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MICROSEISMIC NOISE ON CANADIAN SEISMOGRAPH RECORDS IN 1962 AND STATION CAPABILITIES

P. W. Basham and K. Whitham

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Microseismic Noise on Canadian Seismograph Records in 1962 and Station Capabilities

P. W. BASHAM AND K. WHITHAM

ABSTRACT: Measurements of short- and long-period microseisms from the eight first-order Canadian seismic stations in operation during 1962 are presented. Monthly mean values of specific-hour and daily maximum short- and long-period amplitudes vary considerably from station to station and from season to season. Also presented are cumulative-frequency plots and amplitude-probability levels of specific-hour and daily maximum short-period microseismic amplitudes. Long-period microseismic periods and spectral-peak positions are seen to vary from summer to winter.

Curves are presented illustrating the 90-per-cent and 50-per-cent probability levels of unified-magnitude perceptibility for epicentral distances up to 110 degrees and the 90-per-cent probability level of local-earthquake magnitude perceptibility for epicentral distances up to 20 degrees. These curves are used to explain an easily demonstrated station variability in teleseism reporting and to assess the theoretical coverage of Canadian seismicity for 1962.

RÉSUMÉ: La présente étude donne les enregistrements de microséismes à courte et à longue période recueillis aux huit stations séismiques de premier ordre qui fonctionnaient au Canada en 1962. Les valeurs moyennes mensuelles des amplitudes maximales à courte et à longue période, enregistrées chaque jour à heure fixe, varient considérablement d'une station à l'autre et de saison en saison. L'étude comporte aussi des tracés de fréquence cumulative et des niveaux de probabilité d'amplitude pour des amplitudes microséismiques maximales à courte période enregistrées chaque jour à heure fixe. Les périodes microséismiques à longue période et les positions du sommet spectral varient de l'été à l'hiver.

Des abaques illustrent le degré de perceptibilité probable, dans une mesure de 90 et de 50 p. 100, d'une magnitude unifiée pour des distances à l'épicentre atteignant 110 degrés, ainsi que la perceptibilité probable, à 90 p. 100, d'une magnitude de séisme local pour des distances à l'épicentre atteignant 20 degrés. Ces abaques servent à expliquer les différences manifestes dans les reportages téléséismiques des diverses stations et à évaluer le dépistage théorique de la séismicité au Canada en 1962.

INTRODUCTION

Whilst engaged in a study (Ichikawa and Basham, 1965) of the effects of the location of a seismograph station on the earthquake records obtained, the microseismic background noise was sampled at the eight first-order stations of the Canadian network, which were in operation during 1962. In view of recent requests for quantitative noise figures in different parts of Canada, the manuscript material has been analyzed by the authors and presented herein. It has proved possible to discuss in a preliminary manner the perception capability of the seismic network as it was at that time.

On alternate days throughout 1962 measurements were made of the maximum peak-to-peak amplitudes and corresponding periods of microseisms appearing at 00 and 12 hours plus or minus 3 minutes U.T. on the short-period and long-period north-south component seismograms. These will be referred to as specific-hour amplitudes. On the same days the peak-to-peak amplitude and the corresponding period of the microseisms of daily maximum amplitude were measured on both the short- and the long-period component. All amplitudes referred to throughout this paper will be peak-to-peak values unless it is otherwise stated.

"Short-period" instruments referred to have 0.25-second galvanometers and 1.0-second seismometers. The periods of short-period microseisms measured ranged from 0.5 to 1.5 seconds. "Long-period" instruments have 90-second galvanometers and 15-second seismometers. The periods of long-period microseisms measured ranged from 3 to 8 seconds.

The eight stations studied were Alert, Halifax, London, Mould Bay, Penticton, Resolute, Victoria and Schefferville. Halifax was not operating a north-south short-period instrument; consequently all measurements for this station were made on the short-period vertical component. Schefferville did not become operational until August 1962; so only 5 months of data will be presented for this station.

SHORT-PERIOD MICROSEISMS

The measurements of short-period specific-hour and daily maximum amplitude were averaged for each month and standard deviations in the mean were calculated. The means and standard deviations were converted to ground amplitude by using the magnifications corresponding to the monthly mean microseismic periods. As indicated by consistently overlapping standard deviations, the two specific-hour values were very similar. They were combined, and another standard deviation was calculated; the results, which are equivalent to monthly means of one value per day, are presented in Figure 1. The vertical bars indicate the standard deviations in the mean. The monthly means of the daily maximum amplitudes with standard deviations in the mean are shown in Figure 2.

As seen from Figure 1, the specific hour microseismic background levels vary considerably among the stations, i.e., from less than 10 mμ (millimicron or 10^{-7} cm) during some months at the Arctic stations to more than 100 mμ during some months at the coastal stations. There is an apparent marked annual variation at all stations, but this is not consistent from one station to another. It can be seen that summer levels are generally lower than winter levels. The annual variations of daily maximum amplitudes in Figure 2 are similar to those of the specific hours, except at Alert. Between January and June, 1962, the Alert short-period seismograms contained many peculiar events somewhat similar to small local earthquakes. For purposes of this study, these were considered to be noise, and the daily-maximum noise amplitude measured was usually the maximum amplitude of one of these events. In Table I the $\overline{A}_{max}/\overline{A}_{S.H.}$ value shows that, in consequence of this, the variability in noise during the day at Alert is more than at the other stations. The variability at Mould Bay and Penticton is less than at the other stations.

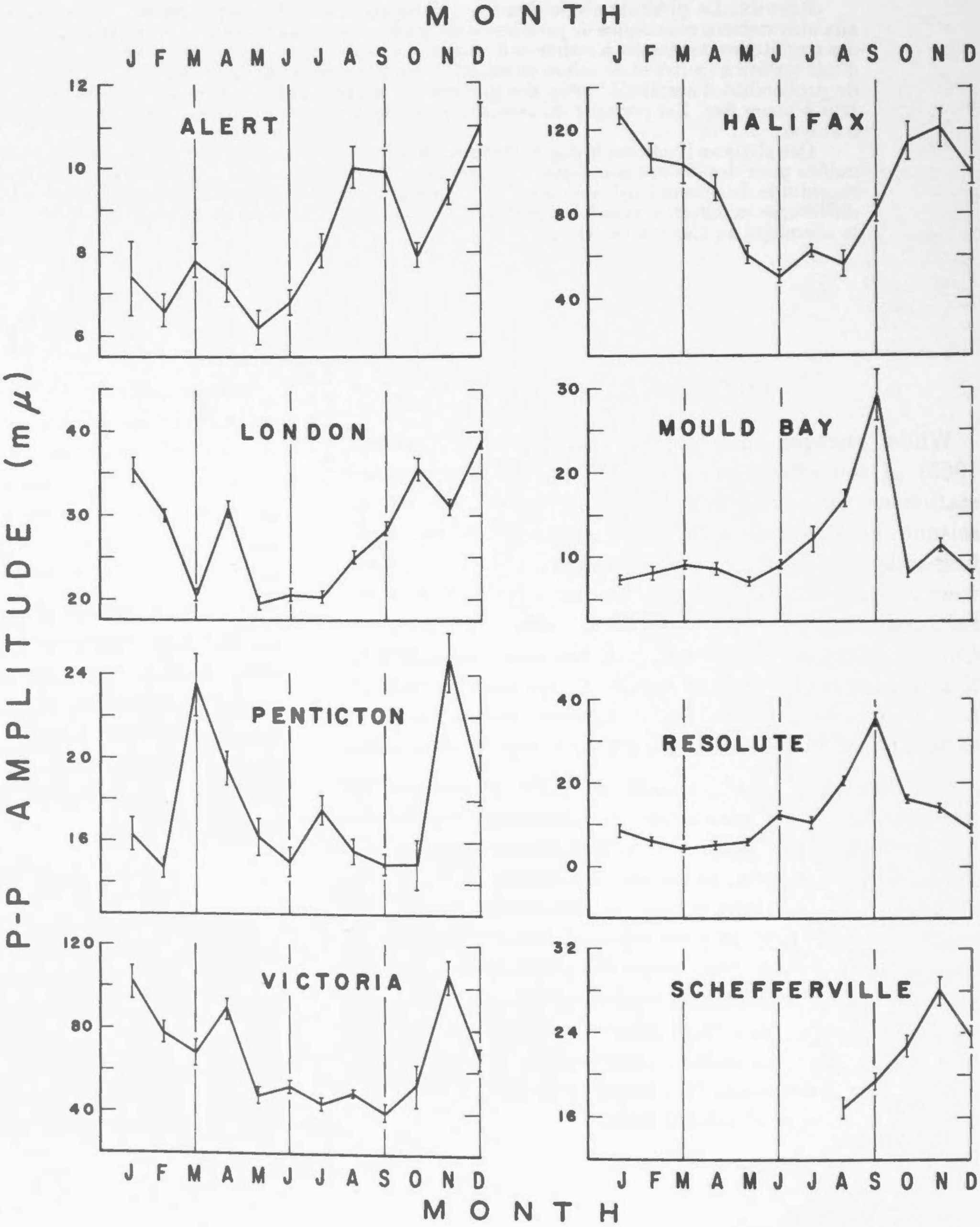

FIGURE 1

Combined monthly means, with standard deviations in the mean, of maximum peak-to-peak short-period microseismic amplitudes at 00 and 12 hours plus or minus 3 minutes U.T.

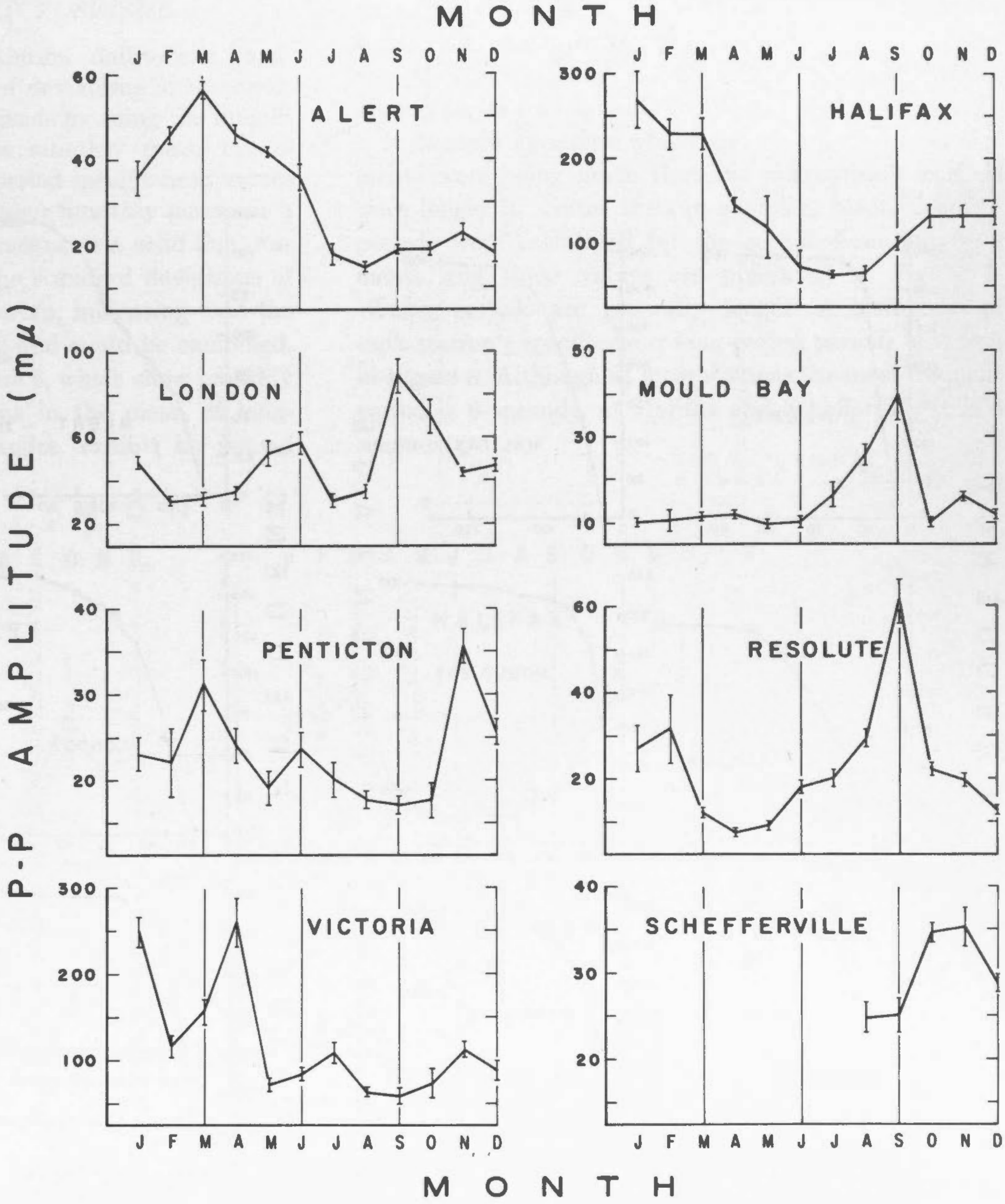

FIGURE 2

Monthly means, with standard deviations in the mean, of maximum daily peak-to-peak short-period microseismic amplitudes.

In Figures 3 and 4 cumulative-frequency distribution curves are shown for the specific-hour and daily maximum microseismic-amplitude measurements respectively. The abscissa interval between successive points is that corresponding to a 0.5-mm increase in peak-to-peak trace amplitude. The right-side ordinate, the cumulative percentage, is, in Figure 3, the percentage probability that the specific-hour maximum peak-to-peak microseismic amplitude will be smaller than the corresponding abscissa value, and, in Figure 4, the percentage probability that the daily-maximum peak-to-peak amplitude will be smaller than the corresponding abscissa value. The last two columns of Table I show the specific-hour peak-to-peak amplitudes in mμ corresponding to the 90-per-cent and the 50-per-cent probability levels of Figure 3.

TABLE I

Mean specific hour ($\bar{A}_{S.H.}$), mean daily maximum ($\bar{A}_{max}$), 90% probability, and 50% probability peak-to-peak microseismic levels in millimicrons

Stat.	$\bar{A}_{S.H.}$	$\bar{A}_{max}$	$\frac{\bar{A}_{max}}{\bar{A}_{S.H.}}$	90% Level $(A_{S.H.})_{90}$	50% Level $(A_{S.H.})_{50}$
Alert	8	30	3.8	12	8
Halifax	89	141	1.6	125	67
London	28	48	1.7	36	21
Mould Bay	11	15	1.4	23	8
Penticton	18	23	1.3	24	19
Resolute	12	22	1.8	25	11
Victoria	66	119	1.8	102	54

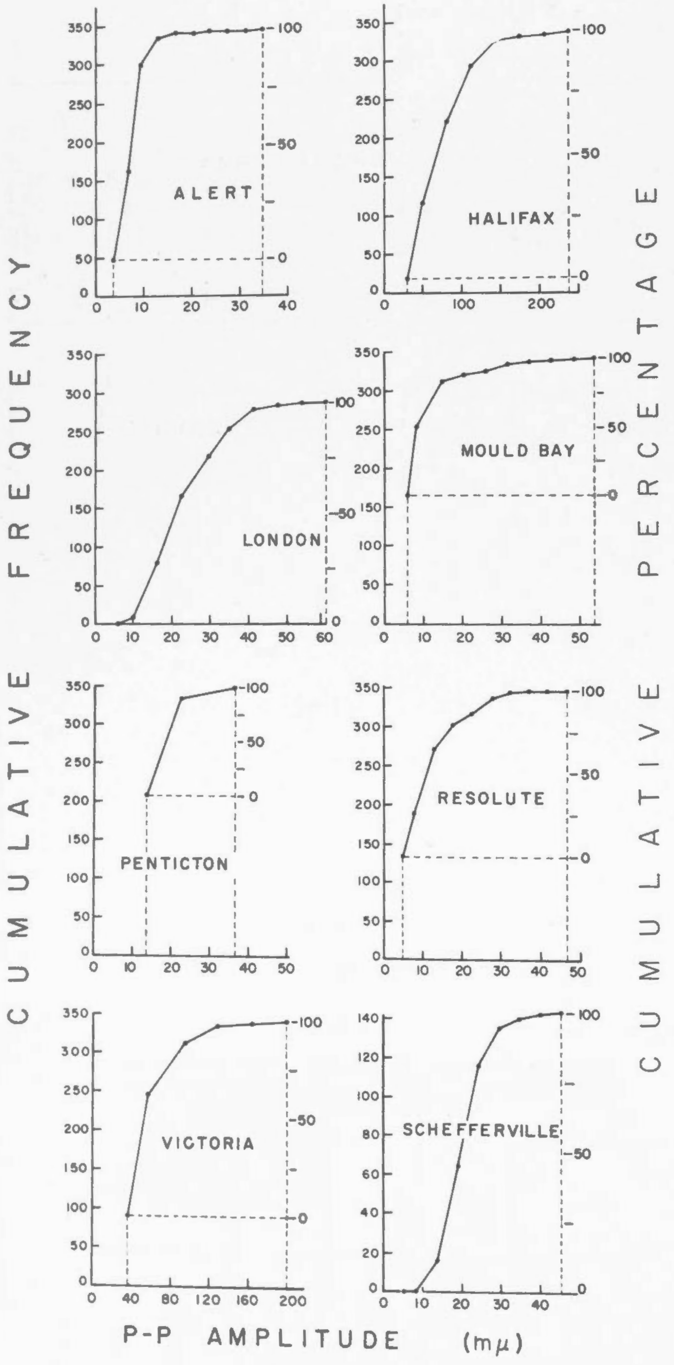

FIGURE 3. Cumulative-frequency distribution of maximum peak-to-peak short-period microseismic amplitudes at 00 and 12 hours plus or minus 3 minutes U.T. The minimum possible amplitude is that corresponding to the seismogram-trace thickness (0.5 mm).

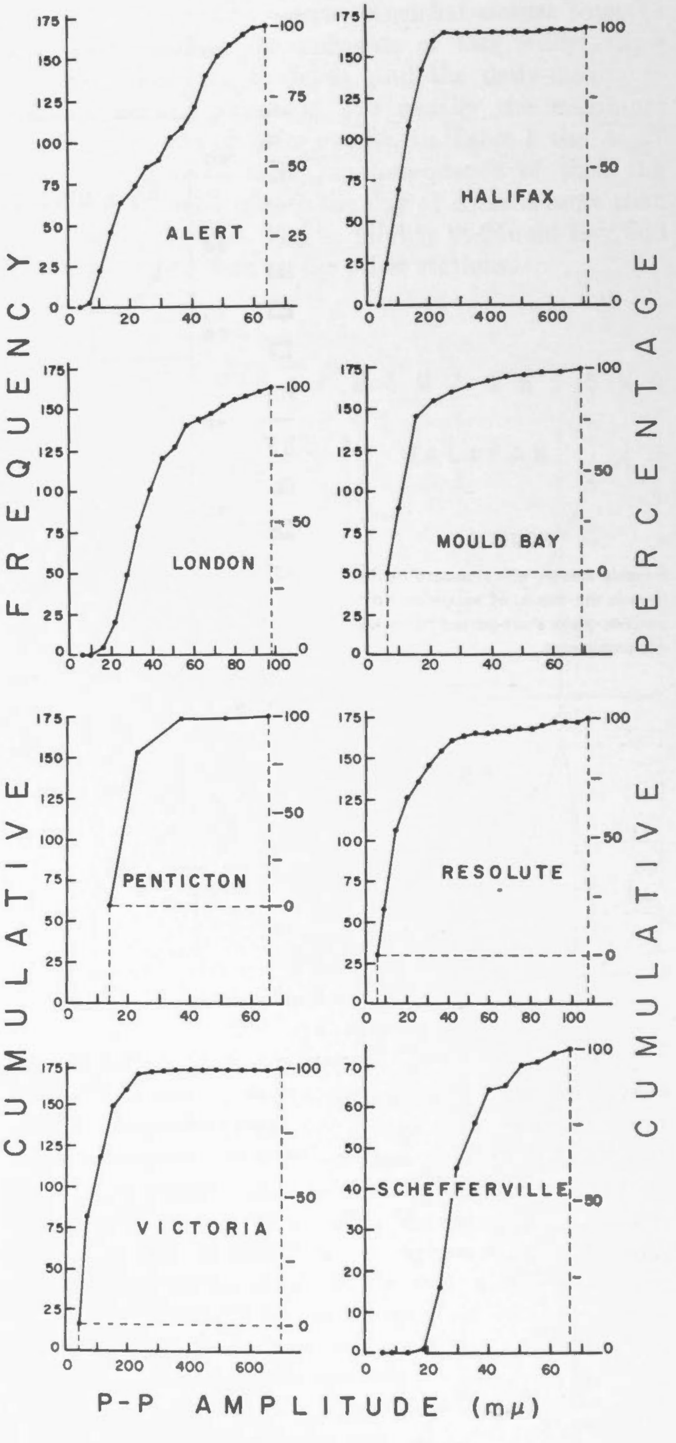

FIGURE 4. Cumulative-frequency distribution of daily maximum peak-to-peak short-period microseismic amplitudes. The minimum possible amplitude is that corresponding to the seismogram-trace thickness (0.5 mm).

LONG-PERIOD MICROSEISMS

The specific-hour and maximum daily-mean long-period amplitudes and standard deviations in the mean were converted to ground amplitude by using the magnifications corresponding to the monthly mean microseismic periods. The two long-period specific-hour values are presented in Figure 5—00-hour monthly means as a broken line, 12-hour monthly means as a solid line. For almost every monthly value the standard deviations of the 00- and 12-hour means overlap, indicating that the curves are essentially the same and could be combined. These curves and those of Figure 6, which show monthly means and standard deviations in the mean of long-period daily maximum amplitudes, exhibit an annual variation of larger winter and smaller summer amplitudes. The short-period and long-period annual noise variation is generally similar except that the Arctic-station peaks are relatively reduced at the longer periods.

It became apparent whilst the long-period measurements were being made that the microseismic periods were longer in winter than in summer. Mean monthly periods were calculated for the specific-hour measurements and these values are presented in Figure 7. Winter periods are generally longer. A histogram of each station's specific-hour long-period periods is shown in Figure 8. Although at most stations the most frequent period is 6 seconds, at Halifax and Schefferville it is 4 seconds.

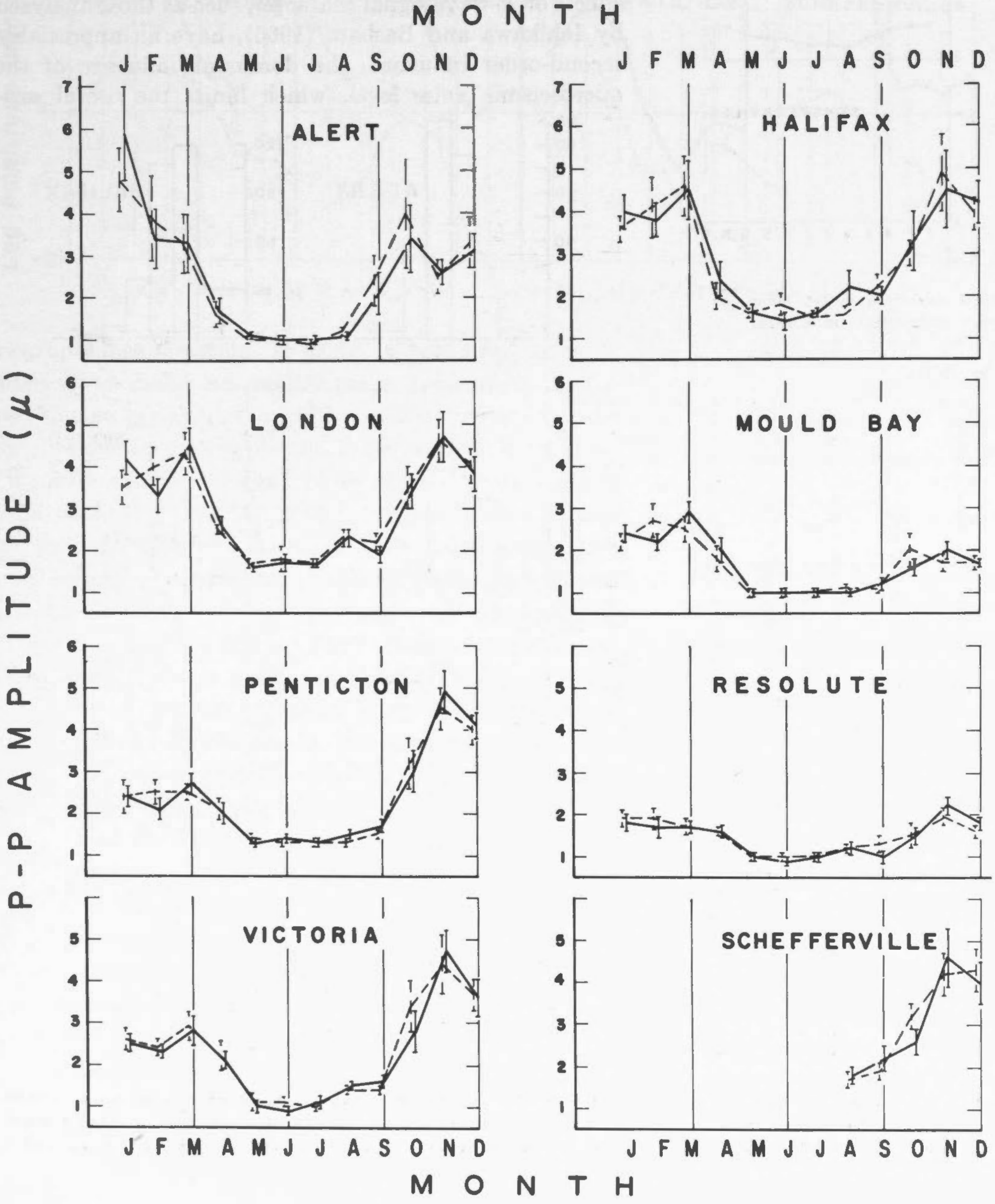

FIGURE 5

Monthly means, with standard deviations in the mean, of maximum peak-to-peak long-period microseismic amplitudes at 00 (broken line) and 12 (solid line) hours plus or minus 3 minutes U.T.

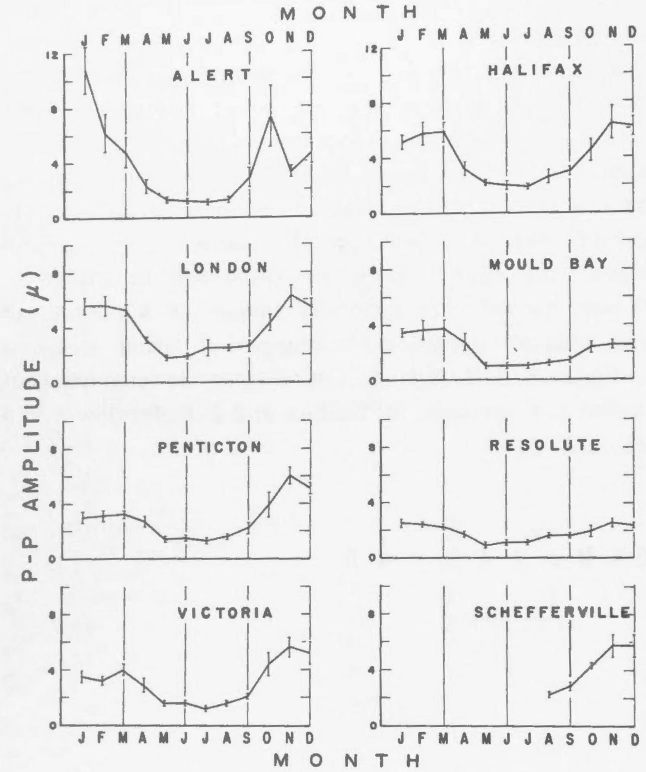

FIGURE 6. Monthly means, with standard deviations in the mean, of maximum daily peak-to-peak long-period microseismic amplitudes.

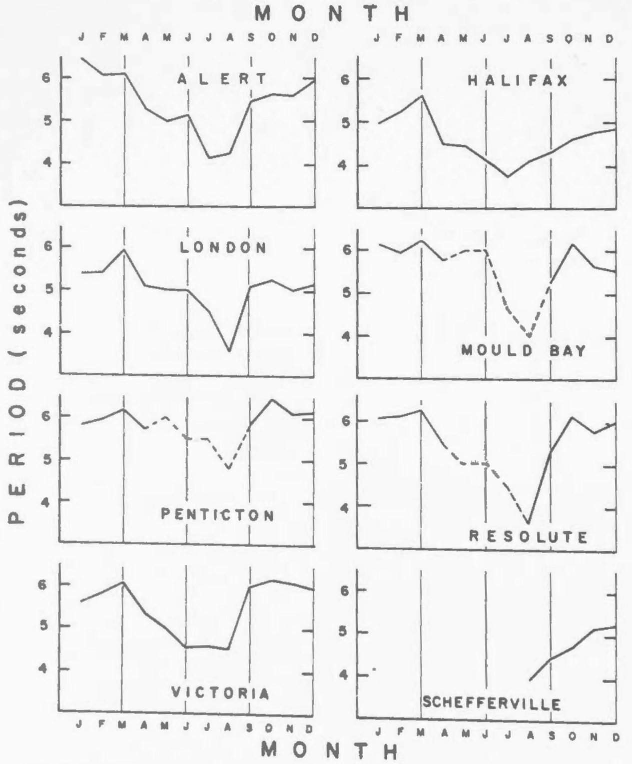

FIGURE 7. Mean monthly periods of long-period 00- and 12-hour microseismic noise. The broken lines join means calculated for months having few measurable period values.

In order to define quantitatively the observed summer-to-winter shift in long-period microseismic periods, Fourier spectra were computed at each station for samples of winter and summer microseisms of approximately 3 minutes' duration. The spectra are shown in Figure 9, where the amplitudes are zero-to-peak, not peak-to-peak. It can be seen that for these typical samples the winter and summer peak periods are considerably different at all stations except London, Penticton and Schefferville.

MAGNITUDE PERCEPTIBILITY

The ease with which earthquake recordings can be recognized on seismograms by the station operator greatly depends on station noise level. Although local effects on P-wave signal character, such as those analyzed by Ichikawa and Basham (1965), have an appreciable second-order influence, the dominant influence of the microseismic noise level, which limits the useful seis-

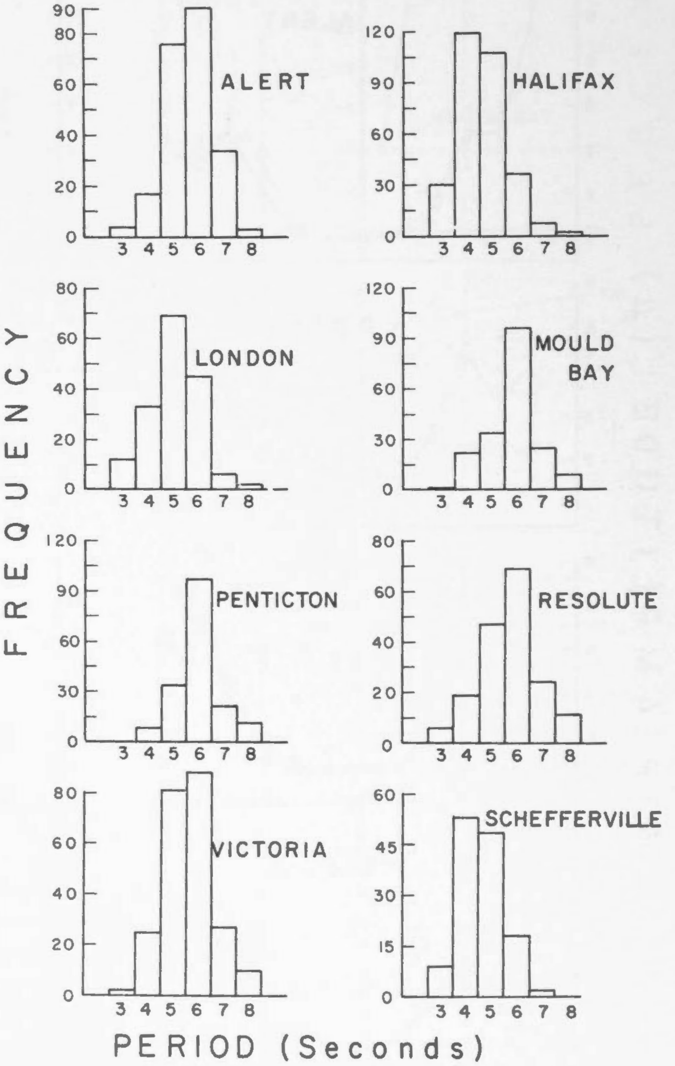

FIGURE 8. Histograms of periods of long-period 00- and 12-hour microseismic noise.

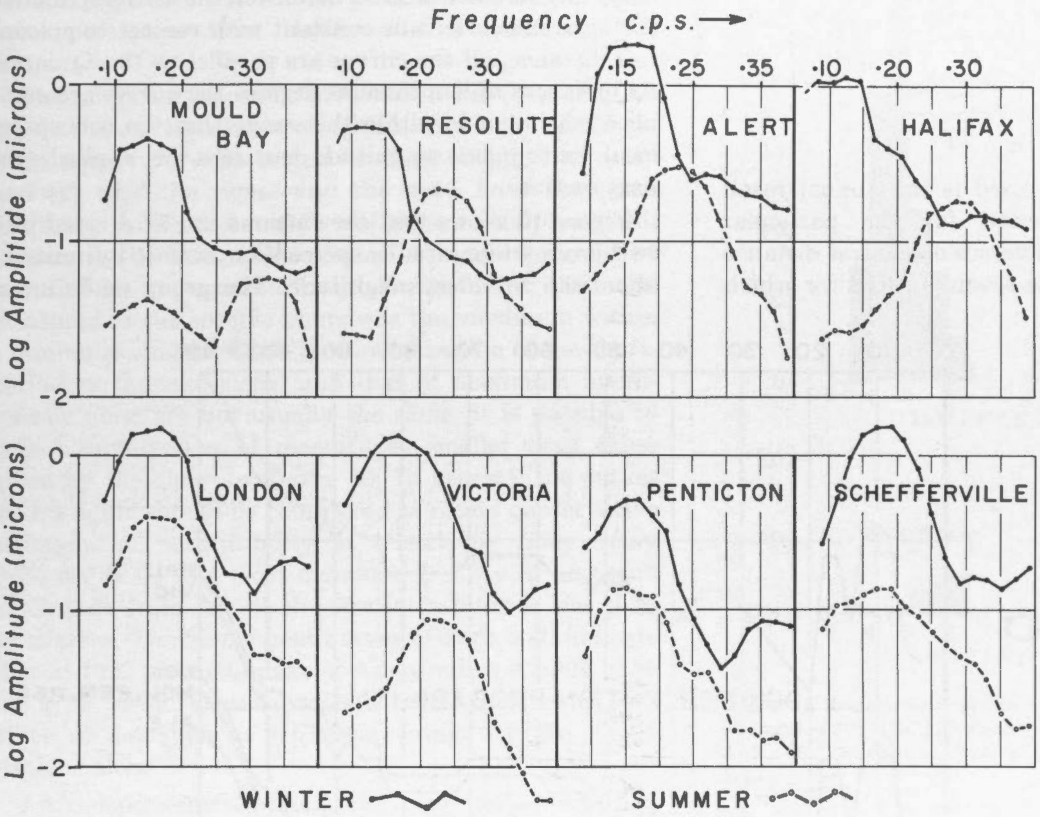

FIGURE 9

Fourier amplitude spectra of representative large-amplitude winter and summer long-period north-south microseisms.

mograph magnification, is clear. Accordingly, it is of interest to make an approximate assessment of the earthquake perceptibility of the 1962 network based on some elementary concepts and the assembled noise data. Strangely enough such estimates appear rarely to have been made. Perhaps the reason for this is that a large number of considerations beyond the short-period noise level enter into the finding of sites for first-order stations. Areal uniformity for seismicity and mechanism studies, geological units for surface wave studies, practical considerations of vault expense and accessibility, and the feasibility of getting operators must all be considered and weighed. Consequently the conclusions outlined farther on, which illustrate the wide variability in the performance of stations of the standard network of 1962, must be considered only in the light of all the operational requirements, and not in the narrow perceptibility sense alone.

To proceed it is necessary to compare mean annual noise amplitudes with the amplitudes expected for earthquakes of different magnitudes at various epicentral distances. Of several magnitude concepts that have been conceived, two—the unified magnitude and the local earthquake magnitude—can be assigned perceptibility probabilities in terms of the short-period noise measurements of this study.

UNIFIED MAGNITUDE

The equation for unified magnitude is given by Gutenberg and Richter (1956a) as

$$m = Q + \log A/T$$

where A is the maximum zero-to-peak ground amplitude of the body wave in microns, T is the corresponding period in seconds, and Q is a distance-depth parameter. Q (Sokolowski, 1964) as a function of epicentral distance for a focal depth of 25 km is shown as the top curve of Figure 10. Assuming that the vertical short-period microseismic noise is much the same as the north-south component measured, the probability is 90 per cent and 50 per cent that the zero-to-peak noise amplitude will be less than

$$\frac{(A_{S.H.})_{90}}{2} \quad \text{and} \quad \frac{(A_{S.H.})_{50}}{2}$$

(Table I) respectively. Assuming that a station can perceive an earthquake whose amplitude will be greater than or equal to the noise amplitude, there will be a 90-per-cent and a 50-per-cent probability that it can perceive an earthquake of magnitude

$$m_{90} = Q + \log\left[\frac{(A_{S.H.})_{90}}{2T}\right]$$

and

$$m_{50} = Q + \log\left[\frac{(A_{S.H.})_{50}}{2T}\right]$$

respectively. The value of T used is the annual mean short-period microseismic period for the particular station. Curves of m_{90} and m_{50} versus epicentral distance are shown in Figure 10 for the seven stations for which noise measurements were made for the entire year. As the logarithmic term is constant with respect to epicentral distance, all the curves are parallel to the Q curve. At distances of less than 20 degrees the curves are complicated, but it is within this range that the concept of local earthquake magnitude can best be applied (see next section).

Figure 10 shows that the stations can be divided into two groups separated in perception ability by units of about 0.5 to 1.0 in magnitude. The group made up of

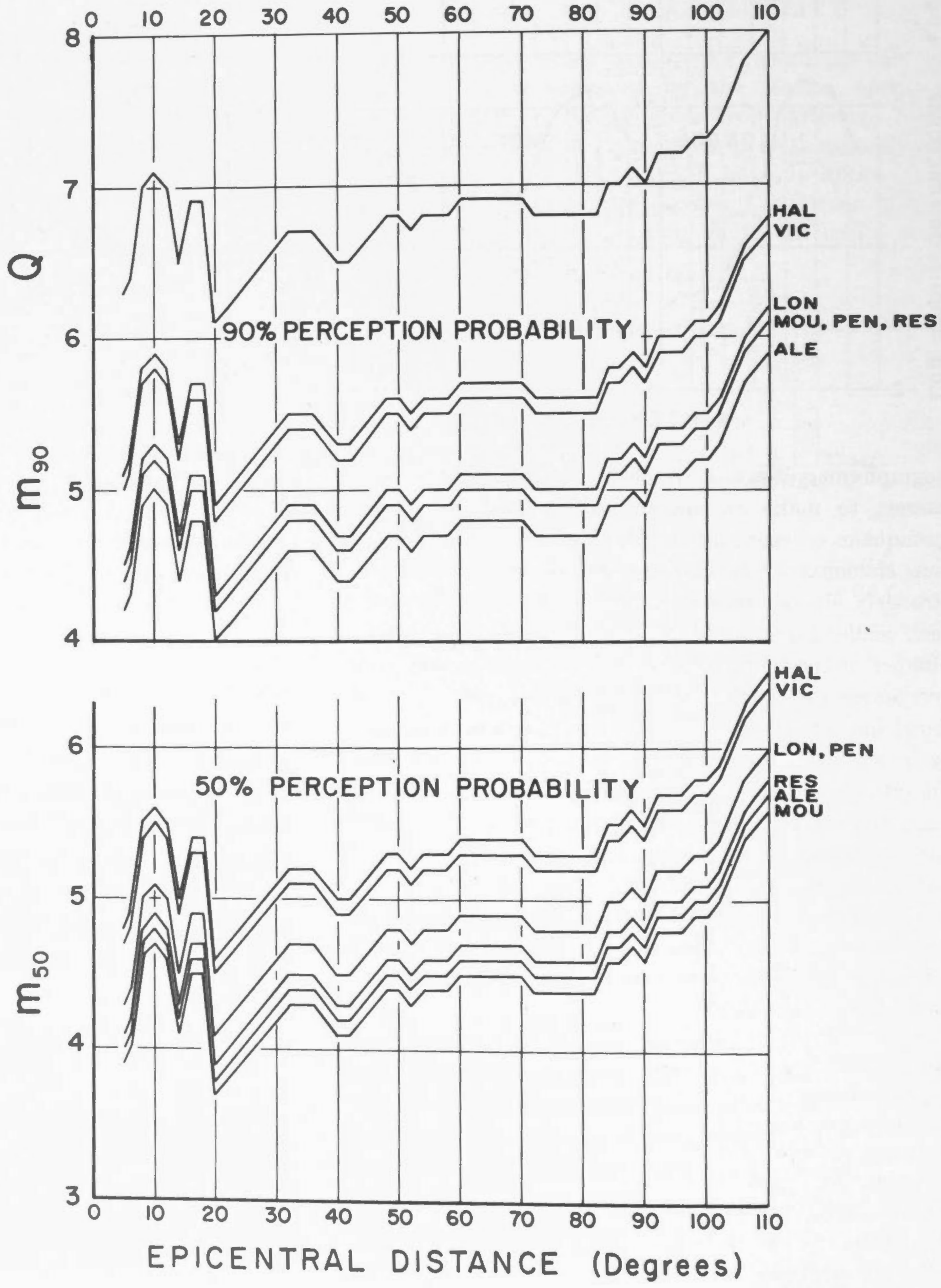

FIGURE 10

Curve of distance-depth (Q) parameter for determination of unified magnitudes. Curves of 90-per-cent and 50-per-cent unified-magnitude perception probability.

Mould Bay, Alert, Resolute, London and Penticton is more perceptive than Halifax and Victoria by this amount.

The major assumptions involved in the foregoing are (1) that an earthquake is perceptible only if the signal-to-noise amplitude ratio is greater than or equal to unity and (2) that the signal and the noise have the same frequency content. As neither of these assumptions will necessarily be true, the curves of Figure 10 should be regarded as approximate only. Furthermore, the noise measured at the specific hours was the maximum within a 6-minute window. Since the time duration of the short-period earthquake signal and that of maximum microseismic noise are not usually the same, it is possible to detect earthquakes of magnitudes smaller than those given by the curve in Figure 10. In general, the curves of this figure should be considered as rather conservative estimates of perceptibility at teleseismic ranges (say >20 degrees). The most distant extremity of any part of Canada from one of the Arctic stations is less than 40 degrees. The 90-per-cent curves of Figure 10 indicate that in 1962 no earthquake of magnitude 4.9 could have occurred inside Canada without a 90-per-cent probability of detection at teleseismic range by the Arctic stations alone.

An independent check on the magnitude-perception ability of these stations is provided by an examination of the list of stations contributing arrival times to the teleseism-epicentre location program of the International Seismological Centre (I.S.C., 1965) for January 1964. The list contained 305 earthquakes, for each of which an epicentre and magnitude were determined by the United States Coast and Geodetic Survey (U.S.C.G.S.). Out of this total, Mould Bay contributed arrival times for 143, Resolute for 58, Alert for 36, Victoria for 14, Halifax for 8 and London for 5. In Figure 11 histograms of each station's contribution are shown as a function of magnitude. Because of operator difficulties Penticton arrival times were not contributed to the program for January 1964. In addition, only Mould Bay of these six stations contributed times for other earthquakes whose magnitudes were not determined; its proportionate contribution in this test sample was therefore slightly greater than that just given.

It is clear that, on the basis of the I.S.C. contribution transmitted by the phase-sheets of the individual operators and therefore complicated by a personal factor, Mould Bay was the most perceptive of the Arctic stations during January 1964, whereas, on the basis of the curves of Figure 10, Alert would be expected to be the most perceptive during 1962. The geographical distribution of epicentres, however, complicates the problem, and it is thought that, during the entire interval of operation of the Arctic stations, Mould Bay has been the most perceptive. The discrepancy from the prediction can be partially explained by the occurrence at Alert of a number of unexplained and very small local events (mentioned in the section on short-period microseisms), which biases an operator against reporting a number of small events that are truly teleseisms.

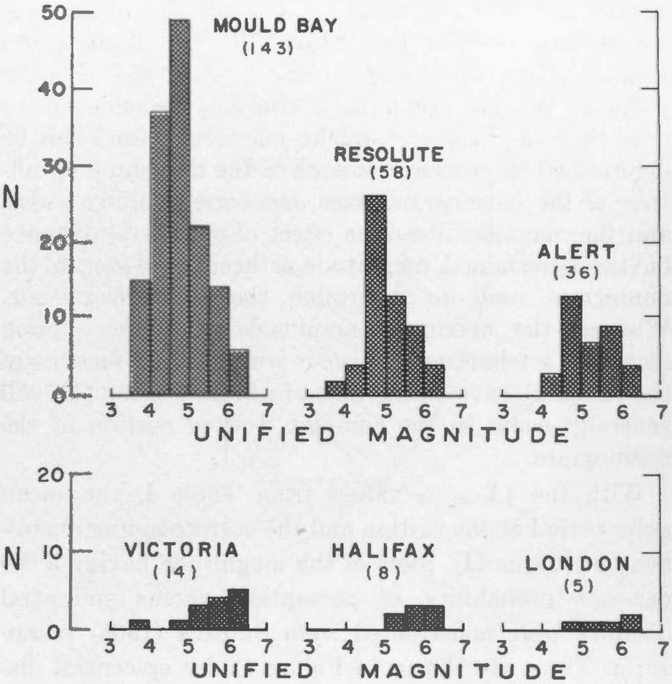

FIGURE 11. Histograms of numbers of earthquakes as a function of magnitude of a total of 305 U.S.C.G.S. epicentre and magnitude determinations reported by the I.S.C. for January 1964, for which the six stations contributed arrival times.

Figure 10 predicts that London's perceptibility will be only slightly worse than that of the Arctic stations. This is not supported by the I.S.C. test. During January, however, London's background noise is near the annual maximum (Figure 1); its contribution to I.S.C. for this month can therefore be expected to be smaller than the prediction based upon an annual average. Furthermore, the prediction is based upon a simplification which neglects the fact that a theoretically perceptible earthquake can be missed through human error resulting from the large trace amplitude of noise at London (Table II). The antithesis of this situation is very revealing. During many months at Mould Bay the noise-trace amplitude is virtually zero, the trace appearing as a straight line. Even the minutest perturbation of the trace can often be identified as a teleseism and its arrival time reported. It is clear that, to increase perceptibility, magnification should not be set too high.

LOCAL-EARTHQUAKE MAGNITUDE

The concept of local-earthquake magnitude is not as unequivocal as that of unified magnitude. The historical development and present status of Canadian procedures are described by Richter (1935), Gutenberg and Richter (1942, 1956a, 1956b) and Smith (1965). For the purposes of this preliminary study it is sufficient to note that the local-earthquake magnitude (m_L) can be determined from measurements of the maximum amplitude of the seismogram trace, the corresponding period and the magnification. The effect of epicentral distance on the determined magnitude is accounted for in the nomogram used to determine the local magnitude. Whereas the maximum amplitude of a short-period record of a teleseism will occur within a few seconds of the initial P-wave onset, that of a local earthquake will generally occur in the complex S-wave portion of the seismogram.

With the $(A_{S.H.})_{90}$ values from Table I, the mean noise period at the station and the corresponding magnification (Table II), plots of the magnitude having a 90-per-cent probability of perception versus epicentral distance were constructed from Smith's (1965) nomogram. These are shown in Figure 12 for epicentral distances up to 20 degrees. The relations involved in the concept of local magnitude are such that when the 50-per-cent noise-probability levels are used instead of the 90-per-cent levels, the perceptible magnitude values are reduced by only 0.1 to 0.2 magnitude units. This small difference can be used in conjunction with the curves of Figure 12 to obtain the 50-per-cent-probability magnitude levels.

The assumptions discussed for the unified magnitude apply also in the case of local magnitude. In particular the frequency content of a local earthquake will usually be different from that of the short-period noise measured in this study; the maximum-amplitude waves of local earthquakes have periods ranging from 0.3 to 0.9 seconds depending on epicentral distance, size and other factors, whereas the short-period microseisms had mean periods near 1.0 seconds. This tends to make the curves of Figure 12 very conservative in terms of perceptibility, but, since P_n and S_n arrivals are usually of smaller amplitude and must be read to locate epicentres, the perceptibility estimate can exaggerate the effectiveness of the stations. It seems likely that Figure 12 represents a reasonable and effective numerical compromise.

By plotting, on a map of Canada, circles around the stations with radii equal to the epicentral distances at which the stations have a 90-per-cent probability of perceiving local earthquakes of certain magnitudes, it is possible to estimate the theoretical earthquake-magnitude coverage of this group of seven first-order stations in operation throughout 1962. Figure 13, where this procedure is used, shows that a local earthquake of magnitude 4.8 occurring anywhere inside Canada would

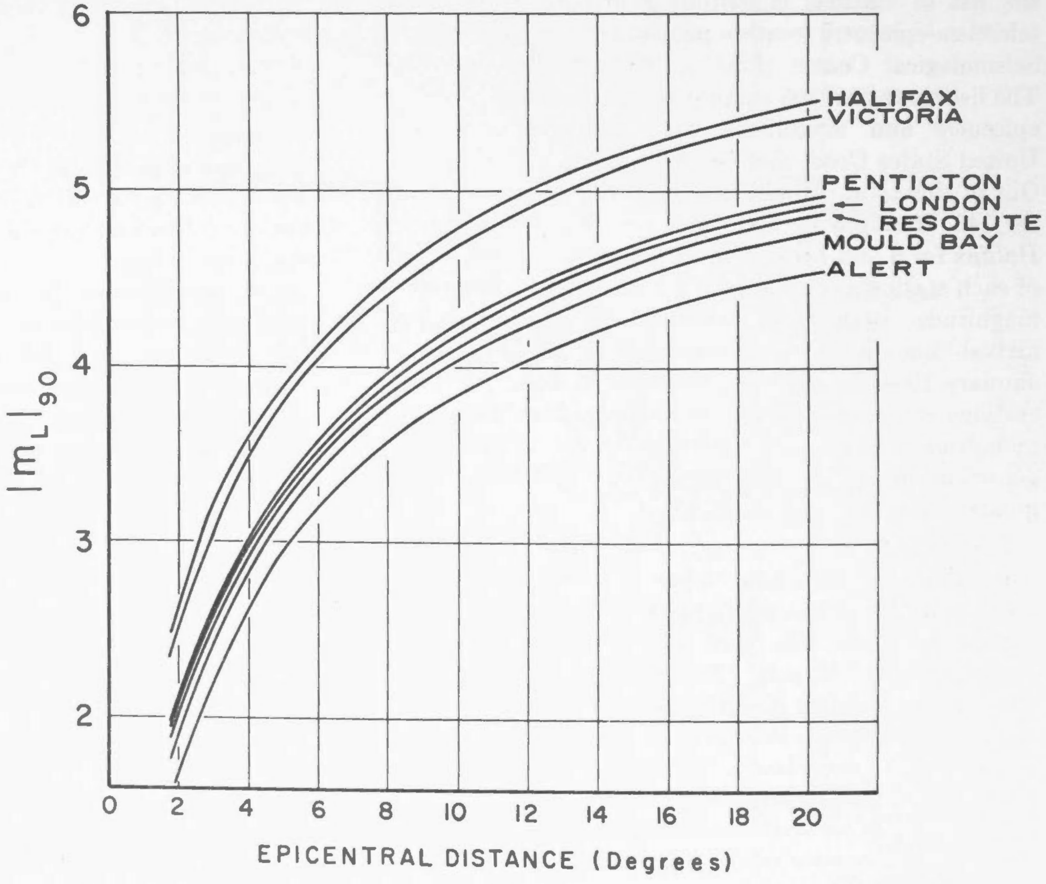

FIGURE 12

Curves of 90-per-cent local-magnitude perception probability.

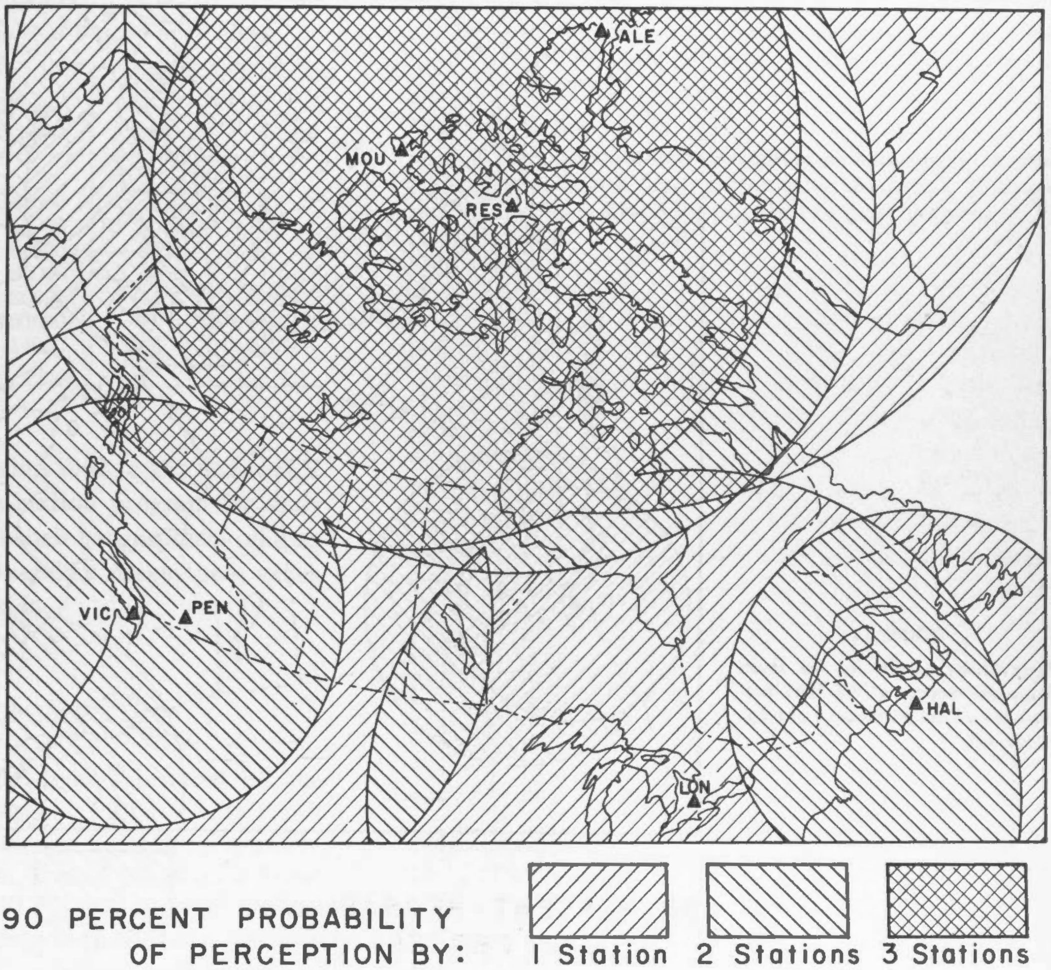

FIGURE 13

Perceptibility ranges for the seven first-order stations of the 1962 network for a local earthquake of magnitude 4.8.

have been recorded by at least one of the seven stations. It would have been recorded by two stations only, if it had occurred in the southern portions of British Columbia, Alberta or Manitoba, in the St. Lawrence Valley or in the Maritime Provinces. It would have been recorded by three stations and its epicentre could have been located if it had occurred anywhere in Canada north of 55° latitude. Although three records of an earthquake are required to locate its epicentre, one of these can be a negative record if one of the two possible locations would have fallen within the perceptible range of the third station. These fields of perceptibility are considerably reduced as the magnitude is lowered, and very little coverage is afforded for magnitudes below 4.0 (Figure 14). For locals of magnitude 3.0, many of which occur and are of importance in seismic regionalization studies in Canada, the perceptibility range of the best first-order stations is from 4 to 5 degrees (450–550 km).

It must be emphasized that this discussion perforce neglects the second-order stations in operation during 1962 (Alberni, Banff, Seven Falls and Shawinigan Falls), which very considerably improve the coverage in the active West Coast area and the St. Lawrence Valley. It also neglects the contribution of United States stations to Canadian seismicity and felt reports. Furthermore, it ignores geometrical difficulties with some epicentres in certain regions. It does, however, suggest that when the first-order network of some 30 stations about evenly distributed throughout the country is complete, no earthquake exceeding magnitude 2.8–3.2 should remain undetected and that earthquakes exceeding 3.4–3.7 should be determined if the performance of the Arctic stations can be matched everywhere. Experience suggests that this is impossible: magnitudes 3.7 and 4.2 respectively represent a minimum performance based on the figures for the coastal stations. The capability of the completed Canadian network remains a subject for future research and practical assessment, but the foregoing figures indicate the levels that appear reasonable from a preliminary analysis of this kind—i.e. complete coverage between 3.0 and 3.7 for detectability and between 3.5 and 4.2 for identification.

REMARKS

Specific explanations for differences in mean noise levels and differences in the annual variation of noise among the stations would require meteorological,

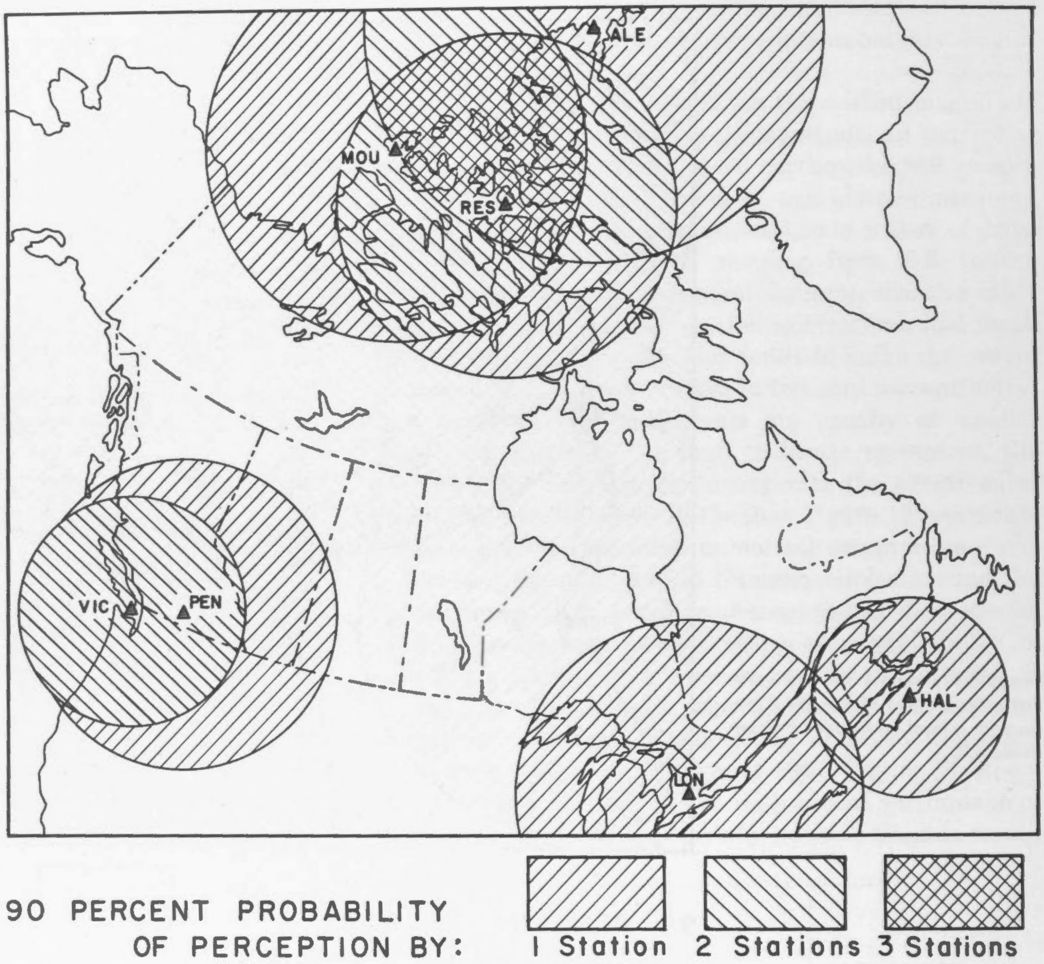

FIGURE 14

Perceptibility ranges for the seven first-order stations of the 1962 network for a local earthquake of magnitude 4.0.

topographical and geological knowledge pertinent to each station. Most of this information is not at present available, but examples can be given from the observation of conditions at some of the stations. Because of sea action, Victoria and Halifax were expected to have higher noise levels than stations in the continental interior. The bays and straits near Mould Bay and Resolute, in the Arctic Archipelago, are free of packed ice during parts of July, August and September, and the consequent open-water condition contributes to the higher short-period noise level prevailing at these stations during those months. At London, where the seismograph vault is inside a water-conservation dam, spring-water runoff contributes to the short-period noise that occurs in April. At Penticton the winds contribute to the short-period noise during March and November, when they are at their highest.

It is an Observatory Branch practice, in installing stations of the Canadian network, to set each magnification so that the noise exhibited by all seismograms will be roughly similar in trace amplitude. The success of this practice for seven stations of the network in operation during 1962 is shown in Table II. The table shows mean short-period microseismic periods, the corresponding magnification, $\bar{A}_{S.H.}$ from Table I, and the annual mean peak-to-peak trace amplitude ($\bar{a}_{trace}$), which is determined by multiplying $\bar{A}_{S.H.}$ by the magnification. It is seen that during 1962 the trace noise at London was about twice that of the network average and that at Penticton it was about half the network average. The latter condition has since been corrected.

The noise levels of stations designated as useful for the detection and possible identification of underground nuclear explosions (Thirlaway, 1965) have been established as a zero-to-peak noise amplitude of 18 mμ at the 50-per-cent probability level for coastal stations and 5.5 mμ for continental stations in the bandwidth bracket of 1 to 5 c.p.s. Table I shows that Halifax and Victoria (coastal stations) and London and Penticton (continental stations) do not fall within this category. The Arctic stations, Alert, Mould Bay and Resolute, are satisfactory continental sites which meet the specifications of the Geneva conference. It is of interest to note that these

TABLE II

Comparison of trace amplitudes of peak-to-peak noise

Stat.	Mean T (sec)	Magnification	$\bar{A}_{S.H.}$ (mμ)	$\bar{a}_{trace}$ (mm)
Alert	0.81	148000	8	1.2
Halifax	1.02	16000	89	1.4
London	1.06	80000	28	2.2
Mould Bay	1.01	89000	11	1.0
Penticton	0.98	36000	18	0.6
Resolute	0.93	103000	12	1.2
Victoria	1.03	14000	66	0.9

three stations contributed during 1962 to the U.S.C.G.S. preliminary epicentral-determination program by daily telegram. It is clear that both their geographical uniqueness and their theoretical capability make them excellent choices for this contribution.

ACKNOWLEDGMENTS

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