouver Island, British Columbia (Ottawa: Queen's Printer, 1963).

[17] Clapp devotes only six pages to the description of surficial despoits in his 1913 work which deals principally with bedrock geology.

[18] Fyles, Geology of Horne Lake, p. 15.

[19] Clapp, Geology of Victoria, p. 114.

[20] Fyles, Geology of Horne Lake, p. 19.

[21] Ibid., p. 20.

[22] Ibid., p. 102.

[23] Clapp, Geology of Victoria, p. 110.

[24] Fyles, Geology of Horne Lake, p. 102.

[25] Ibid., p. 41.

[26] Ibid., p. 102.

[27] Ibid., p. 74.

[28] Ibid., p. 103.

[29] Ibid., p. 104.

[30] C.B. Crawford and J.G. Sutherland, "The Empress Hotel, Victoria, British Columbia. Sixty-Five Years of Foundation Settlements", Canadian Geotechnical Journal 8 (1971): 82.

[31] Ten feet is chosen as the parameter here for no reason other than that adequate information is available only to this depth.

CHAPTER 4

METHODOLOGY

Various differing approaches to seismic microzonation have been developed during the past thirty years. Although all are based on geological and geophysical considerations, there is a considerable lack of uniformity in the ground characteristic parameters and techniques employed in determining them. The examples discussed below illustrate the variety of methods used. Microzonation maps are in official use in the USSR, Japan, and New Zealand, while extensive research into the subject has been conducted in the United States and Chile.

Seismic Microzonation Methods

The first microzonation of a city appears to have been that of Tbilisi in the USSR by Gzelishvili and Safaryan in 1946.[1] The authors, working on a soils map at the scale of 1:6000, divided that city into three zones of possible earthquake intensity and added a fourth zone to indicate potential landslide areas. The zone of highest intensity was characterized by loose alluvium, areas of loam, clay, or loess with a high water table, and areas of loose clay and rubble at the foot of mountain slopes.

By comparing local variations in intensity against ground types for thirty-four earthquakes in different Soviet cities, S.V. Medvedev developed seismic intensity increments for different kinds of ground.[2] The chief physical characteristic used in the evaluation of ground influence on seismic intensity was termed seismic rigidity. This was calculated by multiplying the rate of propagation of longitudinal seismic waves in the top ten metres (33 feet) by the density of that layer. The intensity increment is derived from the formula

$$n - 1.67\ (\log v_o p_o - \log v_n p_n) + e^{-0.04h^2}$$

where n = intensity increment
$v_o p_o$ = seismic rigidity of granite
$v_n p_n$ = seismic rigidity of examined ground
h = depth of ground water table

The intensity increments for various types of ground are shown in Table IV.

The effect of a high water table is reflected in the higher increments for moist ground (Category VII in Table IV). If the water table rises to within 33 feet of the surface an increase in seismic intensity follows. When the water table reaches a level within 13 feet of the foundations in sandy-loam, loam, sand, or pebble ground, an increment of 0.5 can be expected, while a water table immediately below the foundation increases the intensity by an increment of 1.0. An example of the importance of the water table and soil conditions can be seen in the Tonankai, Japan earthquake of 1944. The average percent of damaged buildings on aquiferous clay ground was 26.0 percent, on sand dunes 3.5 percent, on gravel 1.4 percent

TABLE IV

SEISMIC INTENSITY INCREMENTS FOR DIFFERENT GROUND TYPES

Category	Kind of Ground	Intensity Increment
I	Granite	0
	Limestone, shale, compact gneiss	0.2 - 0.4
	Compact sandstone	0.5 - 0.8
	Dislocated sandstone, limestone, shale	0.7 - 1.1
II	Gypsum	0.6 - 0.8
	Marl	0.7 - 1.0
	Cemented sands	1.0 - 1.2
III	Rubble and pebble	0.9 - 1.3
	Crystalline gravel	1.0 - 1.4
	Sedimentary gravel	1.1 - 1.5
IV	Gravelly and coarse-grained sand	1.2 - 1.4
	Medium-grained sand	1.3 - 1.6
	Fine-grained sand	1.4 - 1.8
V	Clay	1.2 - 1.6
	Loam	1.3 - 1.7
	Sandy loam	1.4 - 1.8
	Loam (porosity=1.0), sandy loam (porosity=0.7)	1.7 - 2.1
VI	Filled land	2.3 - 2.6
	Soil	2.6 - 3.0
VII	Moist gravel-pebble	1.6 - 2.0
	Moist sandy ground	2.0 - 2.4
	Moist clayey (sandy loams,loams)	2.4 - 2.8
	Moist filled land and soil	3.3 - 3.9

Source: S.V. Medvedev, Engineering Seismology (Jerusalem: Israel Program for Scientific Translations, 1965), Table 2.5, p. 50.

and on firm ground 0.2 percent.[3] Medvedev suggests three schemes based on intensity increments for amending the

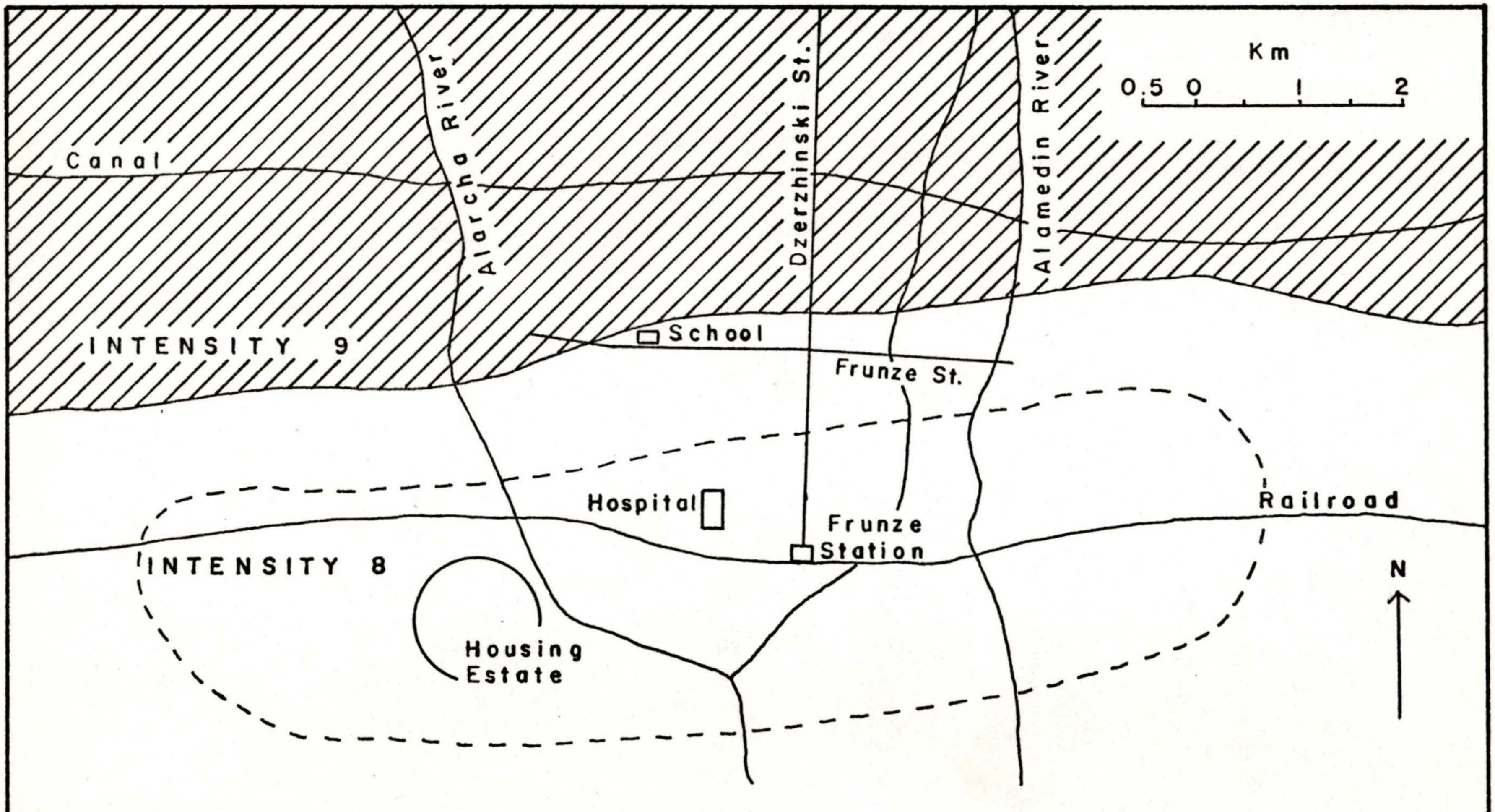


FIGURE 9 - MICROZONATION OF FRUNZE, USSR

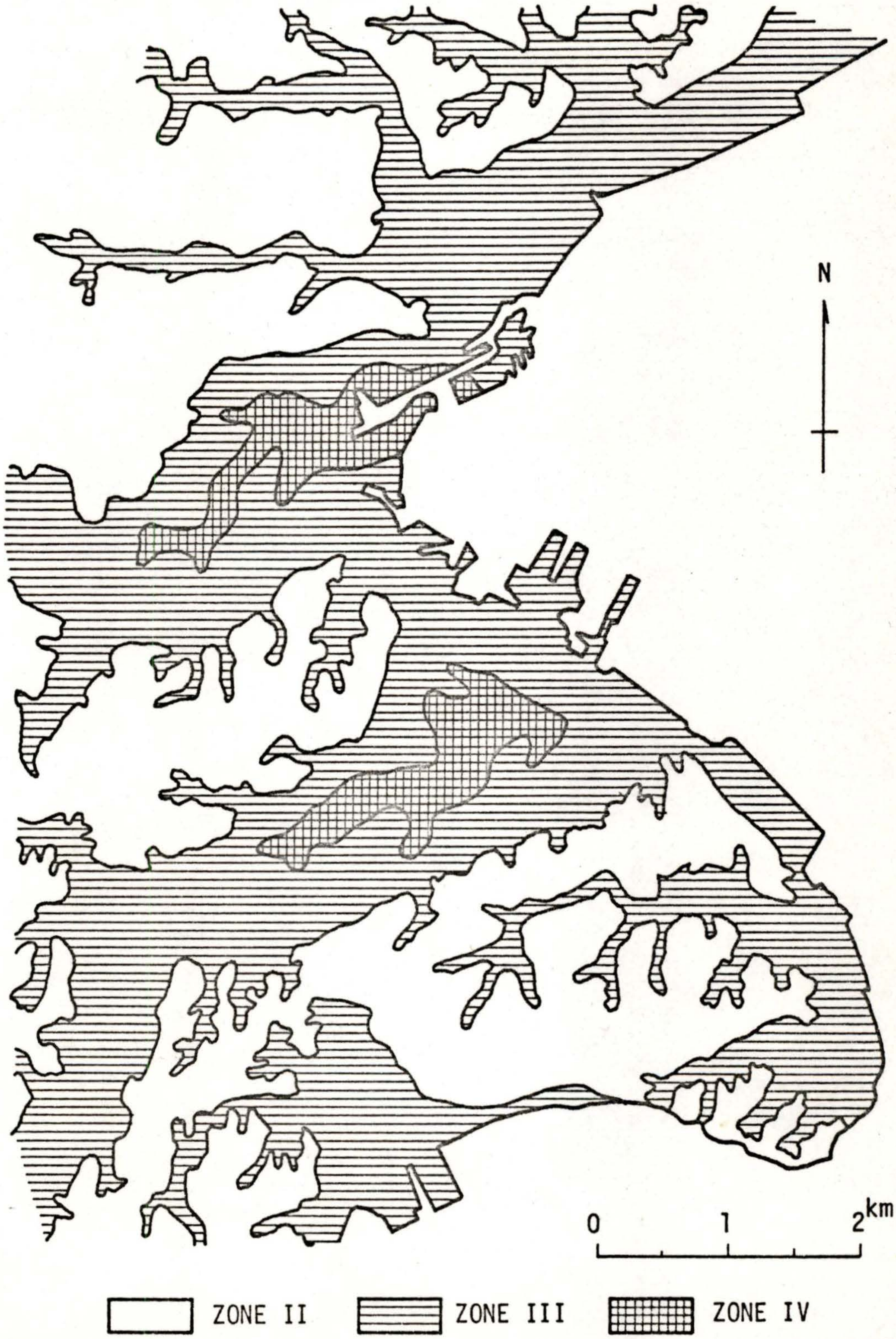
After Medvev

general seismic map as dictated by local ground conditions.[5] If there is no criterion for dividing the area into more than one zone, the city would remain zoned as shown on the national seismic map. If there is a variance of one, some parts of the city would be zoned one intensity unit above or below that indicated by the general map. If the surface geology varies so strongly that the intensity increment between the poorest and best ground is two units, three zones would be required, with the area of average risk being that of the seismic zoning map. In terms of acceleration expressed in percent of gravity, the acceleration in the highest zone would be four times that in the lowest zone.

Figure 9 is an example of the application of the second type of microzoning scheme. Frunze, the capital of the Kirgiz SSR, lies in zone 9 (acceleration 31.6 percent of gravity) on the general zoning map. The intensity increments calculated for the ground range from 0.9 in the south to 2.3 in the north, with an average value of 1.8. Since this latter value is the one on which the zoning for Frunze on the general map was determined, the local variation is found by subtracting 1.8 from each individual intensity increment, yielding a range of -0.9 to 0.5. By rounding off the figures to the nearest whole number, an area of intensity 8 (acceleration 14.7 percent of gravity) is located in the south of the city, separated from the intensity 9 area by a narrow zone where the intensity may reach either 8 or 9.

FIGURE 10

MICROZONATION OF YOKOHAMA, JAPAN



SOURCE: Yorihiko Ohsaki, "Japanese Microzonation Methods", Proceedings, p. 167, figure 7.

As was noted earlier, the thickness of surficial deposits may have a large impact on the degree of earthquake damage. This factor appears to be disregarded in Medvedev's criteria for microzoning which is based on the seismic rigidity of only the top ten metres (33 feet) of unconsolidated material. Despite this shortcoming and some doubt about the precision of the ground water table factor, the criteria have been officially adopted in Bulgaria, Rumania, Turkey, and Yugoslavia as well as the USSR.[6]

In 1954, Yokohama became the first Japanese city to be officially microzoned (see Figure 10).[7] The city was divided into three zones of varying ground conditions as described in Table II, Chapter 3. This ground classification and its corresponding design seismic coefficients had been drawn up on the basis of a comparison of geological conditions and damage experienced in previous earthquakes. The thickness of deposits is considered in addition to their characteristics. The depth to the water table is accounted for only indirectly in the descriptions of the ground types.

Kanai and Tanaka analyzed over one thousand microseism records and showed that the amplitude and period of these waves varied predictably with the different zones shown in Table II. The mean period, largest period, and predominant period are all longer for softer soil deposits. From this analysis, two methods of microzonation were proposed. One is based on the largest period and mean period

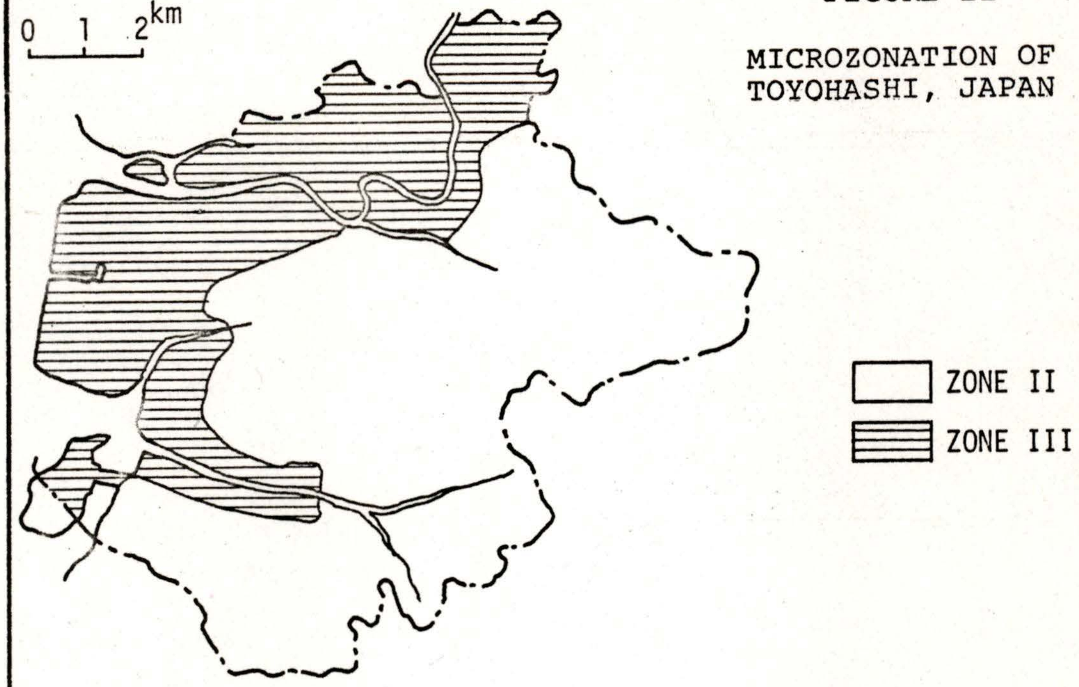


FIGURE 11

MICROZONATION OF
TOYOHASHI, JAPAN

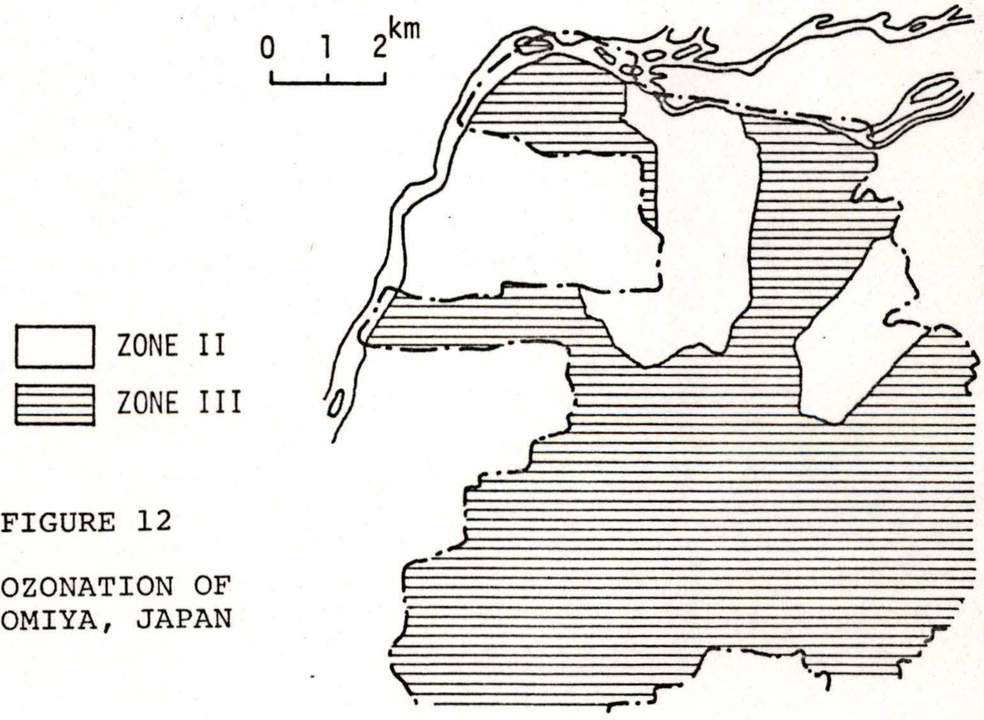


FIGURE 12

MICROZONATION OF
ICHINOMIYA, JAPAN

SOURCE: Yorihiko Ohsaki, "Japanese Microzonation Methods", Proceedings, p. 173, figures 14 and 15.

of microseisms, while the other is based on the largest amplitude and predominant period.[8] These methods permitted microzonation of areas where historical data on earthquake damage were missing. Figures 11 and 12 are examples of microzonation based on this method.

Besides the USSR and Japan, as far as is known to the writer, only New Zealand currently uses microzonation maps for official purposes. A Microzoning Committee of the Department of Scientific and Industrial Research was established in 1968, which was responsible in 1972 for the publication of a microzonation map for the city of Wellington.[9] Based on geology, soil type, and geophysical information (gravity readings and microseism measurements), the city was divided into three intensity zones and a landslide-prone area. Zone 1 comprised areas where bedrock was within 10 metres (33 feet) of the surface, Zone 2 included compact sediments more than 10 metres (33 feet) thick, and Zone 3 consisted of areas of highly porous sediments, including reclaimed land. The authors postulated that the amplification in vibration between successive zones would correspond to one step on the Modified Mercalli Scale.

The descriptions of the ground characteristics of each zone are much simpler than those previously discussed for the USSR and Japan. Depth to bedrock is the important criterion in Zones 1 and 2, and only in

Zone 3 is the type of ground the overriding consideration. The depth of the water table is not included as a factor in zoning.

Investigators from the University of Chile compared different methods of microzoning, using six Chilean cities as test cases.[10] The three basic methods employed were:

1. Damage surveys from recent earthquakes
2. Study of local geology with emphasis on the ground water table, geologic origin of sediments, degree of compaction and classification, and depth of bedrock below the surface
3. Microseism measurements and the Kanai and Tanaka criteria.

Using the damage surveys as a control, since they represent the only quantification of the actual phenomenon, the results showed good correlation with the geological information, especially where near surface data were considered. The Kanai and Tanaka classifications did not agree with the damage surveys, and the authors conclude that this technique is only useful as a complementary investigation, not as the sole means of microzonation. Medvedev's criteria correlated well in some cases, poorly in others.[11]

Richter prepared the first microzonation map in the USA, that of Los Angeles in 1959.[12] Following the USSR example, the zones were labelled by the maximum Modified Mercalli intensity which might be expected in that zone. He translated geology into intensity as follows:

Zone IX - Quaternary alluvium and sand dunes; also landslide areas
Zone VIII - Quaternary, consolidated
Zone VII - Tertiary sediments and volcanics
Zone VI - Granitic; also Mesozoic sediments and metamorphics

In a 1972 revision of his earlier work,[13] Richter expanded the descriptions by listing individually the maximum intensity to be expected on specific geologic formations (for example, VIII on Saugus formation; VII on Pico formation). He admits that microzonation based solely on geologic age is a last resort, and better criteria in order of acceptability, are:

1. Historical record of earthquake effects
2. Seismograph data
3. Velocity profiles, geophysically determined
4. Mechanical properties of rock, as determined in the laboratory
5. Details of local lithology and structure, as determined by field inspection

Santa Barbara was microzoned into areas of low, intermediate and maximum intensity based on a study of the intensities observed in a 1925 earthquake and local stratigraphy.[14] The intensities for the 1925 earthquake were determined by a questionnaire distributed to persons # who lived in the city at that time. The pre-settlement drainage of the city was considered in conjunction with other geologic studies.

A microzonation of Long Beach, California was completed as part of that city's revision of its municipal building code.[15] The soil intensity map, dividing the city into zones of low, medium, and high intensity, relative to the top thirty feet of soil, was based on an investigation of old swamp locations, areas of recent fill, geologic age, and bearing capacity as determined by some 100 boring logs. The authors warned, however, that the map should not be adopted into the building code since the information used in its preparation was too sparse and variable.[16]

Two salient features emerge from the foregoing discussion. The record of previous earthquake intensities is the only quantitative control in assessing the anticipated variation in damage within a restricted area. Secondly, at present the most reliable method of mapping intensity zones on a micro-scale is the extension of the results of a correlation of this previous damage to the geologic conditions. These two features are common to most microzonation maps produced to date, and form the basis of the preliminary microzonation map of Victoria.

Methodology of this Study

Research in the present study centred on gathering previously unrecorded data on the 23 June 1946 earthquake and correlation of this data with variations in local geomorphological conditions. As with much research, lack of adequate data proved to be a major difficulty.

Obviously the ideal time to evaluate the damage caused by an earthquake is immediately after the event, but few investigators have had this opportunity. Written records may be available for later study, but these are likely to be incomplete. In the case of the Victoria earthquake of 23 June 1946, the author was able to find only nine discrete reports of damage preserved in written form.

Although the event occurred over twenty-seven years ago, it had been hoped that many sources of information would be available for a detailed survey of the damage sustained in the city. Unfortunately, this did not prove to be the case.

No records are available at the municipal level. Both the Fire and Police Departments had destroyed their logs for that day. In 1946, city regulations called for building permits on repairs costing twenty-five dollars or more, so a search was made for building permits. None was found, apparently because city officials had not wished to aggravate the situation of people who had suffered losses by insisting on compliance with the regulation. Interviews indicated that several streets had been blocked off due to cave-ins and cracked surfaces (for example, Chapman Street near Howe, and Shelbourne Street near Hillside), but these reports could not be confirmed from Public Works records.

Insurance companies were contacted for information on possible claims made at the time. None had any on file, probably due to the lack of earthquake insurance in effect. The provincial insurance superintendent advised that his department would only have become involved if the private companies were having trouble meeting their obligations, and this had not been the case.

In an earthquake of this magnitude, it is now the practice of seismologists of the Department of Energy, Mines and Resources to send out questionnaires to determine intensities so that isoseismal maps may be drawn. Since the area covered by such maps is usually large, only one intensity is recorded for each city. For Victoria, this intensity was determined by the seismologists themselves, based on personal observations, so no questionnaires from Victoria are on file. However, the official report on the earthquake, which includes comments on the damage in Victoria, was made available to the author.

Both Victoria newspapers naturally carried stories and pictures of the earthquake, but these included only nine reports from which the exact location and intensity could be identified.[17] Lacking other sources of recorded information, interviews were conducted with residents who had experienced the earthquake in the city.

In order to select some respondents on a random basis, the city was divided into 72 squares. Of these, 16 had no dwellings in them, while 9 were only half developed. Using random numbers to select intersections on grid squares, two locations per full square and one per half-empty square were determined, yielding a total of 103 locations. Two dwellings as close as possible to each of these locations were then selected by matching names of 1946 occupants with the current telephone directory, thereby providing a list of 206 possible respondents chosen at random.[18] Two dwellings were chosen at each location to enhance the probability of obtaining at least one response from each location. If responses from two dwellings very close to each other were available, these would serve the additional purpose of allowing comparison of intensities assigned and a check on their reliability.

According to newspaper reports, damage was more severe in some localized areas of the city. In order to delineate these locations more accurately, as many potential respondents as possible were identified from these areas by the same procedure of comparing the 1946 city directory with the 1972 telephone directory. This added 211 contacts to the interview list, while 32 more were identified in the course of the interviews. Including the 9 newspaper reports, a total of 458 discrete sources of information were investigated in this random stratified sample,[19] representing approximately 3.4 percent of the occupied dwellings in Victoria in 1946.[20]

Rated responses were obtained in 202 cases. In 90 cases, the person contacted was not the individual who had been living at the target address in 1946 despite the identical name. Sixty-five respondents did not remember the earthquake, while a further 40 were not home at the time of the tremor. No contact was established on 54 occasions, the phone having been disconnected in 25 cases, the wrong number listed in 21 instances, and no answer after repeated calls in 8 cases. Six potential respondents were out of the city during the interview period and only one person refused to discuss the earthquake. Except for two face-to-face interviews with city officials, all interviews were conducted over the telephone.

The interviewer identified himself by name and stated that he was a graduate student at the University of Victoria, investigating the 1946 earthquake in the city. No further information or coaching was volunteered unless it was required to prevent a termination of the interview at this stage. If it became evident that the respondent needed more help to jog his memory, the month and day of the week were divulged. This was required mainly in cases where the respondent was having trouble in isolating this particular earthquake in his mind.

Two questions naturally arise about the validity of the responses. How accurate were they in terms of details, and what intensity rating would be assigned once specific details were known? To provide some information on its accuracy, each response was classified either as A, B, or did not remember. Responses falling into class A were the ones where the respondent showed immediate recall of the event, was able to pinpoint the month, day of week, or time of day, or recalled conversations and good detail of incidents. Class B responses either required coaching to pinpoint the time, or the respondent had few details to offer. In every case, however, the interviewer was satisfied that it was the 23 June earthquake that had been under discussion. The 65 responses rated "did not remember" were either straightforward cases of no memory of the event, responses where doubt existed as to which earthquake was under discussion, or where no details were forthcoming.

Using these criteria, it might be expected that there would be more B class responses in cases where the intensity was at the low end of the scale. There were 130 "A" class responses and 72 "B" class responses, broken down by intensity as shown in Table V.

Subjectivity enters into the assessment of seismic intensity both directly and indirectly. It forms an inherent part of the ratings on the Modified Mercalli scale as well as being introduced indirectly when eye-witness accounts are assessed by a second party. In an effort to minimize this subjectivity, the measures outlined below were adopted.

The lower and upper limits of intensity were found to be III and VII. Intensity I would not be reported, and the difference between II and III is impossible to assess in the case of a single report from one individual. The upper limit of VII was the intensity officially assigned to the event by seismologists at the time and is corroborated by the evidence in this study.

Intensity can be assessed on the basis of effects on people or effects on inanimate objects. Wherever possible, intensity was assigned in this study on the basis of effect on inanimate objects (for example, dishes broken rather than occupant frightened, for intensity V). In this connection, the quality of construction is a criterion in differentiating intensities VI and VII. Damage to buildings was not used by itself in any assignment of intensity, so the question of having to decide between "poorly built" and "well-built ordinary" buildings did not arise. At these intensities other criteria, such as broken chimneys and cracked or fallen plaster, were used.

In twelve cases, where other data were lacking, effects on personal reactions were the basis of intensity assessment at levels V and VI. In a study to determine how much weight should be given to personal reactions when they are unaccompanied by reports of corresponding effects on inanimate objects, Voigt and Byerly concluded that the "effects on people" criteria justified raising the intensity from IV to V or from V to VI if reports on nearby effects on inanimate objects indicated the lower intensity.[21] The intensity assigned by "effects on people" in this study is considered conservative, since the V or VI ratings thus allocated were in areas where adjacent intensities based on "inanimate objects" were equal or greater.

TABLE V

COMPARISON OF INTENSITY AND CLASS OF RESPONSE

Intensity	Class A	Class B	Total
III	11 (5.4)*	19 (9.4)	30 (14.8)
IV	27 (13.4)	15 (7.4)	42 (20.8)
V	22 (10.9)	19 (9.4)	41 (20.3)
VI	45 (22.3)	16 (7.9)	61 (30.2)
VII	25 (12.4)	3 (1.5)	28 (13.9)
	130 (64.4)	72 (35.6)	202 (100.0)

* Percent of total responses in brackets.

In order to achieve some standardization in the qualitative assessment after each interview, the intensity was rated on the basis of the single highest criterion which had been observed. Although this procedure may have led to an increase of one unit intensity in some cases, it is considered reasonable in that it was uniformly applied, and the important single consideration is the <u>relative</u> intensity of different locations. Had an attempt been made to decide the intensity by averaging the various effects observed, even more subjectivity would have entered the ratings.

The results of the investigation are tabulated in Appendix B, with each site identified by a serial number. The intensity rating and class of response is followed by a brief remark on the effect observed at that location. In every case greater detail was available and the assessment of intensity was based on more information than appears in the appendix. For example, the remark by serial 164 is "fall of considerable plaster". The full report shows that a clock was knocked off a bookcase, a piano moved from the wall to the middle of the floor, pots were knocked off the stove, the plaster ceilings fell down in several rooms, and a rafter was split in the garage.

Each serial is plotted on Map 1 (see back pocket). The serials are numbered sequentially in bands from west to east, starting at the southwest corner of the map.

Isolines separating areas of equal intensity have not been shown, since isoseismals are traditionally used to indicate average intensities, and therefore would not be suitable for an area as small as Victoria. Evernden, Hibbard, and Schneider point out that on isoseismal maps the only critical data are the reported values of seismic intensity at specific points and that published contours of intensity are grossly deceiving unless properly interpreted.[22] Contouring is used in the microzonation map (Chapter 5), where geology as well as reported intensities are taken into consideration.

Information on the depth and stratigraphy of the surficial deposits was gathered from a variety of sources.

Data collected in the Urban Geology Survey, conducted under the auspices of the Terrain Sciences Division of the Geological Survey of Canada, are available on open file at the Building Inspection Department, Capital Regional District Planning Board. Results of 724 boreholes distributed over 103 city blocks were available for Victoria. The coverage is uneven, with comparatively high density in the downtown area where most of the major construction has been undertaken. The data were compiled in early 1972 from the records of Thurber Consultants, the Groundwater Division of the Department of Lands, Forest and Water, and the Department of Highways. Information on each borehole is given on two or three data sheets. The primary data sheet shows the background information on the borehole, while the drill log data sheet describes the sediments by layer and thickness. In some cases, an engineering parameter data sheet is also available, giving results of engineering tests when conducted.

Part of this information is tabulated in Appendix C. Each borehole is identified by a military grid reference which is considered accurate to the nearest five feet. The grid system is superimposed on the one inch to two hundred feet map of Victoria used in the Urban Geology Survey, and is shown on the edge of each major map in this study as a rough guide to position.

Depth to water level is shown in 196 cases. These observations have been either estimated or measured, with varying lengths of time elapsing between the boring of the hole and the observation of water level. Combined with the fact that the logs span a number of years and different seasons, it is considered that the water table data can be of general interest only.

Each layer of unconsolidated material is identified,preceded by the depth in feet from the surface to the top of that deposit. Sediments are classified into fifteen divisions. There are four grades of gravel and gravelly deposits (prefixed G) and four grades of sand and sandy deposits (prefixed S). Silts and clays are divided into six types, with three of low plasticity (suffixed L) and three of high plasticity (suffixed H). Peat and other highly organic soils are identified separately. In some instances, a general term, such as mud, till, muck, or fill is used.

The last item included in the appendix is an indication where drilling was discontinued for reasons other than that the required depth was reached. Bedrock is so indicated only where it was positively identified. In other cases where drilling stopped on rock, it is noted as possible bedrock or simply as rock.

The data of Appendix C were plotted on a working map at the scale 1:2400. The depth of each hole and cases where bedrock or probable bedrock were encountered were displayed.

To investigate the near-surface and surface areas of bedrock, the area plans and plan profiles in the City Engineer's department were examined. The area plans show where bedrock was reached during trenching for water mains, storm drains, gas lines, and underground telephone or hydro lines. A plan profile exists for each street with any of these services, and 453 profiles were examined to determine the depth of the trench and the slope of the bedrock surface. The trenches varied from one to thirty-five feet in depth, with an average depth of ten feet. All rock shown on the profiles could be confidently assumed to exist, whereas the possibility of rock occurring in cases where it was not shown could not be ruled out. The data from these profiles were plotted on the working map.

To complete the survey of rock outcrops, a visual examination of every block in the city was conducted. In the downtown area most of the outcrops have been blasted away and masked with pavement or buildings, but this is not so in the residential areas, thereby providing some balance for the paucity of borehole data from these areas. Tips of isolated boulders of similar lithology to local bedrock may have been confused with genuine outcrops during the fieldwork, but this problem resolved itself when the map was generalized at a later stage.

Preliminary studies had indicated that the old swampy areas and stream beds were of special significance in considering earthquake damage, so an effort was made to delineate the pre-settlement drainage pattern carefully. Three maps published in the period 1861 - 1884 and Clapp's 1910 maps[23] show the location of swamps before they were drained, watercourses before their flow was diverted into the storm drain system, and the shoreline before it was modified by areas of extensive fill. The original drainage pattern is reflected in the present contours of land, and some of these features are shown on Map 2.

A few supplementary sources added some information to the geomorphological picture. A newspaper article described the bedrock at the site of the Hillside Shopping Centre on the northwest corner of Hillside Avenue and Shelbourne Street (163/81) as having a sloping surface, extending from 20 to 123 feet below the surface.[24] Plan profiles at the Greater Victoria Water District yielded information on the bedrock in the extreme north end of the city. Crawford and Sutherland described the reclaimed area in James Bay in great detail.[25]

After all the data had been plotted on the working map at a scale of 1:2400, the information was generalized at a scale of 1:12,000 before being reduced to the scale of 1:24,000 used in Map 2. The information presented in this map varies in accuracy as discussed below.

Considered to be most accurately mapped are the areas where bedrock is at or within ten feet of the surface. If errors exist here, they are errors of omission rather than ones of showing bedrock where it does not occur.

The contour interval of the working map was five feet, so the present-day closed depressions are accurately depicted. Only the ones related to old swamps are shown, however, since several closed depressions in the city are the vestiges of early quarries. The boundaries of pre-settlement swamps are based on the old maps which themselves varied considerably in accuracy. An attempt was made to correlate them with present contours, with the result that the boundaries shown reduce the area of swamps indicated on the original maps.

Despite the lack of ideal data for microzoning the city, the author was able to collect considerable information on the local variation in response to seismic events from 202 interviews and literary sources. Similarly, extensive fieldwork and the examination of 724 borehole records and 453 street plan profiles allowed a comprehensive review of the stratigraphy and bedrock topography of Victoria. This information provided an adequate basis for the preparation of a preliminary microzonation of the city, details of which are presented in the following chapter.

FOOTNOTES

[1] S.V. Medvedev, Engineering Seismology, trans. Israel Program for Scientific Translations staff (Jerusalem: Israel Program for Scientific Translations, 1965), p.87.

[2] Ibid., p. 38.

[3] Ibid., p. 45.

[4] The intensities defined in the Soviet GOST 6249-52 seismic scale correspond to those of the Modified Mercalli scale.

[5] Medvedev, Engineering Seismology, pp. 61-62.

[6] V. Karnik, "Microzoning Programme within the UNDP-UNESCO Survey of the Seismicity of the Balkan Region", Proceedings, pp. 213-15.

[7] Yorihiko Ohsaki, "Japanese Microzonation Methods", Proceedings, p. 166.

[8] Kiyoshi Kanai and Teiji Tanaka, "On Microtremors. VIII." Bulletin of the Earthquake Research Institute 39 (1961): 110-11.

[9] R.D. Adams, "Microzoning for Earthquake Effects in the Wellington City Area", Bulletin of N.Z. Society for Earthquake Engineering 5 (September 1972): 106-7.

[10] Roberto M. Lastrico and Joaquin Monge E., "Chilean Experience in Seismic Microzonation", Proceedings, pp. 231-48.

[11] Ibid., p. 238.

[12] C.F. Richter, "Seismic Regionalization", Bulletin of the Seismological Society of America 49 (April 1959): 129.

[13] C.F. Richter, "Seismic Regionalization or Zoning: Revision", Proceedings, pp. 267-82.

[14] Phil G. Olsen, "Seismic Microzonation in the City of Santa Barbara, California", *Proceedings*, pp. 395-408.

[15] John H. Wiggins, Jr., and Donald F. Moran, *Earthquake Safety in the City of Long Beach Based on the Concept of Balanced Risk* (N. p., 1971).

[16] Ibid., p. A-3.

[17] *Victoria Daily Times*, 24 June 1946, pp. 3, 8 and *Victoria Daily Colonist*, 25 June 1946, pp. 1, 5.

[18] Exact dwelling addresses were located in British Columbia Underwriter's Association, *Insurance Plan of Victoria BC, September 1957* (Vancouver: British Columbia Underwriters' Association, 1957), and names of the head of household from the *B.C. and Yukon Directory, 1946* (Vancouver: Sun Directories, 1946).

[19] P. Haggett, "Scale Components in Geographical Problems", in *Frontiers in Geographical Teaching*, ed. Richard J. Chorley and Peter Haggett (London: Methuen and Co. Ltd., 1965), p. 167.

[20] No exact figures are available for the year 1946, but there were 13,373 dwellings built in Victoria before 1946. Canada, Dominion Bureau of Statistics, *1961 Census of Canada: Housing, Basic Dwelling Characteristics*, Bulletin 2.2-1, p. 18.1.

[21] Dorothy Stanley Voigt and Perry Byerly, "The Intensity of Earthquakes as Rated from Questionnaires", *Bulletin of the Seismological Society of America* 39 (January 1949): 26.

[22] Jack F. Evernden, Richard R. Hibbard, and Joseph F. Schneider, "Interpretation of Seismic Intensity Data" *Bulletin of the Seismological Society of America* 63 (April 1973): 406.

[23] *Map of Victoria and Part of Esquimalt Districts* (London: Day and Son, 1861); Alfred Waddington, *Map of Victoria* (San Francisco: C.C. Kuchel's, 1863); D.R. Harris, *A Map of the City of Victoria* (N.p., 1884); and maps 20A and 71A in Clapp, *Geology of Victoria and Saanich Map-Areas*.

[24] Victoria Daily Times, 11 February 1969, p. 2B.

[25] C.B. Crawford and J.G. Sutherland, "The Empress Hotel, Victoria, British Columbia. Sixty-Five Years of Foundation Settlements", Canadian Geotechnical Journal 8 (1971): 77-93.

CHAPTER 5

ANALYSIS OF MICROZONATION OF VICTORIA

Earthquake wave motions are complex near the focus. Outside the epicentral area, this motion becomes even more complicated due to reflection and refraction at the boundaries of non-homogenous layers in the earth's crust. Seismic wave motion and the resulting ground motion of the earth's surface at any one point will vary with the distance and bearing from the focus and with the magnitude, mechanism, depth, and duration of the earthquake. It should be emphasized, therefore, that the present study is based on a particular earthquake, and the ground motion resulting from other earthquakes will differ.

A microzonation map based upon observed intensity has the major advantage that the effects of all factors are considered. The dominant influence of ground characteristics on local variations in intensity has been discussed in Chapter 3, but it should be stressed that the pattern of resulting damage would not be identical for each earthquake. With this caveat in mind, possible contributing factors which may explain the pattern of intensity of the 23 June 1946 Victoria earthquake are considered.

Possible Factors Affecting Intensity of the 1946 Earthquake

With little evidence to indicate the occurrence of such secondary effects as landslides, land subsidence, or soil liquefaction, the explanation for the variation in intensity in the Victoria earthquake must be sought elsewhere. Either the relative age and condition of buildings or differences in the degree of actual shaking might be invoked as possible reasons.

The age of a building is certainly a factor in the damage to be expected during an earthquake, but as previously noted, the Modified Mercalli scale takes this variable into account in defining the intensity levels. Due to the limited damage during the 1946 earthquake, as reported earlier, only chimney damage might be expected to reflect the age of buildings to any degree. The older residential districts are on the periphery of the downtown area, while areas such as the northeastern corner of the city and that to the east of St. Charles Street (153/81) were only being developed in 1946. Chimneys were damaged on new houses (for example, serials 48 and 200) as well as on older houses (for example, serials 9 and 63). Since there is no clear pattern of intensity radiating out with the growth lines from the centre of the city, the age of construction is not considered to be sufficient to explain the variation in intensity within the city limits.

Examination of any small scale isoseismal map reveals that the most obvious factor affecting intensity is the distance from the epicentre of the earthquake. On a large scale microzonation map, however, distance to the epicentre would only be a major variable controlling intensity differences if the epicentre was extremely close to the city, as in the case of the 1963 Skopje earthquake.[1] The 1946 earthquake was centred in the Strait of Georgia, over one hundred miles north of Victoria. As seen from Map 1 the seismic intensities in Victoria do not increase from south to north.

In considering the influence of ground characteristics it would have been better to test the correlation of intensity with depth to bedrock and type of surficial deposit independently. Lacking sufficient data to attempt this, the type of ground as differentiated on Map 2 was correlated with the intensities displayed on Map 1. The results are shown in Table VI, and the Chi-square test of the independence of categorical variables indicated a positive correlation of a significance level of 0.01.

The lowest intensities were recorded on type A ground. It seems to make little difference what kind of surficial layers rest on bedrock if these layers are less than ten feet thick. In most cases, foundations of structures reach bedrock, and in any event, the amplification of seismic waves is at a minimum in such thin layers.

Type C ground includes areas where fill has been used extensively in shoreline reclamation or where predevelopment marshy ground was known to exist or postulated from a comparison of old maps and present-day topographic contours. As Table VI shows, these areas correlated well with the highest intensities reached in the 1946 earthquake. However, the cause of such higher ground motion amplitudes may not necessarily have been simply the depth of fill or the type of deposit appearing near the surface. In discussing the greater damage incurred on old marsh sites in San Francisco in 1906, Evernden, Hibbard, and Schneider state:

> ...there is a close correlation of deep stratigraphy and surface condition and it is not necessarily obvious that filling in the marsh was responsible for the high damage. The old marsh areas, as indicated by borings, are characterized by weak sedimentary types for appreciable thicknesses below the surface. It seems much more likely to us that the old marsh sites were expressive of a general ground condition rather than that the ground conditions were caused by the marshes.[2]

TABLE VI

CORRELATION OF INTENSITY/TYPE OF GROUND

Type of Ground	Cases of Measured Intensity					
	III	IV	V	VI	VII	Totals
A. Bedrock within 10 ft.	29	30	3	0	0	62
B. Other than A or C	1	12	28	9	6	56
C. Fill or former swamp	0	0	10	52	22	84
Totals	30	42	41	61	28	202

Data are available from several relatively deep boreholes in the areas mapped as type C ground. Near the intersection of Linden and Oxford Streets (151095/85450), forty-eight feet of clays of varying plasticity, probably Victoria clay, were penetrated without reaching bedrock.

Near the intersection of St. Charles Street and Fairfield Road (150910/81840) a thirteen foot layer of a sand-silt mixture rests on clay to a depth of sixty-four feet, which in turn gives way to a further eight feet of a sand-clay mixture before the bottom of the hole is reached at seventy-two feet without encountering bedrock. At the site of the Hillside Shopping Centre, at the northwest corner of Hillside Avenue and Shelbourne Street (163/81), the thickness of surficial deposits is known to reach 123 feet. Under the south end of the Empress Hotel (154/89), twenty feet of fill overlies ninety feet of Victoria clay above bedrock.

Closely related to the areas of C type ground is the level of the water table. As was already noted, the information available on the level of the water table is too incomplete and variable in both time and location for a comprehensive picture of its nature in the city to be derived. However, the data available indicate that the average depth to the water table beneath areas of fill and former swamps is about ten feet. For example, it is shown at eleven feet for borehole 150910/81840, at twelve feet at 150370/84975, and at six feet at 161630/87000.

It is suggested that the higher intensities during the 1946 earthquake in type C areas may be the result of higher amplification of seismic waves in thick layers of saturated Victoria clay. Before urban development, such areas were commonly routes for surface drainage or occupied by bogs, many of which are identifiable by the topographical closed depression now occupying the site. The fact that no ground noise was reported from such areas of highest intensity is probably due to the absence of rock near the surface. It is the grinding in the bedrock which produces the characteristic rumble of an earthquake.

It is evident that less extensive areas of deep Victoria clay exist in locations where they have not been mapped. One such location is the isolated pocket at the north end of Broad Street, where borehole 156740/88440 indicates seventy-five feet of clay over three feet of gravel with no bedrock encountered. Intensity VII was reached near this location. Due to the paucity of data, these isolated pockets are included in type B ground.

The ground classified as type B represents a great variety of layers of differing thicknesses, and obviously includes small areas of type A or type C ground which would have been so classified if more complete data were available. For this reason, the range of intensities found on this ground is wider than that of the other two categories.

Several conclusions may be drawn from the foregoing analysis. There seems to be little doubt that areas where bedrock appears within ten feet of the surface would probably experience the lowest seismic intensities in any future earthquake. In contrast, areas shown as type C ground, known to be underlain by thick deposits of Victoria clay would probably experience the highest intensities. Intermediate intensities are predicted for ground classified as type B, although a wider range is possible. It is also concluded that a microzonation map may be constructed with some confidence due to the excellent correlation between intensity and ground type established in Table VI.

The Microzonation Map

If a city were underlain by surficial deposits exceptionally homogenous both in type and thickness, no microzonation would be necessary and the intensity in any earthquake would be that shown for the area on a regional isoseismal map. At the other extreme, it might be feasible on a microzonation map to delineate as many zones as there were observed levels of intensity. In practice, the upper limit on the number of zones is predicated by other considerations. For engineering purposes, there is little advantage in differentiating areas where the expected Modified Mercalli intensity is V or less, since no structural damage occurs below this level. On the other hand, serious structural damage is general at intensity IX and little is gained in attempting to zone for higher intensities.[3] An excessive number of zones would also militate against the basic purpose of the microzonation map in that the translation of the zonation into building code controls and land use planning would probably become overly cumbersome. A microzonation map with too many zones might also give the impression of greater sophistication in technique than is as yet available.

As discussed in the preceding chapter, Medvedev suggested the use of one, two, or three zones as required by the complexity of ground conditions. Three zones were recommended only where the surface geology was extremely variable. This is the maximum number which has been used in the microzonation of Japanese and New Zealand cities, as noted in Chapter 4. Based on the variability of ground conditions in Victoria and the range of intensities observed in the control earthquake, the city has been tentatively divided into three zones as defined in Table VII.

TABLE VII

ZONES IN VICTORIA MICROZONATION

Zone	Related Ground Type	Intensity Increment
A	Bedrock within 10 feet	-1
B	Other than A or C	0
C	Fill or former swamp	+1

The median intensity reported in the 23 June 1946 earthquake was V, which corresponds with the mode for intensities on ground type B. Since both the seismic intensity and ground characteristics of zone B fall within the mid-range of values noted in this study, this zone is postulated as representing the "average" seismic hazard in Victoria, and therefore has an intensity increment of zero. However, it is emphasized that the wide range of intensities and the imprecise definition of ground type in zone B lead to greater uncertainty about anticipated intensities in this zone than in the others.

It has been possible to define the parameters for zones A and C somewhat more firmly. The description for ground in zone A is quite precise and three reports of intensity V were the only cases where the mode intensity IV was exceeded in this zone. It is postulated that intensities at least one unit lower than those in zone B would be experienced in zone A. Only ten intensity V observations of the total eighty-four cases reported from zone C fell below the mode intensity VI. Intensities of one unit or higher than zone B might be expected in this zone.

The zones are shown on Map 3 which is basically a generalization of Map 2. The temptation to overgeneralize, however, has been resisted. Close attention was paid to present topography as this has an obvious relation to the underlying basement rock. Consideration was also given to the intensity ratings in Map 1 where these provided refutation or confirmation of postulated bedrock surfaces.

Since the resulting map closely resembles the surficial geology as depicted in Map 2, the same or somewhat more severe limitations of accuracy may be applied.

Zones A and C are considered to be quite accurately delineated while a slightly lesser degree of accuracy is claimed for Zone B. Zone B is certain to contain small pockets of ground which belong to the other two zones, and generally is the most variable ground.

Aside from the 1946 earthquake data collected in this study, some further corroboration of the microzonation is available. The two incidents at intensity VII reported from the 6 December 1918 earthquake occurred in zone C. Damage to the Empress Hotel (zone C) was reported after the 29 April 1965 earthquake. Since the installation of a network of accelerographs and seismoscopes to measure ground motion in Victoria, significant readings have only been triggered by the 14 February 1969 earthquake. As expected, it was found that ground motion increased with increasing thickness of surficial deposits. In zone A, at the New Court House located on Blanshard Street between Courtney Street and Burdett Avenue (154/88), the horizontal motion was less than 0.5 mm. In zone C, at the bus station by the Empress Hotel (154/89), a horizontal motion of 2.5 mm. was recorded, while a reading of 1.0 mm. was reached at Margaret Jenkins Public School (152/80), situated in zone B.[4] It should be added that the latter site is very close to the edge of zone A, with bedrock within six feet of the surface under the street in front of the school.

The initial impression gained from an inspection of Map 3 is that a relatively small proportion of the area falls into zone C, while approximately half of the city lies in zone A with a comparatively lower seismic hazard potential. In other words, if Victoria were to be included within the intensity VIII isoseismal as postulated for a hundred year return period, the zone C areas might be expected to reach intensity IX. On the other hand, more than half of the city might be expected to reach only intensity VII during the postulated earthquake.

Several points should be kept in mind when using the map. The lines between zones represent intermediate bands where the intensity may be expected to vary within the limits of both contiguous zones (compare with Figure 9, Chapter 4). Zones A, B, and C represent areas of differing anticipated intensities for an earthquake of any size which might be experienced, and bear no relation to the seismic risk zones discussed in Chapter 1. Any attempt to apply intensity increments as used in this chapter and on Map 3 to modify risk zones would be meaningless.

The zones are based only on the differences in the amplification of seismic vibration by various surficial deposits, and secondary effects have not been considered in defining them. It would be wrong, however, to disregard the possibility of compaction, landslides, faulting or liquefaction occurring during a severe seismic event.

Victoria clay is susceptible to compaction, as has been demonstrated by the differential settlement of the Empress Hotel. The south end of the structure has sunk four and one-half feet below the north end in sixty-five years. However, four feet of this compaction occurred in the first ten years following construction, and an examination of the time-settlement curves, for the period 1912-1968, shows no abrupt increase in settlement in the years when the city experienced major earthquakes.[5] This evidence suggests that sudden compaction from seismic vibration should not be ruled out as a possibility within ten years of the construction of a major structure on thick Victoria clay. Where identified, these deposits are included in zone C due to their property of increasing the amplitude of seismic waves.

Areas where sediments may liquefy and where landslides may be triggered by earthquakes should be displayed on a microzonation map. For example, the Wellington, New Zealand microzonation map includes a Topographic Failure Zone.[6] In Victoria, any of the sediments appearing above the Quadra clays are potentially mobile. The Cordova sands and gravels, Victoria clay, and Capilano marine sand are highly sensitive when wet. If Vashon till is saturated, it can flow. Slips are common on the steep sea cliffs in the south of Victoria, but landslides have not been observed on the more gentle slopes in the city. A possible reason for this is the fact that the most common surficial deposit, Victoria clay, has a desiccated upper layer which

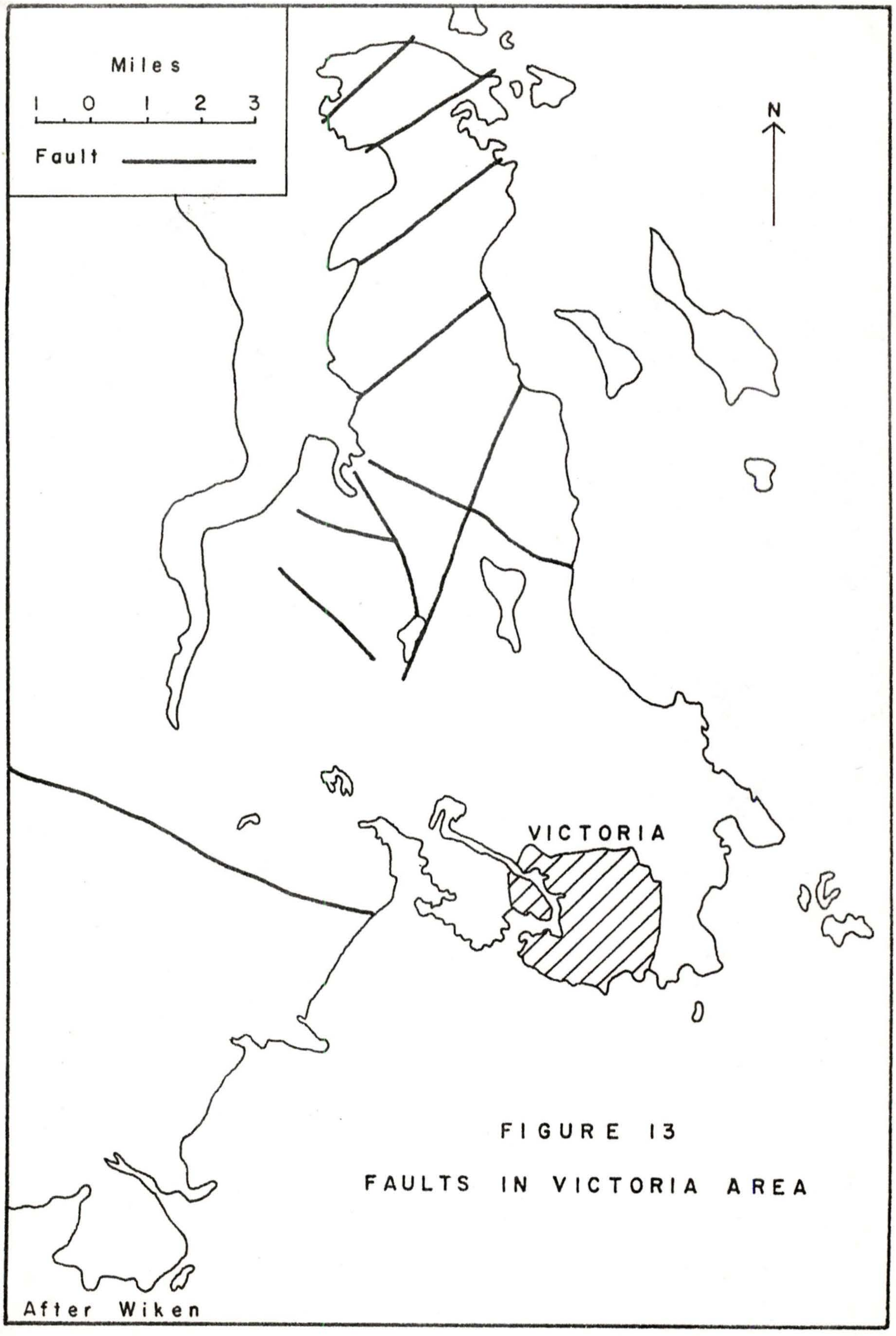


FIGURE 13

FAULTS IN VICTORIA AREA

is not susceptible to liquefaction. The Greater Victoria Regional District Soil Stability Map indicates good to fair stability throughout the city except for the small area of former marshy ground in Victoria West, at the western boundary of the city.[7] However, the possibility of liquefaction and mass movement, especially in the more variable topography of zone B, cannot be eliminated.

In microzoning, active fault zones must be shown since serious damage might be expected in structures subject to lateral or vertical displacement. In some microzoning schemes, as that of Portola Valley, California, fault zones are the only consideration.[8] Active faults may be identified on the basis of historical, seismological, or geomorphological data. Since the historical and seismological record is so short for this area, geomorphological evidence provides more reliable criteria for recognizing active faults. Stratigraphic offset of Quaternary deposits, fault scarps, offset streams, fault rifts, and other similar geomorphic features may indicate that movement along a fault has taken place since the Pleistocene. Figure 13 shows the location of faults in the Victoria area. Since no active faults have been identified in the city itself, they are not considered a factor in the microzonation of Victoria.

When applied to variations in intensities experienced during the 1946 earthquake and differences in underlying stratigraphy, the Chi-square test indicated a definite positive correlation at a significance level of 0.01. Clearly the variations in intensity were not random. This correlation, therefore, provides statistical support for the development of a three-zone microzonation map of the city of Victoria. Although this map has some potential weaknesses, such as small pockets of unidentified unstable sediments in areas possibly subject to liquefaction, local sliding, or other secondary hazards, it nevertheless provides the best available basis for rational decision making concerning adjustments to Victoria's earthquake hazard.

FOOTNOTES

[1] United Nations, Educational Scientific and Cultural Organization. The Skopje Earthquake of 26 July 1963 (Report of the UNESCO Technical Assistance Mission), 1968, p. 103.

[2] Jack F. Evernden, Richard R. Hibbard, and Joseph F. Schneider, "Interpretation of Seismic Intensity Data", Bulletin of the Seismological Society of America 63 (April 1973): 420.

[3] C.F. Richter, "Seismic Regionalization", Bulletin of the Seismological Society of America 49 (April 1959): 129.

[4] W.G. Milne and G.C. Rogers, "Evaluation of Earthquake Risk in Canada", Proceedings, p. 223.

[5] C.B. Crawford and J.G. Sutherland, "The Empress Hotel, Victoria, British Columbia. Sixty-five Years of Foundation Settlements", Canadian Geotechnical Journal 8 (1971): 77-93.

[6] R.D. Adams, "Microzoning for Earthquake Effects in the Wellington City Area", Bulletin of N.Z. Society for Earthquake Engineering 5 (September 1972): 106.

[7] Soil stability map prepared by Soil Survey Unit, Research Station, Canada Department of Agriculture, Vancouver, B.C., n.d.

[8] George G. Mader et al., "Land Use Restrictions along the San Andreas Fault in Portola Valley, California", Proceedings, p. 857.

[9] E.B. Wiken, "Landscape Parameters and Interpretations", in "An Inventory of Land Resources and Resource Potentials in the Capital Regional District". Victoria, 1973.

CHAPTER 6

APPLICATION AND FURTHER RESEARCH

Tremors shake Victoria with great frequency, reminding citizens that a major earthquake is a distinct future possibility. It is not surprising, then, that interest in the subject continues to remain high. In early 1973, within a two-month period, three articles dealing with possible future earthquake damage in the city were featured in the Victoria Daily Times.[1] In considering human adjustments to the seismic threat, attention was focused on earthquake-resistant construction. It is hoped that the present study is both a timely and useful contribution to this discussion, and more significantly, that it serves to heighten perception of the full range of possible adjustments to the earthquake hazard and assist in the evaluation of alternatives.

Microzonation and Adjustments to Earthquakes

Ways in which microzonation maps might aid in making rational decisions on actions to buffer the harmful effects of the seismic hazard were suggested in the opening chapter. With a microzonation map of Victoria available, the process of adjustment to earthquakes illustrated in Figure 1 (page 3) can be considered in more detail.

With our present knowledge of the natural event itself, we can only state that it will occur randomly in time and postulate a local event of intensity VIII in a hundred year return period.

The central element in the model is termed the natural hazard, definable in this case by the Modified Mercalli intensity scale. The microzonation map tentatively identifies areas where the intensity in Victoria may vary from that postulated earlier. Attention is especially directed to zone C where the intensity may reach IX, with its attendant greater damage potential.

The adjustment process control is treated as a 'black box' in this study, but it should be noted that anyone who examines the microzonation map must become more aware of the variability of the seismic hazard in the city. In evaluating alternative adjustments to the hazard, the spatial variation of anticipated intensity is an important consideration.

Although attempts have been made to lubricate active faults by inducing water through boreholes,[2] there is no known practical way to modify the natural event itself at this time. In order to reduce losses from a major seismic disaster, the decision maker is still restricted to modifications of the human use of the area and to improvement of his emergency adjustments.

Regulations governing the quality of construction are the only adjustment to earthquakes dictated by law at the present time. In 1953, earthquake-resistant design requirements were incorporated into the National Building

Code to provide minimum standards to assure public safety by safeguarding against major failure and loss of life. If construction conformed to these standards, no damage might be expected in minor earthquakes and collapse would not result from major earthquakes.[3] The National Building Code applies to all buildings used for assembly, institutional, or high hazard industrial occupancies and to all other buildings exceeding 6000 square feet in area or three storeys in height.[4] Victoria adopted the provisions of the Code into its by-laws in 1963.

In the 1970 National Building Code, one of the factors used in calculating the minimum lateral seismic force assumed to act on a structure is a foundation factor. This is to be 1.5 when the structure is founded on highly compressible soils and 1.0 for all other soils.[5] In terms of the present study, the factor to be used for zone C ground would be 1.5, for zone A ground 1.0, and either factor for zone B, depending on the density of the surficial sediments. The evidence presented here would seem to suggest that in addition to soil compressibility, the depth to bedrock should be considered in the definition of the parameters for the foundation factor. Pending future revision to these parameters, the present map could be used to ensure that a foundation factor of 1.5 is applied to construction in zone C.

The microzonation map may be most useful in

Impt.

planning future changes in land use. In this connection, two trends in the development of the city since 1946 should be mentioned. At that time, a few large areas of the city were under-developed. Several of the areas shown as zone C on Map 3 were almost vacant in 1946, probably because they were unattractive for building as a result of poor drainage. One such area was along Haultain Street east of Cook Street (159/84), while another was bounded by Stannard, Despard, and Richmond Avenues and Earle Street (153/81). By 1963, both areas had been fully developed as residential zones. A second trend is the expansion of multistorey buildings outside the downtown core. Figure 14 shows an example of such a building which is located on the periphery of zone C near the intersection of Vancouver and View Streets (155/86). Experience in the Mexican earthquake of 28 July 1957 indicated that damage to multistorey buildings was more severe than damage to one or two storey buildings on poor ground.[6] The significance of these trends is that now much more of the poorest ground is developed than was the case in 1946, and some of this development is in the form of structures which are more susceptible to damage from strong ground motions. However, it might be noted that the two major proposed construction projects in the city in 1974, the Reid Centre on the waterfront between Yates Street and Fort Street (156/89), and the Victoria - BAPCO development

higher buildings = greatest damage.

FIGURE 14

NEW HIGH-RISE DEVELOPMENT IN VICTORIA

at Laurel Point (155/91), will both have their foundations in bedrock.

City zoning ordinances could be used to restrict certain types of development in zone C areas. These regulations might be in the form of restrictions on types of use, density of development, or maximum height of buildings. It is within the power of the municipal government to use tax incentives to promote development of zone A areas and discourage major building in zone C areas through differential assessment rates.

Another possibility in discouraging further development of zone C areas would be to ensure that buyers of property in such areas are fully informed of the comparatively high hazard in these locations. California provides this type of warning to buyers or lessees in subdivions of more than five homes:

> The Bureau of Mines and Geology, State of California, reports that: This development lies within a fraction of a mile of the San Andreas Fault. In the event of a strong earthquake, severe ground movement, with attendant damage to the structures might be expected.[7]

Insurance against earthquake losses is available but is not carried by many property owners. This may be due to a lack of perception of the magnitude of the seismic hazard, or it may be that the cost of insurance is considered excessive. On wood-frame construction, the annual rate ranges from five cents to thirteen and one-half cents per one hundred dollars coverage, compared to sixteen cents per hundred dollars for fire insurance. The rate varies with type of construction, but not with ground characteristics.[8] The microzonation map enables each Victorian to better assess the advisability of buying such insurance. Even substantial buildings are liable to collapse in an intensity IX earthquake.

Rescue and relief are adjustments which are applied after a disaster has occurred. The Provincial Emergency Programme (formerly Civil Defence) has a responsibility to plan emergency actions to aid and assist the public in such cases. A knowledge of anticipated variation in damage, as shown on the microzonation map, is an obvious asset in preparing contingency plans for such disasters.

It is suggested that the preliminary microzonation map be used in its present state only for land-use planning and as a basis for further investigation. Due to the limited data on which it is based, under no circumstances should the map be considered a substitute for site geologic studies where required by the National Building Code.

Extension of Findings and Further Research

The findings and method used in this study could be extended to include the Greater Victoria area. This would be especially desirable since most of the future development of the metropolitan area will take place outside the city limits, and the seismically hazardous areas should be identified for land-use planning purposes. It appears that there are large areas which probably would be C type ground, such as the area south of Cordova Bay NB and the area around Blenkinsop Lake.

The extension of the microzonation would require geomorphological mapping as was used to compile Map 2, with the added complication of the Colwood sands and gravels which are not found in the city itself. Intensity records would be required from areas of this type of ground, but the correlations noted in this study could be used as the basis for zoning other types of ground. Richter recommends this procedure on a regional basis,[9] so the correlation should be acceptable within the limits of the area suggested.

Under the auspices of the federal Urban Geology Information System, borehole data such as that presented in Appendix C have been collected for all large cities in Canada. This information is being transferred to computer tapes from which various types of maps will be produced by computer mapping systems.[10] One type will be an isopach map which would provide an overall picture of the depth to bedrock, a map which could not be attempted with any degree of sophistication by manual methods. Such a map would be invaluable both in enabling the investigator to better define the type of ground for each zone of earthquake damage potential, and in outlining these zones.

Map 3 is labelled a preliminary microzonation map of the city, suggesting that a refinement is expected in the future. A large step toward such refinement would be an exhaustive damage and intensity survey conducted immediately after the next major earthquake. The present map could serve to indicate which areas of the city deserve the closest investigation after that earthquake. It is considered that the major effort should be expended in verifying the zone C boundaries and in outlining the zone B ground more accurately.

To gather data for microzoning research, a network of accelerographs and seismoscopes have been installed in southwestern British Columbia. In the greater Victoria area, the instrumentation consists of two accelerographs and eleven seismoscopes.[11] Since the instruments have been placed in locations with differing surficial deposits, the response of the various types of ground may be compared. As was noted in Chapter 5, some data have already been provided by this network.

A preliminary study of microseism readings in the Vancouver and Victoria areas indicated that the technique may be worthy of further exploration for microzoning purposes.[12] If it were proven that microseisms are a valid basis for evaluating ground motion characteristics during large earthquakes, this technique would be ideal in microzonation, but unfortunately such proof is still missing.[13]

Milne and Rogers point out that the different techniques of determining local site characteristics are being investigated with the objective of having available all the information possible at each instrument location to make a prediction about site response as a step toward eventual microzoning.[14] It is hoped that the preliminary map presented in this study is a worthwhile contribution toward this growing body of data from which a definitive microzonation of the Greater Victoria area can be established.

FOOTNOTES

[1] "Empress on Shaky Ground", *Victoria Daily Times*, 31 January 1973, p. 3; "Victoria Is Late for Date with Quake", ibid., 24 March 1973, p. 3; and "Building Survey for Quake Urged", ibid., 5 April 1973, p. 2.

[2] National Research Center for Disaster Prevention, Disaster Prevention - Japan", *EMO National Digest* 11 (August-September 1971): 28.

[3] Associate Committee on the National Building Code, *Canadian Structural Design Manual, 1970: Supplement No. 4 to the National Building Code of Canada* (Ottawa: National Research Council, 1970), p. 581.

[4] Ibid., p. 3.

[5] Ibid., p. 14.

[6] Karl V. Steinbrugge, *Earthquake Hazard in the San Francisco Bay Area: A Continuing Problem in Public Policy* (Berkeley: University of California Printing Department, 1968), p. 30.

[7] Robert W. Kates, "Human Adjustment to Earthquake Hazard", in *The Great Alaska Earthquake of 1964: Human Ecology*, Committee on the Alaska Earthquake (Washington: National Academy of Sciences, 1970), p. 26.

[8] Based on a survey of four insurance companies. Rates quoted were for 2 percent deductible. In 1965, the rate for 5 percent deductible was twelve and one half cents per one hundred dollars coverage in nine American western states (Dacy and Kunreuther, *The Economics of Natural Disasters*, p. 236).

[9] C.F. Richter, "Seismic Regionalization", *Bulletin of the Seismological Society of America* 49 (April 1959): 125.

[10] Denis A. St-Onge, personal letter.

[11] G.C. Rogers, W.G. Milne, and M.N. Bone, *The Strong Motion Seismograph Network in Western Canada, 1970* (Ottawa: Department of Energy, Mines and Resources, 1970), pp. 25-27.

[12] S. Cherry and P.E. Salt, "A Preliminary Investigation of Microtremor Spectra in British Columbia", Proceedings First Canadian Conference on Earthquake Engineering (Vancouver: University of British Columbia, 1971), p. 4-8.

[13] H. Bolton Seed and Per B. Schnabel, "Soil and Geologic Effects on Site Response during Earthquakes", Proceedings, p. 68.

[14] W.G. Milne and G.C. Rogers, "Evaluation of Earthquake Risk in Canada", Proceedings, p. 220.

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APPENDIX A

MODIFIED MERCALLI INTENSITY SCALE OF 1931

I A Not felt - or, except rarely under especially favourable circumstances.
Under certain conditions, at and outside the boundary of the area in which a great shock is felt:
sometimes birds, animals, reported uneasy or disturbed;
sometimes dizziness or nausea experienced;
sometimes trees, structures, liquids, bodies of water, may sway - doors may swing, very slowly.

✓ II A Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons.
F *Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially
F when delicately suspended; sometimes trees, structures liquids, bodies of water, may sway, *doors may
G swing, very slowly; sometimes birds, animals, reported uneasy or disturbed;
*sometimes dizziness or nausea experienced.

III A *Felt indoors by several, motion usually rapid vibration.
C *Sometimes not recognized to be an earthquake at first.
*Duration estimated in some cases.
E *Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away.
F *Hanging objects may swing slightly.
Movements may be appreciable on upper levels of tall structures.
H Rocked standing motor cars slightly.

IV A * Felt indoors by many, outdoors by few.
B *Awakened few, especially light sleepers.
D Frightened no one, unless apprehensive from previous experience.
E *Vibration like that due to passing of heavy, or heavily loaded trucks.
Sensation like heavy body striking building, or falling of heavy objects inside.
I *Rattling of dishes, windows, doors; glassware and crockery clink and clash.
J *Creaking of walls, frame, especially in the upper range of this grade.
F *Hanging objects swung, in numerous instances.
K *Disturbed liquids in open vessels slightly.
H Rocked standing motor cars noticeably.

V A* Felt indoors by practically all, outdoors by many or most: outdoors direction estimated.
B* Awakened many, or most.
D* Frightened few - slight excitement, a few ran outdoors.
E* Buildings trembled throughout.
I* Broke dishes, glassware, to some extent.
* Cracked windows - in some cases, but not generally.
✓* Overturned vases, small or unstable objects, in many instances, with occasional fall.
F* Hanging objects, doors, swing generally or considerably.
J* Knocked pictures against walls, or swung them out of place.
* Opened, or closed, doors, shutters, abruptly.
Pendulum clocks stopped, started, or ran fast, or slow.
L✓* Moved small objects, furnishings, the latter to slight extent.
K* Spilled liquids in small amounts from well-filled open containers.
*Trees, bushes, shaken slightly.

VI A* Felt by all, indoors and outdoors.
D Frightened many, excitement general, some alarm, many ran outdoors.
B Awakened all.
Persons made to move unsteadily.
Trees, bushes, shaken slightly to moderately.
Liquid set in strong motion.
Small bells rang - church, chapel, school, etc.
Damage slight in poorly built buildings.
m Fall of plaster in small amount.
m Cracked plaster somewhat, especially fine cracks; chimneys in some instances.
I Broke dishes, glassware, in considerable quantity, also some windows.
\- Fall of knick-knacks, books, pictures.
L Overturned furniture in many instances.
Moved furnishings of moderately heavy kind.

VII Frightened all - general alarm, all ran outdoors.
Some, or many, found it difficult to stand.
Noticed by persons driving motor cars.
Trees and bushes shaken moderately to strongly.
Waves on ponds, lakes, and running water.
Water turbid from mud stirred up.
Incaving to some extent of sand or gravel stream banks.
Rang large bells, etc.
Suspended objects made to quiver.
Damage negligible in buildings of good design and construction, slight to moderate in well-built

ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc.
Cracked chimneys to considerable extent, walls to some extent.
Fall of plaster in considerable to large amount, also some stucco.
Broke numerous windows, furniture to some extent.
Shook down loosened brickwork and tiles.
Broke weak chimneys at the roof-line (sometimes damaging roofs).
Fall of cornices from towers and high buildings.
Dislodged bricks and stones.
Overturned heavy furniture, with damage from breaking.
Damage considerable to concrete irrigation ditches.

VIII Fright general - alarm approaches panic.
Disturbed persons driving motor cars.
Trees shaken strongly - branches, trunks, broken off, especially palm trees.
Ejected sand and mud in small amounts.
Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters.
Damage slight in structures (brick) built especially to withstand earthquakes.
Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling.
Fall of walls.
Cracked, broke, solid stone walls seriously.
Wet ground to some extent, also ground on steep slopes.
Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers.
Moved conspicuously, overturned, very heavy furniture.

IX Panic general.
Cracked ground conspicuously.
Damage considerable in (masonry) structures built especially to withstand earthquakes:
Threw out of plumb some wood-frame houses built especially to withstand earthquakes;
Great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames;
Serious to reservoirs; underground pipes sometimes broken.

X Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a

yard in width ran parallel to canal and stream banks.
Landslides considerable from river banks and steep coasts.
Shifted sand and mud horizontally on beaches and flat land.
Changed level of water in wells.
Threw water on banks of canals, lakes, rivers, etc.
Damage serious to dams, dikes, embankments.
Severe to well-built wooden structures and bridges, some destroyed.
Developed dangerous cracks in excellent brick walls.
Destroyed most masonry and frame structures, also their foundations.
Bent railroad rails slightly.
Tore apart, or crushed endwise, pipe lines buried in earth.
Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI Disturbances in ground many and widespread, varying with ground material.
Broad fissures, earth slumps, and land slips in soft, wet ground.
Ejected water in large amount charged with sand and mud.
Caused sea-waves ("tidal" waves) of significant magnitude.
Damage severe to wood-frame structures, especially near shock centers.
Great to dams, dikes, embankments, often for long distances.
Few, if any (masonry), structures remained standing.
Destroyed large well-built bridges by the wrecking of supporting piers, or pillars.
Affected yielding wooden bridges less.
Bent railroad rails greatly, and thrust them endwise.
Put pipe lines buried in earth completely out of service.

XII Damage total - practically all works of construction damaged greatly or destroyed.
Disturbances in ground great and varied, numerous shearing cracks.
Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive.
Wrenched loose, tore off, large rock masses.
Fault slips in firm rock, with notable horizontal and vertical offset displacements.
Water channels, surface and underground, disturbed and modified greatly.

Dammed lakes, produced waterfalls, deflected rivers, etc.

Waves seen on ground surfaces (actually seen, probably, in some cases).

Distorted lines of sight and level.

Threw objects upward into the air.

SOURCE: Harry O. Wood and Frank Newmann, "Modified Mercalli Intensity Scale of 1931", <u>Bulletin of the Seismological Society of America</u> 21 (December 1931): 278 - 82.

APPENDIX B

INTENSITIES REACHED IN 23 JUNE 1946 EARTHQUAKE IN VICTORIA

Serial	MM Scale Intensity	Class	Remarks
1	V	B	Frightened occupant
2	V	B	Cupboard door flew open
3	V	A	Dishes broken
4	VI	A	Water sloshed out of sink
5	VII	A	Child thrown to ground
6	VII	B	Chimney broken
7	IV	B	Dishes rattled
8	III	A	Light vibration
9	VII	A	Chimney broken
10	VI	B	All ran out frightened
11	VI	A	Many dishes broken
12	VI	A	Plaster cracked
13	VI	A	Lamp knocked over
14	VI	A	Plaster cracked
15	VII	A	Chimney broken
16	VI	B	Bird cage toppled
17	VII	A	Chimney broken
18	VII	A	Chimney broken
19	VII	A	Plaster fell
20	VII	A	Chimney broken
21	VI	A	Pictures fell down
22	VII	A	Plaster fell

Serial	MM Scale Intensity	Class	Remarks
23	VI	B	Plaster cracked
24	VII	A	Chimney broken
25	VII	A	Chimney broken
26	VII	A	Chimney broken
27	VI	B	All ran out frightened
28	VI	A	Water sloshed in fish pond
29	VI	A	Plaster cracked
30	VI	B	Ran out frightened
31	VI	A	Plaster cracked
32	VI	A	Articles off shelves
33	VI	B	Plaster cracked
34	VI	A	Plaster cracked
35	III	B	Light vibration
36	IV	A	Creaking of walls
37	VI	A	Fall of knick-knacks
38	V	B	Broken dishes
39	VI	A	Plaster cracked
40	V	B	Pictures askew
41	V	B	Dishes broken
42	V	B	Door flew open
43	VI	A	Books off shelves
44	VI	B	Ran out frightened
45	VII	A	Chimney broken
46	VII	A	Chimney broken
47	VI	A	Ran out frightened

Serial	MM Scale Intensity	Class	Remarks
48	VII	A	Chimney broken
49	VII	A	Dislodged bricks from chimney
50	V	A	Pot on stove moved
51	VI	A	Plaster cracked
52	VI	A	Fell off stepladder
53	IV	A	Heavy vibration
54	IV	B	Dishes rattled
55	IV	A	Dishes rattled
56	III	A	Light vibration
57	VI	A	Cracked plaster
58	IV	B	Heavy vibration
59	V	B	Chandelier swung considerably
60	IV	A	Heavy vibration
61	III	B	Light vibration
62	V	B	Building trembled
63	VII	A	Chimney broken
64	VII	A	Wall cracked
65	III	A	Light vibration
66	IV	A	Dishes rattled
67	III	B	Light tremor
68	V	A	Dishes broken
69	V	A	Sanctuary lamp swung
70	V	B	Few items off shelf
71	III	B	Slight tremor
72	VI	B	Milk bottles broken

Serial	MM Scale Intensity	Class	Remarks
73	III	B	Barely noticed
74	IV	A	Dishes rattled
75	III	B	Light vibration
76	IV	A	Heavy vibration
77	IV	A	Hanging objects swung
78	III	A	Light vibration
79	III	B	Light vibration
80	IV	B	Heavy vibration
81	IV	A	Picture banged on wall
82	IV	A	Hanging objects swung
83	V	A	Plates knocked off plate rail
84	IV	B	Walls creaked
85	III	B	Barely felt
86	IV	B	Heavy vibration
87	IV	A	Dishes rattled
88	III	B	Light vibration
89	VII	A	Wall cracked
90	IV	A	Dishes rattled
91	III	B	Light vibration
92	IV	A	Heavy vibration
93	IV	A	Chandelier swayed
94	IV	A	Chandelier swayed
95	III	B	Light tremor
96	V	A	Door flew open
97	III	A	Light vibration

Serial	MM Scale Intensity	Class	Remarks
98	V	A	House trembled throughout
99	V	A	House trembled throughout
100	V	B	Bed moved
101	VI	A	Water spilled from kettle
102	V	A	House shook throughout
103	VI	A	Heavy furniture moved
104	VII	A	Chimney broken
105	VII	A	Chimney broken
106	IV	B	Dishes rattled
107	V	B	Dishes knocked off table
108	VI	A	Plaster cracked
109	V	B	Pictures knocked askew
110	III	B	Light vibration
111	V	B	Pictures swung out of place
112	III	B	Light vibration
113	IV	B	Heavy vibration
114	III	A	Light tremor
115	III	B	Light vibration
116	IV	A	Dishes rattled
117	VI	B	Chimney cracked
118	IV	B	Dishes rattled
119	III	B	Tremor felt
120	V	B	Ornaments knocked down
121	IV	A	Dishes rattling
122	III	B	Light vibration

Serial	MM Scale Intensity	Class	Remarks
123	III	B	Light vibration
124	V	A	Dishes broken
125	V	A	Small objects fell
126	IV	A	Heavy vibration
127	IV	B	Heavy vibration
128	IV	A	Dishes rattled
129	V	B	Pictures knocked askew
130	VII	A	Chimney broken
131	VI	A	Difficult to stand
132	VII	B	Chimney broken
133	VI	B	Fall of knick-knacks
134	IV	A	Dishes rattled
135	VI	A	Chimney cracked
136	VI	A	Plaster cracked
137	V	A	Pictures knocked askew
138	IV	B	Dishes rattled
139	VI	B	Chair with occupant moved
140	V	A	House shook throughout
141	IV	B	Dishes rattled
142	V	A	Coffee spilled out of cup
143	VI	B	Cracked plaster
144	VI	B	Bushes shaken moderately
145	VI	A	Articles off shelves
146	III	A	Light vibration
147	VI	A	Plaster cracked

Serial	MM Scale Intensity	Class	Remarks
148	VI	A	Slight damage
149	V	A	Door flew open
150	VI	A	Plaster cracked
151	V	A	Dishes broken
152	IV	A	Door rattled
153	IV	A	Walls cracked
154	IV	B	Dishes rattled
155	V	A	Milk bottled broken
156	V	A	Chair moved
157	VI	B	Difficult to stand
158	IV	B	Heavy vibration
159	VI	A	Washing machine crossed room
160	V	A	Large painting askew
161	IV	A	Dishes rattled
162	VI	A	Pots knocked off stove
163	VII	A	Chimney broken
164	VII	A	Fall of considerable plaster
165	IV	B	Parked car rocked
166	VI	A	Plaster cracked
167	V	B	Whole house shook
168	VI	A	Trees swayed moderately
169	VI	A	Plaster cracked
170	VI	A	Chimney cracked
171	VI	A	Broke many dishes
172	VI	A	Water sloshed in pool

Serial	MM Scale Intensity	Class	Remarks
173	V	A	Dishes broken
174	III	A	Light vibration
175	III	A	Light vibration
176	IV	A	Pictures swung askew
177	IV	A	Dishes rattled
178	V	B	Whole house shook
179	VI	B	Chimney cracked
180	VI	A	Difficult to stand
181	V	A	Vase knocked off table
182	V	B	Dishes broken
183	V	A	Small bed moved
184	VI	A	Ran out frightened
185	VI	A	Difficult to stand
186	VI	A	Plaster cracked
187	VI	A	Plaster cracked
188	VII	B	Trees shaken strongly
189	VII	A	Chimney broken
190	VI	B	Ran out frightened
191	V	A	Mirror knocked askew
192	III	B	Light vibration
193	IV	A	Heavy vibration
194	III	B	Light vibration
195	IV	A	Dishes rattled
196	III	A	Light vibration
197	III	A	Light vibration

Serial	MM Scale Intensity	Class	Remarks
198	VI	A	Bushes shaken moderately
199	VI	A	Plaster cracked
200	VII	A	Chimney broken
201	VI	A	Bushes shaken moderately
202	VI	A	Heavy furniture moved

APPENDIX C

BOREHOLE DATA FOR VICTORIA

ABBREVIATIONS

GW	Well-graded gravel
GP	Poorly-graded gravel
GM	Silty gravel
GC	Clayey gravel
SW	Well-graded sand
SP	Poorly-graded sand
SM	Silty sand
SC	Clayey sand
ML	Inorganic silts of low plasticity
CL	Inorganic clays of low plasticity
OL	Organic silts of low plasticity
MH	Inorganic silts of high plasticity
CH	Inorganic clays of high plasticity
OH	Organic clays of high plasticity
PT	Peat or highly organic soil
BR	Bedrock
PBR	Probable bedrock
R	Rock

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
147410 84470		12CL 17 GP	BR
148245 84475		8OL SM 36 SM GP SW	
148360 84880		5CL 16SW 20 SM SC 36 SW	
148380 84460	8	16CL	

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
148665 84415		5SW SM 24CL 30SM 36 CL	
148675 85230	7	10SW 21CL 29SW 41CL 45SM	
148810 84395		17CL 21CH 32SM	
148920 85800		8GW 19GC 38ML 51SW	
148955 84380	19	9CL 25SW SM SC	PBR
149100 84370		3SM 9CL 23SW SM	R
149140 86570		10SW 24CL 56 SOFT CL	
149240 86630	4-9	9SW 32CL 44GP	
149340 86555		7SW 24CL 56SC SM	R
149380 84480		4CL 7SW 20CL	
149485 89600		5SM 6CL 15GC SC 25 SM SC	R
149495 89670		5SM 16SC CL	PBR
149540 89670	8	3SP 9SM	PBR
149550 86540		6SM 12ML 56CL 59SM	R
149555 89610	3	4GP SM 13SM SC SW 20CL 27SM	R
149565 89640	3	3SW 7SC	PBR
149575 89550		4SW 7SM 26SM SC SW	
149575 89675	3	3SW 6SC	PBR
149580 89650	3	6SW 10CL	PBR
149585 89785	20	2SP 8CL 23SP	R
149610 85080		12SW 19ML 21SW 32GP	R
149670 89690		12CL 31ML	
149690 89750	15	8ML 12CL 22SC	R
149755 86530		6SW 48CL	
149785 85665		4GW 32CL	

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
149830 96520		4SW 39 CL	R
149840 84400		9CL 20SP	
149920 86510		6SW 30CL	R
149970 86570		7SW 21CL	PBR
150020 86500		5SW 31 CL	R
150120 86490		4SW 43CL	R
150175 89280	7	38GW 42 TILL	BR
150200 84650		7SP SM 11SM 30CL	
150220 89310	6	9GW 12SM 24GW	R
150255 89255	6	4GW 12SM 29CL 36SM	R
150265 89305	10	10SP 16ML 22CL 36GW	R
150265 90740		20CL 33SC CL	
150295 89300	14	14GW 25CL 44GM 46 TILL	BR
150305 90705		26CL 42ML	BR
150310 90790	4	20CL 30SC CL	R
150325 86470		4SW 11CL 12SW 32CL	
150345 90760		29CL	R
150345 90855		2SW 17CL	
150370 84975	12	3CL 12SW	
150385 90900	20	4SM 38CL	
150390 90830		34CL	R
150415 90835		36CL	
150415 90885		15CL CH 47CL	BR
150435 85360		4OL CL 12SC CL SM	
150470 90715		3CL 14CH 16SC	BR

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
150480 85645	9	4PT 12CL	
150555 86095		16CL	
150630 86530		8CL 10GM 15CL	
150910 81840	11	13SM 64CL 72SC	
150910 81920	2	9SM 58CL 68SP	
150910 82030	6	60CL	R
150955 90755		7SM SP 10SC 20CL 27CH 39CL 48SC	PBR
151035 90800		22CL 40CH 52SC	PBR
151080 90835		5SM 15CL 36CH 39CL	PBR
151095 85450	7	6ML 9CL 48CH CL	
151130 87785		2GW 5CL	PBR
151140 87740	2	2GW 4CL	PBR
151150 85550		3ML 12CL	
151150 87675	2	6SM	PBR
151185 87790		3GW	PBR
151220 87580		2SM 6CL	PBR
151360 89762		17CL	R
151380 86340		5 FILL 7PT 8SM 12SM SW	
151400 89842		19CL 20 SC	R
151440 89710		6CL 8SM	R
151460 89750		20CL	R
151470 91170		9CL	R
151500 87120	16	10CL 34CH 35GW	PBR
151535 91250	17	17CL	R
151615 87120	3	5SP SC 10CL 32CH	PBR

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
151615 87180		7SC 16CL 44CH 46GW	PBR
151625 87785	2	4 FILL 6CL	R
151630 91060		3SM 21CL 22GW	R
151685 88775	12	21CH 23GW	R
151690 91145	5	2SM 12CL 13SM	R
151740 88765	1	15CH	R
151850 86330	6	4CL 6PT 12CL	
151860 79560	5	9CL 11SC 14	R
151860 79590		7CL 10SC	R
151860 79610		7CL	R
151935 90630		6CL	R
151960 84165		9CL	R
151960 90650		5SC 6CL	R
151965 84135		5CL	R
151970 84105		9CL	R
151975 90620		6CL	R
151980 86935		20CL	
151980 90580		6CL	R
151985 87215		24CL	
151990 89010		?CL 44SM	R
151990 88920		?CL 38GP	BR
152010 79610	6	2SC 24CL	R
152010 79560		11CL 13CH 31CL CH	R
152010 90615		4CL	R
152025 84095		2CL 16CL CH 17CH 20SC	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
152030 88855		14CL	BR
152040 89040		?CL 32GM	BR
152040 89100		?CL 46GM	BR
152045 84170	5	4SC CL 17CL 18GW	R
152050 88970		?CL 18SM	R
152085 89105		?GM 29CL	BR
152090 79560		4CL 6SC 22CL	R
152090 79610	7	4SM 5CL 7SC 10CL 38CL CH 41SM	R
152090 88855		11CL	BR
152090 89030		?CL 13GM	BR
152090 94695		13CL 50GP 69SW SM 97SW ML SM 183ML CL 198CL	PBR
152095 88980		CL5	BR
152110 94345		11GW 55SW 59GW	BR
152135 79560	7	6SW CL26	R
152135 79610	7	2SC 38CL	R
152150 86280		12CL	
152155 88920		7CL	
152160 88980		8CL	R
152225 89085		11ML	BR
152245 88965		4ML	BR
152250 88870		14CL ML	R
152265 89060		6ML	BR
152320 88960		4ML	R
152330 88895		11CL	R

LOCATION		WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
152350	86935		16CL	
152385	88930		5ML	R
152400	88890		5ML	BR
152450	88890		7ML	BR
152450	88965		4CL	R
152450	89065		7ML	R
152455	89910		6ML	
152570	90815	6	16CL	
152580	90840		15CL	R
152600	90860	1	8CL	
152610	87630		24CL	BR
152615	90810	10	3SW 10CL	R
152625	90780		28CL 32SC	R
152650	90820	2	3SW 23CL	R
152670	94120		30SM SP 34 TILL	BR
152680	90740		4SP SM 36CL 38SC	R
152705	90780	6	4SM 30CL	R
152890	88830		13SM 22CL 40ML 93CL	
152895	87550	10	2 FILL 4PT 9SW 20CL	
152930	91260		10CL 11SW	
152950	88910		4CL 12CH 30ML 73CL	
152955	89120		10CL 18SM 23 ML 54CL	
152980	91290		18CL	R
153000	91230	4	13CL	R
153040	91260	4	18CL 20SC	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
153140 90260		48CL 53GW	
153200 88920		13CL 14GM	R
153200 88970		25CL 26GM	R
153210 88860		3ML	R
153225 88920		14CL 15SM	R
153240 88860		5SM	R
153240 88970		19CL 20SM	R
153260 88920		5ML 20CL	R
153270 88970		5ML 17CL	R
153270 90230		15CL 41CL CH	R
153275 88860		5ML 7CL 9GM	R
153280 89390		5ML 30CL 31SM	R
153295 89130	16	4ML 27CL	R
153300 89335		20CL 31SM	R
153300 90240		15CL 66CL CH 69SW	R
153305 88860		4SM	R
153305 88920	7	5SM 11CL	R
153310 88970	18	5SM 16CL 18SM	R
153320 89290		20CL 21SM	R
153340 89130	18	5ML 21CL	R
153340 88310		11SP SC 19CL SC	R
153340 89180	8	5ML 12CL	R
153340 89255		5ML 24CL 27GW	R
153350 88350		14SW 20CL	R
153350 89010	8	4ML 14CL	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
153355 88970	5	3ML 10CL 11SM	R
153360 88300		30SW 42CL 44GW	R
153360 88920		3SM 6CL 7SM	R
153365 88860		3ML 10CL 11SM	R
153370 88320		10SP 28CL	
153390 89130		5CL 9ML 11CL 12SM	R
153390 89180		6ML 14CL 15SM	R
153410 88860		2ML 5CL 6SM	R
153410 88920	7	3ML 5CL 8SM	R
153445 89060	20	9ML 22CL	R
153445 89130		4SM 13CL	R
153445 89180	15	20CL	R
153460 88175		12CL	BR
153460 88860		5SM	
153460 88970	16	18CL	R
153490 89010	20	26CL 30SM	R
153495 89180		6SM 13CL	R
153495 89130		9SM 22CL	R
153500 89060	21	27CL	R
153520 89040	10	10SM 29CL 30SM	R
153540 89210	9	15CL 16SM	R
153550 89080	9	13SM 30CL 31SM	R
153555 89885		11CL	R
153560 89040	9	13SM 29CL 31SM	R
153570 89940		10CL 11SM	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
153585 89210		15CL 16SM	R
153595 89125		23CL	R
153595 89985		8CL	
153595 89865		11CL 12SM	
153600 89040		10 FILL 19SM 36CL	R
153625 89160	7	9SM 30CL	R
153630 88710	10	5CL 18GC ML 21ML 31ML CL 93CH	R
153630 89930		9CL	R
153640 89210	7	20CL 26SM	R
153640 89845		10CL 12SM	
153640 89960		10CL 11SM	R
153665 88705	11	20ML 26CL 31ML 100CL	
153670 89215	8	11CL	R
153680 89890		4SM	R
153690 89835		5SP	R
153690 89130		14SM 36CL 42SM	R
153700 89220		6 FILL 8SM	R
153700 89240	6	12CL 14GM	R
153700 89940		12CL 14SM	R
153705 89165	8	6 FILL 18CL 21SM	R
153720 88700	11	18CL GC 25ML 34CL 94CL CH	R
153720 89890		3CL	R
153730 89285	5	10 MUCK 27CL	R
153730 89930		8CL 10SM	R
153745 89820		5CL	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
153770 89325	10	18SM 32CL	
153775 89870		6CL 8SM	R
153790 89905		12CL	
153795 90820		22CL	PBR
153830 90770		15CL 16SM	PBR
153830 90895		21CL 22CH	PBR
153850 90820		19CL	PBR
153870 90915		8CL 9SM	PBR
153905 90945		22CL 23SM	PBR
153910 90920		12CL 14SM	PBR
153915 91000		25CL 26SW	
153955 90940		16CL	PBR
153985 91000		40CL 42 TILL	R
154080 88355	4	35CL	PBR
154105 88350	4	27CL	PBR
154130 88315		29CL	R
154145 88360	3	21CL 24SP	PBR
154150 88400	3	24CL 27SP	PBR
154155 88280	18	18CL	R
154175 88825		4SM 15CL 19OH 64CL 73SC 78SM	R
154180 88245		8CL	R
154190 88215		6CL 10GP	R
154300 90355		19 WATER 21 MUD	PBR
154340 90380		19 WATER 22 MUD 23CL	PBR
154350 87865		2SP	

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
154360 87730		8SM	R
154370 91580		5CL	R
154375 87420		8SM	R
154400 90490		14 FILL 28CL 30SP	R
154410 91550		7CL	R
154420 90690	9	5CL 7SW 13CL 17SP	
154420 91465		11CL	R
154430 90450		25WATER 36SM 40SP	R
154435 87760		5SP	R
154440 90730	8	5WATER 13OH	BR
154445 87880		5SP	R
154455 87935		7SP	R
154500 90530		24WATER 26MUD 31CL	PBR
15405 91460		3?	BR
154510 91470		5?	BR
154520 91480		5?	BR
154525 91485		5?	BR
154525 91490		5?	BR
154555 88640		8CL 17SW	R
154570 88560		8OL 15CL	R
154575 91455		24CL 26 TILL	BR
154590 88630		9CL	R
154590 91440		19CL 21 TILL	BR
154590 91475		21CL 23 TILL	BR
154595 91455		18CL 23 TILL	BR

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
154600 91590		5CL	R
154610 91610		17CL	R
154615 88580	8	15CL	R
154615 91460		14CL 16 TILL	BR
154620 88625		10CL	R
154630 91640		17CL	R
154635 85895		40CL	PBR
154640 88550		11CL	R
154640 87810		18CL	R
154640 88590		10CL	R
154645 85945		12ML 27CL	PBR
154650 91665		36CL 40SW	
154660 87915		5CL 21CL CH	
154660 91670		30CL 40GP	R
154675 88575		13CL	R
154690 87960		50L 19CL 20CH 21SC	R
154695 88000		20CL	R
154710 85950		4SM 47CL	PBR
154715 85910	6	3CL 11CL ML 52CL CH 54CH	PBR
154730 87795		22CL	R
154740 87930		2CL 22CH CL	R
154745 87950		12CL 23CH 25SC	R
154750 87900		16CL 18CL CH 20SM	
154765 88540	11	12CL CH 16SC	BR
154770 85570		5CL 13GP	BR

LOCATION		WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
154790	87680		5CL 10SM	BR
154800	85565		7GP	
154800	87625		7CL 13SC	BR
154810	85525	15	14CL 17SC	PBR
154820	85740		17CL	
154835	89180		11CL	R
154840	87690		3CL	BR
154850	87610		5CL 10SC	BR
154860	89235	14	16CL	R
154875	89110		10CL 12SP	R
154880	89180	18	21CL	PBR
154895	89230	20	21CL 25SC	PBR
154905	89295		3CL	R
154915	89590		2GW 14GP	BR
154920	89385		1ML	R
154920	89540		5 FILL 13GP	BR
154920	89565		16 FILL 17SM	BR
154935	89180		18CL 25CH 27CL	R
154935	89270		4CL	R
154940	89550		7 FILL	BR
154940	89570		10 FILL 22GP	BR
154945	89600		13 FILL 18 BOULDERS 25SC 29SW	BR
154945	89355		1 FILL	R
154950	89235		29CL	PBR

LOCATION		WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
154960	89310		4CL	R
154970	89260		5CL 6SM	R
154970	89300		5CL	R
155010	83680		13CL	PBR
155030	83370		9CL	PBR
155030	83680	19	19CL	PBR
155030	83715		10CL 13SW	PBR
155045	83680		40OL 22CL 24SW SC	PBR
155045	83700		5CL	PBR
155045	83730		3SW	PBR
155050	88810	3	37CL	
155050	88840		27CL	R
155125	86020		1GM 45CL	BR
155140	85970	4	9CL 12SC 24CL 36CH 47CL	R
155160	89735		18 WATER 22 MUCK 28 CL 55CL CH 58GC	PBR
155190	89645		8 FILL 15SM 25CL 35SW	PBR
155220	85980	4	4SM 28CL 32CH 35SM	R
155220	89705		18 WATER 22 MUCK 28CL 55CL CH 68GC	
155225	89660	10	7GC 8SP 12SC 16CL 20ML 38CL	R
155270	87870	12	9CL 12GP	R
155280	89610	11	4GC 11CL	PBR
155280	89615		8 FILL 15SM 25CL 35SW	PBR
155305	88060	10	8CL 10SP	R
155320	87845	16	15CL 21SW	R

LOCATION		WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
155320	89720		20 WATER 22 MUCK 36CL	R
155360	89630		2 FILL 12CL	R
155360	89680		6 ROCK FILL	
155360	89750		20 WATER 22 MUCK 36CL	PBR
155370	89600		13 FILL 21CL	PBR
155370	89515		5CL	PBR
155370	89680	5	5CL 12SC	PBR
155380	87875	18	17CL 21GW	R
155380	88055	13	12CL 13GP	R
155380	87950		3CL	R
155420	89730		10 WATER 14 MUCK 20CL	PBR
155450	89725		11 WATER 14 MUCK 15CL	R
155480	89600		13 FILL 21CL	PBR
155480	89690		6 ROCK FILL	
155520	89340		31CL 34GM	R
155530	89320	8	23CL	R
155540	89340	10	22CL	R
155590	89330		3CL	R
155630	89320		9CL	BR
155640	89560		3SC	R
155640	89620	6	2GW 7CL	R
155640	89695	10	14CL	
155640	89560		3SC	R
155640	89700	10	3GW 14CL	R
155650	89365		2CL	BR

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
155650 89630	6	2GW 7CL	R
155650 89400		3CL	BR
155650 89430		7CL	BR
155655 89345		2CL	R
155660 89430		12CL	BR
155660 89440		12CL	BR
155660 89450		9CL 11SP	BR
155680 89450		4CL 7SP	BR
155685 89450		3CL	BR
155700 89450		4CL	BR
155700 89460		3CL	R
155830 88190		8CL	
155855 89130		8CL 26CH	R
155875 88230		11CL	R
155900 88200	5	32CL	R
155900 88215		8CL	
155915 88160		32CL	R
155920 88180		7CL	
155925 88195		8CL	
155930 88220		6ML 11CL	
155940 89140		9CL 16CH 27CH CL	R
155950 89230		18CL	R
156090 81420		6SW	R
156095 87720		18CL 27CH 29SW	R
156110 87830		18CL	PBR

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
156115 87140		5CL 16CH	
156130 87920		9SW 13CL 26CL CH 41CH	
156135 87715		15CL 24CH	R
156150 87825		2SW 18CL	BR
156150 81260		8SW 11SC	R
156165 87910	21	8SW 19CH 25CL	PBR
156170 87710		18CL 27CH 29SP	R
156185 87820		4SP	BR
156195 81390		7SW	R
156200 87900		12CL 18SM	BR
156205 88065		10CL	
156210 88090		21CL	R
156215 88105		20CL	R
156220 87145	12	5ML 10CL CH 46CL	R
156225 88060		10CL 16 CONCRETE	
156330 81310		2SP	R
156340 79335		3SC	R
156340 79390		5SC	
156385 79335		3SC	
156385 79390		4CL	R
156430 79335		3CL	R
156430 79390		4SM	R
156530 88420		47CL	R
156585 88460		48CL	
156635 88620		36CL	

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
156650 88660	23	23CL	
156675 88715		5CL	R
156680 88750		9CL 14SW	
156685 88715		7CL	R
156700 88680	15	14CL 15 TILL	
156700 88735		8CL	R
156705 88635		34CL	R
156730 88635	4	34CL 36SC	R
156740 88355	4	36CL	R
156740 88445		75CL 78GW	R
156765 88620	10	39CL 42SC	R
156800 88450	6	46CL	
156815 88745		18CL	R
156815 88335		18CL CH 21ML	R
156840 88610		44CL	R
156845 88690	27	28CL	R
156865 88745	2	22CL 26SC	
156875 88480		52CL	R
156875 88510	2	28CL 34SC	R
156880 88335		6CL	BR
156880 88370	7	9CL	BR
156880 88450		27CL 28SM	
156990 79885		8CL 20CL CH 25CH 34SP SC	PBR
157020 79930		5SP SC 18CL 26CH 37SP SM	PBR
157035 94125		12CL 13SC TILL	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
157035 94205		12CL 13SC TILL	R
157050 80000		16CL 32CL CH 35SC	PBR
157065 90755		21CL 23SW	PBR
157080 79950		16CL 24CH 44SM SP	PBR
157095 94125		15CL 16SC	R
157095 94205		10CL 12SC SM TILL	R
157100 90780	11	23CL 25SW	PBR
157175 90765	22	22CL 26SW	PBR
157230 90765		24CL 26SW	PBR
157270 90765		21CL 24SW	PBR
157300 87930		4SM 9CL 11SM	BR
157300 88020		9SM 17CL	BR
157300 88130		19CL	BR
157325 88040		24CL 26SP	PBR
157340 87960		9CL 13SM 18SP	PBR
157340 88000		18CL	PBR
157325 88100		15CL 17SC	BR
157360 94985		12CL	R
157365 94870		28CL	
157370 87970		5CL 14SM	BR
157370 95060		24CL 25SC	R
157380 85510		5SC 20CL 21SC	PBR
157380 88050		3 CONCRETE	
157390 85600		4SC 34CL 41SC	PBR
157390 88000	6	9SM 12CL 18SM	PBR

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
157390 88050		16CL 19SM	BR
157390 88130		2CL 5SM 19CL	PBR
157400 85780		3CL 8SW 34CL 47SM	PBR
157405 94990		9CL 10GP	R
157410 87930		6CL 13SP	BR
157410 87950		9CL 11SP	BR
157430 85885		13CL	BR
157430 87930		5CL 8SC	PBR
157430 88000	18	5CL 7SC 18CL 24SP	PBR
157435 85655	3	2SC 7SM 35CL 45GC	
157440 87970		5CL 8SM 13CL 25SC	PBR
157440 94930		4SM 11CL	R
157465 84940		17CL 18GC	PBR
157470 85010		17CL 19GC	PBR
157470 88000		9CL 10SW	BR
157470 87960		13CL 20SM	PBR
157480 94910	10	14CL	R
157510 87930		2SP	BR
157510 84970	3	4SM 11CL 12SW	PBR
157510 86005		4GM	BR
157520 78240		10CL	PBR
157535 78070	62	8CL 61CH 63CH SC	PBR
157535 95035	9	8CL 17CH	R
157540 78155	12	10CL 81CH	PBR
157540 84935		18CL 22SC	PBR

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
157565 78260		10CL	PBR
157565 85005		8GM 16CL	PBR
157590 88640		5CL 14CH 17CL	R
157610 88365		15CL 44CL CH 48 TILL	
157615 78275		12CL	PBR
157640 78195		4CL 56CH	
157640 88420	17	4OL 18CL 45CL CH 48SP	
157645 78290		12CL	R
157645 88575		9CL	PBR
157650 88500		6OL 20CL	
157670 88500		5PT 15CL 18SC	
157670 88580	14	3PT 15CL	PBR
157680 78110		5ML 9ML CL 56CH	PBR
157680 78170	19	48CL 53SW SM	R
157710 88690	13	31CL	R
157710 88745	13	31CL	R
157725 88060		7CL 13GC	BR
157730 78080	3	43CL 44SP	R
157745 88870	7	18CL	
157755 78195	12	52CL 58GP GC	R
157770 88650		6 FILL 8CL	
157770 89090	3	6CL 7PT 62CL	
157780 87985		14CL 18GP	BR
157780 88910	25	9CL 32CH 43 SC 45CL	PBR
157790 88630		16GC CH 37CL	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
157810 88650		12GC CH 20 CL	
157820 78100		50CL 52SP	
157830 79320		15SM 16GW	BR
157830 88025		7CL 8GW	BR
157830 87960		9CL 15GC 18GW	BR
157835 78655	3	6GL	R
157890 78620		6SM 8CL 11SW	R
157900 78725		7SM	R
157920 78640	1	10CL	R
157920 79320		4SM	BR
157930 78620		10CL 17SP	R
157945 78655	4	8GC 10 TILL	BR
157945 78720		3SM	R
157950 78620		15CL	R
157950 78670		4ML 11SM 14SP	R
157955 79500		6CL 8 HARDPAN	BR
157965 78705		10CL	R
157970 79400		3SM	BR
158010 79320		8GP	BR
158020 78620		8CL 14SM	R
158020 78670		9CH 16CL 18SC	R
158025 78710	3	14CL 17SW	R
158025 79410		6GP 7 HARDPAN	BR
158045 78870		1 TOPSOIL	R
158050 78690		10CL	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
158055 78930		6GM	R
158060 78610		5CL 6SW 16CL 17ML	R
158065 78880		4GM	R
158060 79475		10SM	BR
158070 78710	7	9SM 14CL 16SP	R
158070 78910		6GM	R
158080 78620		19CH	R
158080 78860		3GM	R
158085 78665	5	16CL 17SC	R
158085 78890		6GM	R
158090 78630	7	14CL 16SC	BR
158090 78930		8GM	R
158100 78600		4CL 6SW 18CL 19SP	R
158120 78700		12CL 16SP	R
158130 78585		23CL 26SP	R
158130 78615		16CH 26SC	R
158140 78570		25CL 40SW 44SP	R
158150 78600		18CL 30SP 41SW 43SP	R
158150 78630		14CL 26SP 31GW	R
158150 78660		5CL 13CH 14SC 21CL	R
158155 78585		18CL CH 37SM	BR
158155 78695	8	9CL 14SM 20SP	R
158155 79560		6GW	BR
158170 78630		16CL 39SP	R
158190 78670		6CL 16CH 22CL	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
158195 78580	13	10CL 26CL CH 49SP	BR
158195 78630		19CL 36SC 39SP	R
158195 78695		13CL 21SM 25SP	BR
158200 78600	5	19CL 51SM	R
158210 78580		10CL 30CL CH 52SM	
158220 78630		16CL 44SP	R
158225 79535		10SP	BR
158240 78625		8CL 18CH 24CL	R
158315 79580	3	4GW 9CL 12SP	BR
158330 86365	7	8ML 10 TILL	R
158330 86430	8	8CL	R
158340 86500	4	4ML	R
158360 86560		3ML	R
158370 86435	4	10ML	R
158370 96530	4	5ML	R
158380 86325		10CL 12SP	R
158385 86500	3	16ML	R
158385 88925	5	59CL	R
158390 87430		7CL	PBR
158390 87455		3CL	PBR
158400 86420		12CL 16SP	R
158400 87480		5SP	PBR
158420 87460	12	8CL 12SM	PBR
158420 87500		9CL	PBR
158430 86530		10CL 12 TILL	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
158430 86560		4ML	R
158435 86490		16ML	
158440 86350		16CL 30CH 48GC	
158475 86460	3	27CL 36GC	PBR
158480 86520	13	9CL 15 TILL	R
158480 86490		34CL	R
158480 86560		5ML	BR
158500 88925		17CL 26CL CH	R
158510 89150		84CL	R
158525 89150		5ML 13CL	
158595 88925		29CL 32SC	R
158630 89150		6OL 14CL 30CH	
158670 89150		50CL	R
158675 88925	7	24CL 26SC	R
158720 89150		24CL	R
158735 79040		9SW 40SW SM SP	
158740 79130		4SW SM 16GP	
158740 78985	18	5SM 44SW SM SP	
158755 79170		5SM 8SW 12CL	
158800 78970		4SM SP	R
158800 79040		4SM	
158800 79105	20	17SP SM 39SP SC	R
158800 79190		10SM	
158810 89150		4 MUCK 32CL 38GW	R
158815 89250	3	11MH 32CL	

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
158815 89265		4 MUCK 32CL 40GW	R
158890 88925	10	9CL 10OL 16CL 20OL 46CL CH	R
158960 87890		6SC 45CL	R
159010 87895		13CL 20SC 52CL	
159140 88135	18	18ML CL 21OL 32CL	
159150 88185		10CL SM OL 42CL	R
159185 89345	30	27CL 31GW	R
159190 89305	20	17CL 21CH	R
159198 89400		16CL 19CH	R
159250 89300		7SC 29CL	R
159255 89385	14	15CL	R
159510 89300		6 FILL 43CL	BR
159535 88435	7	16CL 55CH 61 TILL	R
159545 89245		25CL	BR
159555 88385	12	78CL	
159575 88330	11	16CL 50CH 52 TILL	R
159590 88455		59CL 63 TILL	R
159590 89220		6 FILL 24CL	BR
159595 88280		12CL 22CH 24SP	R
159600 90245	7	47CL 48SP	R
159615 88380		46CL 50SP	R
159630 90140	13	44CL 49SP	R
159640 88455		40H 20CL 28CH 62?	
159665 90000		16CL 26CH	R
159685 90260		17CL 44CH 51SP	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
159710 88490	3	46CL 50SP	R
159710 90170	10	9CL 40CH 42SP	R
159715 88160	23	9CL 21CH 23SP	R
159735 88340	6	17CL 19SP	
159760 90030		15CL 25CH 26SP	
159735 88200		16CH 18SP	R
159895 87295		4CL 5SP	R
159900 87270		5SM 10SP	R
159930 87130		5CL 12SP SM	R
159950 87170		5CL	R
159960 87290		9CL	R
159970 87240		13CL	
159980 87165		9CL 14SC	R
160055 87150		17CL	R
160100 87080		4CL 13SM	R
160390 90815		17CL 18SP	
160400 90785		14CL 16CH 18CL	R
160400 90800	2	14CL 17SP	R
160415 90805		16CL	R
160415 90820		13CL CH 16CH 18SC	R
160420 90790		15CL 18SP	R
160650 88400		8CL	
160660 88350		12CL	
160660 79470		10CL 23CH 25CL	R
160680 88430		8CL	

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
160700 88355		12CL	
160705 88330		8CL	
160800 88375		8CL	
161105 89020	4	15CL 68CL CH	R
161125 88900	8	2PT 67CH CL	R
161130 88855	14	20OL CL 26CH	R
161145 88800		16CL	R
161200 88980		4PT 70CL 72ML TILL	R
161240 89065		25CH CL	R
161270 88910		44CL 46 TILL	R
161300 89085		3CL	R
161300 93755		8CL 17CL CH 20GC	BR
161310 93765		18CL 20GP	R
161340 88920	15	2CL 6PT 50CL 54 TILL	R
161345 94020		12CL	BR
161350 88825		42CL	R
161355 88770		46CL	R
161410 93785	20	16CL 28CL CH 32SC	BR
161420 93950		6CL 8OL 32CL CH 34SP	PBR
161460 94055		17CL	R
161500 94100		18CL CH 19SP	BR
161525 94000		8CL 12CH 16CL 28CH 32GW	PBR
161535 86910		8 FILL 14OL 76CL CH	
161590 89330		10 FILL 16CL	BR
161615 89345		16CL	R

LOCATION	WATER TABLE	DEPTH IN FEET TO BOTTOM OF LAYER	REFUSAL
161630 87000	6	5ML OL 15SP 60CL CH	
161630 89390		13CL	PBR
161660 89360		11CL	
161710 89420		12CL 13SP	R
161955 88950		37CL 40SM	
162155 89030		38CL	
162155 91360		19CL 27CH CL	R
162215 91445		22CL 24SC 26CL	BR
162260 91280		18CL 28CL CH	
162325 93160		2ML 18CL 24CH 25GW	R
162640 89790		12CL	
162660 89740		12CL	
162660 89800	12	12CL	
162680 89750	11	12CL	R
162680 89810		12CL	
162700 89820		12CL	
162700 89760		12CL	
162720 89770	12	12CL	
162990 84245	1	5CL 8CH 9CL	
163800 82280	2	11CL 58CL CH 60SP	
163800 82630	1	12CL 40CL CH	
163805 83125	3	11CL 40CH CL	
163810 83270	3	11CL 40CH	

VITA

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to

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Title of Thesis/Disseration

A PRELIMINARY SEISMIC MICROZONATION OF VICTORIA, BRITISH COLUMBIA.

Author [redacted]

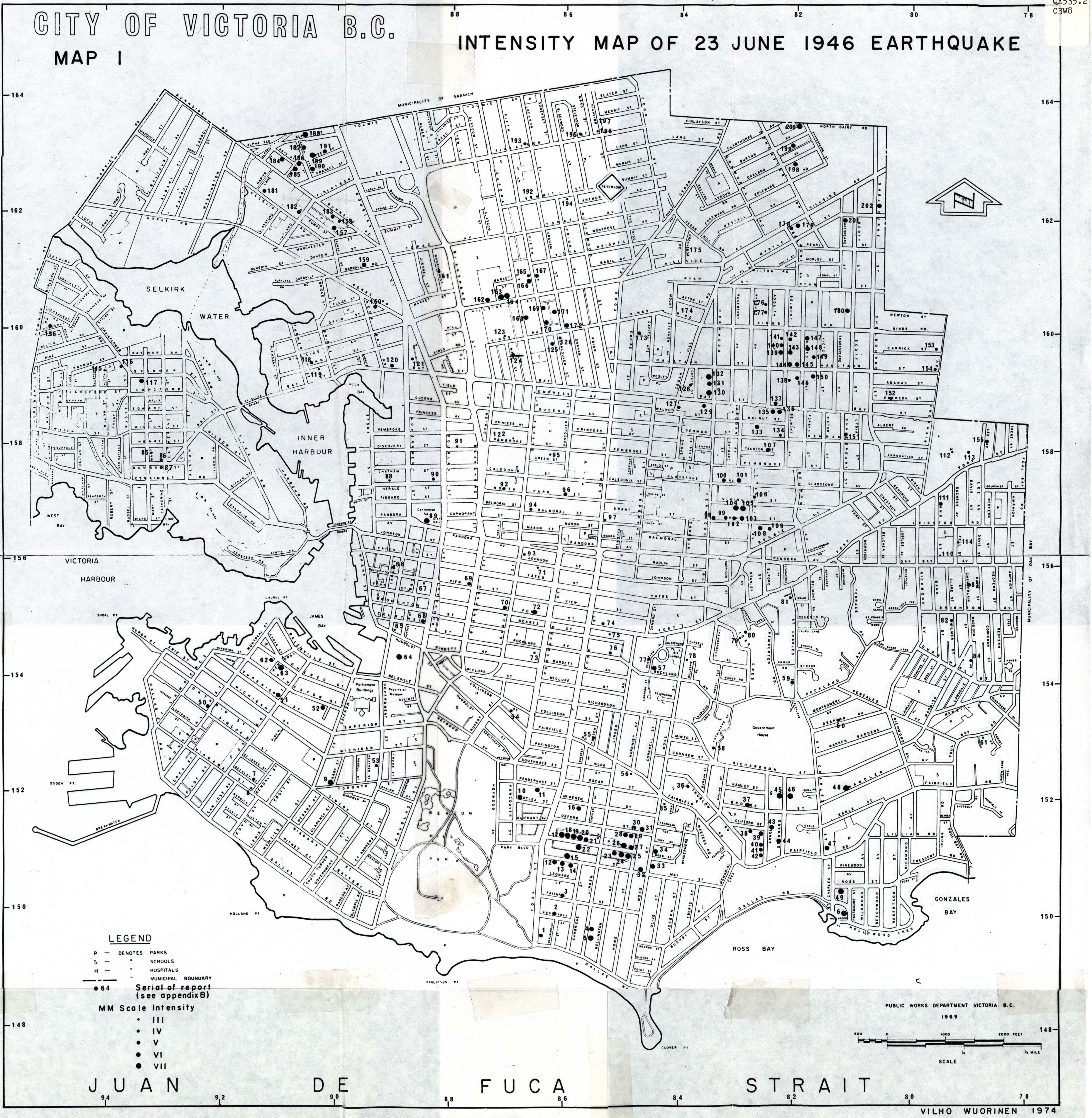
Signature

VILHO WUORINEN

Name

April 18, 1974

Date



CITY OF VICTORIA B.C.

MAP I

INTENSITY MAP OF 23 JUNE 1946 EARTHQUAKE

LEGEND

P — DENOTES PARKS
S — " SCHOOLS
H — " HOSPITALS
— · — " MUNICIPAL BOUNDARY
• 64 Serial of report (see appendix B)

MM Scale Intensity
• III
• IV
• V
● VI
● VII

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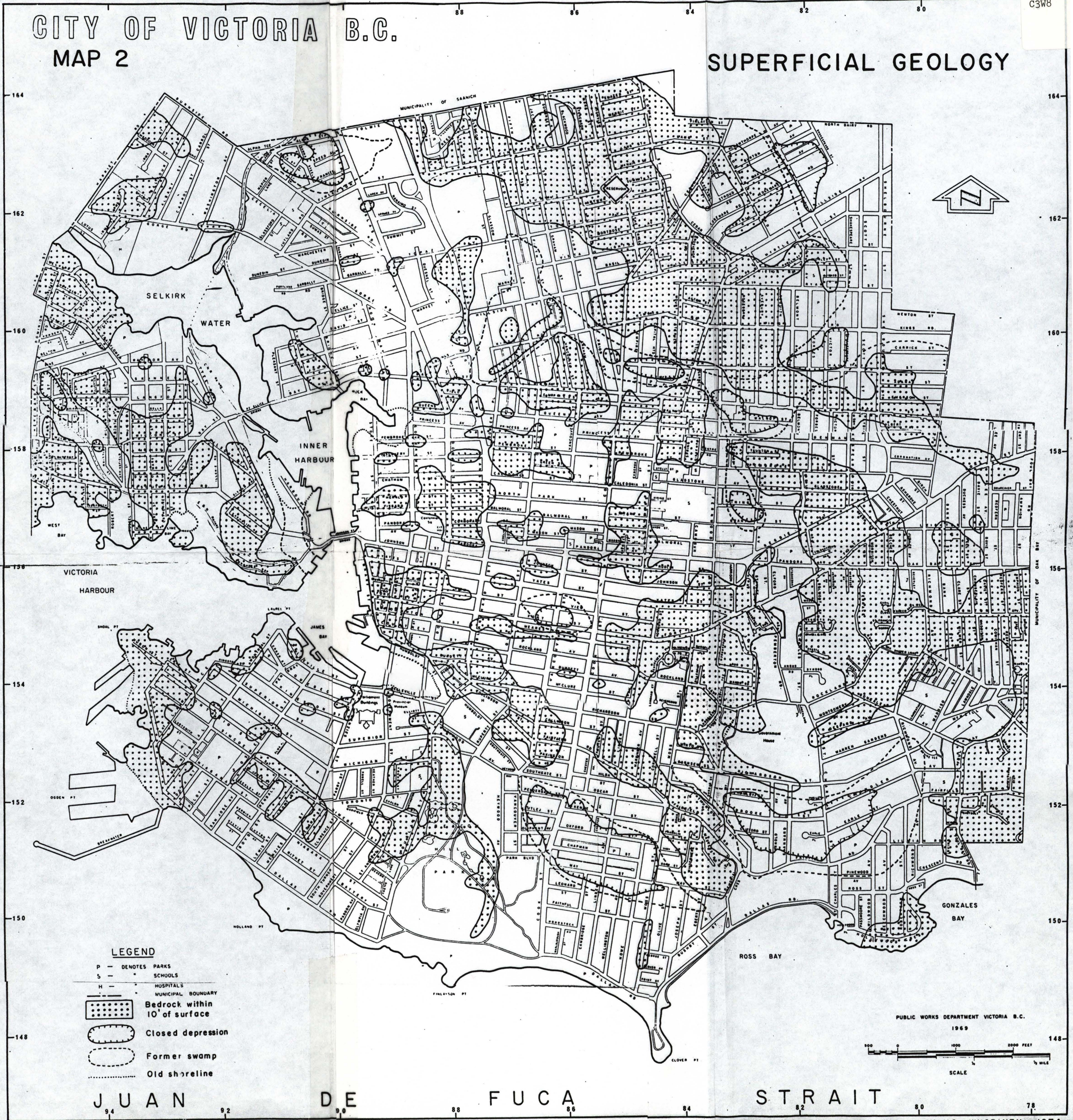
MAP 2

SUPERFICIAL GEOLOGY



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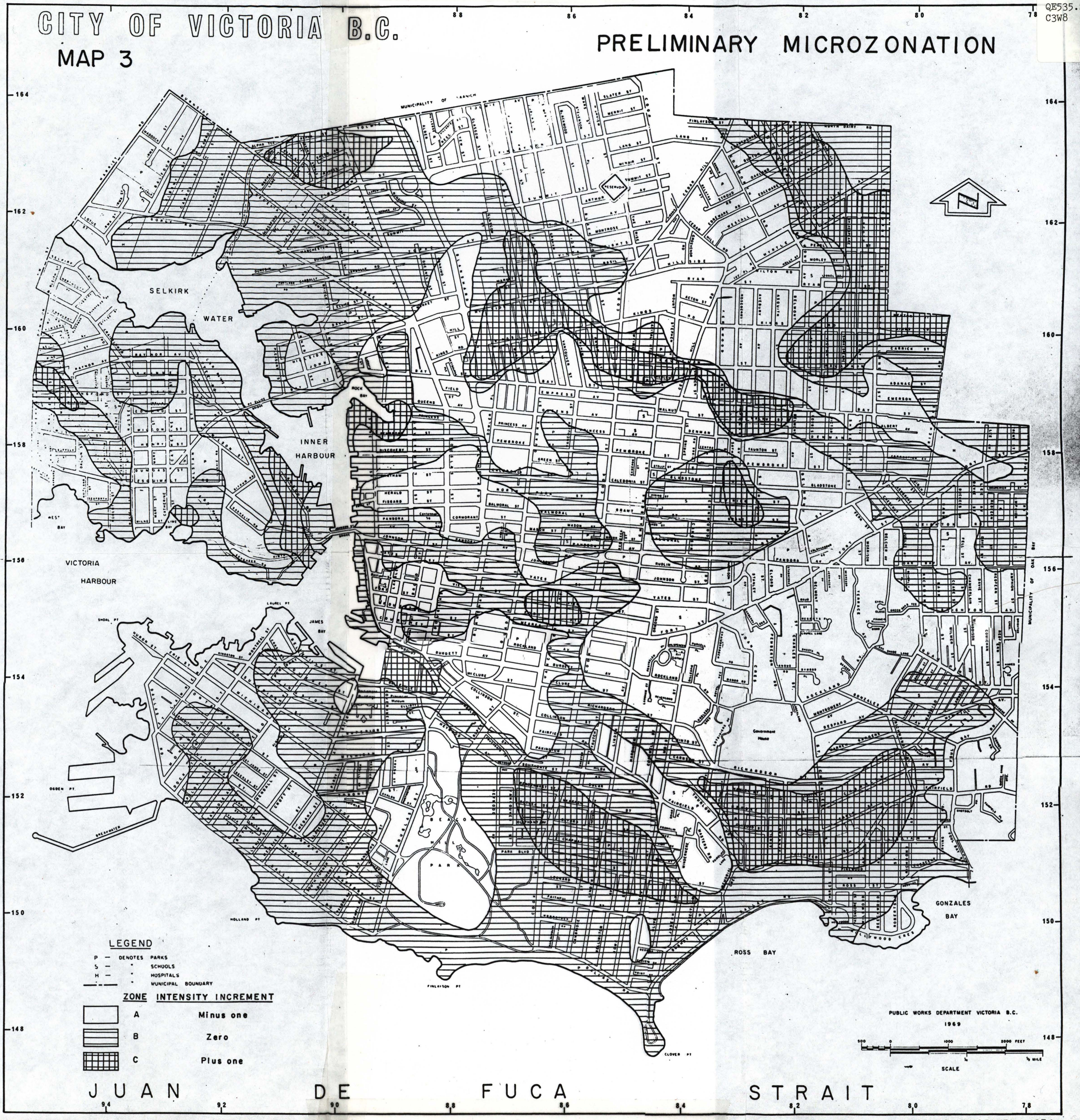
MAP 3

PRELIMINARY MICROZONATION



LEGEND

P — DENOTES PARKS
S — " SCHOOLS
H — " HOSPITALS
— · — MUNICIPAL BOUNDARY

ZONE INTENSITY INCREMENT

☐	A	Minus one
▤	B	Zero
▦	C	Plus one

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