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The Seismicity of Maine

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ABSTRACT

The earthquake activity of Maine appears to be similar to that of other parts of the Appalachian province. The recent seismicity is generally occurring in the same areas which were active historically. Eastern, central, coastal, and western Maine have most of the earthquakes and are the areas where the largest known events have occurred. Return times estimated from recent instrumental data for earthquakes of magnitudes 5, 6, and 7 are about 50 years, 350 years, and 2600 years, respectively, in the state. While the earthquakes probably are caused by reactivations of old zones of weakness in the present plate tectonic stress field, no individual faults or other structural features have been confirmed to be seismically active.

INTRODUCTION

Earthquake activity in the State of Maine is quite typical of that in the northern Appalachian region of northeastern North America as well as of that from other intraplate regions at passive continental margins. The seismicity in the state is characterized by a relatively low but steady rate of earthquake occurrence and by a generally widespread pattern of epicenters, though there are regions in Maine where more localized clusters of events occur. Most of the earthquakes are of small magnitude, although occasional events with more significant sizes, including some that have been damaging, have taken place (Ebel, 1984). Those larger earthquakes have been felt over very wide areas, a characteristic common to events throughout all of eastern North America (Street, 1976).

The causes of the earthquakes in Maine are understood only in the most general sense. While the seismic activity must be related in some way to the past and present tectonic evolution of the North American plate, the particulars concerning the earthquake causes have not been worked out. No surface faulting has been observed in association with modern earthquakes in the state, although this is not surprising given the small and moderate magnitudes of the events which have occurred. Furthermore, there are no clear correlations of the earthquake epicenters with either local or regional geologic features (Anderson and others, 1984; Ebel, 1985). Thus, the identification of those geologic structures which are most prone to future earthquake activity is a speculative exercise at present. Even so, the existence of the persistent earthquake activity is evidence that neotectonic deformations must be occurring in the crust in Maine.

NATURE OF THE EARTHQUAKE RECORD OF MAINE

Written records of historic earthquakes and instrumental recordings of modern events are the two primary sources of information concerning earthquake activity in Maine. A number of catalogs of historic earthquakes from northeastern North America have been assembled, including those of Bloxsom (1975), Brigham (1871), Brooks (1960), Chiburis (1981), Heck and Eppley (1958), Mather and Godfrey (1927), and Smith (1962, 1966). While the original sources for these compilations are newspaper reports, diary and journal entries, scientific publications and unpublished written records, many of those who put together the later catalogs of earthquakes relied heavily on

the earlier published lists. There are probably many errors, both of commission and of omission, in these published compilations. Recent efforts to verify and improve these catalogs have been made by Nottis (1983), Silverman (personal communication, 1984), and Smith and others (this volume). These investigators have uncovered a number of historic earthquakes not included in any of the published catalogs, and Nottis (1983) has also determined that some events included in the catalogs either were not earthquakes or did not exist at all.

There may be a substantial error associated with the epicenters of some of the historic earthquakes, since the pinpointing of the location depends upon identifying the locality where the strongest shaking was experienced. This is obviously a tenuous process in areas of low population density. Chinnery and Rogers (1973) estimated that historic earthquake locations could be in error by 20 km or more. The sizes of the events can be estimated from the maximum epicentral intensity (Chiburis, 1981) or the felt area (Street and Lacroix, 1977). In either case, the population distribution and density play an important role in determining the error in the estimation of event sizes.

While instrumental monitoring of seismicity began in northeastern North America shortly after the turn of the century, the earliest seismic station installed in Maine was operated near East Machias from 1932 to 1940 by the Massachusetts Institute of Technology (Poppe, 1980). Colby College installed a seismograph in 1951, primarily for teaching purposes (Poppe, 1980). In the early 1960's, Weston Observatory of Boston College installed stations at East Machias (EMM), Milo (MIM), and Caribou (CBM) in Maine, and Teledyne Geotech installed LRSM stations for the VELA-Uniform project at Bangor (BGME) and Houlton (HNME). By 1968, funding had ended for almost all of these stations and only the Houlton site remained operative. In the mid-1970's, the modern regional seismic network was installed by Weston Observatory, with a maximum of 18 stations being operative in the state around 1980. The present configuration of the network in Maine is shown in Figure 1. The data from these stations are presently being telemetered to Weston Observatory in Weston, Massachusetts, where they are combined with other regional data before being scanned for all earthquake activity.

All of the earthquake epicenters computed using this modern network are accurate to within 10 km and many are within 5 km of the true location (Ebel, 1984). While depths are less well constrained, they probably all lie within 15 km of the earth's surface and many are probably much shallower (Ebel, 1984). The magnitudes are well determined for these modern events (Ebel, 1985). Reports on the present seismicity are published in the quarterly Northeastern U.S. Seismic Network (NEUSSN) bulletins by Weston Observatory. From 1935 to 1950, epicenters of regional earthquakes, including those from Maine, were published also at Weston Observatory by the Northeastern Seismic Association (NESA). No magnitudes were computed by NESA, and epicenters are probably accurate only to within 10 km for the events located by NESA in Maine.

HISTORICAL SEISMICITY

The record of earthquake activity in Maine prior to the mid-1800's is very sparse. Undoubtedly this was due to the small population of the state and the paucity of original records available from that time period (Leblanc and Burke, 1985). By the end of the 1800's the earthquake record becomes more extensive and therefore more complete. About 200 earthquakes are known to have taken place in Maine before 1975 when the NEUSSN began its reporting. Several of these were of sufficient strength to cause some damage, primarily to chimneys, glass, etc., near the epicenters. The largest earthquake recorded in Maine to date occurred on March 21, 1904, and was centered in easternmost Maine near the town of Eastport (Reid, 1911). It caused Modified Mercalli intensity VII shaking at towns near the epicenter, and it was felt throughout the entire state. Leblanc and Burke (1985) have argued that the October 22, 1869 earthquake, reported by Chiburis (1981) to have been in the Bay of Fundy, also occurred in this same area and had a maximum epicentral Modified Mercalli intensity of VI. Leblanc and Burke (1985) have estimated the L_g wave magnitudes (see Nuttli, 1973, for a definition of this magnitude scale) of the 1904 and 1869 events

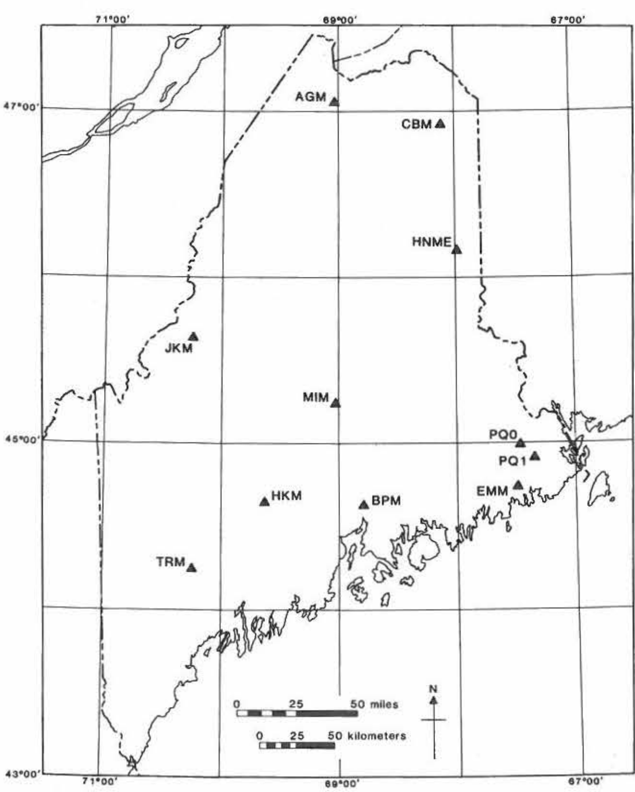

Figure 1. Map showing locations of Weston Observatory New England Seismic Network stations in Maine. Station codes are: AGM - Allagash; BPM - Bucksport; CBM - Caribou; EMM - East Machias; HKM - Hinckley; HNME - Houlton; JKM - Jackman; MIM - Milo; PQ0 - Cooper Hill; PQ1 - East Ridge; TRM - Turner

to have been $m_{blg} = 5.9$ and $m_{blg} = 5.7$ respectively. Earthquakes in Maine with Modified Mercalli intensity VI shaking at the epicenters occurred near: Lewiston on December 23, 1857 (estimated $m_{blg} = 3.8$); Sabbatus on July 15, 1905 (estimated $m_{blg} = 4.6$); Eastport on December 11, 1912; Bridgton and Norway on August 21, 1918; Milo on February 8, 1928; Houghton on October 5, 1949 ($m_{blg} = 4.4$); Portland on April 26, 1957 ($m_{blg} = 4.7$); and the New Hampshire-Quebec-Maine border on June 15, 1973 ($m_{blg} = 4.8$). Many of these larger earthquakes were accompanied by some aftershocks, as were some of the smaller historical events. Foreshocks, multiple main shocks, and swarms of earthquakes also show up in the historic record. A notable swarm of earthquakes took place near Augusta, Maine, on July 1, 1967. The largest event in this swarm had a magnitude of 3.4.

RECENT SEISMICITY

Since the inception of modern seismic instrumental monitoring in 1975, all earthquake activity down to magnitude 2 has been recorded (Ebel, 1984), and in many areas the completeness threshold may be as low as magnitude 1.5. During that time period the most significant earthquakes in Maine occurred near: Bath on April 18, 1979 ($M_c = 4.0$; maximum Modified Mercalli intensity V); Dixfield in 1983 ($M_c = 4.4$; maximum Modified Mercalli intensity V); and Machias in 1984 ($M_c = 3.6$). (M_c is a magnitude scale based on the duration of the coda waves of an earthquake. It is defined in the NEUSSN bulletins and is calibrated to be equivalent to the m_{blg} magnitude scale.) None of these earthquakes caused damage, but all were widely felt throughout the state. The 1984 event was one of five events with magnitudes greater than 3.0 which took place in the area west of Passamaquoddy Bay in eastern Maine. This widespread swarm represented one of the largest releases of seismic energy in Maine during the recent monitoring period. The Bath and Dixfield earthquakes were followed by only a few aftershocks each and were studied by Ebel (1983) and Ebel and McCaffrey (1984), respectively. In 1982, a series of earthquakes occurred which were centered in the Miramichi region of New Brunswick. The largest of these shocks, $m_b = 5.7$, was felt throughout the entire state of Maine and caused some minor damage in the eastern part of the state in Aroostook and Washington Counties (Stevens, 1983). The main event was followed by a protracted aftershock sequence of several thousand instrumentally recorded events (Wetmiller and others, 1984). A map of all earthquakes in Maine from 1534 to 1985 is shown in Figure 2.

As has also been noted for the northeastern United States as a whole (Ebel, 1985), the modern instrumentally-recorded earthquakes in Maine are occurring preferentially in the same areas where the highest concentrations of historic seismicity have been recorded. The eastern, central, and southwestern parts of the state show locally high activity in both recent and historic time.

EARTHQUAKE RECURRENCE TIMES

Ebel (1984) published a recurrence curve and mean return times for earthquakes in New England based upon the seismicity between magnitude 2 and 4.5 from October, 1975, through November, 1982. From the New England recurrence relation and the assumption that earthquake activity is relatively evenly spread over the entire region, an earthquake recurrence curve for Maine can be calculated by multiplying the New England recurrence curve intercept by the fraction of the total area of New England represented by Maine. The resulting annualized recurrence curve is

$$\log N \text{ (per year)} = 2.48 (\pm 0.06) - 0.84 (\pm 0.03) M_c \quad (1)$$

where N is the number of earthquakes equaling or exceeding magnitude M_c in a given year. This can be compared to the recurrence curve derived from seismicity within the state of Maine for the time period from October, 1975, through June, 1986, which is

$$\log N \text{ (per year)} = 2.79 (\pm 0.029) - 0.89 (\pm 0.014) M_c \quad (2)$$

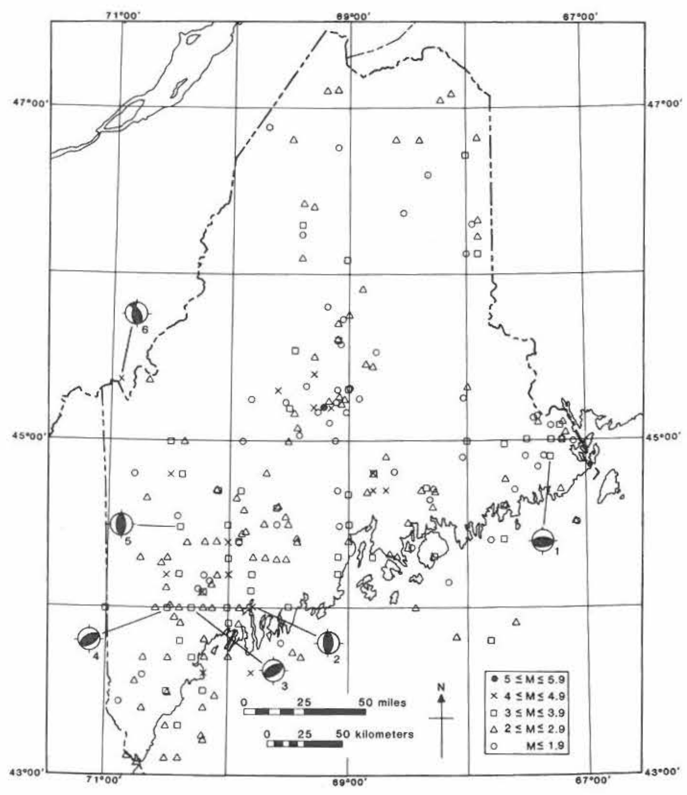

Figure 2. Map showing the locations of earthquakes that occurred in Maine during the period 1534-1985. Also shown are focal mechanisms for some of the larger recent events: 1 - January 19, 1984; 2 - April 18, 1979; 3 - October 29, 1978; 4 - January 4, 1978; 5 - May 29, 1983; 6 - January 15, 1973. The focal mechanisms are lower hemisphere projections with the compressional quadrant black

By linear extrapolations of these relations to larger magnitudes, the mean return times of larger earthquakes in the state can be estimated (Table 1). The similarity of the return times for these two different, but overlapping, data sets suggests that the rate of earthquake occurrence in Maine is similar to that in New England as a whole. The return times also indicate that a potentially damaging earthquake of magnitude 5.0 or greater might be expected to recur in Maine approximately once every 50 years. The specific locations of the events used in the recurrence curve analysis have been ignored. Therefore, the values in Table 1 are appropriate for earthquakes occurring anywhere within the state and do not represent the return times at a particular locality. Also, the accuracy of the values in Table 1 depends upon the appropriateness of the extrapolation of the 1975-1982 data set to longer time periods and larger magnitudes. Ebel (1984) has given arguments to justify this extrapolation, although he also pointed out that the time period used to compute these recurrence curves may have been more seismically active than the longer-term average. Thus, it is possible that the return times in Table 1 underestimate the actual mean return times for larger events.

TABLE 1. ESTIMATED RETURN TIMES FOR EARTHQUAKES IN MAINE.

Magnitude	4.6	5.0	5.5	6.0	6.5	7.0
Return Time (in yrs.) from equation (1)	24 ± 5	52 ± 11	138 ± 31	363 ± 87	955 ± 244	2512 ± 678
Return Time (in yrs.) from equation (2)	20 ± 2	46 ± 5	127 ± 13	355 ± 42	989 ± 119	2754 ± 350

EARTHQUAKE SPATIAL PATTERNS

It is obvious from an inspection of Figure 2 that the seismicity is not spread uniformly across the state but that there are areas of locally higher activity. In particular, the coastal areas, the western part of the state, and an area in the center of the state near Dover-Foxcroft have been regions with relatively more seismicity and where the largest earthquakes to date have been recorded. Ebel (1984) noted that the embayments along the coast, Passamaquoddy Bay, Penobscot Bay, and Casco Bay, have experienced persistent and relatively more significant seismicity in both historic and more recent times (Figure 3). However, even the more remote northern part of the state has not been totally free of earthquake epicenters, especially since the modern seismic network became operational. Earthquakes too small to be felt, or with epicenters away from population centers, have been detected and located in this region by the modern network. It is quite likely that the historic seismicity of this part of the state is highly underestimated due to its remoteness and sparse population. Thus, the entire state appears to be susceptible to at least minor earthquake activity.

RELATIONSHIP OF SEISMICITY WITH STRUCTURE

The spatial variations in the occurrences of earthquakes in Maine suggests that there may be some controlling relationship between the earthquake activity and geologic or tectonic structures. However, when examined on a finer scale, no strong correlation between the seismicity and any particular structure can be found. The earthquakes do not tend to follow the major faults in the state, nor do they preferentially concentrate along known or proposed tectonic boundaries. The area of active major subsidence reported by Anderson and others (1984) in eastern Maine at Passamaquoddy Bay does have seismicity associated with it, including the 1869 and 1904 earthquakes noted above. However, the earthquakes recorded by the modern seismic network are spread throughout the subsiding area (Figure 4) and do not appear to correlate with any of the locally mapped faults. Furthermore, Reilinger and others (1986) have argued that the subsidence rate there is much smaller than that claimed by Anderson and others (1984), thus calling into question the apparent relationship between a strong local deformation and earthquake activity.

Detailed analyses of the locations of the April 18, 1979, M_c = 4.0, Bath earthquake (Ebel, 1983) and the May 29, 1983, M_c = 4.4, Dixfield earthquake yielded ambiguous correlations between the earthquake epicenters and locally mapped faults. In the case of the Bath earthquake, Ebel (1983) noted that the main shock epicenter was quite close to the Phippsburg Fault inferred by Hussey (1981) but that the aftershocks were located on a strand of the Cape Elizabeth Fault. The focal mechanism of the main shock, which showed east-west compression on a north-south fault plane, is at odds with the strike of the Cape Elizabeth Fault but consistent with the trend of the Phippsburg Fault (Figure 5; see Figure 2 for the focal mechanism). The main shock and aftershocks of the Bath, Maine, earthquake cannot be clearly ascribed to either the Phippsburg Fault or Cape Elizabeth Fault but are more consistent with the location and trend of the Cape Elizabeth Fault. In the case of the Dixfield event, the well-resolved location of an aftershock coincided closely with the hypocenter of the main shock, verifying the main shock location (Figure 6; Ebel and McCaffrey, 1984). This location does not place the events on any mapped geologic fault, although Ebel and McCaffrey (1984) note that the shocks may be indicative of an unmapped fault at the main shock epicenter (Figure 6; see Figure 2 for the focal mechanism).

CAUSES OF EARTHQUAKE ACTIVITY IN MAINE

While a number of different mechanisms have been proposed to explain the causes of earthquakes in eastern North

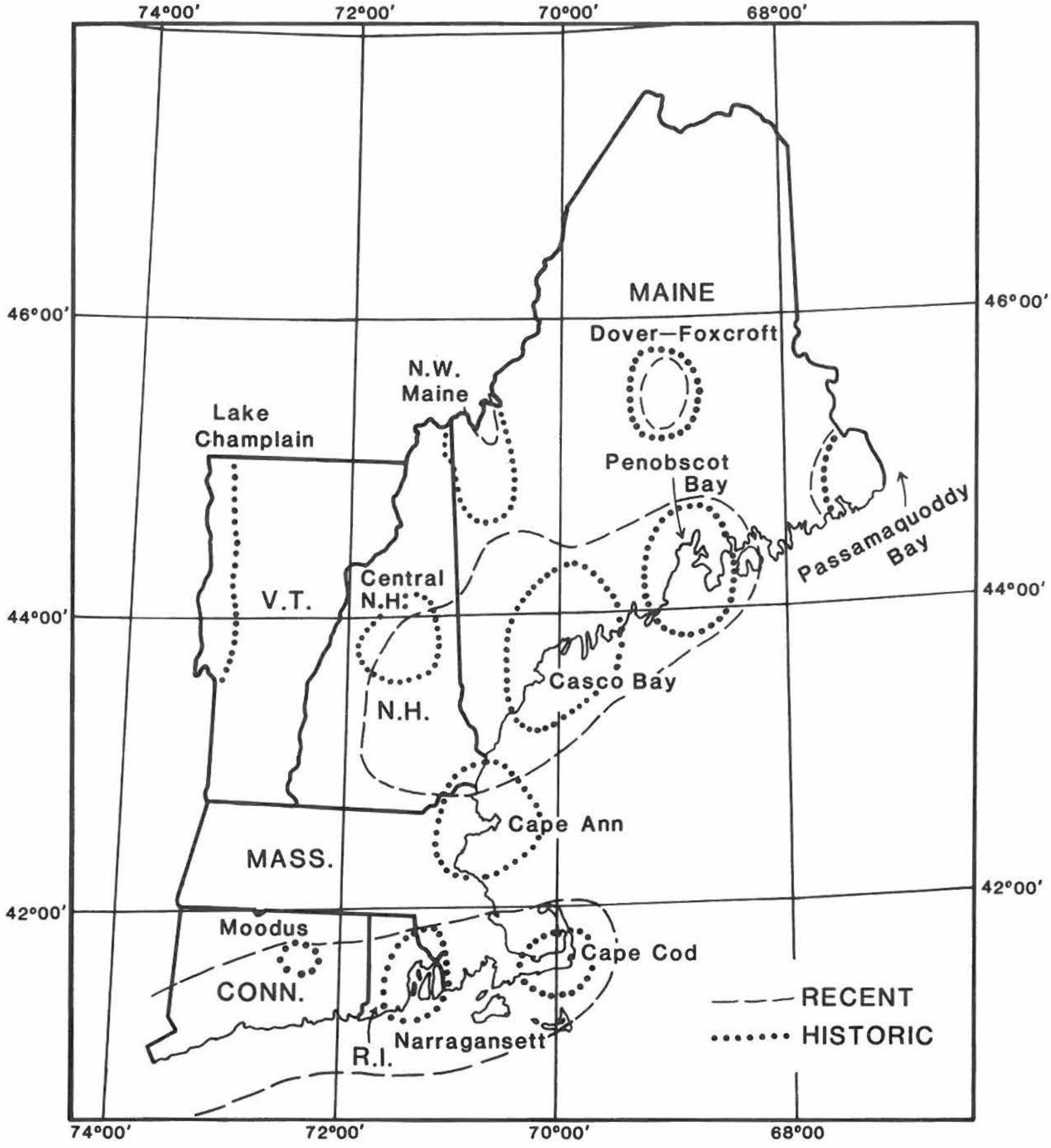

Figure 3. Map showing interpreted areas of significant earthquake activity in New England (modified from Ebel, 1984).

America, most of these rely on the present configuration of plate motions as the major source of regional stress. The simplest idea to explain this intraplate seismicity is that the present plate tectonic stress field is reactivating pre-existing zones of weakness in the crust (Sykes, 1978). The Appalachian region of northeastern North America is riddled with numerous large and small-scale faults due to past episodes of tectonic rifting and convergence (Bird and Dewey, 1970; Keppie, 1985; Sykes, 1978). These faults are preserved in the crust today, and perhaps some of them are being reactivated in the modern stress field. Campbell (1978) and Kane (1977), on the other hand, argued that plutonic bodies could concentrate stress near their edges if they lie in a regional stress field. Stein and others (1979) claimed that postglacial rebound may account for some northeastern North American seismicity, while Chase (1979) proposed that asthenospheric counterflow could explain intraplate seismicity. These and other causes of eastern seismicity are discussed by Zoback and Zoback (1981).

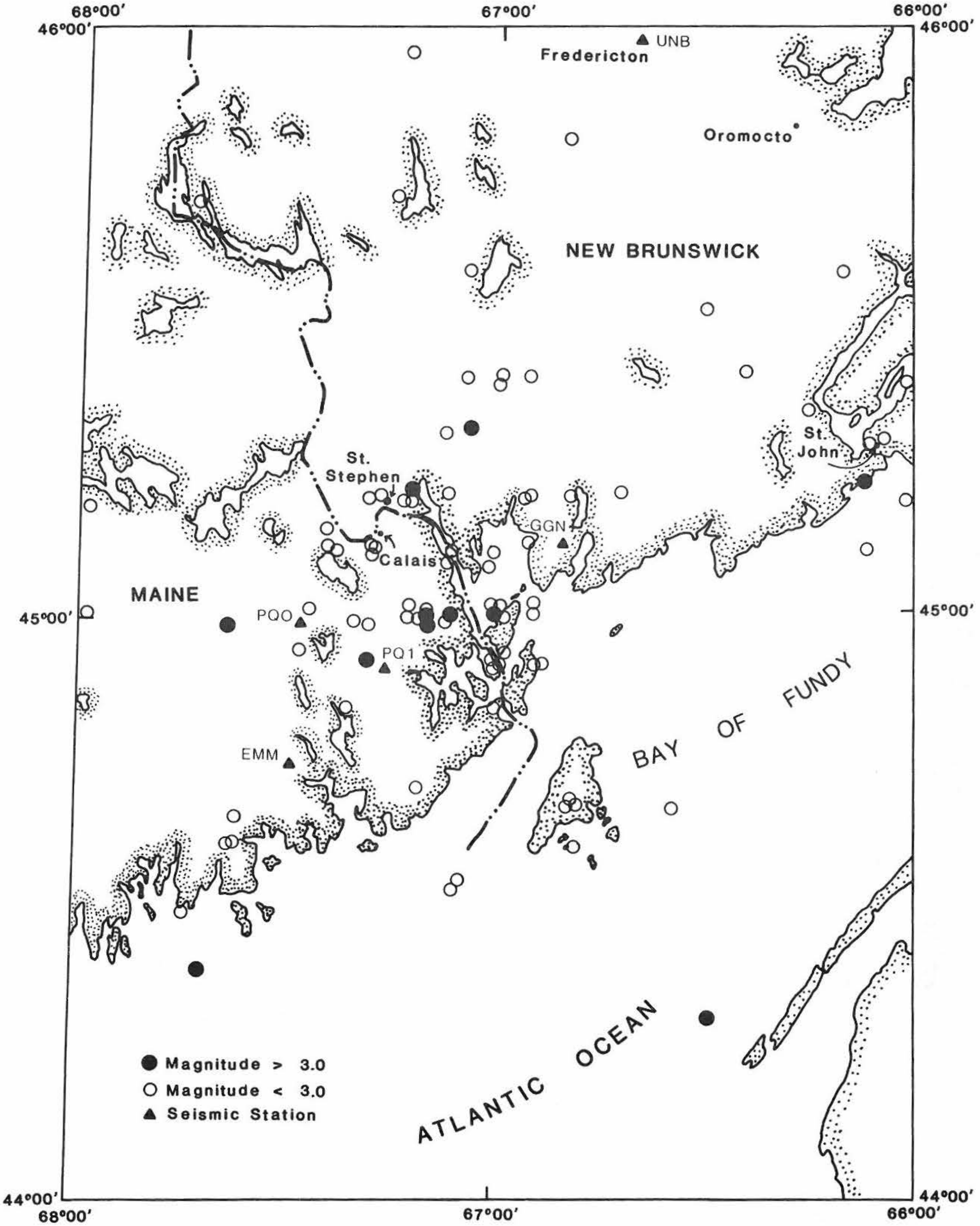

Figure 4. Map of all known seismicity in easternmost Maine and southwestern New Brunswick. The triangles denote the locations of seismic stations.

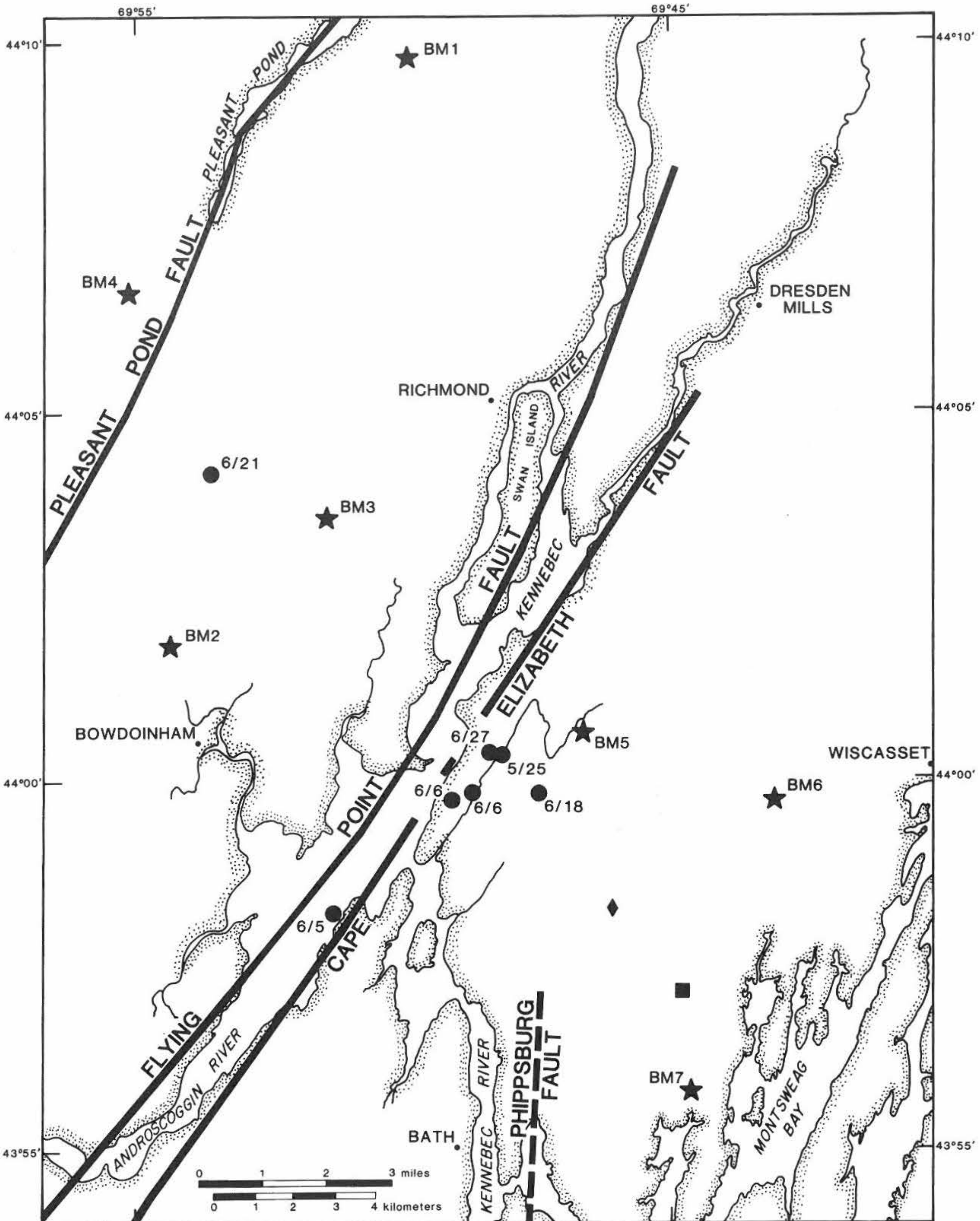

Figure 5. Aftershocks (circles) and possible main shock locations (diamond and square) for the April 19, 1979, Bath, Maine earthquake, from Ebel (1983). Stars indicate portable seismic station locations. The geology is from Hussey (1981).

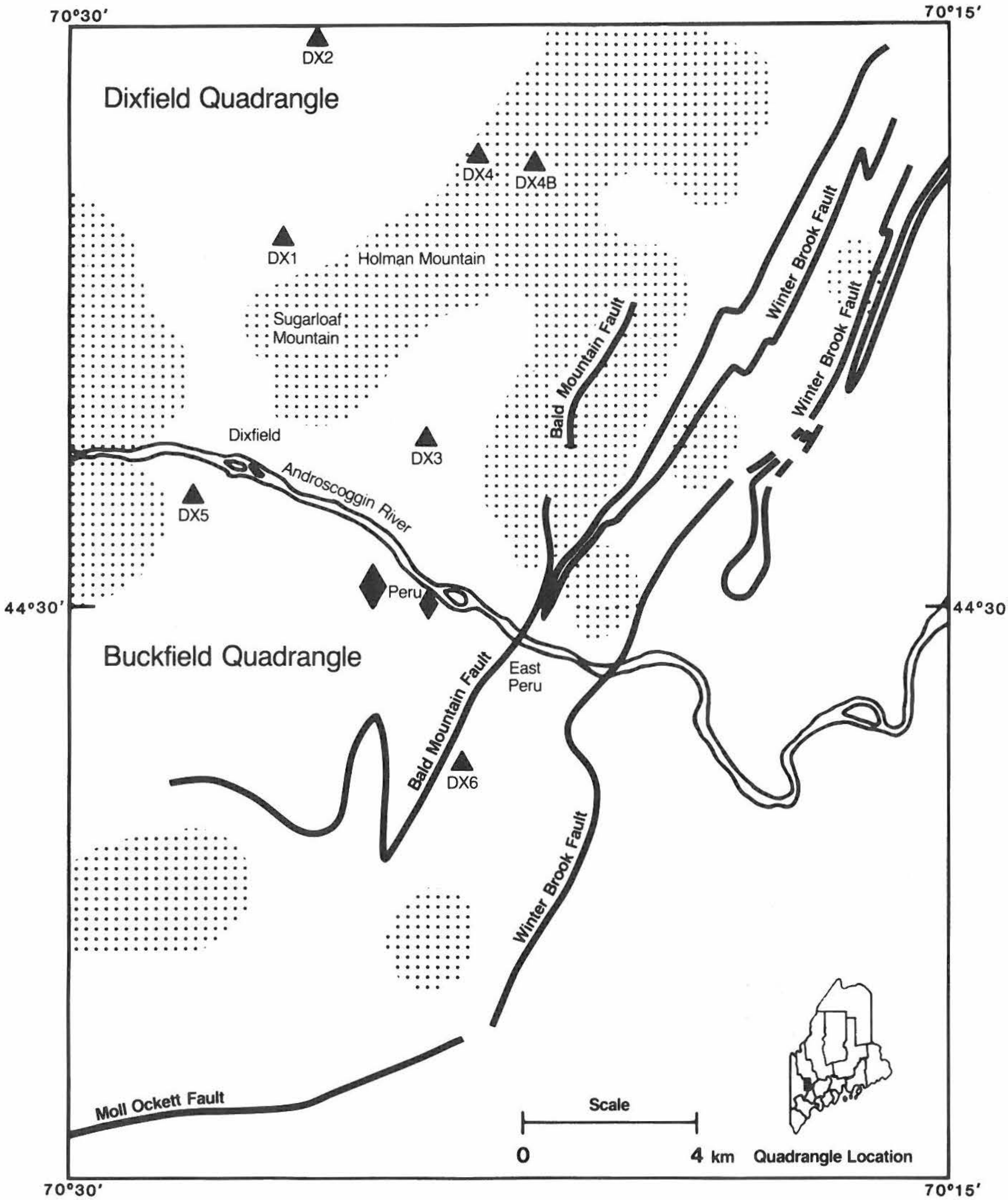

Figure 6. Main shock (large diamond), aftershock (small diamond), and portable seismic station locations (triangles) for the May 29, 1983, Dixfield, Maine earthquake. The stippled areas indicate locally elevated topography. This figure is from Ebel and McCaffrey (1984).

The orientation of the stress field in Maine as well as throughout New England provides the strongest constraint upon the possible models to explain the cause of the earthquakes in the state (Figure 2). Graham and Chiburis (1980) and Pulli and Toksoz (1981) presented a number of focal mechanisms of earthquakes in New England. Other focal mechanisms have been published by Ebel (1985). Gephart and Forsyth (1985) showed that all of the New England focal mechanisms, while displaying a great deal of scatter, are statistically consistent with an east-west to northeast-southwest oriented maximum compression. This maximum stress direction was also found by Lee (this volume) for the Passamaquoddy Bay area from borehole stress measurements. However, this maximum stress direction near Passamaquoddy Bay conflicts with a north-south oriented maximum stress reported by Foley and others (1984) and Ebel (1985) for an earthquake in that area. The hypocenter for that earthquake was about 12 km deep, whereas the borehole measurements reported by Lee (this volume) were taken at depths of 0.95 to 6.4 m. It is not clear why there is such a strong difference between the stress directions found from the surface stress measurement and the deeper earthquake focal mechanism at this locality.

The average orientation of the regional stress field closely matches that predicted from present plate motions (Richardson and others, 1979; Yang and Aggarwal, 1981). This strongly supports the notion that structures are being activated or reactivated in the present stress field. However, there is no strong correspondence between the earthquakes and plutons, nor do the well-located earthquakes identify any particular faults which are being reactivated. Thus, further data are needed to answer these questions and to more clearly define the causes of the seismicity in the region.

CONCLUSIONS

The present earthquake activity in Maine is widespread and occurring at a low but steady rate. Larger and locally damaging earthquakes have occurred in the past and are likely to occur in the future. The areas most prone to strong earthquakes are the western part of the state, the coastal areas in general and the embayments in particular, and the central part of the state. No relationship between the seismicity and either local or regional geologic structures has been found, although the most likely cause of the seismicity is the activation or reactivation of structures in the present plate tectonic stress field.

REFERENCES CITED

Anderson, W. A., Kelley, J. T., Thompson, W. B., Borns, H. W., Jr., Sanger, D., Smith, D. C., Tyler, D. A., Anderson, R. S., Bridges, A. E., Crossen, K. J., Ladd, J. W., Andersen, B. G., and Lee, F. T., 1984, Crustal warping in coastal Maine: Geology, v. 12, p. 677-680.

Bird, J. M., and Dewey, J. F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian Orogen: Geological Society of America Bulletin, v. 81, p. 1031-1060.

Bloxsom, H., 1975, The seismicity of Maine: Honors Thesis, Bowdoin College, Brunswick, Maine, 90 p.

Brigham, W. T., 1871, Historical notes on the earthquakes of New England 1638-1869: Memoirs of the Boston Society of Natural History, v. II, p. 1-28.

Brooks, J. W., S. J., 1960, A study in seismicity and structural geology, Part III - Earthquakes of northeastern United States and eastern Canada: Bulletin of Geophysics College Jean-de Breuf, no. 7.

Campbell, D. L., 1978, Investigation of the stress-concentration mechanism for intraplate earthquakes: Geophysical Research Letters, v. 5, p. 477-479.

Chase, C. G., 1979, Asthenospheric counterflow: a kinematic model: Geophysical Journal of the Royal Astronomical Society, v. 56, p. 1-18.

Chiburis, E. F., 1981, Seismicity, recurrence rates and regionalization of the northeastern United States and adjacent southeastern Canada: Report for U.S. Nuclear Regulatory Commission, NUREG/CR-2309.

Chinnery, M. A., and Rogers, D. A., 1973, Earthquake statistics in southern New England: Earthquake Notes, v. 44, p. 89-103.

Ebel, J. E., 1983, A detailed study of the aftershocks of the 1979 earthquakes near Bath, Maine: Earthquake Notes, v. 54, no. 4, p. 27-40.

__________, 1984, Statistical aspects of New England seismicity from 1975 to 1983 and implications for past and future earthquakes: Seismological Society of America Bulletin, v. 74, p. 1311-1330.

__________, 1985, A study of seismicity and tectonics in New England: U.S. Nuclear Regulatory Commission Final Report, NUREG/CR-4354.

Ebel, J. E. and McCaffrey, J. P., S. J., 1984, The Mc=4.4 earthquake near Dixfield, Maine: Earthquake Notes, v. 55, p. 21-24.

Foley, J. E., Ebel, J. E., and Kafka, A. L., 1984, Recent and historic seismicity of southeastern Maine: Abstracts of the Canadian Geophysical Union meeting, Halifax, Nova Scotia, p. 65.

Gephart, J. W., and Forsyth, D. W., 1985, On the state of stress in New England as determined from earthquake focal mechanisms: Geology, v. 13, p. 70-72.

Graham, T., and Chiburis, E. F., 1980, Fault plane solutions and the state of stress in New England: Earthquake Notes, v. 51, p. 3-12.

Heck, N. H., and Epply, R. A., 1958, Earthquake history of the United States -Part I: United States Coast and Geodetic Survey, publication no. 41-1, Washington, D.C.

Hussey, A. M., II, 1981, Bedrock geology of the Lower Androscoggin Valley - Casco Bay area, Maine: Augusta, Maine, Maine Geological Survey, Open-File Report 81-29, 25 p.

Kane, M. F., 1977, Correlation of major eastern earthquake centers with mafic/ultramafic basement masses: U.S. Geological Survey Professional Paper 1028-0, p. 199-204.

Keppie, J. D., 1985, The Appalachian collage, *in* Gee, D. G., and Sturt, B. A., eds., The Caledonide Orogen - Scandinavia and related areas: John Wiley and Sons Ltd., p. 1217-1226.

Leblanc, G., and Burke, K. B. S., 1985, Re-evaluation of the 1817, 1855, 1869, and 1904 Maine-New Brunswick area earthquakes: Earthquake Notes, v. 54, no. 4, p. 107-124.

Mather, K. F., and Godfrey, J., 1927, The earthquake record in New England: Unpublished paper presented to the Eastern Section of the Seismological Society of America.

Nottis, G. N., 1983, Epicenters of northeastern United States and southeastern Canada, onshore and offshore; Time period 1534-1980: New York State Geological Survey, New York State Museum, Map and Chart Series Number 38.

Nuttli, O. W., 1973, Seismic wave attenuation and magnitude relations for eastern North America: Journal of Geophysical Research, v. 78, p. 876-855.

Poppe, B. B., 1980, Directory of world seismograph stations, Volume 1: Americas-Part 1. United States, Canada, Bermuda: World Data Center A for Solid Earth Geophysics, NOAA, Boulder, Colorado.

Pulli, J. J., and Toksoz, M. N., 1981, Fault plane solutions for northeastern United States earthquakes: Seismological Society of America Bulletin, v. 71, p. 1875-1882.

Reid, H. F., 1911, The earthquake of southeastern Maine, March 21, 1904: Seismological Society of America Bulletin, v. 1, p. 44-47.

Reilinger, R., Larsen, S., and Krumhansi, P., 1986, Reanalysis of contemporary crustal downwarping of coastal Maine: Earthquake Notes, v. 53, p. 113.

Richardson, R. M., Solomon, S. C., and Sleep, N. H., 1979, Tectonic stress in the plates: Reviews of Geophysics and Space Physics, v. 17, p. 981-1019.

Smith, W. E. T., 1962, Earthquakes of eastern Canada and adjacent areas, 1535-1927: Publication of the Dominion Observatory, Ottawa, v. XXVI, no. 5, Canada Department of Mines and Technical Surveys, p. 271-301.

__________, 1966, Earthquakes of eastern Canada and adjacent areas, 1928-1959: Publication of the Dominion Observatory, Ottawa, v. XXXII, p. 87-121, Canada Department of Mines and Technical Surveys.

Stein, S., Sleep, N. H., Geller, R. J., Wang, Shi-Chen, and Kroeger, G. C., 1979, Earthquakes along the passive margin of eastern Canada: Geophysical Research Letters, v. 6, p. 537-540.

Stevens, A. E., ed., 1983, Miramichi, New Brunswick, Canada earthquake sequence of 1982, A preliminary report: Earthquake Engineering Research Institute, Berkeley, California, 99 p.

Street, R. L., 1976, Scaling northeastern United States/southeastern Canada earthquakes by their Lg waves: Seismological Society of America Bulletin, v. 66, p. 1525-1538.

Street, R. L., and LaCroix, A., 1979, An empirical study of New England seismicity: 1727-1977: Seismological Society of America Bulletin, v. 69, p. 159-175.

Sykes, L. R., 1978, Intraplate seismicity, reactivation of pre-existing zones of weakness, alkaline magmatism, and other tectonism postdating continental fragmentation: Reviews of Geophysics and Space Physics, v. 16, p. 621-688.

Wetmiller, R. J., Adams, J., Anglin, F. M., Hasegawa, H. S., and Stevens, A. E., 1984, Aftershock sequences of the 1982 Miramichi, New Brunswick, earthquake: Seismological Society of America Bulletin, v. 74, p. 621-654.

Yang, J. P., and Aggarwal, Y. P., 1981, Seismotectonics of northeastern United States and adjacent Canada: Journal of Geophysical Research, v. 86, p. 4981-4998.

Zoback, M. D., and Zoback, M. L., 1981, State of stress and intraplate earthquakes in the United States: Science, v. 213, p. 96-104.