A CRITICAL REVIEW OF THE WALLACH REPORT OF MAY 1989 ENTITLED "NEWLY DISCOVERED GEOLOGICAL FEATURES AND THEIR POTENTIAL IMPACT ON DARLINGTON AND PICKERING"

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Geological Survey of Canada

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Review by Anne E. Stevens, seismologist, Geological Survey of Canada, Ottawa, September 1989.

Geophysics Division, Internal Report 89-6

TABLE OF CONTENTS

1.0 Preamble

This review replies in part to the letter of 28 April 1989 from J.W. Beare, Director, Research and Radiation Protection Branch of the Atomic Energy Control Board (AECB) addressed to E.A. Babcock, Assistant Deputy Minister, Geological Survey of Canada, Department of Energy, Mines and Resources (EMR). This letter requested a critical review of the report by J.L. Wallach, AECB, entitled *Newly discovered geological features and their potential impact on Darlington and Pickering.*

This review focuses on the seismological and basic earthquake engineering aspects of the Wallach report, with relatively few comments on the geologic and other geophysical aspects of the report. These latter aspects are better addressed by other members of the Geological Survey of Canada (GSC).

It is outside the mandate of the GSC, as well as beyond its expertise, to analyze the manner in which its estimates of seismic design parameters are used by engineers to design or to evaluate designs of structures and components. In particular, the 28 April letter from the AECB stresses the importance of independent safety systems and the avoidance of common-mode failure in nuclear facilities. The GSC cannot comment upon the adequacy of safety systems at the Darlington and Pickering nuclear power facilities. These are engineering matters that depend at least as much upon the manner in which GSC's advice has been applied as upon the actual advice itself.

To reply to the third last paragraph of the AECB letter of 28 April, the general conclusion of the present review of the Wallach report is two-fold:

1. The numerical values of seismic design parameters provided by EMR seismologists in 1975 for Darlington A are substantially the same as numerical values that might be provided for the same parameters today (1989) by EMR seismologists. Reports that estimated seismic hazard or reviewed seismic design for Ontario nuclear power plants have been recently published (1987 and 1988) by authorities in seismology and engineering who are independent of EMR; no safety concerns were expressed or implied. Contrary to Wallach's conclusion, there is therefore no need for another new re-evaluation of the design basis seismic ground motion parameters for Darlington and Pickering.

2. As to "whether the information in the [Wallach] report, alone, is sufficient indication that the hazard from earthquakes at the Pickering and Darlington sites is higher than that evaluated by the GSC in its previous advice to the Board", GSC's answer to AECB is no; the Wallach report, alone, does not provide sufficient indication of an increase in seismic hazard.

This review will now provide a detailed justification of the above general conclusion.

Following the introduction in section 2.0, sections 3.0 to 5.0 deal with earthquake-resistant design. Sections 6.0 and 7.0 deal with geoscientific data. Some explanatory material on peak ground accelerations appear in Appendix 1. Analyses of certain earthquakes appear in Appendices 2 and 3. The preceding table of contents provides an overview of the structure of the review including tables, figures and appendices.

2.0 Introduction

J.L. Wallach, author of the report *Newly discovered geological features and their potential impact on Darlington and Pickering,* is concerned about seismic hazard[1] near the Darlington and Pickering nuclear power plant sites on the north shore of Lake Ontario, east of Toronto. Wallach (1989) asserts that two linear crustal structures, each several hundred km in length, intersect near the Darlington and Pickering sites and that this intersection could mark a preferred location of future significant earthquakes.

For these two sites, Wallach suggests that:

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[1] Note the difference between the terms "hazard" and "risk"; earlier publications (to the mid-1980s) used only the word "risk" to include both concepts. Nowadays, a clear distinction is made to distinguish the scientific phenomenon (hazard) from its social and economic consequences (risk). Where citations are presented from older reports, the word "hazard" is inserted for clarification after the word "risk", where appropriate.

1. an earthquake of magnitude 5.0 is a "credible event" (Section G, paragraph 2, page 12),

2. an earthquake of magnitude 5.8 to 6.25 is "not unreasonable" (Section G, paragraph 3, page 13), and

3. a "larger magnitude earthquake cannot be ruled out" (Section G, paragraph 3, page 13).

The present review will show that the earthquakes mentioned in points 1 and 2 were explicitly included as design earthquakes by EMR in its 1975 evaluation for the Darlington site.

For the Darlington and Pickering sites, Wallach further suggests that peak accelerations in the design basis seismic ground motion (DBSGM) for each site could be exceeded by:

4. a "relatively small" earthquake at short distance (Section H, paragraph 2, page 13) or

5. a "moderate to large earthquake" (Section H, paragraph 1, page 13) near these sites.

The present review will show that the effects of these latter two earthquakes upon engineered structures or components were fully considered in the design parameters recommended by EMR in its 1975 evaluation for the Darlington site.

The Wallach report implies, but does not explicitly state, that the design basis seismic ground motion used for Darlington and Pickering does not take into consideration points 1, 2 and 3 above. His report further implies rather strongly that the accelerations described in the DBSGM are too low to include the effects of earthquakes described in points 4 and 5 above.

As indicated by the report title, Wallach's main hypothesis is that new geologic features have been discovered and that these features are or could become seismically active. Even if this hypothesis could be accepted, his subsequent suggestion, that the earthquake-resistant design of Darlington and Pickering may be inadequate, is based on a misunderstanding of the principles of earthquake-resistant design and on an inadequate analyis of the earthquake locations.

Thus this assessment of the Wallach report begins with a review of the design earthquakes and earthquake-resistant design parameters suggested for Darlington A by seismologists of the Department of Energy, Mines and Resources in 1975. This review will show that points 1 to 5 above had indeed been considered, in whole or in large part, in the design recommendations of EMR, contrary to Wallach's suggestions. As already noted in section 1.0, how these design recommendations of EMR were used by Ontario Hydro in the actual design of Darlington A is beyond the mandate of the GSC to judge.

Earthquake data used by Wallach are summarized in a later section and some specific earthquakes discussed more fully in Appendices 2 and 3.

This review of the Wallach report will also remind its readers that 1) earthquake data must be critically examined prior to their use in hazard assessment and 2) the adequacy of an earthquake-resistant design cannot be judged solely on the basis of one recommended design parameter. As will be seen, these two points are not new. Literature examples abound on the proper ways to select earthquake data for hazard assessment and to apply ground motion parameters to earthquake-resistant design.

The following section 3.0 deals specifically with design parameters recommended for Darlington A, with no reference to Pickering, whose seismic design parameters had been established much earlier using other methods of evaluation. Pickering and Darlington are located about 30 km apart on the north shore of Lake Ontario; there is no reason to believe that earthquake hazard changes significantly between these two locations. The first reactor unit at Pickering entered service in 1971; the first unit for Darlington is scheduled for late 1989. Seismic design parameters were established at the approximate dates shown in Table A[2].

TABLE A: Design and In-service Dates for Pickering and Darlington

Nuclear power station	Design date	In-service date	Design acceleration
Pickering A (4 units)	1965	1971--1973	0.03g
Pickering B (4 units)	1972	1983--1986	0.05g
Darlington A (4 units)	1975	1989--1992	0.08g

Data source: Hare, 1988 (volume 1, annex 2, Table A-2, pages 203-204; Stevenson and Associates, 1987 (Figure 3.1, page 63).

Note: Other design parameters, in addition to acceleration, must be examined in order to compare overall seismic design of these three stations.

Design and construction practices have obviously evolved over this period of time resulting in new ways to reach the same goal of a safe and efficient nuclear facility. It is beyond GSC's mandate to comment on the question of retrofit for older reactors; this is a policy matter for AECB. Section 1.0 has already alluded to a recent safety review of all nuclear power plants in Ontario; this subject is further discussed in section 5.0.

2 Tables and figures in the present review are denoted A, B, C, etc. to avoid any confusion with references to tables and figures in other reports.

3.0 Earthquakes considered in estimating the design ground motion for Darlington A

Internal Report 75-16, dated December 1975 (Basham, 1975), explains in detail the rationale for the estimate of the design basis seismic ground motion proposed by the Earth Physics Branch[3] for Ontario Hydro's Darlington Nuclear Generating Station A. The report had been requested by AECB in September 1975 in order to assist AECB in assessing the seismic design parameters being proposed by Ontario Hydro for Darlington A.

The parts of this Internal Report most pertinent to the present review are the sections entitled "Darlington Design Earthquakes", pages 19 to 22 and Table 4, and "Darlington Design Basis Seismic Ground Motion", pages 22 to 31, Tablès 5, 6, 7 and Figure 8. Tables 4 and 5 are combined into the following table for convenience of reference.

TABLE B: Darlington Design Earthquakes and Design Peak Ground Accelerations (Basham, 1975)

Design earthquake (DE)	Magnitude	Epicentral distance (km)	Average peak horizontal acceleration	Design peak horizontal acceleration	Remarks on the location of each design earthquake (DE)
DE1	6.7	200	0.027g	0.06g	On the southwestern boundary of the Western Quebec Zone.
DE2	6.5	110	0.038g	0.08g	On an extension of the Clarendon-Linden structure on the south shore of Lake Ontario.
DE3	6.	70	0.041g	0.08g	In any direction from the Darlington site.
DE4	5.	20	0.063g	0.12g	In any direction from the Darlington site.

[note: mid-crustal focal depth (h=18 km) is assumed for all earthquakes;
the four design earthquakes are assumed to have an annual recurrence rate of 10^{-3}, corresponding to a probability of exceedance of 10^{-3} per annum or of 5% in 50 years.

Tables 6 and 7 of Basham (1975) presented corresponding values of velocity and displacement for the same four design earthquakes. As noted in Table B, design earthquakes DE1 and DE2 were assumed to occur in specific earthquake zones. The resulting design ground motion values however were calculated as a function of magnitude and distance, without reference to azimuth.

As shown in Table B, a moderate earthquake (magnitude 5) close to the site was included among the proposed design earthquakes, as well as an earthquake of magnitude 6. Thus the earthquakes mentioned in points 1, 2, 4 and 5 of

3 The Earth Physics Branch and its earthquake-related projects were incorporated into a restructured Geological Survey of Canada in April 1986.

Wallach [see above, section 2.0, Introduction] were indeed included in the 1975 Basham analysis.

To incorporate the observed standard deviation of a factor of about two associated with empirical peak ground accelerations, the calculated accelerations in column four were doubled by Basham (1975) to produce the design peak ground accelerations of column 5. The peak design ground motion values of velocity and displacement were increased by a further 30% for the corresponding response spectrum parameters to allow for uncertainties in eastern Canada attenuation relations for velocity and displacement, which were under development in 1975.

As discussed below in section 4.0, there is an important difference between strong ground motion recorded by an instrument tuned to this motion, and strong ground motion that causes building vibration. While Basham quite properly increased the calculated average peak ground motion values by one standard deviation to allow for the real variability in observed peak ground motions, it does not follow that a building would necessarily experience those peak values. The building response depends, among other things, on the periods at which the peak ground motion values occur and on the duration of strong ground motions near those peak values.

After proposing four design earthquakes and estimating their peak ground motions at the Darlington site, Basham outlined some of the effects that should be taken into consideration when selecting engineering design parameters for Darlington. He summarized his recommendations for seismic ground motion parameters as follows, (1975, page 31):

> ...These [earthquake] effects include a high frequency transient acceleration with duration about 3 seconds and peak acceleration about 0.12*g* [DE4], and strong motion time histories with durations up to about 40 seconds and peak accelerations, velocities and displacements up to about 0.08*g*, 7 cm/sec and 4.6 cm, respectively [DE1, DE2, DE3]. The ground motion response spectrum representation of the DBSGM [design basis seismic ground motion] would have acceleration-, velocity- and displacement-flat segments set to about 0.08*g*, 9 cm/sec and 6 cm respectively, with further adjustment, as necessary, to account for the influences of local site conditions.

The detailed earthquake design parameters adopted by Ontario Hydro for the nuclear facilities at the Darlington site are not known to this reviewer. It is understood, however, that Ontario Hydro did adopt horizontal design seismic ground motion values of 0.08*g*, 9.0 cm/s and 6.0 cm, respectively, for acceleration, velocity and displacement. It is believed that a response spectrum similar to Figure 1 in CSA Standard N289.3 (CSA, 1981) and normalized to 0.08*g* was used as the design response spectrum.

To summarize section 3.0, the four different design earthquakes proposed by Basham in 1975 for Darlington include four of the five types of earthquakes of current concern to Wallach (1989). Most, if not all, of the potential effects at the Darlington site of the four design earthquakes, as described by

Basham in the above quotation, appear to have been considered by Ontario Hydro when selecting earthquake-resistant design parameters for Darlington.

4.0 Peak Accelerations

The Wallach report states that design peak accelerations for Darlington and Pickering are lower than peak ground accelerations recorded during a specific recent moderate earthquake and suggests therefore that their design might not be adequate. This line of reasoning results from an incorrect understanding of earthquake-resistant design parameters.

In any discussion of peak accelerations, one must distinguish carefully between peak *ground* acceleration and peak *design ground* acceleration. Furthermore, one must not assume that a peak design acceleration for a *Canadian* nuclear plant (or any other Canadian critical structure) has been defined in exactly the same way as a peak design acceleration for an *American* nuclear plant (or any other American critical structure). Failure to observe these distinctions can lead to faulty conclusions.

Given the importance of such distinctions, these two accelerations are first defined before proceeding with specific points raised in the Wallach report. Appendix 1 provides further clarification.

4.1 Peak ground acceleration

Peak ground acceleration refers to the maximum ground acceleration recorded at a particular location during an earthquake and generally expressed as a fraction of *g* (gravitational acceleration). Note that the "ground" acceleration recorded by an instrument located near the base of a structure (whether inside or outside) will not be the same as that recorded by a true "free-field" instrument located outside and beyond the influence of any structure. In comparing ground accelerations, it is good practice to specify whether these are free-field accelerations or accelerations recorded near the base of a structure.

To be useful in an engineering sense, the numerical value of a peak ground acceleration should be accompanied by other numerical or descriptive data indicating the frequency or period of this peak acceleration, the number of cycles of motion near this maximum and the duration of motion near this maximum. This additional information indicates whether the specific peak ground acceleration is likely to be potentially damaging to a particular structure.

4.2 Peak design ground acceleration

A *peak design ground acceleration* is, as its name indicates, a value used in design, a value that depends in part upon the manner in which a particular structure would respond when acted upon by an earthquake. The peak design value thus may differ from one structure to another. For example, a structure that, by its nature, cannot respond to vibrations in certain frequency ranges need not be designed to resist the vibrations that might be generated in those frequency ranges by an external source, such as an earthquake. While the foregoing sentences (and other later parts of this review) refer to a structure, they are equally valid for the components of a structure, including its equipment.

The ground acceleration value used for design has sometimes been termed "effective acceleration" to distinguish it from peak ground acceleration. Appendix 1 provides further clarification and explains why "peak design" ground acceleration is almost invariably less than "peak" ground acceleration.

4.3 Wallach and acceleration

4.31 Leroy, Ohio, earthquake of 31 January 1986

Wallach (1989, page 11, bottom paragraph) contrasts a peak ground acceleration value of 0.18*g*--0.20*g*, recorded at the Perry, Ohio, nuclear power plant with its design acceleration value of 0.15*g*, and further notes that 0.18*g*--0.20*g* is much higher than peak accelerations used in the design of Darlington and Pickering. The Perry plant is located about 17 km north of the moderate earthquake (magnitude 5.0) that occurred on 31 January 1986 near Leroy, Ohio, about 40 km east of Cleveland (Nicholson et al., 1988).

According to another reference (Munroe and Stevenson, 1986), peak ground accelerations of 0.18*g* in the north-south direction and 0.10*g* in the east-west direction were recorded at the base of the reactor containment structure at a dominant frequency of about 20 Hz. The peak free-field values were 0.15*g* north-south and 0.08*g* east-west. There is perhaps little difference here between these pairs of north-south and east-west values. However, as noted in subsection 4.1 above, a clear distinction should be maintained at all times between ground values recorded near a structure and those at free-field locations.

Appendix 1, as well as subsections 4.1 and 4.2 above, explain why peak ground acceleration and peak design ground acceleration are not equivalent and why design acceleration is invariably lower. This is illustrated in Figure A, which compares (Figure 1) design time histories [accelerations] and (Figure 2) time histories recorded at the base of the Perry reactor containment structure during the Leroy earthquake of 31 January 1986. As noted by Munroe and Stevenson (1986):

> The time history seismic design basis for the Perry Station is shown in Figure 1. By way of comparison, the measured time history from the earthquake [Leroy earthquake of 31 January 1986] is shown in Figure 2. Obviously, the measured earthquake is characteristic of short duration, low energy, high frequency motion with little potential for damage. The design basis motion contains high energy, broad frequency and long duration associated with damaging strong motion earthquakes as shown in the Figure 1 time history motion.

An earthquake-resistant design is often characterized by the value of its peak design acceleration, even though other parameters must be specified to adequately describe the earthquake-resistant features of the design. Figure A strikingly illustrates why other parameters, such as frequency and duration, are necessary to describe the potential effects of an earthquake on a structure.

While the information presented by Wallach in the above-referenced paragraph (1989, page 11) is factually correct, the distinction between design and recorded acceleration is not drawn to the reader's attention. Thus the reader might conclude, incorrectly, that the seismic design of the Perry plant is marginally adequate and that the seismic designs of Darlington and Pickering are inadequate. Wallach himself in paragraph two of his summary and conclusions (page 13) uses the Leroy-Perry example to imply that a relatively small earthquake near Darlington or Pickering could be potentially damaging. [He does not state this explicitly, but the inference is clear.]

4.32 Acceleration at short distance

Wallach returns to the subject of peak acceleration on page 13 (section G, last paragraph), but again confuses design ground motion with recorded ground motion. He mentions the design acceleration values of Darlington and Pickering then proceeds to cite higher acceleration values at short distances, with the implication that the design values are inadequate. The specific examples of magnitude-distance-acceleration values cited by him in this paragraph are summarized in Table C. These numbers and those of his Tables 4

Table C: Magnitude-Distance-Ground Accelerations Selected by Wallach, page 13

Magnitude	Distance (km)	Ground acceleration
Hasegawa et al., 1981 [hypocentral distance]		
5.0	≤17	≥0.10g
5.8	≤30	≥0.15g
6.25	≤30	≥0.27g
Boore and Atkinson, 1987 [epicentral distance]		
5.0	≤17	≥0.10g
5.8	≤30	≥0.13g
6.25	≤30	≥0.19g

and 5 (pages 19 and 20) refer to calculated peak ground motion and not to design values. As noted above (section 4.31), both duration and frequency must be specified in order to know what relevance these ground accelerations might have to structural response and hence to selection of earthquake-resistant design values.

4.33 Seismic zoning map and design accelerations

In this same section (page 13, section G, last paragraph) Wallach notes design acceleration values of 0.03*g*, 0.05*g* and 0.08*g* for Pickering and Darlington, but fails to remind the reader that these values were used in quite different ways to calculate design loads for the three different nuclear power plants. He also omits to mention that Pickering A and B were designed about 1965 and 1972, respectively, (see Table A, section 2.0), when previous editions of the National Building Code of Canada (NBCC) were in effect, with different seismic zoning maps and different relations for using seismic parameters to calculate earthquake design loads. He further omits to mention that Darlington was designed using probabilistic methods, whereas Pickering A and B were not. While critical structures are not designed according to the seismic provisions of the National Building Code, that code and, in particular, methods used to derive its seismic provisions do serve as a reference.

One may express the relation between design load and design acceleration as follows: *design load = design acceleration x other parameters*. The reader might assume from the Wallach report that the quantity "other parameters" has remained virtually constant over the years and that therefore doubling the design acceleration doubled the design load, resulting in a much stronger structure with respect to earthquakes. In fact, the term "other parameters" has also changed over the years. One cannot simply compare the design accelerations without a prior knowledge of other factors that contributed to the calculation of earthquake design loads. This is equally true for critical structures and for ordinary structures.

The 1985 National Building Code of Canada seismic zoning map for acceleration, to which Wallach refers on his page 13 and Figure 20, shows <u>design</u> ground accelerations for an annual recurrence rate of 0.002 (10% probability of exceedance in 50 years). The previous NBCC seismic zoning map (1970, 1975 and 1980 editions) was based on an annual recurrence rate of 0.01 (40% probability of exceedance in 50 years). The design motions proposed by Basham (1975) for Darlington were associated with an annual recurrence rate of 0.001 (5% probability of exceedance in 50 years). [Basham's estimates were prepared prior to completion of the seismic provisions of the 1985 NBCC.] Peak acceleration values calculated for different recurrence rates (or exceedance probabilities) cannot be directly compared without simultaneous reference to their corresponding probabilities.

Table D shows a seismic hazard calculation for four levels of probability for a site between Darlington and Pickering using the method employed for the 1985 seismic zoning maps. The acceleration value for an annual recurrence rate of 0.001 is compatible with and the velocity value is lower than the values proposed by Basham in 1975 (see section 3.0 above).

Wallach's juxtaposition of design acceleration and ground acceleration values, without distinguishing between them and his neglect of relevant factors such as duration and frequency content when comparing peak accelerations, have greatly weakened his argument that the seismic design of Darlington and Pickering may be inadequate. In fact, in his various references to acceleration, he has not provided any evidence whatsoever that the seismic

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SEISMIC HAZARD CALCULATION * / CALCUL DE PERIL SEISMIQUE *

REQUESTED BY/ DEMANDE PAR ----

SITE Darlington/Pickering

LOCATED AT/ SITUE AU 43.90 NORTH/NORD 79.00 WEST/OUEST

PROBABILITY OF EXCEEDENCE PER ANNUM/ PROBABILITE DE DEPASSEMENT PAR ANNEE	0.010	0.005	0.0021	0.001
PROBABILITY OF EXCEEDENCE IN 50 YEARS/ PROBABILITE DE DEPASSEMENT EN 50 ANS	40 %	22 %	10 %	5 %
PEAK HORIZONTAL GROUND ACCELERATION (G) / ACCELERATION HORIZONTALE MAXIMALE DU SOL (G)	0.032	0.043	0.064	0.084
PEAK HORIZONTAL GROUND VELOCITY (M/SEC) / VITESSE HORIZONTALE MAXIMALE DU SOL (M/SEC)	0.015	0.026	0.041	0.060

* REFERENCES

1. NEW PROBABILISTIC STRONG SEISMIC GROUND MOTION MAPS OF CANADA: A COMPILATION OF EARTHQUAKE SOURCE ZONES, METHODS AND RESULTS. P.W. BASHAM, D.H. WEICHERT, F.M. ANGLIN, AND M.J. BERRY EARTH PHYSICS BRANCH OPEN FILE NUMBER 82-33, OTTAWA, CANADA 1982.

2. ENGINEERING APPLICATIONS OF NEW PROBABILISTIC SEISMIC GROUND-MOTION MAPS OF CANADA. A.C. HEIDEBRECHT, P.W. BASHAM, J.H. RAINER, AND M.J. BERRY CANADIAN JOURNAL OF CIVIL ENGINEERING, VOL. 10, NO. 4, P. 670-680, 1983.

3. NEW PROBABILISTIC STRONG GROUND MOTION MAPS OF CANADA. P.W. BASHAM, D.H. WEICHERT, F.M. ANGLIN, AND M.J. BERRY, BULLETIN OF THE SEISMOLOGICAL SOCIETY OF AMERICA, VOL. 75, NO. 2, P. 563-595, 1985.

4A. SUPPLEMENT TO THE NATIONAL BUILDING CODE OF CANADA 1985, NRCC NO. 23178. CHAPTER 1: CLIMATIC INFORMATION FOR BUILDING DESIGN IN CANADA. CHAPTER 4: COMMENTARY J: EFFECTS OF EARTHQUAKES.

4B. SUPPLEMENT DU CODE NATIONAL DU BATIMENT DU CANADA 1985, CNRC NO 23178F. CHAPITRE 1: DONNEES CLIMATIQUES POUR LE CALCUL DES BATIMENTS AU CANADA. CHAPITRE 4: COMMENTAIRE J: EFFETS DES SEISMES.

(2)

SITE Darlington/Pickering

ZONING FOR ABOVE SITE/ ZONAGE DU SITE CI-DESSUS

** 1985 NBCC/CNBC: Za = 1; Zv = 1

ACCELERATION ZONE/ ZONE D'ACCELERATION Za = 1
ZONAL ACCELERATION/ ACCELERATION ZONALE a = 0.05 G

** VELOCITY ZONE/ ZONE DE VITESSE Zv = 1
** ZONAL VELOCITY/ VITESSE ZONALE v = 0.05 M/S

1985 NBCC/CNBC
SEISMIC ZONING MAPS/ CARTES DU ZONAGE SEISMIQUE

PROBABILITY LEVEL: 10% IN 50 YEARS
NIVEAU DE PROBABILITE: 10% EN 50 ANNEES

G OR M/S	ZONE	ZONAL VALUE/ VALEUR ZONALE
0.00		
	0	0.00
0.04		
	1	0.05
0.08		
	2	0.10
0.11		
	3	0.15
0.16		
	4	0.20
0.23		
	5	0.30
0.32		
	6*	0.40

* ZONE 6: NOMINAL VALUE/ VALEUR NOMINALE 0.40;
SITE-SPECIFIC STUDIES SUGGESTED FOR IMPORTANT PROJECTS/
ETUDES COMPLEMENTAIRES SUGGEREES POUR DES PROJETS D'IMPORTANCE.

** For NBCC applications, when Zv=0 and Za>0, the values of Zv and v should be taken as 1 and 0.05, respectively. See NBCC 1985, Sentence 4.1.9.1 (4).

Pour applications selon le CNBC, lorsque Zv=0 et Za>0, les valeurs Zv et v deviendraient 1 et 0.05, respectivement. Voir CNBC 1985, paragraphe 4.1.9.1 4).

design parameters selected for Darlington and Pickering have led to an unsafe design.

4.4 Distinction in design between Canadian and American critical structures

Before comparing peak design ground motion values of critical structures in different countries and/or subject to different seismic codes, one must ascertain the intent of the design -- for example, whether the structure must remain within elastic limits at all times, or whether some inelastic response is permissible; whether the facility is intended to continue in operation during the earthquake, or whether the facility is to be quickly shut down. The levels of damping assumed in the design are also important; the damping varies with material properties and with the nature of the component. Wallach's comparison of design values and recorded acceleration at the Perry, Ohio, plant with respect to the design of Darlington and Pickering is thus incomplete, leading to incorrect inferences about safety.

For a detailed comparison of Canadian and American design philosophies, see Stevenson and Associates (1987), a consultant's report prepared at the request of the Hare Commission (1988) studying the safety of Ontario nuclear power reactors. As noted in the following section 5.0, peak design acceleration values are different for reactors on the Canadian and American shores of Lake Ontario. These differences do not imply that the earthquake design of the Canadian plants is inadequate.

5.0 Previous re-evaluations/reviews of seismic hazard and seismic design

The design of Ontario nuclear power plants has been reviewed at various times since their initial designs were approved. Two particular reports are noted here.

In August 1987, Acres International Limited prepared a report for Ontario Hydro entitled *Seismic hazard at Ontario Hydro dam and nuclear plant sites* (Atkinson and Stagg, 1987). This study evaluated hazard at nine dam sites in eastern Ontario and two nuclear plant sites, namely Darlington and Bruce, in southern Ontario. The authors analyzed geologic and seismic data, proposed several different seismic source models and performed sensitivity analyses. Results were expressed as design response spectra (5% damping), as representative earthquakes and as time histories. The authors followed the probabilistic Cornell-McGuire method, as did Basham (1975), but had the benefit of longer data bases and an additional decade of seismological, geologic and earthquake engineering research results. Nevertheless, the resulting seismic hazard estimates for the Darlington site were not more severe than those proposed by Basham in 1975. For example, the representative earthquakes recommended for generation of time histories at Darlington were magnitude 6 earthquakes at 60 and at 100 km, plus magnitude 5 at 18 km. These are compatible with the design earthquakes proposed by Basham (see Table B, section 3.0 above).

In December 1986, the Government of Ontario, through its Ministry of Energy, commissioned a scientific and technical review of the safety of Ontario's nuclear power reactors (Hare, 1988). This review included an examination of the design of Ontario Hydro's CANDU nuclear generating plants. Prior to formal submission to the Government of Ontario, the resulting report was reviewed by an expert panel appointed by the Royal Society of Canada, who gave it its unqualified approval.

The two main volumes of the final report had little to say directly about earthquake-resistant design. However, one of the consultants' reports commissioned by Dr. Hare did deal in some detail with the design of containment structures, systems and components at Darlington, Pickering and Bruce. The report by Stevenson and Associates (1987) compared the historical development of Canadian, American and international design and behaviour criteria, both for normal and for abnormal loads, including earthquakes loads.

The consultants noted that whereas the design ground accelerations for Ontario plants were smaller than those at nearby American plants, on the other hand, certain behaviour criteria were more stringent for the Ontario plants. They discussed other differences but concluded that the differences between Canadian and American earthquake-resistant design were not considered significant from an overall safety standpoint.

These two examples (Acres and Hare) serve to illustrate that the seismic designs of Darlington and Pickering have been recently examined from a scientific and engineering perspective by qualified professionals. No design deficiencies affecting safety were noted. The Stevenson report illustrates clearly that the relative safety of two nuclear power plants (or their absolute safety) cannot be judged solely from a simple comparison of one design or one behaviour parameter.

6.0 Earthquake data used by Wallach to illustrate spatial correlation with various geophysical/geological parameters

Sections 3.0, 4.0 and 5.0 have just shown that Wallach's misunderstanding of the application of earthquake parameters to earthquake-resistant design has led to faulty conclusions, or at least to faulty inferences and suggestions, about the safety of the seismic design of Darlington and Pickering. Sections 6.0 and 7.0 will analyze the geoscientific data presented by Wallach and show that here also his analysis and hence his conclusions are faulty.

The data for some of the earthquakes mentioned in the text are discussed briefly below in sections 6.2 to 6.4 and, in more detail, in Appendices 2 and 3.

Wallach did not consider any uncertainties whatsoever in earthquake magnitudes. He did acknowledge that <u>locations</u> of earthquakes could be uncertain (Section C, final paragraph, page 8); "pre-instrumented earthquakes may be in error by as much as 50 km...instrumented events may also be imprecise." However, he did not distinguish earthquakes located with instrumental data from those located with pre-instrumental data (e.g. Figure 4, Niagara-Pickering, and Figure 8, Georgian Bay). The reader, therefore, cannot judge, using only information contained within the Wallach report, whether the apparent alignments of epicentres are actually consistent with the accuracy of the epicentres.

Furthermore, Wallach failed to consider whether the spatial correlations that he proposes between certain earthquakes and the Niagara-Pickering (Figure 4), Georgian Bay (Figure 8) and Akron (Figure 17) structures would still remain valid when uncertainties in location and size of the specific earthquakes are considered. As the following sections show, these spatial correlations largely evaporate when the earthquake history is carefully examined.

6.1 Associating groups of earthquakes to estimate hazard

It has been the practice of seismologists, when considering questions of earthquake hazard, to place much lower weight on the catalogued locations and magnitudes of pre-instrumental earthquakes than on those of more recent instrumentally-recorded events, knowing that considerable uncertainty is attached to these earlier earthquakes, many of which have not been critically examined since their initial cataloguing. Two examples from EMR are now presented. For examples from other organizations, see Atkinson and Stagg, 1987, and recent reports on seismic hazard assessment in the United States sponsored by the Electric Power Research Institute and by Lawrence Livermore Laboratories.

Basham et al. (1979) presented a series of five maps showing all known earthquakes in eastern Canada and the immediately adjacent United States in the following periods: 1661--1849, 1850--1899, 1900--1924, 1925--1949, 1950--1975. The authors noted the following biases in these data (page 1577):

> The types of biases...that are of concern are early earthquake reporting only in the regions first settled, inaccurate epicentres and nonuniform earthquake reporting thresholds in both the pre- and early post-instrumental eras, and nonuniform reporting of small magnitudes in the recent decades.

These biases were reduced by plotting a subset of the total data on a single map with the following date-magnitude restrictions (page 1578, figure 5). The resulting map was used to derive earthquake source zones from which a seismic hazard map was subsequently developed.

1970--1975, magnitude < 3
1960--1975, $3 \leq$ magnitude < 4
1925--1975, $4 \leq$ magnitude < 5
1850--1975, $5 \leq$ magnitude < 6
1661--1975, $6 \leq$ magnitude

Figures B and C show earthquakes in southern Ontario and the adjacent United States plotted in two ways. Figure B shows all earthquakes in this area that are listed in the Canadian Earthquake Epicentre File (CEEF) to mid-1989. [Note that the file is incomplete for earthquakes in the United States.] Figure C shows a subset restricted by magnitude and date, as defined in the figure legend. These restrictions correspond to those tabulated above except that the closing year is mid-1989 instead of 1975, as more data are now available than were available to Basham et al. in 1979. Figures B and C include all the regions for which earthquakes have been plotted in Wallach's report, namely, his Figures 4, 8, and 17. A comparison of Figures B and C shows a striking difference in the earthquake pattern, particularly in central and southern Ontario.

As a second published example, similar, but not identical, date-magnitude restrictions were followed by Basham et al. (1982a) in analyzing eastern Canada seismicity in order to estimate earthquake hazard near Gros Cacouna, Québec, and Melford Point, Nova Scotia, where liquefied natural gas facilities were being proposed.

1970--1979,	magnitude < 3
1960--1979,	3 ≤ magnitude < 4
1950--1979,	4 ≤ magnitude < 5
1568--1979,	5 ≤ magnitude

The authors further commented (pages 5 and 7):

> ...Earthquakes in magnitude ranges less than 5 are restricted to those reported in the last three decades. This avoids possibly very inaccurate epicentres of earlier events reported felt in single locations, and is a better reflection of the capabilities of the seismograph network as it developed to its current configuration.
>
> The distribution of seismicity in the earliest years shows concentrations of events in the regions first settled, e.g., near Boston and Montreal. Epicentral locations based on isoseismal information and early seismographic observations are less accurate than has been possible with the modern seismograph network of the last two decades. Nevertheless, Figure 2 is a useful depiction of the general distribution of historic and recent seismicity. More careful assessment of the completeness of reporting of the various magnitude categories, which varies throughout the map area of Figure 2, is required for modelling the earthquake source zones for earthquake risk [hazard] estimation (Basham et al., 1979; with further modification by Basham et al., 1982b).

Figures 18 and 19 in the Wallach report show a magnitude-year restriction similar to the one presented above from Basham et al. (1979), but Wallach has not noted the differences between the earthquake distribution on these figures and that on his Figures 4 and 8.

The practice of critically examining the catalogued parameters of individual earthquakes or groups of earthquakes before using them in seismic hazard assessment is not new, as the examples above have shown. Wallach should have been aware of this. As already noted, he did comment on a possible 50-km uncertainty in pre-instrumented earthquakes, but failed, even as a minimum, to draw a circle of radius 50 km around all such epicentres in his Figures 4 and 8. [The earthquake map that he requested from the Geophysics Division, from which his Figures 4 and 8 are extracts, was accompanied by a complete listing of the plotted epicentres; he had the necessary information to draw such circles, or otherwise analyze the data by historical period.]

As the following sections show, this lack of attention to earthquake accuracy has led Wallach to propose that certain structures may be seismically active because spatially associated with earthquakes, whereas these spatial associations are tenuous at best.

6.2 Niagara-Pickering Magnetic Lineament

Aeromagnetic data are used by Wallach to identify the Niagara-Pickering Magnetic Lineament (NPML), which he says extends from the Niagara Peninsula north-northeastward to the latitude of Lake Simcoe (approximately from 43.0°N, 79.5°W to 44.3°N, 78.8°W). He further supports the existence of this feature by reference to other geologic features including the Clarendon-Linden fault, the Central Metasedimentary Belt Boundary Zone, and the Akron Magnetic Boundary. He suggests that both aeromagnetic and geologic data imply that the Niagara-Pickering Magnetic Lineament may represent a fault.

Earthquake data were not used either to <u>define</u> the Niagara-Pickering Magnetic Lineament nor to <u>suggest</u> it may represent a <u>fault</u>.

However, two earthquakes (1853, 1873), apparently located on the Niagara Peninsula, were used by Wallach to suggest that the Niagara-Pickering Magnetic Lineament might be a seismically active structure. He did not associate any other specific earthquakes with this structure.

In reaching his conclusion, Wallach assumed the locations of these two earthquakes were "reasonably accurate" (page 6, Section B, last paragraph), but did not place a numerical uncertainty on the locations. [Later he mentions an uncertainty of up to 50 km in pre-instrumental epicentres (page 8, Section C, last paragraph).]

As detailed in Appendix 2, the two earthquakes (13 March 1853, 6 July 1873) are pre-instrumental and are uncertain in location, on the basis of presently available information, by more than ±50 km (i.e. more than 0.5 degree in latitude and longitude). The 1873 earthquake did not occur on the Niagara Peninsula, and is not therefore spatially associated with the Niagara-Pickering Magnetic Lineament. The 1853 earthquake may not have been centred in the Niagara Peninsula, although reported felt there. But, in any case, it is too poorly located from presently available information, to be said to be spatially associated with the Niagara-Pickering Magnetic Lineament.

Figure 4 of Wallach shows other epicentres on the Niagara Peninsula plotted at distances of about 15 km or greater, both east and west of the Niagara-Pickering Magnetic Lineament. Wallach did not comment on their possible association with the Niagara-Pickering Magnetic Lineament. A comparison of Figures B and C indicates that some of these are also likely quite uncertain in location.

Appendix 2 provides some further details on the four Niagara Peninsula earthquakes plotted in Figure C, which occurred in 1954, 1958, 1962 and 1963. Their catalogued locations were based on very limited instrumental data and a few sketchy felt reports. A review of these data indicated uncertainties of the order of ±50 km. Further data, if available, would be necessary to determine which, if any, of these earthquakes actually occurred on the Niagara Peninsula.

6.3 Georgian Bay Linear Zone

Gravity, aeromagnetic, topographic and geologic data are used by Wallach to identify the Georgian Bay Linear Zone, which he defines as a zone trending north-northwest from approximately 43.0°N, 78.5°W, east of Buffalo, N.Y., to approximately 46.0°N, 80.8°W, just along the east coast of Georgian Bay. He notes a linear zone of earthquakes, about 30 to 40 km in width, which seems to be spatially associated with the Georgian Bay Linear Zone.

As for the Niagara-Pickering Magnetic Lineament, Wallach does not use earthquakes to define the Georgian Bay Linear Zone, but rather to suggest that the zone is or may become seismically active. He mentions specifically in his text the moderate 1857 Lockport and 1929 Attica earthquakes in New York State, east of Buffalo, and a minor 1877 earthquake near Oshawa, Ontario. Appendix 3 first lists the 14 earthquakes (Wallach Table 2) that he spatially associates with this zone, six in Ontario and eight in New York State, and then briefly discusses the Ontario events.

All of the six epicentres in Canada that Wallach spatially associated with this zone are poorly known and of small magnitude. A comparison of Figures B and C shows that five of these six, having not met the date-magnitude requirements, are not plotted on Figure C. The sixth event, on 01 April 1965, plotted just east of Georgian Bay, is mislocated, as explained in Appendix 3; it was a rockburst or an explosion in one of the Sudbury mines. Appendix 3 shows also that the locations of the other five epicentres in Ontario are far too uncertain to be said to be spatially associated with the Georgian Bay Linear Zone. Thus the events selected by Wallach to suggest that the Georgian Bay Linear zone may be seismogenic in Canada do not support this hypothesis.

6.4 Akron, Ohio, Magnetic Boundary

Wallach cites the work of Seeber (1987) who spatially associated about seven earthquakes with the Akron Magnetic Boundary, all of which lie within about 10 km of this boundary (see Figure 17 of Wallach, taken directly from Seeber, 1987, Figure 7). Figure 17 spans only about one degree in latitude and longitude; all known earthquakes within this degree square have not been plotted. The spatial relation with other earthquakes in adjacent areas is not indicated.

One of the earthquakes said to be spatially associated with the Akron Magnetic Boundary illustrates the uncertainly in location of even some of the early instrumentally-located earthquakes. The 09 March 1943 earthquake, magnitude 4.5, appears in several earthquake catalogues with coordinates at or near 42.2°N, 80.9°W, which is its position in Figures B and C, while a recent recalculation by Gordon (1988) lists coordinates 41.6°N, 81.3°W, fully 75 km to the southwest, which is its position in Figure 17. The relocation of Gordon was based upon essentially the same instrumental data as the original epicentre; he assigned a statistical uncertainty of ±10 to ±15 km to the recalculated epicentre. The true uncertainty is certainly greater.

Error bars on Figure 17 indicate that only the recent 1983 and 1986 (Leroy) earthquakes are well located. The two most southerly earthquakes occurred in 1885 and 1932; their locations are based on only a few felt reports and the location uncertainty is almost certainly larger than the ±10 to ±15 km indicated in Figure 17. The two 1955 earthquakes were relocated from instrumental data by Weston Geophysical Corporation (1988). The position shown in Figure 17 is more accurate than that published in previous American catalogues and shown in Figures B and C, which was about 30 km further northwest; however, the epicentral uncertainty is still of the order of ±20 km.

Thus the spatial association of earthquakes with the Akron Magnetic Boundary may be limited to the two earthquakes of 1955 (nearly identical epicentres, magnitudes about 3.4 and 3.6) and the earthquakes of 1983 (magnitude 2.7) and 1986 (magnitude 5.0), spanning a distance of about 50 km.

Whether any of these earthquakes is associated with the Akron Magnetic Boundary and, if so, the nature of this association, is a subject of discussion among certain geoscientists in the United States. There is no consensus that the Akron Magnetic Boundary has been proven seismogenic.

Wallach had introduced the Akron Magnetic Boundary since he believes it may continue into Canada and connect with his proposed Niagara-Pickering Lineament (page 12, section F). As already shown in section 6.2, this lineament has no earthquakes spatially associated with it. The relevance of the Akron Magnetic Boundary to seismic hazard near Darlington and Pickering, at least 250 km to the northeast, is somewhat questionable.

7.0 Western Lake Ontario

7.1 Pop-ups

Wallach describes pop-ups in various parts of eastern North America and alleges that a spatial relation exists between pop-ups and some of the larger earthquakes in eastern North America. However, he fails to document his case.

Whether pop-ups are in fact reliable indicators of zones of weakness that may lead to significant earthquakes, I leave for others to discuss. However, in the context of this report, Wallach has not tabulated the specific pop-ups or swarms of pop-ups that he alleges have been recognized in the areas of the six specific earthquakes he has named (1732 Montréal, Québec; 1929 Attica, New York; 1944, Cornwall-Massena, Ontario-New York border; 1980 [note Wallach typographical error in year] Sharpsburg, Kentucky; 1982 Miramichi, New Brunswick; 1986 Leroy, Ohio).

Literature references cited by Wallach for five of these events deal with the earthquakes, but make no reference whatsoever to pop-ups. References given for the 1929 Attica earthquake were not examined, since not readily available

(Wallach reference: Ontario Hydro 1969, 1974, 1978). The way he has placed these references into the text may lead the reader to infer, incorrectly, that these references contain material supporting his thesis that pop-ups have been observed near these earthquake locations.

7.2 Localized linear features in western Lake Ontario

Wallach describes pop-ups, plumose structures and elongate pods (possibly related to "sand volcanoes"), all observed recently (1987) in western Lake Ontario between Toronto Island and Burlington, and adds an example of offset boreholes in the Darlington excavation on the north shore of Lake Ontario. He suggests that all four phenomena may indicate seismic activity, past or future. However, he fails to mention other possible relations or to explain why none of these alternate relations is less plausible than the tectonic origin that he has retained as the sole hypothesis.

The reference to "sand volcanoes" induced by earthquakes in Charlevoix should be tempered by other references that indicate that, in general, not all sand volcanoes are earthquake-related. In fact, the majority are associated with landslides and subsequent erosion. Furthermore, the specific features referenced in Charlevoix may or may not be earthquake-related; they were not formed by the recent large earthquakes of 1925 nor by those in the 1800s.

It might be noted that Wallach has neglected to give the exact location of the features observed in western Lake Ontario in 1987, and to indicate the resolution and reliability of the survey data. Figure 16 is identified as a portion of a side-scan sonar record; no distance scale is included in the figure. The size of the plumose structures and elongate pods is unknown to the reader.

Test results from the Darlington boreholes presented in Table 3 of Wallach were taken at depths from 0.02 km to 0.2 km. Whether these are influenced more by regional tectonic stresses than by shallow localized sources is debatable. In any case, Wallach should mention other possible explanations.

Only one specific earthquake, 23 July 1987, magnitude 3.4, is spatially associated by Wallach with these east-northeast trending structures. This earthquake is well-located, with an uncertainty of about 10 km in epicentral coordinates. It is located about 20 km west of the Niagara-Pickering Magnetic Lineament and about 40 km west of the Georgian Bay Linear Zone. On 05 August 1989, [after completion of the Wallach report] an earthquake of similar size (magnitude 3.2) occurred about 30 km southwest of the 1987 event.

Small earthquakes (magnitudes 2 and 3) located in the western end of Lake Ontario and adjacent shorelines since the late 1970s are real events, with location uncertainties of the order of ±10 km. The only question that might be raised is whether they are all tectonic earthquakes, or whether some may be induced earthquakes, i.e. related directly or indirectly to human activities such as injection or extraction of fluids in deep wells. For example, induced earthquakes have been identified about 50 km west of Hamilton in the Gobles oil field (Mereu et al., 1986). Up to the present, such activities have not been able to be documented in or near the western end of Lake Ontario.

8.0 Conclusions

Wallach has examined various sets of geologic and geophysical data in an effort to find correlations that might suggest the presence of major, or at least important, crustal structures traversing parts of southern Ontario near Darlington and Pickering. He then has examined earthquake data to see whether the structures could be considered seismogenic.

In general, the types of data examined and the methods of intercomparison follow methods of study commonly employed by geoscientists in recent years, if not even earlier. Whether the structures he discusses are "newly discovered" or known for some time, or whether they are considered to be, in the vicinity of Darlington and Pickering at least, important structures, I leave for others to debate. At any rate, the idea of intercomparing various sets of geoscientific data in order to find seismogenic crustal structures cannot be faulted.

One of the major criticisms that can be levelled against the Wallach report concerns the way that its author has analyzed the earthquake data. He has failed to critically examine the selected earthquake data before looking for spatial correlations with his "newly discovered" structures, despite the fact that it is common practice by other geoscientists to subject earthquake data to a critical examination prior to their use in seismic hazard assessment. Unfortunately for his hypothesis, the selected data are too imprecise as well as, in some cases, definitely too inaccurate to support his hypothesis. Hence, Wallach has failed to prove that any of his structures are seismogenic or even potentially seismogenic in the immediate vicinity of Darlington and Pickering or elsewhere. He has provided no evidence that seismic hazard near Darlington and Pickering needs to be urgently re-assessed.

The second major criticism is his use of peak acceleration values to try to suggest that the seismic design of Darlington and Pickering may be inadequate. He has not maintained a distinction between recorded peak accelerations and design peak accelerations and has also demonstrated a lack of understanding of the response of real structures to earthquake-generated vibrations. Because of this lack of understanding of the principles of earthquake-resistant design, he has failed to provide convincing evidence that the seismic design parameters and the resulting earthquake-resistant design of Darlington and Pickering are or might be inadequate and consequently could be jeopardizing the safety of these facilities.

9.0 References (note: additional references are given in each Appendix)

Atkinson, G. and Stagg, M., 1987. Seismic hazard at Ontario Hydro dam and nuclear plant sites. Report prepared by Acres International Limited, Toronto, for Ontario Hydro, 108 pages plus appendices.

Basham, P.W., 1975. Design basis seismic ground motion for Darlington Nuclear Generating Station A. Seismological Service of Canada, Internal Report 75-16, December 1975, Earth Physics Branch, Ottawa, 34 p. plus tables, figures and appendix.

Basham, P.W., D.H. Weichert, and M.J. Berry, 1979. Regional assessment of seismic risk [hazard] in eastern Canada. Bulletin of the Seismological Society of America, volume 69, 1567-1602.

Basham, P.W., P. Morel-à-l'Huissier and F.M. Anglin, 1982a. Earthquake risk [hazard] at Gros Cacouna, Quebec, and Melford Point, Nova Scotia. Earth Physics Branch, Ottawa, Open File Number 82-2, 51 p.

Basham, P.W., D.H. Weichert, F.M. Anglin and M.J. Berry, 1982b. New probabilistic strong seismic ground motion maps of Canada: a compilation of earthquake source zones, methods and results. Earth Physics Branch, Ottawa, Open File Number 82-33, 205 pages.

Boore, D.M. and G.M. Atkinson, 1987. Stochastic prediction of ground motion and spectral response parameters at hard-rock sites in eastern North America. Bulletin of the Seismological Society of America, volume 77, 440-467.

CSA, 1981. CSA Standard CAN3-N289.3--Design procedures for seismic qualification of CANDU nuclear power plants. Canadian Standards Association, Rexdale, Ontario.

Gordon, D.W., 1988. Revised instrumental hypocenters and correlation of earthquake locations and tectonics in the central United States. U.S. Geological Survey Professional Paper 1364, United States Government Printing Office, Washington, 69 p.

Hare, F.K., 1988. The safety of Ontario's nuclear power reactors -- a scientific and technical review, F. Kenneth Hare, Commissioner, Ontario Nuclear Safety Review, Toronto, Ontario, 29 February 1988 [report in several volumes commissioned by and presented to the Minister of Energy, Government of Ontario].

Hasegawa, H.S., P.W. Basham and M.J. Berry, 1981. Attenuation relations for strong seismic ground motion in Canada. Bulletin of the Seismological Society of America, volume 71, 1943-1962.

Mereu, R.F., J. Brunet, K. Morrissey, B. Price and A. Yapp, 1986. A study of the microearthquakes of the Gobles oil field area of southwestern Ontario. Bulletin of the Seismological Society of America, volume 76, 1215-1223.

Munroe, N.J. and J.D. Stevenson, 1986. Preliminary report on the Ohio earthquake of January 31, 1986. Earthquake Engineering Research Institute April Newsletter, volume 20, number 4, 5-8.

Nicholson, C., E. Roeloffs and R.L. Wesson, 1988. The northeastern Ohio earthquake of 31 January 1986: was it induced? Bulletin of the Seismological Society of America, volume 78, 188-217.

Seeber, L. 1987. Problems in intraplate seismogenesis and earthquake hazard. In: Proceedings from the Symposium on seismic hazards, ground motions, soil-liquefaction and engineering practice in eastern North America, Technical Report NCEER-87-0025, National Center for Earthquake Engineering Research, Buffalo, 143-162.

Stevenson and Associates, 1987. Report on the safety evaluation of Ontario Hydro nuclear power plant containment and containment systems, prepared for the Ontario Nuclear Safety Review by Stevenson and Associates, Cleveland, Ohio, 31 August 1987.

Wallach, J.L., 1989. Newly discovered geological features and their potential impact on Darlington and Pickering, Report of the Atomic Energy Control Board, Ottawa, 20 p. [undated, but issued in May 1989].

Weston Geophysical Corporation, 1988. Analyses of northeastern Ohio seismicity and tectonics. Report prepared for the Cleveland Electric Illuminating Company, June 1988 [seismicity in section IV].

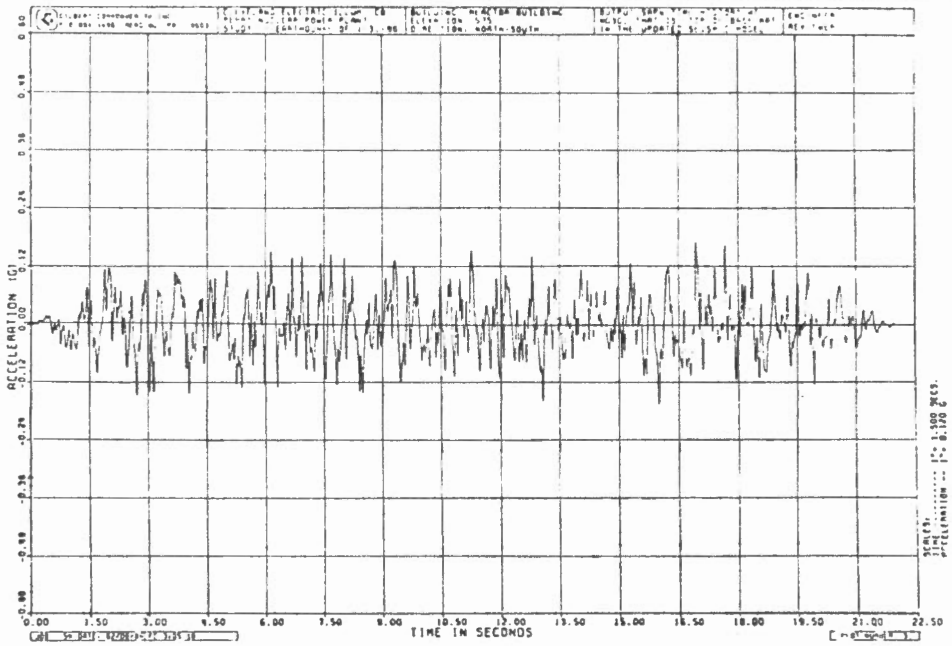


Figure 1. Perry Design Time History Ground Motion Based on R.G. .60 Spectra

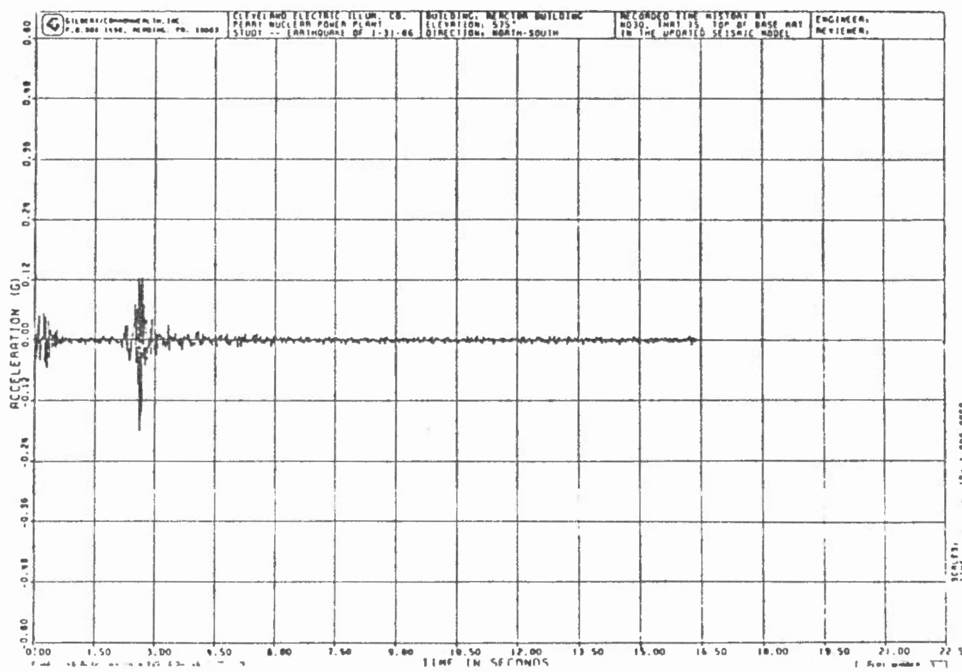
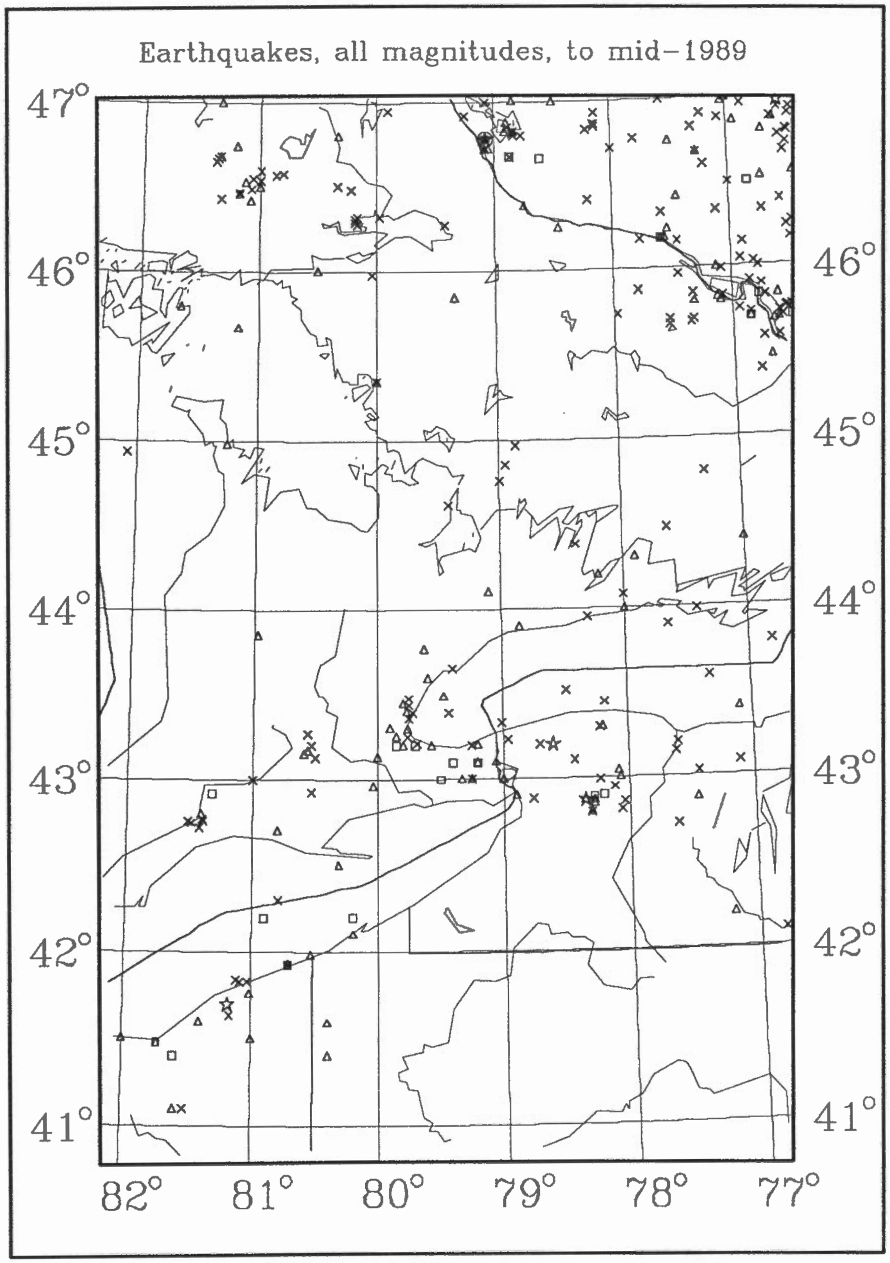


Figure 2. Recorder Motion of Ohio, 1986 Earthquake Motion at Base of Perry Containment Structure

FIGURE A Comparison of design and recorded accelerations versus time at the base of the Perry, Ohio, reactor containment structure.
(from Figures 1 and 2 of Monroe and Stevenson, 1986)

Earthquakes, all magnitudes, to mid-1989

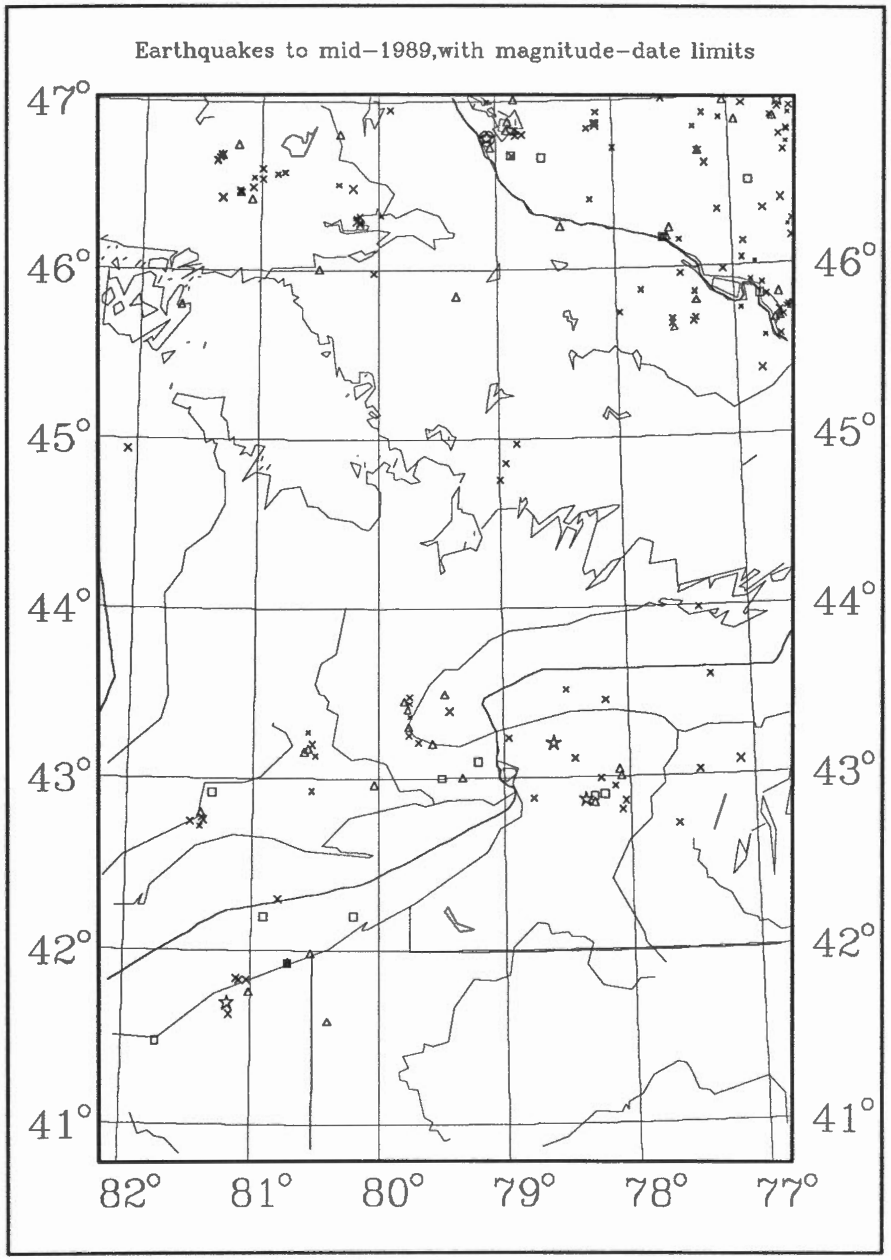


GEOPHYSICS DIVISION GEOLOGICAL SURVEY OF CANADA
DIVISION DE LA GEOPHYSIQUE COMMISSION GEOLOGIQUE DU CANADA

0 200 400 KM

DEFINITIONS

M<3	×
M≧3	△
M≧4	□
M≧5	☆
M≧6	⊛



GEOPHYSICS DIVISION GEOLOGICAL SURVEY OF CANADA
DIVISION DE LA GEOPHYSIQUE COMMISSION GEOLOGIQUE DU CANADA

0 200 400 KM

DEFINITIONS

M≧1.0	1970+	·
M≧3.0	1960+	△
M≧4.0	1925+	□
M≧5.0	1850+	☆
M≧6.0	1661+	⊛

FIGURE C

Earthquakes to mid-1989, with magnitude-date limits

APPENDIX 1

THE DISTINCTION BETWEEN PEAK GROUND ACCELERATION AND PEAK DESIGN GROUND ACCELERATION

Lengthy quotations from three different authoritative sources are presented below to assist the reader in appreciating the difference between peak ground acceleration and peak design ground acceleration. Some authors have preferred the term *effective acceleration* to denote the acceleration used for design.

When discussing the ability of a particular engineered structure (or component, or equipment within the structure) to resist earthquake damage, it is essential not to confuse these terms. Part of the concern voiced by Wallach about the earthquake-resistant design of the Darlington and Pickering nuclear power facilities stems from a misunderstanding of these terms.

The purpose of this appendix is not to justify nor to criticize the acceleration values chosen for the earthquake-resistant design of Darlington and Pickering. Its purpose is rather to emphasize that a discussion of their design values should be based upon a proper understanding of the terminology.

CITATION 1

N.M. Newmark and W.J. Hall, ***Earthquake Spectra and Design***, EERI Monograph 3, Earthquake Engineering Research Institute, Berkeley, California, 103 p., 1982.

Citation from pages 25--26

The concept of effective acceleration, as defined recently by Newmark and Hall in some special design studies, may be stated in the following manner:

> It is that acceleration which is most closely related to structural response and to damage potential of an earthquake. It differs from and is less than the peak free-field ground acceleration. It is a function of the size of the loaded area, the frequency content of the excitation, which in turn depends on the closeness to the source of the earthquake, and to the weight, embedment, damping characteristic, and stiffness of the structure and its foundation.

As employed for design and review analyses of critical facilities, the term "effective acceleration" is associated with the significant part of the ground motion containing repetitive motion portions that possess strong energy content and that produce significant linear and nonlinear deformation; obviously, duration of shaking as well as amplitude and frequency (time) characteristics are among the important parameters to be considered. These portions of the ground motion are of primary importance in evaluating the response and behavior of the structure or equipment elements, and thereby are of importance in design and in assessing damage potential. In this sense, then, in accordance with the definition given above, the effective acceleration normally is not the peak instrumentally recorded high-frequency accelerations commonly found to occur close to the source of seismic energy release, especially for structural foundations of some size or weight. On the other hand, the effective acceleration would be expected to be very close to the peak instrumental acceleration for locations at significant distances from the source, zones [i.e. locations] where such high frequency acceleration peaks normally are not encountered. Accordingly, for design purposes it is believed that the effective acceleration value should be used in the basic process of arriving at the anchor point for the design response spectrum.

CITATION 2

G.W. Housner and P.C. Jennings, *Earthquake Design Criteria*, EERI Monograph 4, Earthquake Engineering Research Institute, Berkeley, California, 140 p., 1982.

<u>Citation from pages 39 and 41</u>

The intensity of the ground shaking indicates to the engineer how severely his structures will vibrate....

Often the intensity of ground shaking is described by giving a value of peak acceleration, but by itself this is an ambiguous and oversimplified description, for two ground motions having the same peak acceleration can have appreciably different intensities so far as structural response is concerned....

In some instances, the seismologist or geotechnical consultant may describe the ground motion by recommending a smooth "design spectrum", often tied to an estimate of the peak ground acceleration. This, however, is a mistake, for a "design spectrum" is not the same as a response spectrum of actual ground motion or a smoothed "average spectrum", and it is precisely this difference that involves engineering judgment. For example, removing the top 15% of the highest peak on an accelerogram would, in general, have very little effect on the computed response of structures. Therefore, when an engineer selects a smooth design spectrum based on an accelerogram or response spectrum, the zero-period spectral acceleration of the design spectrum may, with justification, be smaller than the peak ground acceleration. If the structure to be designed is highly ductile and ductile response to the motion under consideration is acceptable, the project manager may set the entire design spectrum at a lower level than the response spectrum of the design ground motion. The task of specifying the design spectrum depends on knowing how to correlate the spectrum with the properties of the structure to be designed.

CITATION 3

Citation from pages 48 and 50

The concept of an actual resistive capacity beyond that indicated by the design coefficients has been implicit in seismic portions of building codes since their inception, but only recently have sufficient instrumental data become available to quantify this effect. The apparent paradox that the code value of acceleration for which a structure was designed is much smaller than the recorded peak acceleration of the ground motion that the structure successfully survived often causes confusion and has led to misunderstandings in the design of major projects. It is important to realize that the paradox can be explained without recourse to such terms as "effective peak acceleration" and "sustained peak acceleration", which are smaller than the peak acceleration itself. The explanation lies primarily in the fact that the allowable design stresses and strains in the building code are not directly indicative of the material and structural resistances under dynamic conditions. In addition, there are conservative features in codes and practices that add to the actual capacity of a structure. To clarify this situation it is necessary to establish the true relation between the dynamic capacity of engineered structures and the levels of the basic components of the design criteria. This represents one of the major challenges of earthquake engineering research.

CITATION 4

Federal Emergency Management Agency, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*, Part 2, Commentary, 1985 edition, FEMA 96/ February 1986, Earthquake Hazards Reduction Series 18; Building Seismic Safety Council, Washington, D.C., 1985, 200 pages.

Citation, pages 7--9

In developing the design provisions, two parameters were used to characterize the intensity of design ground-shaking. These parameters are called the Effective Peak Acceleration (EPA), A_a, and the Effective Peak Velocity (EPV), A_v. These parameters do not at present have precise definitions in physical terms but their significance may be understood from the following paragraphs.

To best understand the meaning of EPA and EPV, they should be considered as normalizing factors for construction of smoothed elastic response spectra for ground motions of normal duration.... The EPA and EPV thus obtained are related to peak ground acceleration and peak ground velocity but are not necessarily the same as or even proportional to peak acceleration and velocity. When very high frequencies are present in the ground motion, the EPA may be significantly less than the peak acceleration. This is consistent with the observation that chopping off the highest peak in an acceleration time history has very little effect on the response spectrum computed from that motion, except at periods much shorter than those of interest in ordinary building practice. Furthermore, a rigid foundation tends to screen out very high frequencies in the free field motion....

If an earthquake is of very short or very long duration, it is necessary to correct the EPA and EPV values to more closely represent the event. It is well documented that two motions having different durations but similar response spectra cause different degrees of damage, the damage being less for the shorter duration. In particular, there have been numerous instances where motions with very large accelerations and short durations have caused very little or even no damage. Thus, when expressing the significance of a ground motion to design, it is appropriate to decrease the EPA and EPV obtained from the elastic spectrum for a motion of short duration. On the other hand, for a motion of very long duration, it would be appropriate to increase the EPA and EPV. There are at present, however, no agreed-upon procedures for determining the appropriate correction; it must be done by judgment.

Thus, the EPA and EPV for a motion may be either greater or smaller than the peak acceleration and velocity although the EPA generally will be smaller than peak acceleration while the EPV will be larger than the peak velocity. Despite the lack of precise definitions, the EPA and EPV are valuable tools for taking into consideration the important factors relating ground-shaking to the performance of a building.

At any specific location, either the EPA or the EPV may govern the design of a building. In general, however, it is desirable to know both values.

APPENDIX 2

EARTHQUAKES ON OR NEAR THE NIAGARA PENINSULA

The material presented in this appendix illustrates both the quality and quantity of information available in standard earthquake catalogues concerning small and minor felt earthquakes prior to the advent of instrumental monitoring. This appendix also indicates that some earthquakes in the era of instrumental monitoring might not be well located. Hence seismologists are well justified in making selective use of data in earthquake catalogues whenever it is not feasible to scrutinize individual earthquakes.

Part 1: Earthquakes of 13 March 1853 and 06 July 1873

The information given in the Wallach report about these two earthquakes of 1853 and 1873 is presented below in the first brief section.

Each earthquake is then discussed independently in a self-contained section. The primary source cited by Smith (1962) is identified and further primary sources noted.

For each earthquake are presented the numerical data maintained in the current Canadian Earthquake Epicentre File (CEEF) followed by the information published in the 1962 Smith catalogue of Canadian earthquakes to 1927. The CEEF is the database of earthquakes in and near Canada maintained by the Geological Survey of Canada. The CEEF is regularly updated with data on recent earthquakes and updated from time to time after new research on older earthquakes is published.

In his 1962 catalogue, Smith considered all his epicentre locations to be of quality C, unless otherwise designated as A or B. Quality B denoted "a fairly reliable estimate based on considerable data". Quality C denoted "a less certain result sometimes based on scanty information". Smith further noted that the catalogued locations "for the most part...define the central point of an area over which the shock is reported as felt....the tenths of degree frequently cited, must not be construed as indicating their precision" (Smith, 1962, page 275, left column). The reader should be reminded that virtually all epicentres in Smith's first catalogue were based on felt reports only and that much of the information had been collected from other published sources.

<u>Information presented in the Wallach text</u>

1853 - MM intensity V - on the Niagara Peninsula, near St. Catharines.

1873 - intensity VI - on the Niagara Peninsula.

Both were said to lie on or near the Niagara-Pickering Magnetic Lineament. The Wallach reference for both was Smith (1962). Wallach did not pay any attention to Smith's comments on epicentral accuracy.

<u>Event of Sunday, 13 March 1853</u>

CEEF: 1853 03 13, 10:00 UT, 43.1°N, 79.4°W, magnitude 4.0; magnitude revised downwards from 4.3 by Basham et al. (1982) by considering the felt area; they had no data beyond that published by Smith (1962).

Smith Catalogue #54: 13 March 1853: Shock near St. Catharines, Ontario; 43.1°N, 79.4°W; 5:00 a.m. local time; intensity V. Smith references B5 and L2. Smith quotation from L2-- The same day at the same hour at Grimsby, Jordan, Thorold, Fells [sic], Queenston, Fort Mississangua [sic] and in all Canada, four shocks.

<u>Smith references</u>

Reference B5 is a catalogue compiled from other catalogues; it is not a primary source and will not be further discussed.

Reference L2: Lancaster (1873) -- The complete reference to March 1853 is as follows:

> Mars. Le 13, 5 h. du matin, à Ste. Catherine, Niagara, secousse. Le même jour, à la même heure, à Grimsby, Jordon, Thorold, Fells [sic], Queenston, Fort Mississangua [sic] et dans tout le Canada, quatre secousses.

No further specific information is available in this reference about the 1853 event, although some general information can be inferred from the introductory material.

Note that in 1853 "Canada" designated the southern parts of what are now the provinces of Ontario and Québec; Grimsby and Niagara Falls are about 40 km apart.

<u>Analysis of the catalogued location of the 13 March 1853 event</u>

The catalogued coordinates of the 13 March 1853 event, denoted as quality C, correspond to a point about 20 km southwest of St. Catharines. One may infer that Smith selected a location based on the seven communities where the shock was reported felt by Lancaster (1873), his reference L2.

Lancaster did not give a specific reference for each earthquake in his paper, but noted his sources in the introduction. The sources were all secondary sources, whose accuracy he did not (and perhaps could not readily) verify. His paper was intended to correct and supplement information published by Brigham (1871) in the same journal. Some of Lancaster's additional information has proven to be helpful, but at times it is erroneous.

One may infer from his introduction that his source for the 13 March 1853 earthquake was *The American Journal of Science and Arts*, which periodically published summaries of earthquake information based on reports sent by its scientific correspondents, whose information in most cases came from newspaper reports. Some of the newspaper reports were firsthand; some were derived from other newspapers. The reliability of the reports was thus quite variable.

The earthquake of early Sunday morning, 13 March is preceded in the Smith catalogue by an earthquake on early Saturday morning, 12 March. Because of the similarity of the times of day, the two events may have been one and the same event. From new information, presented later, the date is more likely Sunday 13 March than Saturday 12 March.

<u>Event of Saturday, 12 March 1853</u>

CEEF: 1853 03 12, 07:00 UT, 43.7°N, 75.5°W, magnitude 4.5; magnitude revised downwards from 5.0 by Basham et al. (1982) by considering the felt area; they had no data beyond that published by Smith (1962).

Smith Catalogue #53: 12 March 1853: Machinery thrown down at Lowville, N.Y. Felt also in Canada. 43.7°N, 75.5°W, quality B; 2:00--3:00 a.m. local time; intensity VI. Smith references B4, B5, H1, M7 and W4.4.

The same information is given in the American section of Smith's catalogue for event #151.

<u>Smith references</u>

Reference B5 is a catalogue compiled from other catalogues; it is not a primary source and will not be further discussed.

Reference H1 is an American catalogue, M7 an international catalogue, neither of which are primary sources; they are not further discussed here. It might however be noted that H1 cites as sources Brigham (1871) [B4] and Anonymous (1853), the first of which was Smith's primary source, as discussed below.

References B4 and W4.4 contain information derived from newspaper accounts and are presented in the following paragraphs.

<u>Analysis of the catalogued location of the 12 March 1853 event</u>

The Smith location is about 50 km southeast of Watertown, and about 320 km east of event #54 (13 March 1853).

Smith's primary source was B4 (Brigham, 1871), whose source in turn was *The American Journal of Science and Arts*, second series, volume 16, November 1853, page 294, item 6 in the section entitled "Miscellaneous Intelligence" (Anonymous, 1853). The two paragraphs are quoted verbatim, as follows:

6. *A Supposed Earthquake*, (Northern Journal, Lowville, N.Y., March 16, 1853.)--At Lowville, N.Y., and in its vicinity, early on the morning of Saturday, (between 2 and 3 o'clock) on the 12th of March, there was a shock like an earthquake. It commenced with a heavy distant rumbling sound, apparently beneath, which gradually increased, and at its maximum broke out in a grand explosion, louder than the loudest thunder. There were other reports, but it diminished, and ended with the same heavy rumbling with which it began. Houses were shaken so that dishes and furniture were displaced, and the bell of the church struck nine or ten times. The academy bell also rung, although less high. One chimney was thrown down. The people were all aroused and many rushed to the streets. The editors of the paper from which we cite, ask, "Was it an earthquake; or a concussion of the atmosphere, produced by some meteor or aerolite?" and then gives reasons for believing it an actual earthquake, viz: the subterranean character of the sound, the motion of the earth, the absence of any light or flash, and no sudden barometric change.

The direction is stated at from east to west, or the reverse. It was felt at Turin and Copenhagen quite heavy, at Adams heavy, at Watertown slight, at Remsen, Trenton and Holland Patent not at all. The wind was southeast. The preceding day had been clear, but at 10 in the evening of Friday, the sky became overcast, and unusual darkness prevailed, which continued till the time of the occurrence. The thermometer and barometer gave the following observations:

		Thermometer	Att.Thermometer	Barometer
Friday,	6 a.m.	30.0	45.0	29.252
	2 p.m.	39.5	53.0	29.205
	10 p.m.	27.0	60.0	29.220
Saturday	2:30 a.m. time of shock	34.0	52.5	29.140
	6 a.m.	32.5	47.8	29.095
	2 p.m.	40.5	57.0	28.975

The Lowville newpaper dateline proves that the event(s) occurred no later than 16 March. The article refers only to communities in its vicinity. Information from more distant points may not have been available when the newspaper went to press. The community of Adams is located 20 km south of Watertown; Copenhagen lies 20 km southeast of Watertown and Lowville 40 km southeast of Watertown. The report in *The American Journal of Science and Arts* may be a summary of information published in the Lowville newspaper and not a direct quotation. The original newspaper article is needed to verify the reported facts.

Smith reference W4.4 was Woodsworth (1915), who discussed various historical earthquakes after presenting the instrumental data from the Harvard, Massachusetts, seismograph station for 1914. The following quotation is the entire reference to March 1853; his information source is not stated.

> ...in 1853. The records begin with a shock in the interior on the western slope of the Adirondacks at Lowville, on March 13.

Note that Woodworth's date is 13 March, not 12 March.

New information on the March 1853 earthquake(s)

Additional information from contemporary newspapers is required to determine how widely the event(s) were felt and whether there were two earthquakes or only one.

Two different reports in three Nova Scotia newspapers were reported by Ruffman and Peterson (1988), which tend to confirm that an earthquake did occur on Sunday morning, 13 March.

Two newspapers in Nova Scotia on 2 April 1853 carried identical reports of an earthquake from the *St. Catharines Journal* as follows:

> Evident signs of an earthquake were felt on Sunday morning last, for several miles around this neighbourhood. Just about five o'clock A.M. a heavy shock was felt, accompanied by a rumbling sound, as if hundreds of heavily laden wagons were passing the streets; then followed three other shocks, which caused everything to tremble to its very centre. It was felt in the neighbourhood of Grimsby, Jordon, Thorold, the Falls, Queenston and Niagara. At Fort Mississaugua everything reverberated again with the crash. The cause of this unaccountable freak of nature has not as yet been ascertained, but we have no doubt it has had its origin in the Niagara river, or some part of Lake Ontario adjacent to this neighbourhood.

The Halifax *Daily Sun* reported as follows on 12 April 1853:

> The St. Catharines and Niagara papers contain accounts of the shock of an Earthquake that occurred there. It was felt in Niagara about one o'clock, on Sunday morning the 19th ult [March], preceded by a rumbling noise, as if ten thousand carriages were rattling at some distance, on the pavement. Several persons affirm that they were thrown out of bed by the violence of the concussion.

The date and time of the earthquake are not clear since the publication date of the Ontario papers is not included in the above articles. However, the reported details are similar to those reported by Lancaster (1873).

Without further information from contemporary newspapers, the location and importance of the earthquake of 13 March 1853 cannot be determined. However, it is clear that the epicentral location of the event of 13 March 1853 is too poorly known at present to spatially associate it with the Niagara-Pickering Magnetic Lineament.

Earthquake of Sunday 06 July 1873

CEEF: 1873 07 06, 14:30 UT, 43.0°N, 79.5°W, magnitude 4.5; magnitude revised downwards from 5.0 by Basham et al. (1982) by considering the felt area; they had no data beyond that published by Smith (1962).

Smith Catalogue #107: 6 July 1873: About 15 miles west of Welland, Ontario. Felt in western New York State and adjacent portions of Pennsylvania and at St. Catharines, Hamilton and London, Ontario, over an area of 30,000 square miles; 43.0°N, 79.5°W; 9:30 a.m. local time; intensity VI. Smith references B5, H1, R4.5.

Smith references

Reference B5 is a catalogue compiled from other catalogues; it is not a primary source and will not be further discussed.

Reference H1 is the American catalogue *Earthquake History of the United States*, which is re-issued periodically; it is not a primary source. Smith referenced its 1958 edition (Heck and Eppley, 1958). It is interesting to compare the description of this earthquake given in its 1958 edition with that in the following 1973 edition. The tabulated epicentral parameters are the same in both editions.

> 1873. July 6. West New York and Canada; felt in Pennsylvania. It was apparently in Canada west of Niagara. It lasted 1 minute in Buffalo. Rumbling was heard in many places in New York State. The shock was felt in Erie, Meadville, and Titusville, Pa., and in Wheeling, W.Va. Felt in Ohio, West Virginia, Pennsylvania, New York and Ontario. (Heck and Eppley, 1958)

> 1873. July 6. Ontario, Canada. Apparently centred west of Niagara, N.Y. It lasted 1 minute in Buffalo. Rumbling was heard in many places in New York State. The shock was felt in Erie, Meadville, and Titusville, Pa., and in Wheeling, W.Va. Felt in Ohio and Ontario also. (Coffman and von Hake, 1973)

The information source for both editions of H1 was *The American Journal of Science and Arts*, 1874, probably the same issue as the Smith reference R4.5.

Reference R4.5 is the column "Notices of recent earthquakes", which appeared regularly in the scientific journal, *The American Journal of Science and Arts*, as a summary of newspaper reports of earthquakes, as sent to the journal editor by certain correspondents.

Analysis of the catalogued location of the July 1873 event

The coordinates given by Smith are those in the publication *Earthquake History* *of the United States*, and correspond to a location about 20 km west of Welland and 40 km southeast of Hamilton.

Recent archival searches of contemporary Canadian newspapers by A.A. Mohajer (private communication, 1989) have shown that this earthquake was not felt in London, Ontario; was felt mildly in Hamilton and St. Catharines; was felt more strongly in the United States than in Canada; and was probably located in the United States, at least 60 km southeast of its catalogued position.

While more information is required from American sources before new coordinates can be determined, it is clear that this earthquake was not located anywhere on the Niagara Peninsula. It cannot therefore be spatially associated with the Niagara-Pickering Magnetic Lineament.

Part 2: Earthquakes of 27 April 1954, 22 July 1958, 27 March 1962 and 27 February 1963

These four earthquakes were catalogued by Smith (1966) and by Milne and Smith (1963, 1966) with epicentres on the Niagara Peninsula and were said to be poorly located. The earthquake of 27 February 1963 was reported felt, but not instrumentally recorded; the earthquakes of 1954 and 1962 were recorded by only one or two seismograph stations; instrumental data for 1958 were inconsistent leading to large location uncertainties. The instrumental data for these earthquakes had been analyzed by graphical methods.

A listing of the CEEF and catalogued information is given for each, plus a brief discussion of the currently available data. The uncertainties in the catalogued epicentres are confirmed; no reliable new epicentres have been determined. In all cases, the original seismograms need to be re-examined and additional instrumental and newspaper information needs to be sought.

None of these events is sufficiently well located to be said to be spatially associated with the Niagara-Pickering Magnetic Lineament.

Earthquake of 27 April 1954

CEEF: 1954 04 27, 02:14:08 UT, 43.1°N, 79.2°W, magnitude 4.1

Smith Catalogue #638: 27 April 1954: 02:14:08 U.T. M_L=4.1. 43.1°N, 79.2°W. A few miles north of Welland, Ontario. Smith references S3, S5.

Comments: not mentioned in the catalogue *United States Earthquakes*; limited instrumental data from only two stations (Ottawa and Shawinigan Falls).

These data, when re-run in the standard Canadian earthquake location computer programme, produced an epicentre near Buffalo, New York, 50 to 75 km southeast of the catalogued epicentre. This new location has standard errors of ±25 km; the true uncertainty may be ±50 km.

Earthquake of 22 July 1958

CEEF: 1958 07 22, 01:46:40 UT, 43.00°N, 79.50°W, magnitude 4.3

Smith Catalogue #719: 22 July 1958: 01:46:40 U.T. M_L=4.3. 43°00'N±25', 79°30'W±25'. Depth 5 km. About 15 miles west of Welland, Ont. Felt at St. Catharines and vicinity. Smith references S1.46, S3, S5.

Comments: not mentioned in the catalogue *United States Earthquakes*; limited instrumental data from four Canadian stations (Ottawa, Montréal, Shawinigan Falls, Seven Falls); the calculated depth should be ignored (see Smith, 1966, page 90, righthand column). Note that Smith had assigned uncertainties of ±25 minutes of arc, i.e. about ±40 km.

These data, when re-run in the standard Canadian earthquake location computer programme, produced a poorly defined epicentre different from the catalogued epicentre but with large uncertainties.

Earthquake of 27 March 1962

CEEF: 1962 03 27, 06:35:05 UT, 43.00°N, 79.33°W, magnitude 3.0

Milne and Smith Catalogue: 27 March 1962: 06:35:05 U.T. 43°00'±25', 79°20'±10'. M=3.0. On the Niagara Peninsula. Felt at Buffalo, N.Y. and in adjacent parts of Ontario.

Comments: The earthquake was recorded in Canada only at London, Ontario; these instrumental data, plus the felt report at Buffalo were used by Smith to estimate location and magnitude. He assigned a latitude uncertainty of ±40 km to his epicentre estimate. The London data indicated a distance of about 180 km from the seismograph station, but could not determine the direction. The distance between London and Buffalo is about 200 km. The publication *United States Earthquakes--1962* assigned an intensity V and a location at Niagara Falls, N.Y.; their location was not based on instrumental data.

Earthquake of 27 February 1963

CEEF: 1963 02 27, 06:00:00 UT, 43.20, 79.57, magnitude 3.0

Milne and Smith Catalogue: 27 February 1963: 06:00 U.T. 43°12'N, 79°34'W. M=3.0. Grimsby, Ont. Newspaper reports said that residents "came spilling outside" to investigate and that the burglar alarm at the bank was tripped. London station was out of operation that day, however the shock left a "record" at McMaster

University where it caused an irregularity in a graphline depicting the regular compression of a muskeg sample.

Comments: Local time was approximately 01 a.m., E.S.T. The catalogued coordinates are the town of Grimsby from which the event was reported; no uncertainties are given with these coordinates. No instrumental data were available to Smith. It is not clear whether the event was investigated in any detail to confirm the details of the newspaper report. It is possible that the event could have been a sonic boom, or some other phenomenon unrelated to an earthquake. If it had been an earthquake, it might have been expected to have been felt in more than one locality in the fairly densely-populated Niagara Peninsula. In any case, the event merits further investigation to ascertain whether it was was an earthquake located on the Niagara Peninsula, as catalogued in the present CEEF.

REFERENCES

Anonymous, 1853. Miscellaneous Intelligence, Item 6: A supposed earthquake. The American Journal of Science and Arts, second series, volume 16, November 1853, page 294.

Basham, P.W., D.H. Weichert, F.M. Anglin and M.J. Berry, 1982. New probabilistic strong seismic ground motion maps of Canada: a compilation of earthquake source zones, methods and results. Earth Physics Branch, Ottawa, Open File Number 82-33, 205 pages.

Brigham, W.T., 1871. Volcanic manifestations in New England: being an enumeration of the principal earthquakes from 1638 to 1869. Memoirs of the Boston Society of Natural History, volume 2, pp. 1-28.

Coffman, J.L. and C.A. von Hake, 1973. Earthquake history of the United States (revised edition through 1970), Publication 41-1, United States Department of Commerce.

Heck, N.H. and R.A. Eppley, 1958. Earthquake history of the United States, United States Government Printing Office, Washington, 80 pages.

Lancaster, A., 1873. Note additionnelle au mémoire de M. W.-T. Brigham, intitulé "Volcanic manifestations in New England, 1638--1870": Memoirs of the Boston Society of Natural History, vol.2, part 2, no. 4, 241-247.

Milne, W.G. and W.E.T. Smith, 1963. Canadian earthquakes--1962. Seismological Series, Dominion Observatory, Ottawa, 1962-2, 22 p.

Milne, W.G. and W.E.T. Smith, 1966. Canadian earthquakes--1963. Seismological Series, Dominion Observatory, Ottawa, 1963-4, 30 p.

Ruffman, A. and J. Peterson, 1988. Pre-confederation historical seismicity of Nova Scotia with an examination of selected later events. Geological Survey of Canada, Ottawa, Open File 1917, 900 p.

Smith, W.E.T., 1962. Earthquakes of eastern Canada and adjacent areas, 1534--1927. Publications of the Dominion Observatory, Ottawa, vol. 26, no. 5, 271-301.

Smith, W.E.T., 1966. Earthquakes of eastern Canada and adjacent areas, 1928--1959. Publications of the Dominion Observatory, Ottawa, vol. 32, no. 3, 87-121.

Woodsworth, J.B., 1915. Harvard Seismographic Station -- Sixth Annual Report including records, 1 January--31 December, 1914. Bulletin of the Museum of Comparative Zoology, Geological Series, vol.9, no.4,,81-107. [This report includes brief references to earlier earthquakes]

APPENDIX 3

EARTHQUAKES CATALOGUED NEAR THE GEORGIAN BAY LINEAR ZONE

As the material presented in Appendix 2 illustrated clearly the problems inherent in information available in standard earthquake catalogues concerning small and minor felt earthquakes prior to the advent of instrumental monitoring, the present appendix provides only a brief discussion of six of the 14 earthquakes listed in Table 2 (page 7) of the Wallach report. Only one of these six (April 1965) is plotted in Figure C of the present review, indicating that the other five are likely too imprecise to be used at face value in any seismic hazard assessment.

The table below lists the 14 earthquakes of Wallach's Table 2, which he spatially associated with the Georgian Bay Linear Zone on his Figure 8 and in the text. Only the earthquakes whose location is denoted as Ontario in the table below are discussed further. The earthquake in Lake Ontario is quite recent; the locations of the seven earthquakes in New York State are of variable quality.

The numerical parameters in the table are those found in the current Canadian Earthquake Epicentre File (CEEF), which is the database of earthquakes in and near Canada maintained by the Geological Survey of Canada.

Date	Time UT	Lat °N	Long °W	Magnitude	Location (* = see discussion below)
1852 12 15	00:00	43.30	78.20	3.0	New York State
1857 10 23	20:15	43.20	78.60	5.0	Lockport, New York State
1877 05 02	00:00	43.90	78.85	3.0	Oshawa, Ontario *
1887 02 19	00:00	45.35	80.00	3.7	Parry Sound, Ontario *
1887 03 19	00:00	45.35	80.00	2.4	Parry Sound, Ontario *
1907 01 25	06:00	44.10	79.10	3.7	Goodwood, Ontario *
1929 08 12	11:24	42.87	78.35	5.5	Attica, New York State
1965 02 19	10:25	44.62	79.42	2.0	Orillia, Ontario *
1965 04 01	06:30	46.00	80.50	3.4	French River, Ontario*
1965 07 16	11:06	43.04	78.08	3.1	New York State
1969 08 13	02:42	43.30	78.22	2.5	New York State
1975 10 08	09:00	43.52	78.49	2.0	Lake Ontario
1986 07 16	00:02	42.99	78.23	2.3	New York State
1987 03 20	22:50	43.111	78.430	2.4	New York State

Wednesday 2 May 1877

The catalogued location and magnitude were based on a single felt report from Oshawa, Ontario (Smith, 1962). Recent archival research of Ontario newspapers by A.A. Mohajer (private communication, 1989) has not produced other reports. The limited data could be explained as well by a meteorological storm (roll of thunder) as by an earthquake.

Saturday 19 February and 19 March 1887

The catalogued location and magnitude of these two events were based solely on information received from McGill University, Montréal, who had received information from the Toronto meteorological office that an earthquake had been reported near Parry Sound (Smith, 1962). Considering the coincidence of dates, it is highly likely that a transcription error occurred and that there was only one event. Further investigation will undoubtedly show either that no earthquake occurred, or that the information had been confused with an earthquake elsewhere.

Friday 25 January 1907

The catalogued location and magnitude published by Smith (1962) were based solely on the following newspaper report published on 28 [Monday] January 1907 on page 3 of the *Ottawa Citizen* with a dateline Toronto 26 [Saturday] January 1907.

> Wm. Douglas of 99 Marion street, Toronto, who was in Goodwood, Ont., this week, reports that several earthquake shocks were felt there early Friday morning, ranging from one o'clock to five o'clock. He was visiting at the home of Mr. Thos. Sintzel, Stouffville road, a large rough-cast house. The first shock woke him up and the family did not dare to go to bed again all night as there were repeated shocks which shook the door and windows. Goodwood is 35 miles from Toronto, between Stouffville and Uxbridge.

The information in this newspaper article is not consistent with an earthquake. Shocks in populated areas seldom are noticed at only one house; if repeated shocks had occurred they should have been reported elsewhere. While further investigation is warranted, it is quite possible that the family in question may have been unduly nervous about earthquakes due to newspaper reports of a destructive earthquake in Kingston, Jamaica, on 14 January 1907.

Sunday 19 February 1965

This event was not instrumentally recorded; a radio report said an earth tremor had been felt near Orillia between 5 and 6 a.m. local time (Smith and Milne, 1970). Without further information, this event cannot be considered a confirmed earthquake. It should be noted that in 1965 sensitive seismograph stations were being operated in Ontario at Scarborough, London and Ottawa, at distances of 100 to 300 km from Orillia.

Thursday 01 April 1965

This event was instrumentally recorded at four Canadian seismograph stations (Scarborough, London, Ottawa and Montréal) and located, by graphical methods, near the French River, just east of Georgian Bay (Smith and Milne, 1970). When these instrumental data were re-examined and processed with the standard Canadian earthquake location computer programme, a new epicentre was determined that better fit the data. The new epicentre places the event at Sudbury, Ontario; the event is assumed to have been either a mining blast or a rockburst as both are common in that area.

Conclusion

None of the above six events is likely to have been an earthquake. Except for the 01 April 1965 event that was associated with mining activity at Sudbury, the available information is sketchy and not suggestive of true earthquakes. Further investigation may be warranted to confirm without doubt that the five alleged earthquakes were not earthquakes. In the meantime, the uncertainty associated with each alleged earthquake is sufficiently large that none can be said to be spatially associated with the Georgian Bay Linear Zone.

References

Smith, W.E.T., 1962. Earthquakes of eastern Canada and adjacent areas, 1534--1927. Publications of the Dominion Observatory, Ottawa, vol. 26, no. 5, 271-301.

Smith, W.E.T. and W.G. Milne, 1970. Canadian earthquakes--1965. Seismological Series, Dominion Observatory, Ottawa, 1965-2, 38 p.