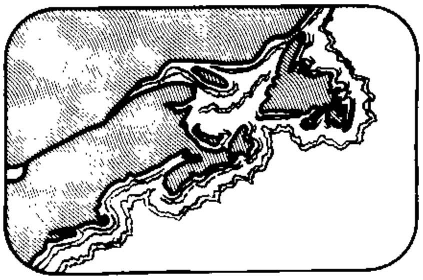

Earthquake Activity in the Maritime Provinces

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Summary
Earthquakes have been felt or reported in the Maritime Provinces for over two hundred years but it is only within the last decade that enough seismographs have been in place to detect the smaller events.

In general, the epicenters of more recent earthquakes are in the same area as the larger historical earthquakes:Grand Banks, Bay of Fundy, Moncton-Dorchester area and the Central Highlands of New Brunswick, although the latter area has only been really emphasized by the Miramichi earthquakes of 1982. Values of magnitude for historical earthquakes have been reduced by basing them on felt area, rather than on maximum intensity, and there is some evidence that the epicenter of the large earthquake of 1869 in New Brunswick may have a more northerly location. Reactivation along old fault lines, concentration of stress at pluton boundaries and glacio-isostatic movements have all been offered as explanations for the cause of earthquakes in the region. Support for all three hypotheses has been found in various studies and it is not possible at the moment to refute any of these explanations.

Résumé
Dans les provinces maritimes, des tremblements de terre ont été ressentis ou rapportés sur plus de 200 ans, mais ce n'est que durant les dix dernières années qu'un nombre suffisant de sismographes en place a permis de détecter des événements de moinures ampleurs. Généralement, les épicentres des tremblements de terre récents se situent aux environs mêmes de ceux des grands tremblements de terre historiques: les Grands Bancs, la Baie de Fundy, la région de Moncton/Dorchester et les Hautes Terres du Nauveau Brunswick, quoique l'attention n'ait été attirée sur cette dernière région que depuis le tremblement de terre de Miramichi en 1982. Les magnitudes des tremblements de terre du passé ont des valeurs inférieures aux intensités maximales car elle ont été déduites de ce qui a été ressenti dans les régions secouées et il existe dés evidences indiquant que l'épicentre du tremblement de terre de 1869, au Nouveau Brunswick, aurait eu une position plus Nord que celle antérieurement admise. Diverses origines pour ces tremblements de terre ont été proposées: réactivation d'anciennes failles, concentration des contraintes en bordure des plutons ou réajustement isotastique. Des arguments en faveur de l'une ou de l'autre de ces hypothèses peuvent être trouvé dans différentes études et il n'est actuellement guère possible d'en rejeter une seule.

Introduction
The first recorded account of an earthquake in the Maritime Provinces is a brief news item from the *Halifax Gazette* of December 13, 1764: "We hear from St. John's (Saint John) in this province that on the 30th of September last about 12 o'clock noon that a very severe shock of an earthquake was felt there."(Smith, 1962). Since then more than one hundred earthquakes have been reported or recorded in the region (Figure 1).

Epicenters for pre-1928 earthquakes shown in Figure 1 have been replotted from Smith (1962). Most of these earthquakes are known only from historical records and

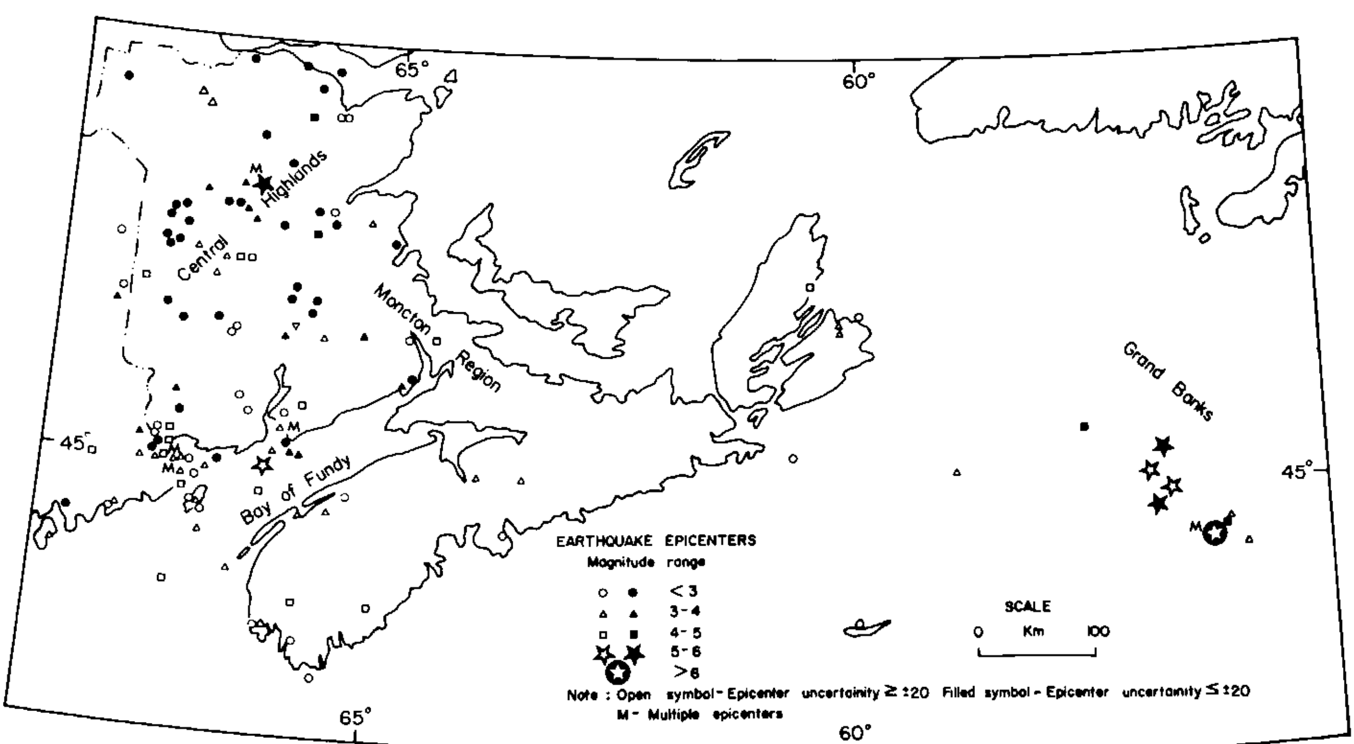

Figure 1 *Distribution of epicenters in the Maritime Provinces. Epicenters based on Smith (1962; 1966) and annual listings of Seismological Service of Canada. Some magnitude values taken from Rast* et al., *1979*

newspaper accounts and their epicenters are defined as the central position of the area over which the earthquake was felt or, in some cases, the epicenter represents a single community from which the earthquake was reported. Thus, there is considerable uncertainty in the positions of epicenters for these earthquakes and they are shown as open circles in Figure 1.

Epicenters for earthquakes after 1928 are based on a later catalogue by Smith (1966) for the period 1928 to 1959 and the bi monthly and annual listings of the Seismological Service of Canada for the post-1959 period. Most of these epicenters have been determined from the analysis of seismograph records from Canadian and U.S. stations and those with an uncertainty in position of less than 20' are plotted as filled circles in Figure 1. From the distribution of epicenters shown in this latter figure, it is seen that those regions that have been active in the past remain so today, although perhaps the importance of the Central Highlands of New Brunswick and the Grand Banks Region has only been realised since seismographs have been installed in places close enough to locate earthquakes from these rather remote regions.

Size of Earthquakes

Intensity scales. One method to assess the size of an earthquake is to map areas where similar effects or damage are observed. Groups of similar phenomena are ranked together at numbers on an intensity scale that increase as the effects of the earthquake become more noticeable and damage becomes more severe. Because cultural practices and building techniques have changed with time, and differ in many parts of the world, several different intensity scales have been developed. For example, the Mercalli Scale was developed by Mercalli in Italy in 1902 and then modified by H.O. Wood and F. Neumann in 1931 to fit the cultural practices and building techniques used in California (Bolt, 1978). This Modified Mercalli Intensity Scale (1931) is the one used in Canada.

In Eastern Canada the Earth Physics Branch of the Department of Energy, Mines and Resources distributes questionnaires to potential respondents in a region affected by an earthquake. Based on the replies to these questionnaires, areas of equal intensity are determined. An isoseismal map is then drawn showing contours dividing the region into zones of equal intensity.

An isoseismal map produced for the 1929 Grand Banks earthquake is shown in Figure 2 (Smith, 1966). This shows a typical concentric ring pattern with intensity decreasing with distance from the epicenter, although the contours are obviously incomplete because of the sea covered areas. The earthquake caused minor damage in eastern Cape Breton and was extensively felt throughout mainland Nova Scotia.

Although intensity normally decreases with distance from an epicenter, the soil and rock at an observation site is a significant modifying factor in how intensely an earthquake is felt. This is illustrated in Figure 3, which shows the felt area for an earthquake in New Brunswick on August 8th, 1970 (Horner et al., 1975). This earthquake was felt to much greater distances at those places underlain by thick alluvial deposits, for example, in the Saint John river valley, compared to those places where the overburden is thin, for example, just north of Fredericton.

Site conditions and the quality of building construction also govern the degree of earthquake damage. Structures with foundations on firm bedrock sustain less damage than similar structures on other soils. One particularly hazardous soil is thixotropic clay. Some of the Pleistocene marine clays in eastern Canada are of this type. These clays act like gels that when suddenly jarred by an earthquake may either wobble like jelly or turn into a liquid, with the resultant collapse of structures that depend on the clay for their foundations.

Magnitude scales. If a comparison is to be made of the size of earthquakes in different regions, it is necessary to have a measure that is more objective than intensity scales. A scale based upon the measurement of ground motion recorded on a seismograph obviously meets this requirement.

It was a seismologist, Charles Richter, who proposed the first magnitude scale of this kind in 1935. Richter based his magnitude scale on records obtained from the California network of stations, in which identical, calibrated, Wood-Anderson seismographs were used. He found that there was a systematic decrease in amplitude with distance on plots of the logarithm of the maximum trace amplitude against distance. A logarithm scale was necessary because of the wide range of amplitude values associated with different size earthquakes. Richter selected a 'zero' magnitude earthquake to be the one that gave a maximum trace deflection of 0.001 mm at 100 km and defined his magnitude scale in terms of the following relationship.

$M_L = \log A - \log A_0$

where M_L is the Richter magnitude

A is the maximum trace amplitude of the earthquake

A_0 is the maximum trace amplitude of the "zero" earthquake at the same distance.

The Richter magnitude can thus be obtained from a single record, although for any sizeable earthquake the reported mag-

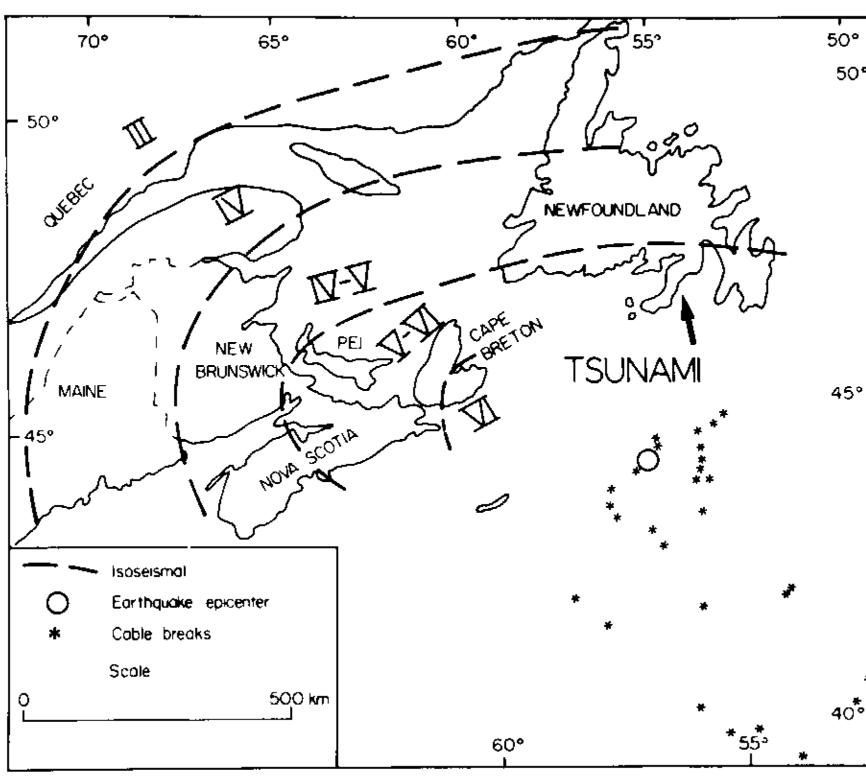

Figure 2 *Isoseismal map for the 1929 Grand Banks Earthquake (based on Smith, 1966)*

nitude figure is usually given as the mean of determinations for all stations that recorded the earthquake at less than 600 km, together with a standard deviation to indicate the scatter of the results.

Because Richter's scale was developed using local earthquakes in California—hence the subscript L to identify the scale—the succeeding years since 1935 have seen the proposal and use of many other magnitude scales. For example, the extension of magnitude determinations to distant earthquakes has been based on the amplitudes of seismic waves on seismograph records that have travelled particular paths through the earth. In fact, in a recent review article by Bath (1981), he estimated that one paper a week has been published on the topic of magnitudes since 1967. Bath (*op. cit.*) gives a comprehensive review of the magnitude scales developed by various seismologists over the years.

In respect to magnitude scales for local earthquakes, it has been recognized in recent years that the high attenuation rate for seismic waves in California causes problems in the application of the Richter scale to other regions where the attenuation rate is different. In eastern North America, the attenuation rate is much lower than it is in California. For this region, Nuttli (1973) proposed the following magnitude expression, based on the amplitude of the Lg waves, a wave that is associated with transmission through a granitic crust and generally recognizable in the distance range 400 to 3000 km.

$m_b = -0.10 + 1.66 \log \Delta + \log (A/T)$

where A is the maximum ground amplitude of the vertical component of a 1 second period Lg wave

T is the period

Δ is the epicentral distance.

In eastern Canada, Nuttli's magnitude scale, identified as m_n, is the one now used for local earthquakes at distances greater than 400 km, provided the propagation path does not include a substantial section of oceanic crust (Wetmiller *et al.*, 1981). The Richter M_L magnitude scale is still used at shorter distance.

Intensity and magnitude values based on historical accounts of earthquakes. The study of seismicity in a region can be enhanced considerably by studying historical records. This is particularly the case for the Maritime Provinces, where earthquakes do not occur frequently and a regional network of seismographs has only been put in place during the last few years. For example, Smith (1962) based his catalogue of earthquakes in Eastern Canada between 1534 and 1927 on such sources as old newspaper accounts and diaries. In addition, maximum intensity values were estimated from the descriptive written accounts of the earthquakes.

Seismologists have also constructed isoseismal maps for those larger earthquakes that were given detailed coverage in the newspapers and journals of the period in which they occurred (e.g., Street and Lacroix, 1979). A similar study of larger historical earthquakes in New Brunswick also is in progress (Burke, in preparation). A map of intensity values for the earthquake of October 22, 1869 is shown in Figure 4. Because of the high intensity values in the northern part of the province, this map suggests that the epicentral position for this earthquake listed in Smith's catalogue (1962) may be incorrect.

Magnitudes of earthquakes have been represented by dot size in the figure that accompanies the catalogue of Smith (1962). Smith used the relationship

$M = 1 + 2I/3$

where M is the magnitude

and I is the maximum intensity

to determine his magnitude values.

Street and Turcotte (1977), after examining the relationship between instrumentally determined magnitudes and epicentral intensity for 12 earthquakes in northeastern North America, showed that magnitude and intensity were poorly correlated. Two earthquakes of identical epicentral intensity had instrumentally determined magnitudes differing by 1.5 units and all of the data were badly scattered.

Magnitude estimates for historically reported earthquakes can also be based on the criterion of the area over which the earthquake is felt, or alternatively, the area within the MM intensity IV isoseismal (Nuttli and Zollweg, 1974; Street and Lacroix, 1979). Rast *et al.* (1979) used the magnitude-felt area relationships of the above authors to determine magnitude values of earthquakes in the Maritime Provinces for which there was no seismograph record available, but whose felt area can be estimated from the reports in Smith's catalogues (Table I *op. cit.*). This study showed that magnitudes based on felt area are smaller than those based on epicentral intensity, the reduction being as much as 1 unit for the 1869 earthquake. Thus, it is suggested that the magnitudes of historical earthquakes probably lie in the range bounded by the higher estimate based on intensity in Smith's catalogues and a lower value based on felt area.

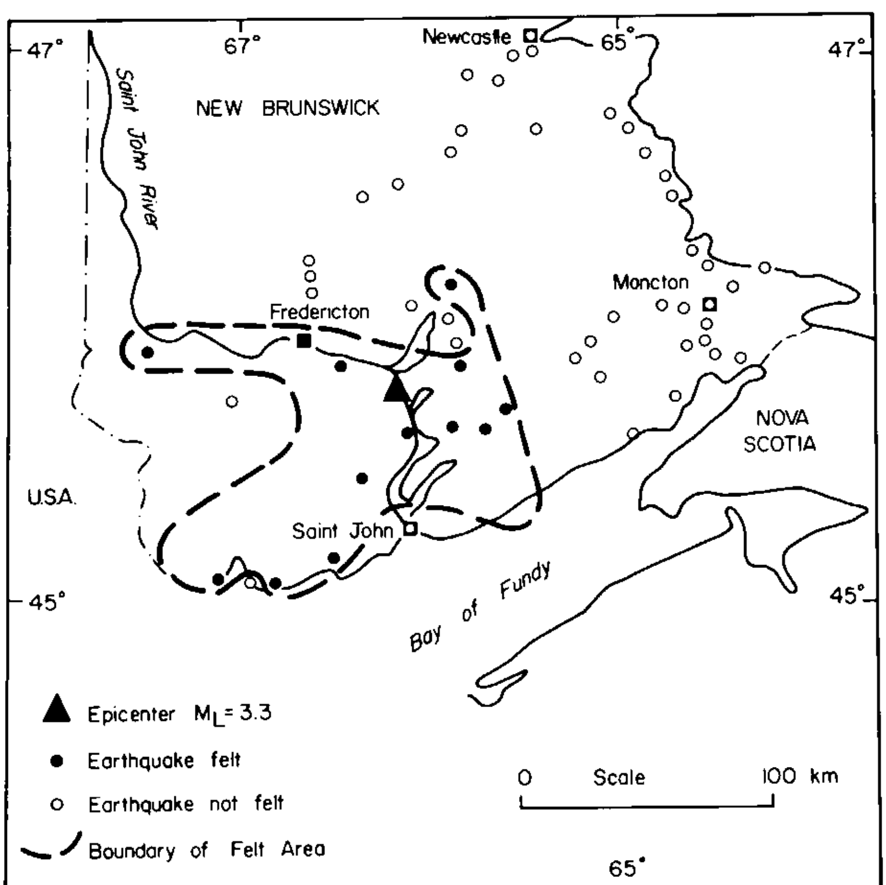

Figure 3 *Felt area map for August 8th, 1970 earthquake in Brunswick (based on Horner* et al.*, 1975)*

Regions of Major Seismicity in the Maritime Provinces

Although epicenters are scattered throughout most of the Maritime Provinces and offshore areas, there are four known major regions where earthquakes occur more frequently and have been of a size to be potentially damaging (See Fig. 1). These four regions are

1) The Grand Banks Region
2) New Brunswick Central Highlands
3) Bay of Fundy
4) Moncton-Dorchester area

The Grand Banks Region. The seismic activity of this region first came to people's attention with the Grand Banks earthquake of November 18, 1929. This earthquake occurred at 20^h 31^m 53^s Greenwich Mean Time (GMT) at a position of approximately 44.5°N latitude and 55.0°W longitude just beyond the continental shelf (Doxsee, 1948). A surface wave magnitude of 7.2 was assigned to the Grand Banks earthquake by Gutenberg and Richter (1954).

Damage caused directly by seismic waves from the Grand Banks earthquake was relatively minor: some chimneys were thrown down or cracked, loose objects were shaken down from shelves and highways were blocked by small landslides, all in Cape Breton. However, the earthquake also caused a tsunami, a large amplitude sea wave which spread out rapidly across the ocean. About $2^1/_2$ hours after the earthquake, a 5 metre-high tsunami struck the southern coast of Newfoundland (Fig. 3) and was responsible for the loss of 27 lives and property damage estimated to exceed a million dollars (Stevens, 1977). The earthquake also caused a submarine landslide and turbidity current that broke 12 trans-Atlantic telephone cables at successively increasing times with distance (Heezen and Ewing, 1952).

Other earthquakes as large as M_L = 5.3 have been reported for the Grand Banks region in succeeding years, confirming its continuing seismic activity. Earthquakes in this region have generally been associated with fault movements in the ocean floor (e.g., Doxsee, 1948; King *et al.*, 1970; Rast *et al.*, 1979.) However, a short note has been published by Gussow (1982) in which it is suggested that excessive loading of sediments, at the mouth of the Laurentian Channel, caused a catastrophic collapse of the sedimentary pile, causing both a submarine landslide and the earthquake shock.

New Brunswick Central Highlands. The importance of earthquake activity in the New Brunswick Central Highlands has been revealed recently by the 1982 Miramichi earthquake and its long aftershock sequence. However, an inspection of the epicenter plot in Figure 1 shows that there have been many smaller earthquakes in this region, particularly when it is realised that most of the earthquakes shown for the Central Highlands represent only the last 10 years, when location of small events became possible with the seismograph network. Prior to this time, a few earthquakes had been reported as being felt in the Bathurst area, with an earthquake on July 2, 1922 causing chimney damage in this community, and one earthquake on January 4, 1930 in the Blackville area, just to the southeast of the Central Highlands, being felt throughout most of the Miramichi valley and having a magnitude of M_L = 4.6 (Smith, 1966).

The 1982 Miramichi earthquake occurred at 8:53 a.m. (AST) on January 9 in the Central Highlands with an epicenter at 46.99°N latitude and 66.62°W longitude (Berry *et al.*, 1982). The main shock was estimated to have a magnitude m_b = 5.7 and was followed by two major after-

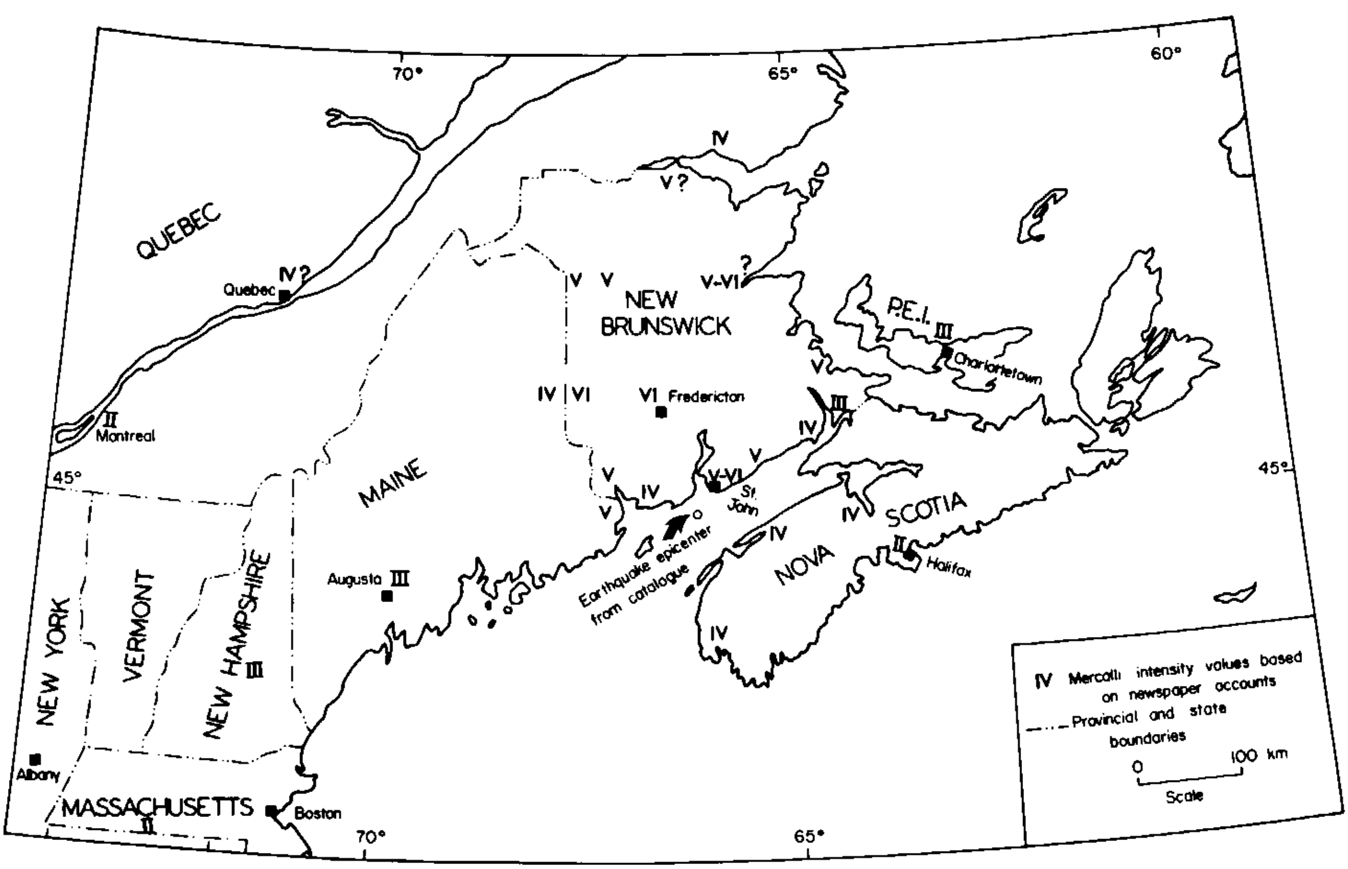

Figure 4 *Map of intensity values for the 1869 earthquake in New Brunswick*

shocks, one of magnitude m_b = 5.1 at 12:36 p.m. (AST) on January 9 and the other of magnitude m_b = 5.4 at 5:41 p.m. (AST) on January 11. A long aftershock sequence has continued with several aftershocks being in the magnitude range 4—5. The epicenters of the aftershocks appear to be confined to a 6 km by 4 km area around the epicenter of the main shock. What is believed to be a separate earthquake of magnitude 4.7 occurred on June 16 with an epicenter about 30 kilometres to the west (Stevens, oral communication, June 18, 1982).

The main shock and two major aftershocks were widely felt throughout the Maritime Provinces, Quebec and the northeastern USA (Berry *et al.*, 1982). Minor damage, mostly in the form of cracked plaster, was reported from several communities in New Brunswick and Maine. The epicentral region is underlain by igneous rocks, granite and diorite, intruded into older metasedimentary and igneous rocks. No major fault has been mapped in the area, although more detailed geological mapping over the summer months has revealed two shear zones with a northwest to southeast trend (Fyffe, 1982). One fresh crack with a 2cm displacement has been found in a small diorite outcrop. A preliminary analysis of seismic records has suggested a thrust mechanism in the upper part of the crust as a possible cause of the earthquake sequence, although this is a subject of continuing investigation.

Bay of Fundy. Earthquakes in the Bay of Fundy region tend to cluster in two main groups (Fig. 1):
1)Along the western edge of Passamaquoddy Bay
2)Along an approximate NNE-SSW trend through Saint John.

1) Passamaquoddy Bay area
Passamaquoddy Bay has been identified by Barosh (1981) as a seismically active area with more than 50 earthquakes having been reported since 1870. After a network of three seismograph stations was installed in the southeastern part of Maine in 1975, an average of 7 earthquakes per year have been recorded with a magnitude range of 1.0—3.2. The largest historically reported event was on March 21, 1904, when an earthquake with an estimated magnitude of 5.1 (Rast *et al.*, 1979) overthrew chimneys at St. Stephen, N.B. and Eastport, Maine, and was felt throughout the Maritime Provinces and northern New England (Smith, 1962). The epicenter was placed at 45.0°N and 67.2°W.

If epicenters are plotted on a geological map of the Passamaquoddy Bay area, a correlation is suggested between earthquakes and the Oak Bay Fault (Rast *et al., op. cit.;* Fig. 1). This north to northwest trending fault offsets rock units with the predominant regional strike direction of northeast to southwest and shows a major discontinuity in those aeromagnetic and gravity maps that reflect regional structure. Whether active movement is still occurring along this fault is under study at the moment. Newman (1979) reports that he observed no signs of Pleistocene—Holocene movement along the Oak Bay Fault zone. The trend of a Triassic (?) dyke near to St. Andrews appears not to be offset by the fault (Stringer and Burke, in preparation). However, there is evidence of postglacial movement in a borehole section on Campobello Island (McLeod, 1979). Also, Barosh (1981) relates the earthquake activity to a general subsidence of Passamaquoddy Bay with accompanying minor movements on the Oak Bay and other faults in the area.

2)Saint John area
The apparent NNE trend of epicenters in the Saint John area may be false and caused by inaccuracies in determining epicenters from historical records. It has already been mentioned in earlier sections that the 1869 earthquake may be located in Central New Brunswick, rather than in the Bay of Fundy at 45.0°N and 66.2°N as reported in Smith's catalogue (1962). Emphasis on the accounts in Saint John newspapers and lack of access to newspaper accounts from more northerly communities may have biased Smith's estimate of the position of the epicenter for this earthquake. However, instrumentally recorded earthquakes have occurred in the Saint John area, the last one being an earthquake M_L = 2.8 recorded on April 20, 1979 with an epicenter a few miles offshore in the Bay of Fundy. Two other earthquakes of magnitudes 2.7 and 3.1 also were recorded in October of 1975, about 20 km to the southeast of Saint John. There is therefore adequate evidence of a moderate level of seismic activity in this area.

One explanation of this earthquake activity in the Bay of Fundy is minor movements along the part of the Fundy-Coboquid (Glooscap) fault system that parallels the southern New Brunswick coastline (Stevens, 1977). Matthew (1894) proposed post-glacial movement on faults in the Saint John area based on the evidence of offset of glacial striae. Again, as in the Passamaquoddy Bay area, the high rate of submergence of the coast may also be causing reactivation of rift faults at the margins of the Bay.

Moncton Dorchester Region. While the seismic activity in the three previously discussed regions has been confirmed by the occurrence of significant events in more recent times, the identification of the Moncton Dorchester region as one of enhanced seismicity is of a more speculative nature. However, the only New Brunswick earthquake to be included in "The Catalog of Significant Earthquakes 2000 BC-1979" by Ganse and Nelson (1981) is one on February 8, 1855 with an epicenter (46.0°N, 64.5°W) in the Moncton Dorchester area. This earthquake was assigned a magnitude of 5.7 on the figure accompanying Smith's catalogue (1962), but using the felt area criterion this magnitude is reduced to 4.8 (Rast *et al.*, 1979). Again, the position of the epicenter is uncertain but, nevertheless, from contemporary accounts, minor damage was confined to the Moncton Region.

In the last 20 years, 3 earthquakes have been felt in the Moncton Dorchester area, one, on October 19, 1972, having a magnitude M_N = 3.0. Again, the explanation of this infrequent seismic activity may simply be minor reactivation of pre-existing faults. However, another interesting possibility is that the earthquakes are associated with subsurface solution of salt deposits which occur in this region, a mechanism suggested by Horner *et al.* (1978) to explain earthquakes in southern Saskatchewan.

Review of Hypotheses on Causes of Earthquakes in Maritime Provinces

The fundamental cause of most earthquakes is believed to be movements of lithospheric plates in response to change in the earth's thermal regime. Stress accumulations at the edges of plates caused by their slow relative movement are relieved from time to time by the fracture of rocks and the release of energy in the form of an earthquake. An earthquake of this type is called an interplate earthquake. This explanation can hardly be applied to earthquakes in the Maritime Provinces because of the large distance from any known plate margin. In this case, these 'intraplate' earthquakes must be caused by a different mechanism.

Intraplate earthquakes do not occur as frequently as interplate earthquakes and therefore their study is still at a relatively early stage. Because we are considering the interior of the plates, rather than their edges, the relative motion of the plate edges can hardly be a direct cause. However, there are still forces acting within the plates and a stress system may develop in which one of the principal components of stress is significantly greater than the other two. This differential stress is sustained by the inherent strength of the rocks in most places, but in others the accumulated stress is released suddenly by failure and causes an earthquake.

Why an intraplate earthquake occurs at a particular location and time is not yet clear. In eastern North America, including the Maritime Provinces, three main hypotheses or models have been proposed. The first one is that intraplate earthquakes occur along old fault lines that represent zones of weakness in a stronger crust. Yang and Aggarwal (1981) review the evidence for this model and give examples, including the Ramapo fault system in New York and New Jersey, where there is an excellent correlation between epicenters and the individual fault traces. The maximum principal stress component has a horizontal direction of W to WNW throughout most of the Northern Appalachians and movement appears to be taking place on thrust or strike slip faults. The Oak Bay Fault system may be an example of the latter type in the Maritime provinces.

A second hypothesis that may give a better explanation of the Miramichi earthquakes is concentration of the regional stress by plutons in the area. The stress levels can be increased by 20% to 30% if the pluton is cylindrical in shape and stronger than the surrounding rocks, and by more than 200% if the pluton is weaker (Campbell, 1978). The increased stress level can cause fracturing to occur and, hence, an earthquake.

The pluton hypothesis was first proposed by Kane (1976) to explain the association of several earthquakes in eastern North America with mafic plutons and was then used by Simmons (1978) to explain the large historical earthquakes that have occurred in the Boston area and central New Hampshire. Tang and Aggarwal (1981) are critical of this hypothesis because of the much poorer correlation of epicenters and the mafic plutons in question provided by present day networks. They also believe that unfaulted blocks of igneous rocks inhibit, rather than facilitate, the development of conditions for earthquakes to occur. However, the definitive association of epicenters with plutonic rocks in the Miramichi area suggest that this hypothesis requires further evaluation.

The third hypothesis to be considered is that earthquakes are associated with the up and down movements of the earth's crust caused by the removal of the Pleistocene ice sheet. Stein *et al.* (1979) have used the unloading effects of deglaciation to explain earthquakes that occur along the passive margin of Eastern Canada, including the 1929 Grand Banks earthquake. They propose that the upward flexure of the lithospheric plate caused by the removal of the ice sheet results in extensional stresses in the upper part of the crust below the previously glaciated area. The downward movement in the seaward direction causes compressive stresses. These stresses lead to reactivation of basement faults and the resultant earthquakes. Focal mechanism studies of seven earthquakes in the Baffin Bay and Labrador Sea areas support this proposed model. The earthquakes seaward of the 1000 m seabottom contour show the thrust faulting that one expects to be associated with a compressive stress regime, while the landward earthquakes show the primarily normal faulting of an extensional stress regime.

As already mentioned, Barosh (1981) has suggested that earthquakes in the Passamaquoddy Bay area may be related to subsidence of the area reactivating the faults of the Oak Bay system. Relevelling surveys have indicated that the rate of subsidence of Passamaquoddy Bay relative to Bangor, Maine, is 9 mm/year.

Another interesting possible explanation for the 1982 Miramichi earthquakes is that they are related to the high rate of uplift in this region. The most recently published map of contemporary vertical crustal movement, by Lambert and Vanicek (1979), shows an uplift rate of about 80 cm/century for the Miramichi epicentral region, but control points in central New Brunswick are scarce and more work is required to reduce the uncertainty in this estimate.

Conclusion

From this review of earthquake activity in the Maritime Provinces, it is seen that it is a region of moderate seismicity. The historical records do show that earthquakes of sufficient magnitude to cause damage have occurred in the past, but so far they have been centred in places remote from more populated areas. It is essential that the earthquake-prone areas are identified more clearly, particularly as we become involved in environmental problems associated with hydroelectric dams, nuclear power plants and other large engineering projects whose failure might have serious consequences.

In 1981 the Eastern Canada Telemetered Network (ECTN) was extended into the Maritime Provinces by installation of vertical component, digitally recording seismographs at Edmundston, St. George and Caledonia Mountain in New Brunswick. After the January 1982 earthquakes in central New Brunswick an additional telemetric station was established at McKendrick Lake. This extension of the ECTN network of seismographs into the Maritime Provinces will do much to allow us to fill the gap in our knowledge of low level seismicity. The continuing study of the 1982 Miramichi earthquake should also provide us with a clearer understanding of the mechanisms by which earthquakes in this part of the world occur. It is hoped that the results of these studies will determine the true level of earthquake risk in our region and perhaps even allow us to predict future large earthquakes.

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