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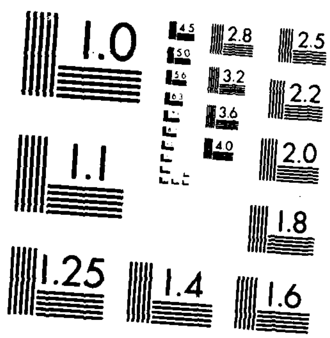

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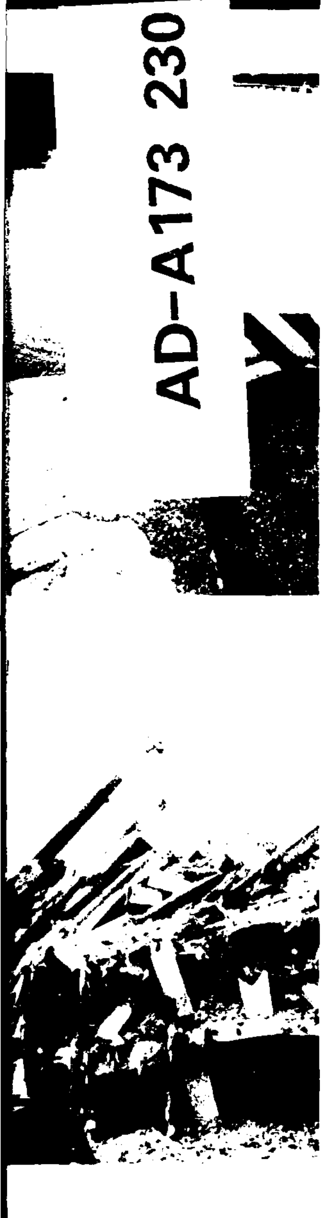

TECHNICAL REPORT GL-86-16

GEOLOGICAL-SEISMOLOGICAL EVALUATION OF EARTHQUAKE HAZARDS AT FRANKLIN FALLS DAMSITE, NEW HAMPSHIRE

by

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Seismic zones were developed for northern New England based on geological and geophysical data and on historic seismicity. Each zone was assigned a floating maximum earthquake and earthquake motions were attenuated to the site from their sources. The site was found to be subject to a local earthquake (acceleration 0.15 g, velocity 27 cm/sec, and duration $\geq$ 0.5 g of 9 sec) and an earthquake originating from the Ossipee area (acceleration 0.38 g, velocity 25 cm/sec, and duration $\geq$ 0.05 g of 6 sec). Accelerograms and response spectra appropriate to these values were selected.

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PREFACE

The US Army Engineer Waterways Experiment Station (WES) was authorized to conduct this study by the US Army Engineer Division, New England. This study was prepared by Dr. E. L. Krinitzsky, Engineering Geology and Rock Mechanics Division (EGRMD), and Mr. J. B. Dunbar, Regional Studies Unit (RSU), Engineering Geology Applications Group (EGAG), EGRMD, Geotechnical Laboratory (GL). A field reconnaissance of the Franklin Falls damsite and vicinity was made by Mr. Dunbar with Dr. P. J. Barosh of Concord, Mass. Mr D. Barefoot, EGRMD, assisted in compiling the data. The project was under the general supervision of Dr. L. M. Smith, Chief, RSU, EGAG, and Mr. J. H. Shamburger, Chief, EGAG, EGRMD, and under the general direction of Dr. D. C. Banks, Chief, EGRMD, and Dr. W. F. Marcuson III, Chief, GL.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

CONTENTS

GEOLOGICAL-SEISMOLOGICAL EVALUATION OF EARTHQUAKE HAZARDS AT FRANKLIN FALLS DAMSITE, NEW HAMPSHIRE

PART I: INTRODUCTION

Purpose and Scope

1. The purpose of this investigation was to define the maximum potential for earthquakes at the Franklin Falls damsite, located in New Hampshire, and to provide appropriate ground motions for earthquake shaking at the dam. These ground motions are for use in the design analysis of the present earth dam and associated structures.

2. This investigation includes both a geological and seismological study and consists of the following parts: (a) an examination of the local and regional geology including an evaluation of faulting, (b) a review of the historical seismicity of the northern New England region, and (c) the determination of the maximum earthquakes that will affect the damsite as well as the attenuated peak ground motions at the damsite.

Study Area

3. The area covered by this study includes that portion of the eastern United States in which earthquakes have occurred that might affect the damsite, roughly a five-state area ranging from New York to Maine, with Massachusetts along the southern boundary and southern Quebec in Canada along the northern boundary. Extremely severe earthquakes, centered outside the study area, were examined on an individual basis to determine their effects, if any, on the damsite.

4. Franklin Falls Dam is located in south-central New Hampshire, approximately 32 km (20 miles) north of Concord, the state's capital. The dam derives its name from the town of Franklin Falls where it is located. Franklin Falls Dam is an earth-and-rock fill dam constructed between 1939 and 1943 on the Pemigewasset River, a tributary to the Merrimack River.

PART II: GEOLOGY

Regional Geology

Tectonic provinces

5. The bedrock geology of the New England region is composed of highly folded and faulted sedimentary, metamorphic, and volcanic rocks of Paleozoic age (570 to 245 million years (M.Y.) before present) and Mesozoic age (245 to 66 M.Y. before present), with numerous unconformable and isolated Precambrian age (before 570 M.Y.) exposures of crystalline basement rock.

6. The state of New Hampshire is characterized by north and northeast trending highly folded metamorphosed sedimentary belts that are occasionally separated by faulting. These metasedimentary belts form a parallel series of distinct topographic ridges, anticlines or anticlinoriums, separated by topographic lows or valleys, synclines or synclinoriums.

7. The Franklin Falls damsite is situated in the approximate central portion of the Merrimack synclinorium (see Figure 1), bounded on the north by the White Mountain Series of volcanic intrusives, on the west by the Connecticut Valley synclinorium and Bronson Hill anticline, and on the south by the Fitchburg Pluton and Rockingham anticlinorium (from Billings, 1955). Mapped faulting is absent at the Franklin Falls damsite, but it is present to the west along the Bronson Hill anticline, to the north along the northern margin of the Ossipee hotspot, and to the south along the northern margin of the Fitchburg Pluton.

Tectonic history

8. The Franklin Falls damsite is located in the northern portion of the Appalachian Mountains. The geology of the northern Appalachians is extremely complex, with a rock record spanning a time frame in excess of one billion years (B.Y.). The stratigraphic record reveals that virtually all rock types are present in this region and outcrop at the surface. These rocks have a broad range of origins and environments of deposition. Rock types range from those found only in the lower crust or upper mantle of the earth, to those formed on the continent, to those formed in the deep ocean basins. It is beyond the scope of this study to examine the tectonic history of this region in detail, but the following summary of events should provide the reader with

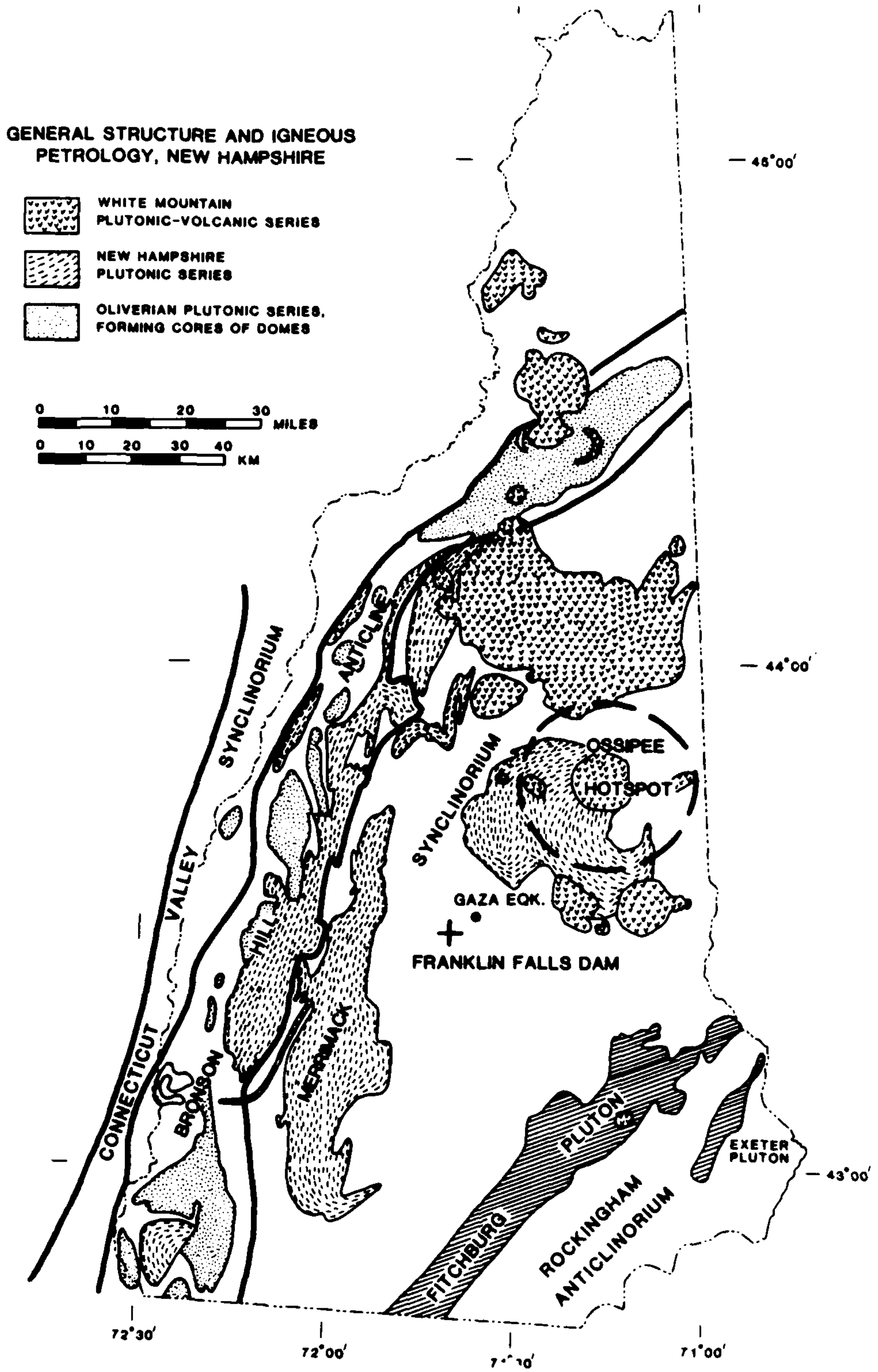


Figure 1. Tetonic provinces of New Hampshire (from Billings, 1955)

an insight into the complexity of the geologic fabric comprising the New England region.

9. The stratigraphic record identifies three major orogenic periods, or mountain building episodes since the Cambrian (beginning 570 M.Y. before the present) along the eastern margin of the North American continent. Each individual orogenic event lasted for a period of well over several tens of millions of years and created vast mountain chains that have subsequently been destroyed or reshaped by the powerful forces of erosion. Thick sedimentary sequences, deposited in elongated depositional basins, mark the former presence of these eroded mountain belts in addition to providing source materials for future periods of mountain building. From these thick sedimentary sequences we obtain our knowledge of the earth's early history as these sedimentary accumulations afford an indirect view of the distant past.

10. The history of the New England states begins with the Precambrian crystalline basement rock. These basement rocks are exposed in the Adirondack Mountains of northeastern New York and in the Green Mountains of Vermont. The continent containing these crystalline basement rocks began to split sometime during the Precambrian, forming an ocean basin that separated the severed continent. The Precambrian and Paleozoic sediments were deposited in and adjacent to this ocean basin, similar to modern deposition along the eastern and southern margin of North America.

11. The early Paleozoic ocean began closing by Middle Ordovician (505 to 435 M.Y. before present) with eventual collision of the continents during the Taconic Orogeny in the Late Ordovician period. The Taconic Orogeny produced large-scale folding, thrust faulting of relatively thin but generally intact crustal slices, metamorphism, and igneous intrusion. In short, the New England region was subjected to intense regional deformation.

12. Stanley and Ratcliffe (1985) concluded in a detailed analysis of the Taconic Orogeny that as much as 1,000 km (625 miles) of crustal shortening occurred in the New England region during this period of mountain building activity. The igneous Ordovician rocks (Oliverian Plutonic Series and Ammonoosuc Volcanics) of the Bronson Hill anticlinorium in western New Hampshire and similar rocks in the Maritime provinces of Canada and Newfoundland appear to be the remains of an island arc complex related to this orogeny. An island arc is formed when crustal plates converge and collide, resulting in one plate being subducted into the interior of the earth and forming an offshore island

with an associated deep oceanic trench. It appears that the Bronson Hill island arc was the leading edge of the plate that collided with the eastern margin of North America during the Taconic Orogeny (Suppe, 1985; and Stanley and Ratcliffe, 1985). The Oliverian Plutonic Series are thought to be a series of deformed subvolcanic plutons.

13. By Middle Silurian (time period beginning at 420 M.Y. before the present), erosion eventually wore down the Taconic Mountain Range and the ocean again transgressed over the eroded continent. The passage of the Taconic Mountain Range from a prominent physiographic feature to a low area transgressed by an ocean is recorded by the thick accumulation of sediment beginning in western New York that is known as the Queenston Delta.

14. The cycle was again repeated in the New England region with the Acadian Orogeny during the Late Devonian Period (375 M.Y. before present). The ocean was expelled as the crustal plates collided. Large-scale deformations were produced during this period of mountain building, that is, folding, faulting, metamorphism, and igneous intrusion. The New Hampshire Plutonic Series is related to this period of orogenic activity. The more prominent types of deformation to occur during this orogeny were large-scale folding and metamorphism. Several different periods of folding are recorded in the Bronson Hill antclinorium. The geologic record for this period of mountain building is defined by the thick sedimentary accumulation beginning in western New York. This thick clastic wedge, the Catskill Delta, records the erosion of the Acadian Mountains with the passing of time.

15. The next large-scale period of deformation that occurred along the eastern continental United States began in the Pennsylvanian Period (320 M.Y. before the present) and ended sometime during the early Permian Period 275 M.Y. before the present), affecting the central and southern Appalachian Mountains in what is known as the Alleghenian Orogeny. The northern Appalachian region did not generally experience any major deformation attributable to this orogeny period. The deformations associated with this orogeny are better displayed by the large-scale folding associated with the sediments of western Pennsylvania, and the igneous intrusion and metamorphism in Rhode Island.

16. The next major event to mark the geologic record in the northern Appalachian region occurs during the Mesozoic age in the Middle to Late Jurassic Period (180 M.Y. before the present) with the opening of the present Atlantic

Ocean. Associated with this opening is the emplacement of the White Mountain Plutonic-Volcanic Series in New Hampshire and adjacent states. This large intrusive series is primarily centered in New Hampshire, representing a group of volcanic calderas that trend in a general north-to-northeasterly direction. This volcanic complex was active during the breakup of the supercontinent Pangea.

17. The last and final chapter in this brief series of events that left its mark on the geologic record of the New England region occurred during the Pleistocene Period (1.6 M.Y. to 12,000 years before the present), when, on several occasions, continental glaciation covered much of North America with massive ice sheet.

18. In New Hampshire, the passing of this glacial period is recorded by the thick accumulations of unconsolidated sediment in the numerous stream valleys and the deposition of distinct or characteristic tills throughout much of the New England region. The Franklin Falls area, transversed by the Merrimack River, was the site of numerous minor and major glacial lakes. Post-glacial rebound analyses on the associated lacustrine sediments from this area indicate that vertical movement of approximately 1.3 to 1.5 m per 1.6 km (4-1/2 to 5 ft per mile) has occurred since the Laurentide ice sheet retreated approximately 9,500 years before the present (Weston Geophysical Research, 1976a).

Local Geology

19. The Franklin Falls Dam is an earth-and-rock dam, trending in a southwest-to-northeast direction. The dam is approximately 518 m (1,700 ft) in length and has a maximum height of 43 m (140 ft) above its streambed. It is located in a narrow reach of the Pemigewasset River Valley, a tributary to the Merrimack River. The Pemigewasset River, in the vicinity of the dam, flows in a narrow bedrock valley filled with unconsolidated sediment that is primarily of glacial origin. At the damsite, the Pemigewasset River is flanked by a steep glacially derived sand-and-gravel terrace that forms the foundation for the left abutment of the dam. The foundation of the dam rests primarily on unconsolidated sediment. Bedrock outcrops along the right abutment and forms the foundation for the spillway and outlet structures. Along the left abutment, the depth to bedrock is in excess of 30 m (100 ft).

20. The unconsolidated sediment underlying the dam is predominantly coarse grained, consisting primarily of stratified sandy silt and silty sand. In addition, these unconsolidated sediments generally contain minor amounts of gravel. It should be noted, however, that a boring drilled near the center of the dam during the initial foundation analysis encountered a 6-m- (20-ft-) thick zone of cobbles and small boulders beginning at a depth of approximately 16.5 m (55 ft).

21. The bedrock underlying the Pemigewasset River and outcropping near the right abutment is a micaceous gneiss and granular mica schist with numerous but minor veins of coarse-grained granite. Detailed boring logs indicate that the bedrock is generally solid with only slight weathering. In addition, a general site inspection of the damsite also revealed a narrow (less than 1 m) andesitic dike that outcrops downstream from the spillway and is orientated roughly parallel to the spillway. On a much larger scale, the bedrock underlying the Franklin Falls Dam is part of the Littleton Formation (Billings, 1955).

22. The Littleton Formation is present throughout much of central New Hampshire and has been defined as a series of Devonian metamorphic sediments believed to have been deformed and metamorphosed during the Acadian Orogeny. The Littleton Formation varies from a schist to a gneiss and displays different metamorphic grades or facies. These metamorphic grades are defined by unique metamorphic minerals formed under different temperature and pressure regimes (i.e., garnet, staurolite, and sillimanite).

23. The stratigraphy of the central New Hampshire area is extremely complex. The rocks in this area have undergone intense deformation and repeated episodes of volcanic or igneous intrusion. The geology of the Franklin Falls damsite and vicinity is presented in Figure 2 with a detailed definition and description of individual rock types presented in Appendix A (from Billings, 1955). It should be noted that several rock or stratigraphic units from the Billings Geologic Map of New Hampshire have been reassigned to different geologic periods based on more recent geologic data. These changes are described below.

24. In general, the stratigraphic succession of the central New Hampshire area consists of the intruded Ordovician Oliverian Plutonic domes, composed primarily of granite, quartz monzonite, and granodiorite. The domes are overlain by the Ammonoosuc Volcanics, a series of metamorphic volcanics in the

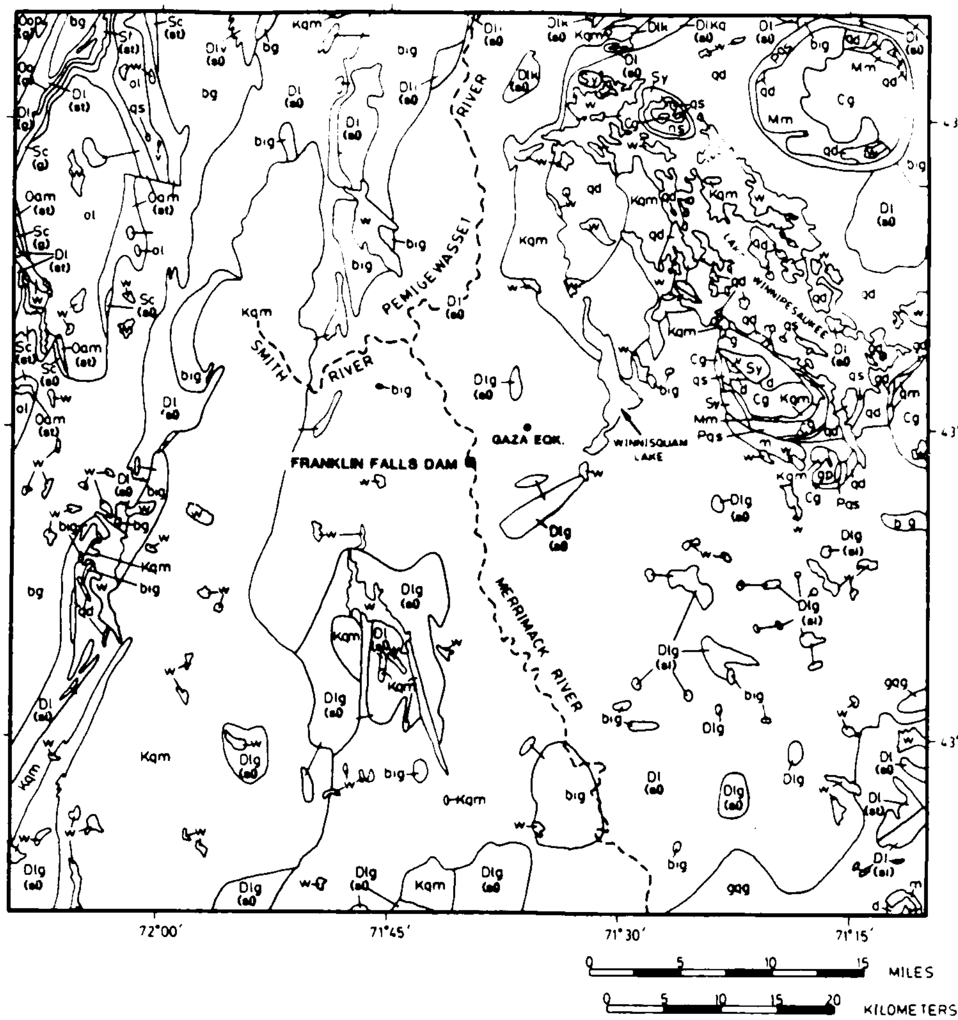


Figure 2. Geology of Franklin Falls Dam and vicinity

form of amphibolites, in turn overlain by the Fitch Formation, composed of marble, quartzite, and shist, and in turn overlain by a thin discontinuous quartzite and conglomerate known as the Clough Quartzite, and finally topped by the Littleton Formation.

25. The Silurian age Clough Quartzite marks a major stratigraphic bound ary between the underlying older Ordovician rock and the younger rocks above. The base of the Clough Quartzite is an angular unconformity associated with the Taconic unconformity which can best be observed further to the west in the Appalachian foreland. This series of metamorphic sediments has undergone intense folding which may make the simplified age relationships difficult to interpret in surface exposures. To this simplified account of the stratigraphic

sequence of the central New Hampshire area, a period of Late Paleozoic and Mesozoic volcanic intrusions (associated with the New Hampshire and White Mountain Plutonic Series) is added. Both intrusive series are generally felsic in composition.

26. It should be noted that the Oliverian Plutonic Series and the White Mountain Intrusive Series have been reassigned to different geologic time periods than described by Billings' (1955) New Hampshire Geologic Map (see Figure 2 and Appendix A). In the case of the Oliverian Plutonic Series--it has been moved to the Ordovician Period. The White Mountain Series has been moved to the Late Permian and Early Cretaceous Periods (260 to 190 M.Y.) as a result of more recent work (including isotopic dating) (Weston Geophysical Research, 1976a; and Suppe, 1985).

27. An alternate and more recent view of the rock underlying the Franklin Falls damsite and surrounding vicinity has been expressed by Barosh (1984). Barosh includes the rocks underlying the damsite, and the majority of those belonging to the Merrimack synclinorium (including the Littleton Formation), as part of the Sturbridge geocline. The Sturbridge geocline is a northeasterly trending belt of generally northwesterly dipping strata, extending from Connecticut through Massachusetts and into southeastern New Hampshire.

28. Rock beneath the dam is assigned to the Brimfield Group, the upper most stratigraphic sequence in the Sturbridge geocline. Use of the term Littleton Formation under this more recent classification of New England geology is restricted to its type local in the Bronson Hill anticlinorium and other minor exposures. Under this interpretation, the bulk of the rock classified as belonging to the Littleton Formation by the Billings' (1955) geologic map is reassigned to the Brimfield Group. In general, the igneous geology remains unchanged.

29. The age of the Brimfield Group is considered to be Ordovician (Pepper, Pease, and Seiders, 1975) and may even be Precambrian in age (Barosh, 1984). It was originally formed of siltstone, graywacke, and shale that was later highly metamorphosed to shists and gneiss, intruded by several different igneous periods, and also cut by numerous west-dipping thrust faults.

30. In summary, the foundation of the Franklin Falls Dam rests primarily on glacial and fluvial unconsolidated sediments. These sediments are generally coarse grained, composed of sandy silts and silty sands with minor

amounts of gravel. Metamorphic rock outcrops along the right abutment of the dam and immediately upstream and downstream from the dam's outlet structure. In addition, a narrow andesitic dike outcrops downstream from the spillway and is orientated generally parallel to it. The metamorphic rock beneath the dam is chiefly shist and gneiss with minor granitic veins. Stratigraphic and age relationships of the metamorphic rocks underlying the damsite are questionable and require further definition. Rock beneath the dam has been assigned to Littleton Formation by Billings (1955) and to the undifferentiated Brimfield Group by Barosh (1984). Under the Brimfield Group classification, the term Littleton Formation is primarily restricted to its type local.

Faulting and Lineaments

31. Surface faulting and lineaments at the Franklin Falls damsite and vicinity are presented in Figure 3 (from Slemmons and Glass, 1978). Mapped faulting nearest to the Franklin Falls Dam is located approximately 55 km (35 miles) to the northeast at Ossipee. Faulting at Ossipee is confined to the north edge of the igneous intrusion with short fault segments trending in northeast and north directions. Other areas of known faulting near the damsite include short northwest and northeast trending faults approximately 55 km (35 miles) southeast of the dam, between Manchester and Portsmouth, and also approximately 40 km (25 miles) northwest of the dam, near the Vermont and New Hampshire border. Intense north-to-northeast and northwest faulting occurs west of the Vermont-New Hampshire border in the area known as the Bronson Hill anticlinorium (see Figure 1), and also to the south, near Boston.

32. On a smaller scale, a general field reconnaissance of the Franklin Falls damsite and vicinity revealed possible faulting (not previously mapped) along the rock face forming the right abutment of the dam. The vertical cliff face along the right abutment is orientated in a northwesterly direction measuring approximately 120 m (400 ft) in length with approximately 23 m (75 ft) of exposed relief along segments of the cliff face. A suspected fault zone is approximately centered on this vertical rock exposure located immediately downstream from the crest of the spillway. The fracture zone measures approximately 23 m (75 ft) in width with two normal faults orientated at right angles to the rock face along a variable north/south to north/15-deg east strike with an approximate 70-deg north dip that marks the lateral limits

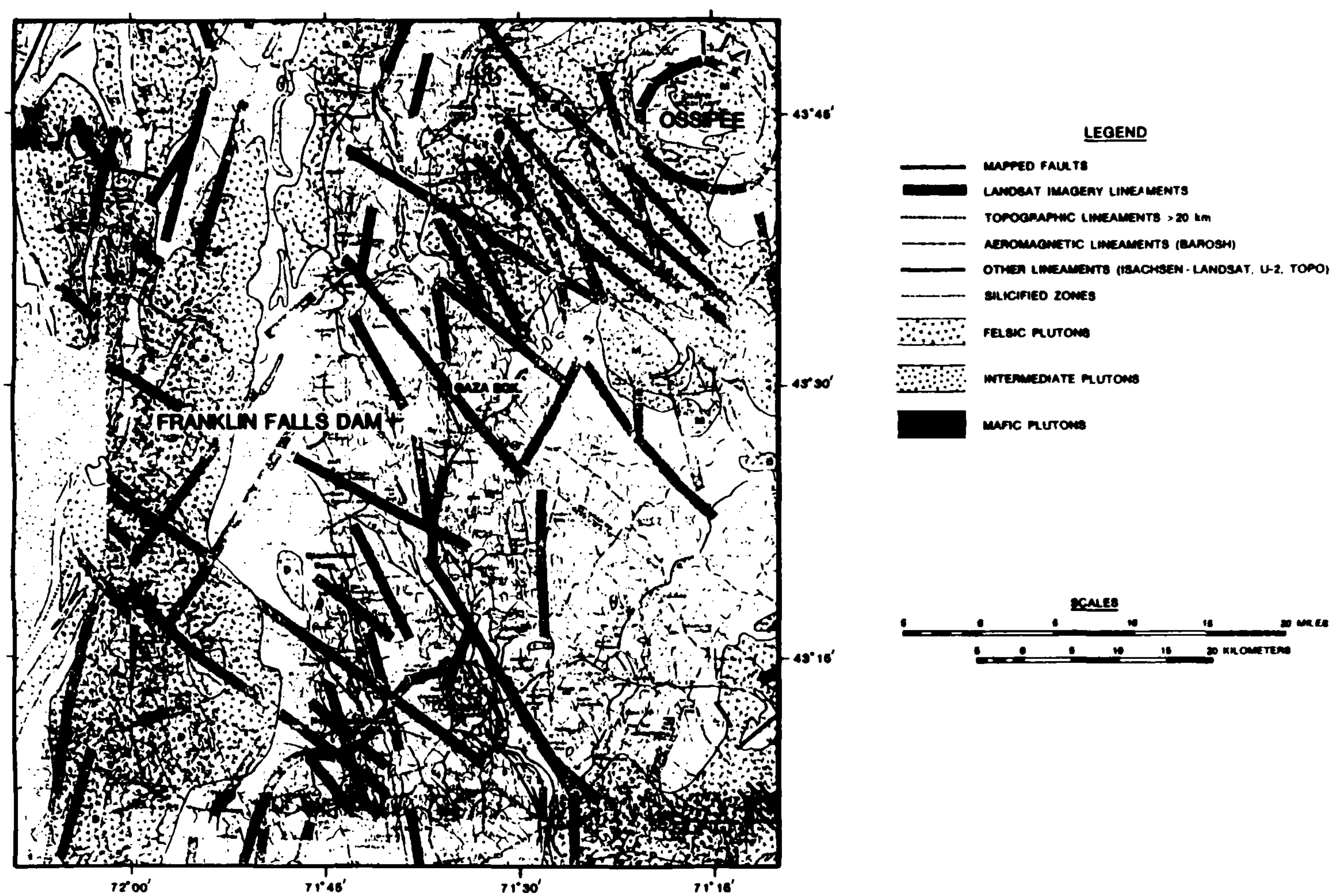


Figure 3. Surface faulting and lineaments at Franklin Falls Dam and vicinity

of the zone. Evidence of plastic deformation is visible along the north end of the fault zone with drag features present. On the south margin of this zone, chatter marks and slickensides are visible. Surface evidence for this fault zone is lacking as vegetation and glacial deposits have covered the area where the suspected zone would intersect the surface. No evidence of recent faulting was observed along this zone. It is believed that the age of the faulting is related to the regional faulting of this area.

33. Mapped lineaments near the Franklin Falls Dam are more numerous than the mapped faults. The mapped lineaments are shown in Figure 3 and consist of several types including those determined by Landsat imagery, topography, aeromagnetism, and those compiled from other data (Slemmons and Glass, 1978, which includes data from Barosh, 1977, and Weston Geophysical Research, 1976b). The general trend of these linear features is orientated along northeast and northwest directions. A major northwest-to-southeast linear is mapped adjacent to the dam and runs parallel to the Merrimack River Valley. Barosh (1985) includes this linear as belonging to a general zone of northwest trending lineaments that collectively form the Winnipesaukee-Winooski lineament zone. This narrow lineament zone extends from coastal New Hampshire and Maine through central New Hampshire and into north-central Vermont (see Figure 20 in Appendix C). In addition to the northwest-to-southeast trend of the Merrimack River, stream drainage throughout the Winnipesaukee-Winooski lineament zone typically follows this same general orientation.

34. The age of the youngest faulting in the northern New England area, particularly the state of New Hampshire and near the damsite, is approximately middle Mesozoic and is related to emplacement of the White Mountain Intrusive Series which marks the opening of the Atlantic Ocean. Using geological and seismological analyses for nuclear power plant evaluation, detailed studies were conducted by Weston Geophysical Research (1976c) on unmineralized jointing from the White Mountain Intrusive Series of the central and northern New England area to identify signs of postintrusion subsidence and offsets. Studies conducted at numerous locations along both linear and circular igneous intrusions revealed no major structural offsets. It was concluded that, with the exception of crustal depression and rebound associated with the Pleistocene continental glaciation, no evidence was detected of anomalous crustal deformation since emplacement of the White Mountain Series of intrusives. The Weston studies found no evidence of Pleistocene faulting in the central New Hampshire area.

35. A later study for signs of active faulting in New England was performed by Slemmons, Sanders, and Whitney (1980). Their study included a low-sun angle aerial reconnaissance examination of major faults, lineaments, and seismic zones. Their study examined faulting north of the Boston area along the Clinton-Newberry fault zone, at Cape Ann, at the Ossipee hot spots, and other areas in New England. Their study concluded that the faults were inactive and that the age of the faulting was Paleozoic or Mesozoic.

PART III: SEISMIC HISTORY

Distribution of Historic Earthquakes

Introduction

36. The distribution of historic earthquakes for the northern New England region from 1627 to 1982 is presented in Figure 4. A catalog listing these earthquakes is presented in Appendix B and is derived primarily from Nottis (1983), with additional data from Nuttli (1973), Richter (1935), Barosh (1985, see Appendix C), and Chiburis (1981). The list of historic earthquakes is arranged by state and includes geographic and coordinate location of the epicenter, date, earthquake magnitude, and earthquake intensity.

37. The magnitude scale in common use is the Richter Scale that is retricted to fairly recent events as seisometers are used in magnatude determinations. In the New England region, only since 1977 have adequate earthquake motions been instrumentally measured and recorded, particularly for very weak or low magnitude earthquakes.

38. The intensity scale in common use is the Modified Mercalli (MM) Intensity Scale (see Figure 5) that rates earthquakes according to the damage produced in structures and landforms and by the manner in which the earthquake is felt. Use of this scale allows historic earthquakes to be catalogued from written accounts as described by newspapers or personal diaries. A review of Figure 5 indicates that at intensity MM III ground shaking is just noticeable, at intensity MM VIII damage is slight in well-engineered structures, and at intensity MM XII the damage is total.

Historical seismicity

39. An examination of the historic earthquake catalog (Appendix B) and Figure 4 identifies New Hampshire and the northern New England and adjacent areas as experiencing low-to-moderate seismic activity. Over a period of more than 350 years, two events of MM VIII occurred offshore from Cape Ann in Massachusetts, and one event occurred at Massena, New York. Five events of MM VII have occurred at several locations--one event in southeast Maine, one at Cape Ann, two at Ossipee in New Hampshire, and one event at Warensburg, New York. The remaining historic earthquakes (approximately 600) are less than MM VII. The overwhelming majority of historic earthquakes have been MM IV, or less.

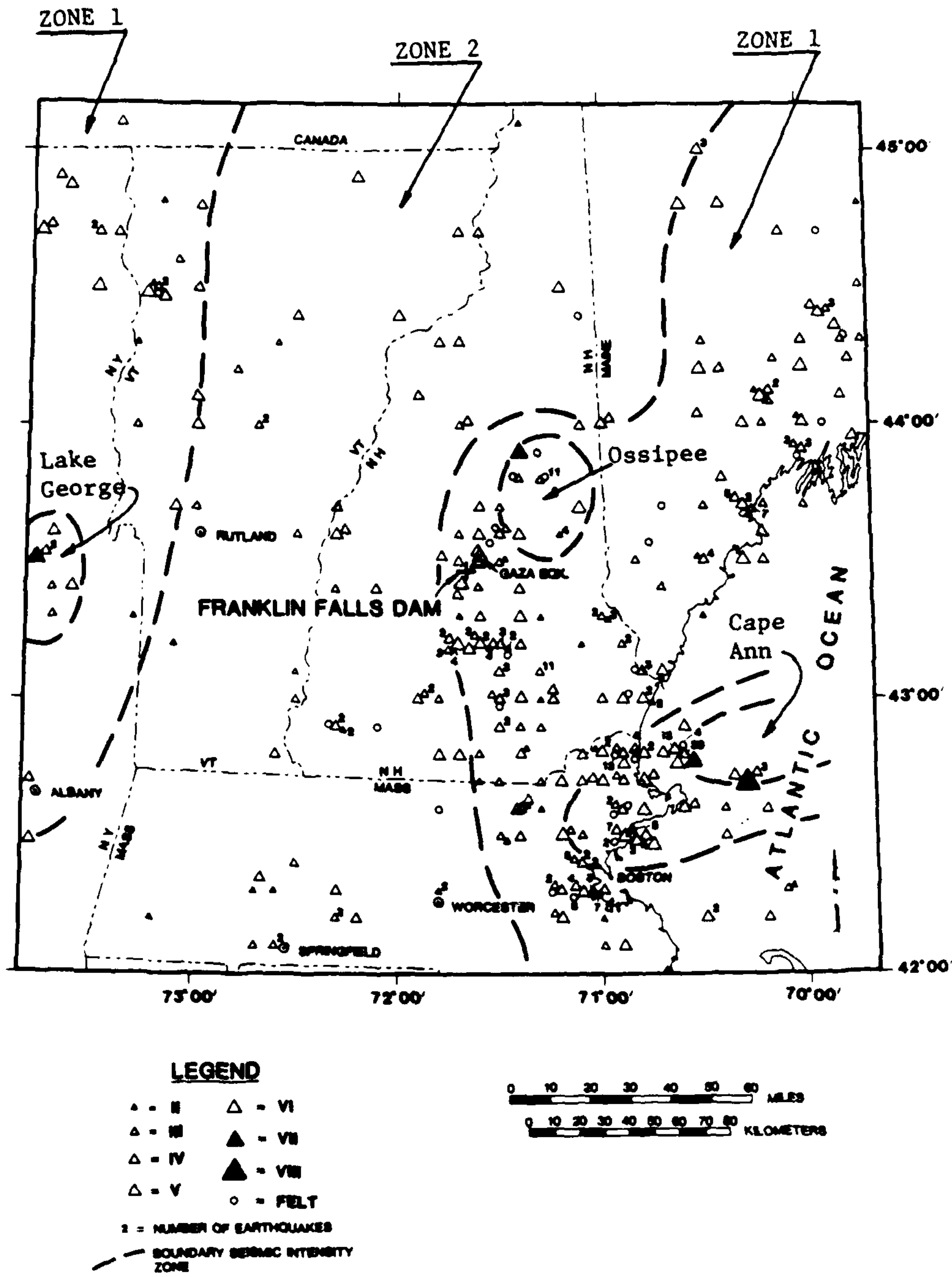


Figure 4. Historic earthquakes in northern New England (from Nottis, 1983; Nuttli, 1973; Richter, 1935; Borosh, 1985; and Chiburis, 1981)

MODIFIED MERCALLI INTENSITY SCALE OF 1931

(Abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse: great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Figure 5. Modified Mercalli Intensity Scale of 1931 (abridged) (from Barosh, 1969)

40. North of the New England states, well removed from the Franklin Falls damsite, and along the St. Lawrence River Valley in Quebec, Canada, moderate to severe earthquake activity has occurred. The St. Lawrence River Valley has had one event of MM X, four events of MM IX, one event of MM VIII, and two events of MM VII. The ground motions created by these earthquakes and felt at the Franklin Falls damsite are examined in greater detail.

41. An examination of the historic earthquake record for the New Hampshire area identifies well over 200 earthquakes occurring between 1728 and 1982. These are concentrated primarily along the eastern boundary and in the southern half of the state. Moving outside of New Hampshire's boundaries,

the distribution of historical earthquakes is primarily concentrated in a narrow zone along the eastern margin of the continental United States, along a 100-km- (60-mile-) wide zone extending from southern Massachusetts into Maine. Earthquake activity is generally diminished outside this zone. Further to the west, in western Vermont and eastern New York, the distribution of earthquake activity is again appreciably increased. Earthquake activity in this area is concentrated around Lake George, New York. Within the coastal zone, earthquake activity is concentrated in several distinct areas--off the coast of Massachusetts at Cape Ann, the Ossipee area in New Hampshire, and along the Merrimack River in New Hampshire and Massachusetts.

Earthquake zones

42. In Figure 4 on the basis of the distribution of historic earthquakes, seismic boundaries were drawn. These boundaries separate the northern New England region into distinct earthquake zones--a coastal zone of relatively greater seismicity (Zone 1` and a relatively stable interior region (Zone 2). In addition, an interior region in eastern New York is shown as Zone 1 because of its locally greater seismicity. An earthquake zone as used in this report is an inclusive area over which a given maximum credible earthquake can be assigned. This is the largest earthquake that can reasonably be expected to occur. It may be moved anywhere in the earthquake zone, and thus is a floating earthquake. The earthquake is moved in this manner because causative faults in the northern New England area have not been identified.

43. The presence of causative surface faulting is important as earthquake sources and an estimation of intensity can be easily determined. Earthquakes are produced when strain energy is suddenly released in the form of movement along a fault, either an existing or newly created fault. Strain energy causing faulting is derived from regional tectonic stresses produced within the earth's crust. The sudden movement or slip of the earth's crust produces an elastic rebound between the fractured segments resulting in vibrations felt as an earthquake. Severe earthquakes are caused by slippage along large fault segments from tens to hundreds of kilometres in length. The depth of fault movement must also reach crystalline basement rock in order to provide the large stress drop and energy release to produce the severe earthquake shaking.

44. In the Franklin Falls area, surface evidence of recent movement

along existing faults or lineaments has not been found (Weston Geophysical Research, 1976b;, and Slemmons, Sanders, and Whitney, 1980). In addition, the focal depths of recorded earthquakes for this area are generally shallow, less than 10 km. It is concluded that the potential for a severe earthquake in the Franklin Falls damsite is extremely remote. Based on the seismicity shown in Figure 4, maximum earthquake shaking at the damsite will be generated by earthquakes from the Cape Ann or the Ossipee areas.

Seismicity and Geology Relationship

Geophysical studies

45. Geophysical studies are useful in identifying anomalous structural zones deep within the subsurface, particularly in areas where no surface faulting is present. These studies help to detect geologic irregularities or anomalies where regional stresses may be concentrated. Geophysical studies commonly associated with seismic studies include magnetic and Bouguer gravity surveys.

46. Results of a regional magnetic survey are shown in Figure 6 (from Harwood and Zietz, 1977). In general, magnetic surveys reflect spatial changes or distortions in the earth's magnetic field caused by variations in rock types. The distribution of historic seismicity for northern New England is concentrated along narrow zones and in hot spots. The seismic hot spots appear as dark areas on the magnetic map, reflecting intense magnetic differences.

47. Results of a regional Bouguer gravity survey are shown in Figure 7 (from Bothner, Simpson, and Diment, 1980). The general subsurface structure of northern New England is defined by the gravity map. Gravity surveys define changes in the mass properties of the underlying rock by measuring through appreciable portions of the earth's crust. The Ossipee and Cape Ann seismic hot spots are areas of anomalous gravity highs indicating areas of rock denser than that of the surrounding host rock.

48. The regional trend for the area defined by the gravity map in Figure 7 is toward the north-northeast mirroring the regional geologic and topographic structure for the eastern United States. In addition to this regional component, a second but less pronounced structural trend is identified for the central New Hampshire area. A southeast-to-northwest component,

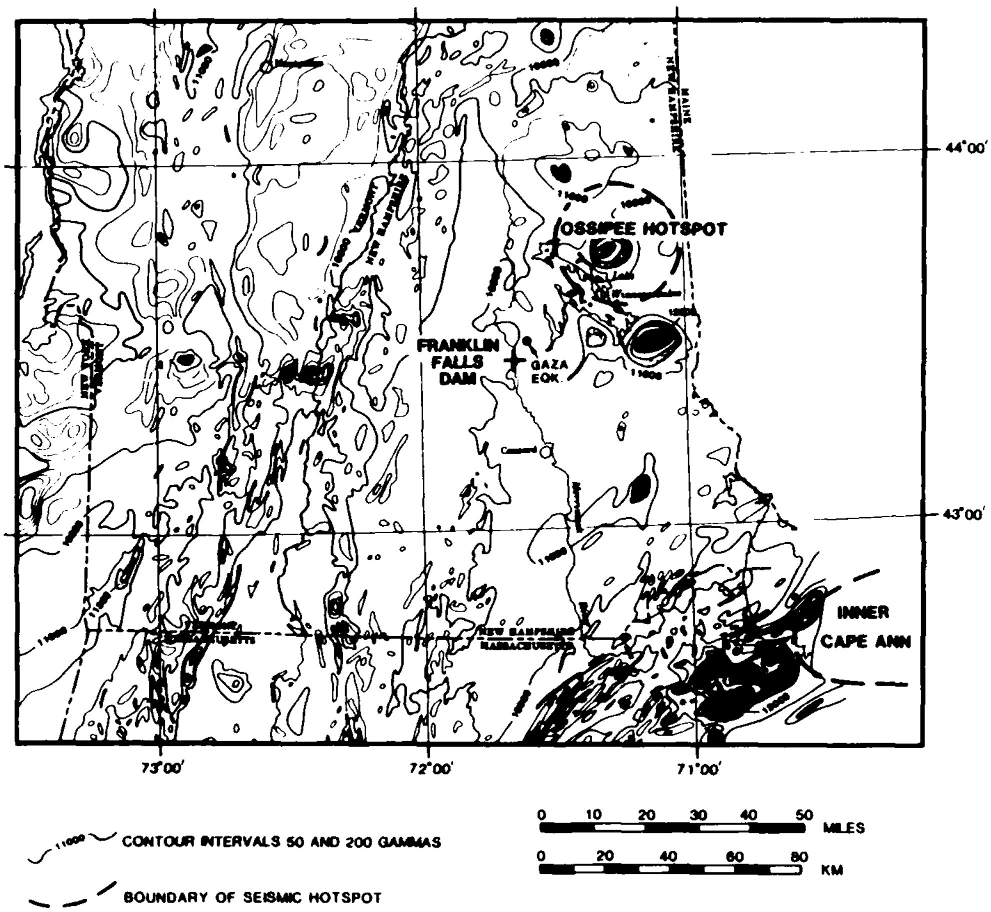


Figure 6. Magnetic anomalies with seismic hot spots (from Harwood and Zietz, 1977)

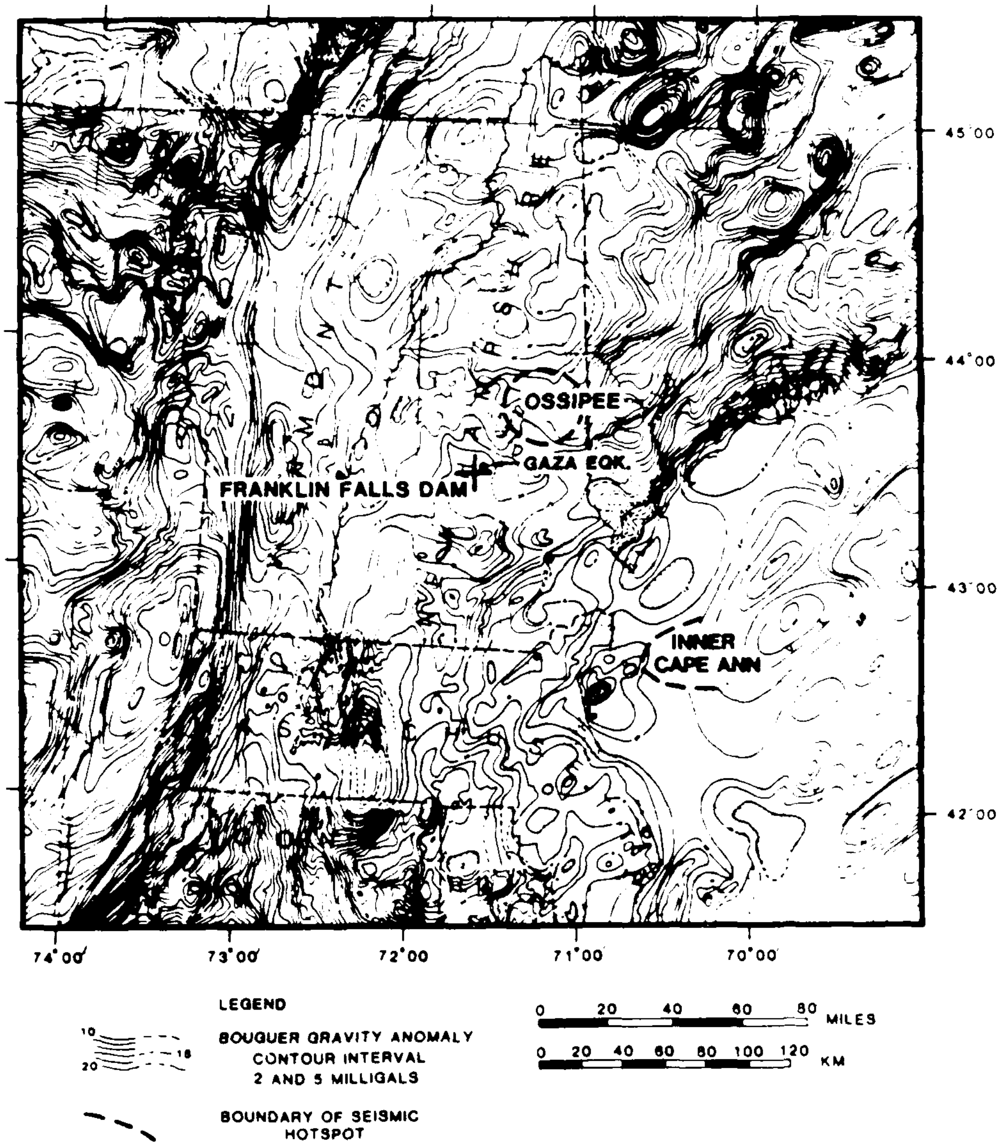


Figure 7. Bouguer gravity contours with seimic hot spots (from Bothner, Simpson, and Diment, 1980)

between the Ossipee and Cape Ann area, is reflected by the slight shift in contour orientation which is best displayed to the northwest of the damsite. This northwest structural zone marks the zone of maximum seismicity for New Hampshire (Barosh, 1984 and 1985).

Seismic trends

49. The general northwest distribution of seismicity observed in central

New Hampshire is believed to be part of a much longer seismic belt that extends from Boston to north of Ottawa, Canada (Fletcher, Sbar, and Sykes, 1978). The Boston-Ottawa trend is approximately 160 km (100 miles) in width and is inferred to extend offshore to the northwest extension of the New England Seamounts. This trend parallels a similar trend (postulated by the above authors) to extend from Charleston, South Carolina, to New Madrid, Missouri. The New Madrid area was the site of intense earthquake activity during the early 1800s.

50. These long and linear seismic trends, according to Fletcher and his associates, mark Middle-to-Late Mesozoic rift zones that formed during the opening of the Atlantic Ocean. These Paleo-rift zones are regions of crustal weakness containing large-scaled igneous intrusions (i.e., White Mountain Intrusive Series). As a result, the ancient rift zones are regions where crustal stresses are focused, and when released produce earthquake activity. A major implication of this theory is that severe earthquakes can occur along the full length of the seismic zone, even in areas where the historical record indicates that no such activity has occurred.

51. Another seismic trend previously mentioned is a general north-to-northeast seismic distribution identified by Aggarwal (1978) as the Piedmont-Appalachian trend. This northeast trend extends from northern Virginia into Maine, paralleling the Atlantic coastline. This trend is discussed later in greater detail.

52. In summary, the distribution of historic earthquakes, based on a nearly 400-year record, defines areas or zones where seismic activity is concentrated. Seismic limits as used in this report are restricted to zones or areas where historical activity has previously occurred. To project an earthquake into an area or a zone that has displayed no seismic history, but is considered part of a major trend, such as in the Boston-Ottawa seismic trend, is not considered valid by the present authors unless there is some additional evidence in the form of seismicity that suggests a hot spot or a tendency to produce a hot spot.

Causes of seismicity

53. Several theories have been proposed to explain seismicity for the New England states as no major faulting has been identified to account for the moderate earthquake activity. Barosh (1981) suggests that most of the seismic activity along the northern Atlantic coast can be explained in terms of

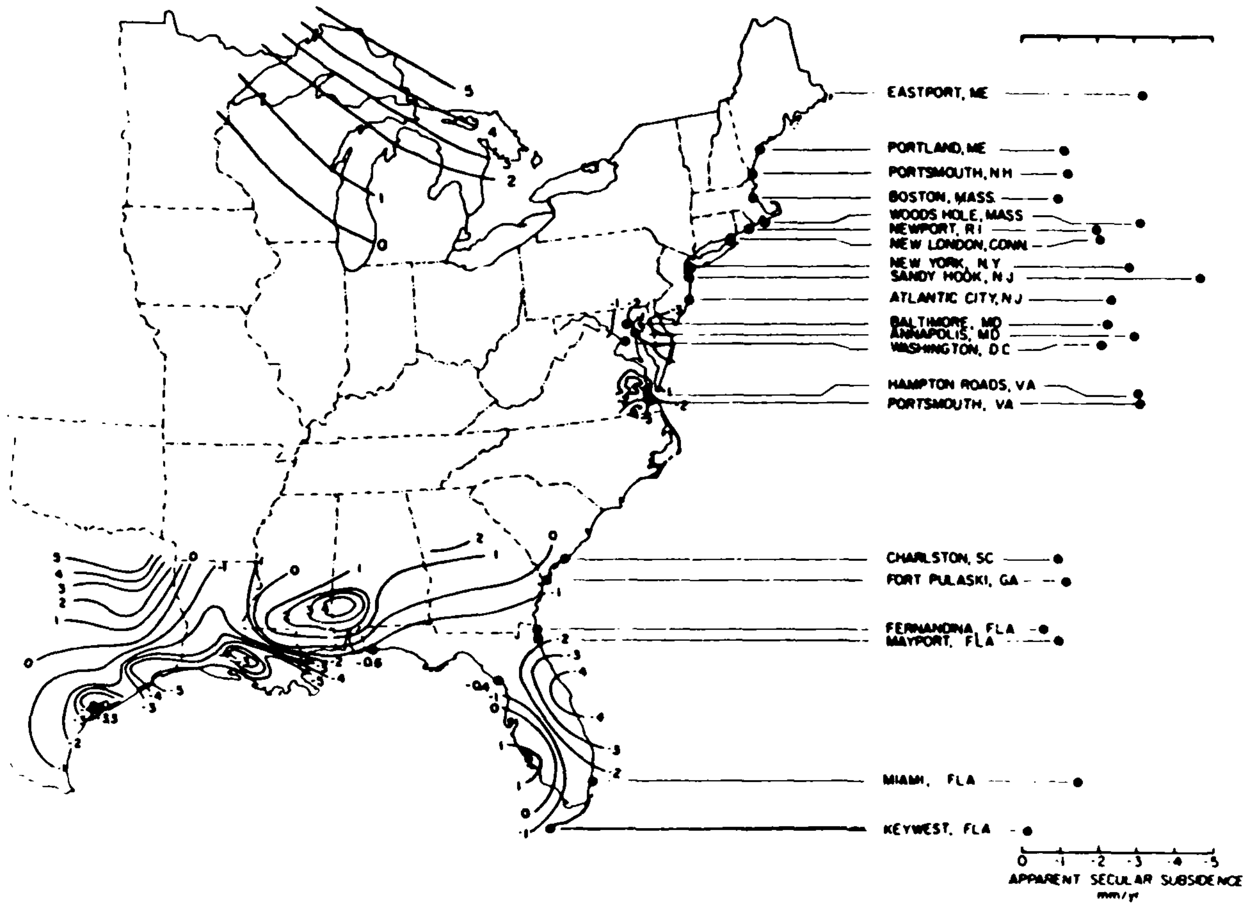


Figure 8. Vertical movement in eastern United States (from Brown and Reilinger, 1980)

regional subsidence. This subsidence is apparently caused by the continued opening of the Atlantic Ocean. Subsidence along the eastern coastline for selected cities was defined by Brown and Reilinger (1980) indicating a variable subsidence rate, between 1 and 4 mm (in.) per year, from coastal Connecticut to Maine, as shown by Figure 8.

54. Other views of New England seismicity, particularly at Cape Ann and Ossipee, are described below (from Krinitzsky, 1984).

a. Focusing of regional stresses at heterogeneities (plutons) in the subsurface and release of the stresses along preexisting deep seated faults (Weston Geophysical Research, 1976d).

b. Possible small-scale introduction of magmatic material into the plutons at depth with an accompanying buildup of stresses.

c. Focusing and release of regional stresses along the Boston-Ottawa trend (Sbar and Sykes, 1973). This trend is interpreted as an ancient rift zone with magmatic intrusions and is thus a zone of weakness.

d. Slow regional compression causing activation of preexisting regional overthrusts (Wentworth and Mergner-Keefer, 1980).

e. Extensional movement which activates irregularities in the coastline, principally where major grabens intersect the downwarping. Inland these forces may cause activation of preexisting faults with northwesterly and northerly orientations (Barosh, 1981). This view is an extension for the cause of seismicity that was initally proposed in this section.

Earthquake Recurrence

55. Prediction of seismic hazards or earthquake recurrence of a specific intensity for a designated geographical location is based on probability theory. A major problem with a probability approach is that earthquake preaiction requires personal judgment of the seismic source areas and attenu ation of the earthquake event to the area of interest. A second major problem with this approach is that it fails to identify a maximum event which can realistically be expected to occur. The probability approach assumes that because no maximum event is specified, the frequency of such an event be comes greater with more and more time elapsing. In terms of the operating life for an engineering structure, such an approach can be misleading as the typical operating life for a dam is approximately 100 years.

56. A probablistic approach was employed by Acharya, Lucks, and Christian (1982) for the Boston, Massachusetts, area, which is approximately

145 km (90 miles) south of the Franklin Falls Dam. Results of this study, calculated by several different workers and methods, indicated that the recurrence interval for a intensity VII (MM) earthquake for the Boston area ranges from approximately 1,000 years to nearly 12 million years.

57. Another study of interest describing earthquake recurrence in close proximity to the Franklin Falls damsite was conducted by Toksoz (1982) on the Knightville Dam in Huntington, Massachusetts. An earthquake catalog similar to the one presented in Appendix B was used by Toksoz for estimating earthquake recurrence. This study concluded that for an intensity VII (MM) earthquake, the return time was approximately 80 years, an intensity VIII (MM) earthquake could be assumed to occur every 330 years, and an intensity IX (MM) earthquake every 1,300 years.

58. An alternate study for the entire New England area, as opposed to a specific geographical location, was conducted by Chiburis (1980) and the return frequencies for various intensity levels are as follows.

MM Intensity	M*	Mean Return Time, years
VI	4.6	0.6
	5.0	1.1
VII	5.2	1.5
	5.5	8.8
VIII	5.8	53
	6.0	175
IX	6.4	1,923
	6.5	3,500

* M = Magnitude (M_S) for events greater than 6.5 (not specified for less than 6.5).

59. For the purposes of this report, the rate of recurrence is not used. Instead, a deterministic approach is followed where a maximum earthquake is interpreted to occur for the seismic region or zone, regardless of recurrence time. As a result, a maximum earthquake is thus assigned to a site or seismic zone and is attenuated to the area of interest from the site

or zone boundary. The basic assumption in this deterministic approach is that the engineering structure of interest must be designed to withstand the predicted intensity of a maximum credible earthquake and its associated ground motions.

PART IV: SEISMIC SOURCE ZONES

Earthquakes Felt at Franklin Falls Damsite

60. An individual examination was conducted for all historic earthquakes of intensity MM VI or greater for the study area (see earthquake catalog in Appendix B) that were judged to have been felt at the Franklin Falls damsite. These earthquakes are presented geographically and chronologically in Table 1. Included in Table 1 are several major earthquakes judged to have been felt at the Franklin Falls damsite but well removed from the study area boundaries (i.e., at New Madrid, Missouri, Charleston, South Carolina, and in the St. Lawrence River Valley, Quebec, Canada). Distances from the damsite to the earthquake source area are included in Table 1 along with the interpretation of attenuated earthquake intensity at the damsite.

61. The attenuation procedure selected for this study is based on the diminution of intensity with distance, as determined by Chandra (1979). This procedure, using the curve for the eastern province, is shown in Figure 9. Attenuation of MM intenstiy with distance is determined by first calculating the distance in kilometres between the earthquake epicenter and the area of interest, selecting this distance on the horizontal axis of the attenuation curve in Figure 9, and then deriving the MM intensity reduction factor on the vertical axis. The intensity reduction factor is subtracted from the MM intensity value at the source to produce the attenuated intensity at the site of interest.

62. The earthquake list in Table 1 spans approximately 350 years of record and shows that only 39 earthquakes were judged to have been felt at the damsite for this period. The distribution of felt earthquakes is as follows: five events of MM intensity II, seven events of MM intensity III, thirteen events of MM intensity IV, and seven events of MM intensity V. The severest earthquakes interpreted to have been felt at the damsite were MM intensity VI on seven separate occasions. These seven earthquakes are all centered less than 150 km (93 miles) from the damsite. The vast majority of these earthquakes occurred less than 60 km (37 miles) from the damsite. These seven earthquakes originated from three general locations: Cape Ann, Ossipee, and along a 40-km (25-miles) reach of the Merrimack River with Franklin Falls located in the approximate center of this zone.

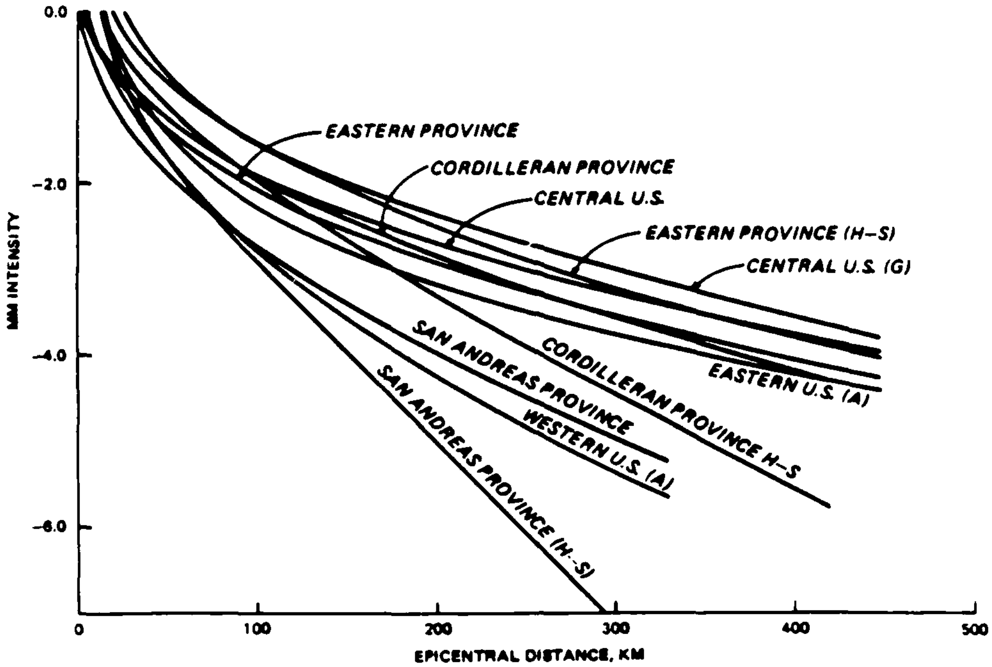


Figure 9. Attenuation of MM intensities, with distance (A = Anderson, G = Gupta, H-S = Howell-Schultz) (from Chandra, 1979)

63. A recent and well-recorded MM intensity VI earthquake, centered approximately at Gaza, New Hampshire, occurred on 19 January 1982 (time expressed in Universal Coordinate Time; time expressed in Eastern Standard Time would have the earthquake occurring on 18 January 1982). This earthquake was recorded by several strong motion accelerograms, including instruments located at the Franklin Falls Dam approximately 9.0 km (6 miles) southwest of the epicenter. The strong motion records from the dam registered a peak acceleration of 0.55 g. Other locations of strong motion recordings are shown in Figure 10 (from Chang, 1983). Strong motion recordings were registered at four other dams--Union Village, North Hartland, North Springfield, and Ball Mountain.

64. The strong motion recordings generated by the Gaza earthquake include the highest values recorded east of the Rocky Mountains. In addition, these strong motion recordings indicate that earthquake motions attenuate more rapidly to the south than to the west and southwest (Krinitzsky, 1984). These relationships are valuable for the development of earthquake patterns and distance-related motions in the New England region. The peak ground motions at the Franklin Falls damsite have been incorporated into the Corps of

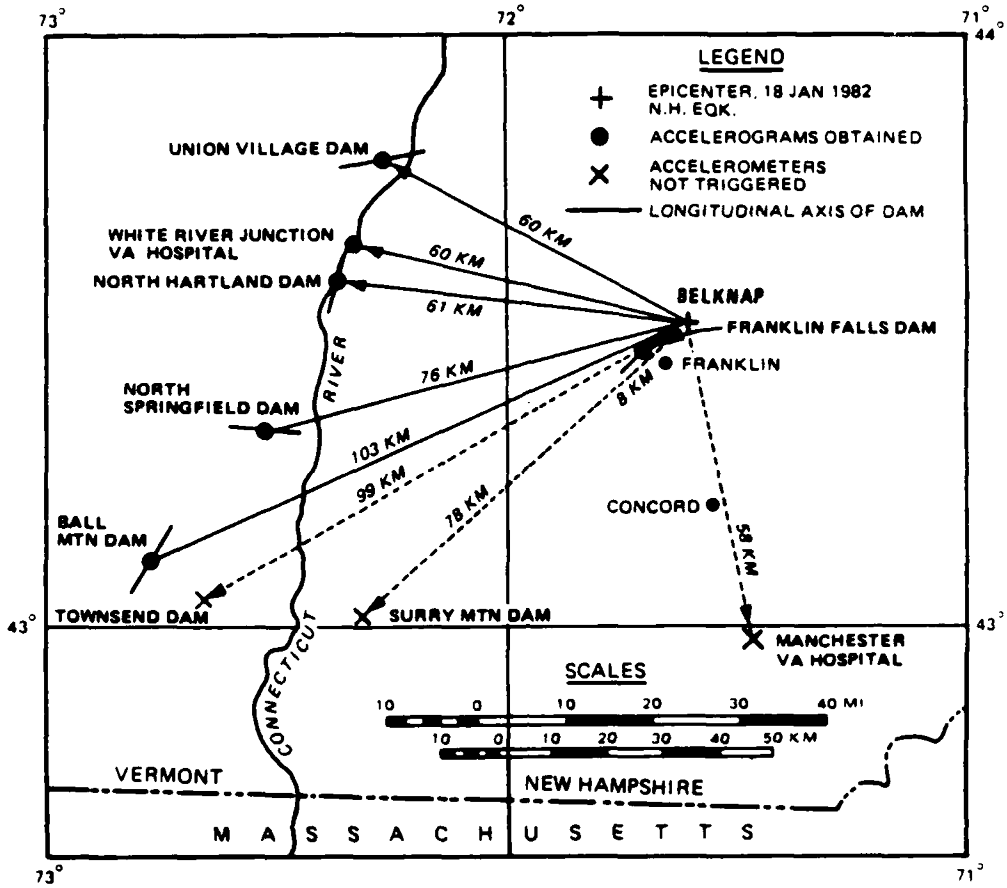


Figure 10. Locations of principal strong motion recordings generated by the 18 January 1982 New Hampshire earthquake (from Chang, 1983)

Engineers' strong motion data collection and the specifications on near field motions (Chang, in press).

65. A detailed report of the Gaza earthquake is included in Appendix C (Barosh, 1985). The Gaza earthquake was felt over much of the New England region and parts of Canada. This earthquake was judged to have been felt over an area of approximately 127,000 sq km of the United States (Stover et al, 1983) (see Figure C8, Appendix C). Included in Appendix C is a detailed assessment of the damage in the epicentral area of the Gaza area, as investigated and described by Barosh.

Earthquake Zones and Intensities

66. The earthquake zones previously defined (see Figure 4) are assigned a floating MM intensity value based on a detailed review and analyses of the regional and local geology and historic seismicity. Within each earthquake zone, the assigned value is constant for any site in the zone or the hot spot boundary. The earthquake intensity value assigned to each zone is relatively conservative with one MM intensity value greater than the largest historical earthquake identified for that zone. Two seismic zones and three hot spot areas are identified by the data described above. Floating earthquake intensities and the approximate corresponding Richter magnitude for these areas are as follows (see Figure 11):

Area	MM Intensity	Richter Magnitude
Zone 1	VII	5.5
Zone 2	VI	5.0
Cape Ann (inner)	IX	6.3
Cape Ann (outer)	VIII	6.0
Ossipee	VIII	6.0
Lake George	VII	5.5

67. The corresponding Richter magnitudes shown above are based on the general relationships developed by Mitronovas (1982) for New York and adjacent areas. In addition, the Cape Ann area is judged to have an inner and outer seismic zone, as defined by the historical seismicity (see Figures 4 and 11 for limits). The earthquake intensities from these source zones attenuated to the Franklin Falls damsite, including the distance from the source (Io) to the site (Is), are defined as follows.

Source	Distance, km	MM Io	MM Is
Zone 1	Local	VII	VII
Zone 2	12	VI	VI
Cape Ann (inner)	110	IV	VII
Cape Ann (outer)	94	VIII	VI
Ossipee	21	VIII	VIII
Lake George	152	VII	IV

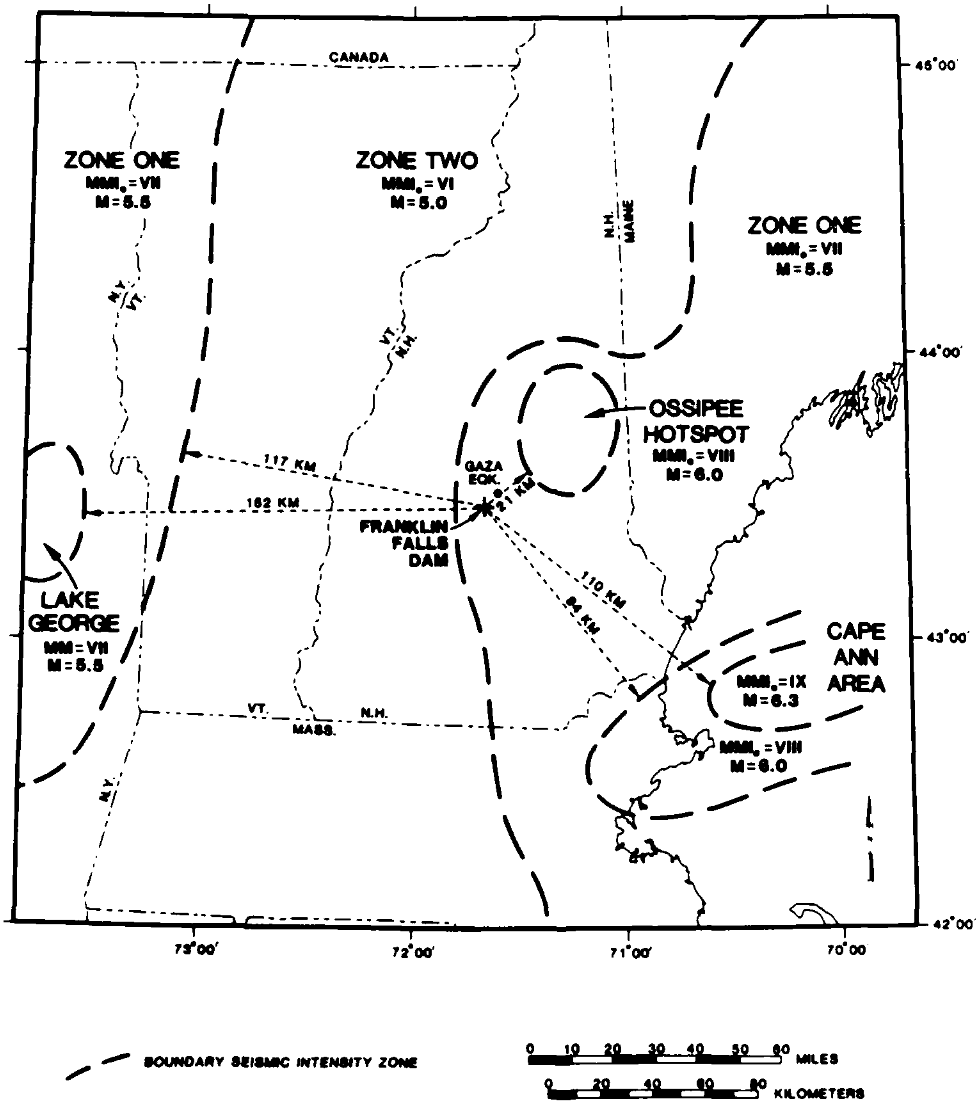


Figure 11. Seismic source zones and maximum earthquake intensities

68. In summary, the most severe earthquakes that have the potential to be felt at the Franklin Falls damsite are those originating from the Ossipee hot spot. The maximum earthquake interpreted for the Franklin Falls damsite from the Ossipee area is an intensity MM VIII earthquake. Intensity VII earthquakes at the damsite are possible from a severe earthquake originating in the inner Cape Ann area and from a local earthquake in Zone 1.

PART V: EARTHQUAKE MOTIONS AT FRANKLIN FALLS DAMSITE

Field Conditions

69. Ground motions from the above-identified sources and felt at the Franklin Falls damsite are of two general types. Ground motions originate either from near field or far field sources. Simply defined, near field sources or conditions are those occurring near the source and characterized by a large range of ground motions caused by asperities in the fault plane that produce the earthquake, complicated reflection and refraction patterns, resonance effects, and impedance mismatches. Near field conditions are difficult to predict because of the numerous complications associated with the motions. In contrast, far field conditions are well removed from the source, the wave patterns are generally muted or dampened, and as a result the ground motions are more predictable.

70. Near or far field conditions are determined by the following empirical relationship of distance and magnitude developed by Krinitzsky and Chang (1977).

Richter Magnitude M	MM Maximum Intensity Io	Radius of Near Field km
5.0	VI	5
5.5	VII	15
6.0	VIII	25
6.3 to 6.5	IX	35

71. In summary, the near and far field conditions are determined by the severity of the earthquake that governs the distance of separation between the two field conditions.

Recommended Motions

72. The Franklin Falls damsite is susceptible to earthquakes by both near and far field sources as follows (see Figure 11):

Zone 1-near field: MM intensity VII, M = 5.5

Zone 1-far field: MM intensity VII, M = 5.5

Ossipee-near field: MM intensity VIII, M = 6.3 to 6.5

Ossipee-far field: MM intensity VIII, M = 6.3 to 6.5

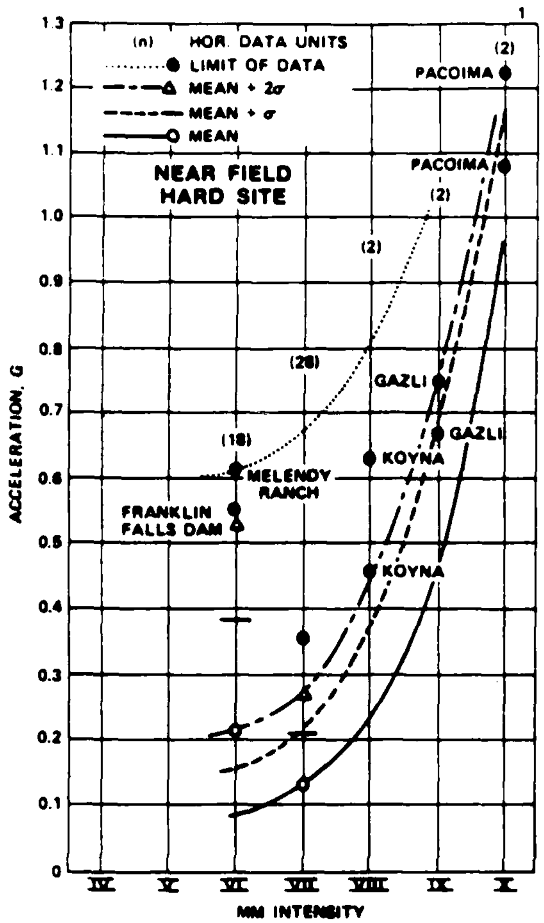
Other: Earthquake Zone 2 and the Lake George and the Cape Ann hot spots are eliminated from consideration as earthquakes from Zone 1 and the Ossipee hot spot would be equal to or greater than earthquakes from these sources.

73. The parameters for earthquake motions specified in this report are horizontal peak acceleration, velocity, and duration. Duration or the total time of measured ground motion is bracketed duration and is greater than or equal to 0.05 g. Values are for free-field motions on rock at the surface.

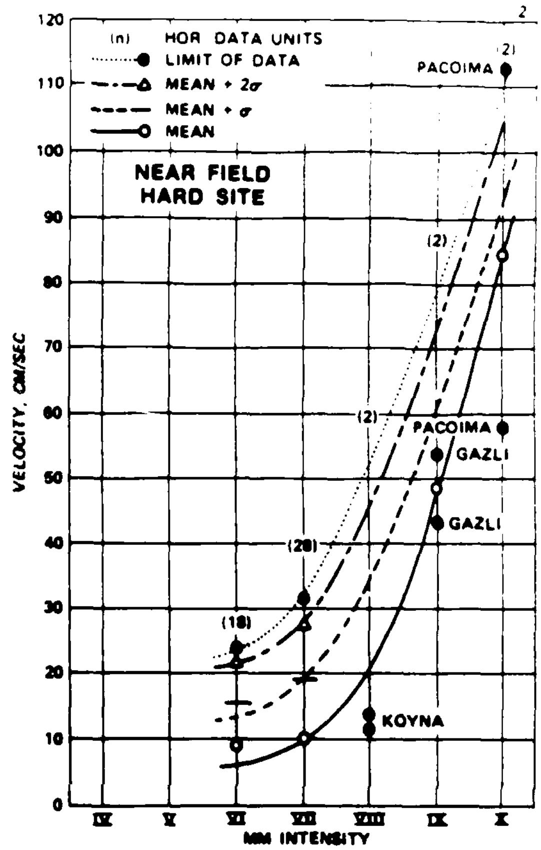
74. The ground motion parameters of interest to the engineer are determined from the Krinitzsky and Chang curves (see Krinitzsky and Marcuson, 1983) relating intensity to the three ground motion variables. Figure 12 is for a near field (NF) hard site and relates intensity to acceleration (Figure 12a), velocity (Figure 12b), and duration (Figure 12c). Similarly, Figure 13 is for a far field (FF) hard site. The maximum ground motion values from the source areas of concern are summarized in Table 2 where G equals acceleration based on one G = 980 cm/sec^2 (G = 32 ft/sec^2), V = velocity expressed in centimetres per second, and T = duration in sec.

75. As shown by Table 2 and Figure 13, far field ground motion data for a hard site having an intensity MM VIII earthquake are missing. Recorded ground motion data for a far field, hard site, intensity MM VIII earthquake have not been measured and are believed not to exist. An intensity VII earthquake marks the threshold of intensity for a far field site for which ground motions have been identified. As an alternative for the MM VIII data for a hard site however, ground motion data are available for an intensity MM VIII earthquake for a soft site and are presented in Figure 14 (see also Table 2). It should be noted that, except for duration, the near field hard site data exceed the far field soft site data for the Ossipee area. Duration for the soft site is three to four times greater than the near field hard site.

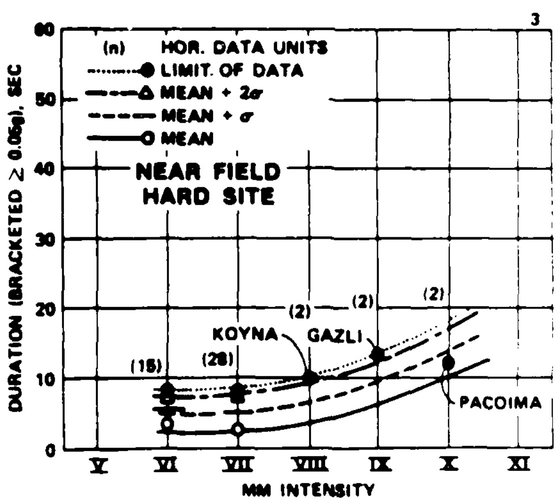
76. Recommended peak motions are the mean plus one standard deviation or the 84 percentile. Values at this level are conservative as these values are determined from the historic seismicity which also includes a conservative safety margin. Values from the mean plus two standard deviations are used only if a proven causative fault were present at or adjacent to the site. No



a. Acceleration versus MM intensity

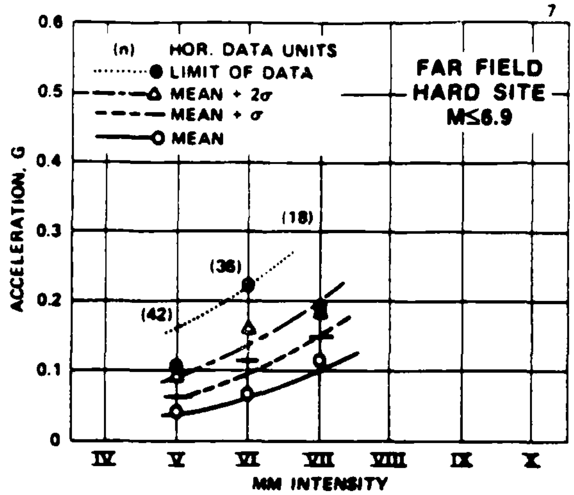


b. Velocity versus MM intensity

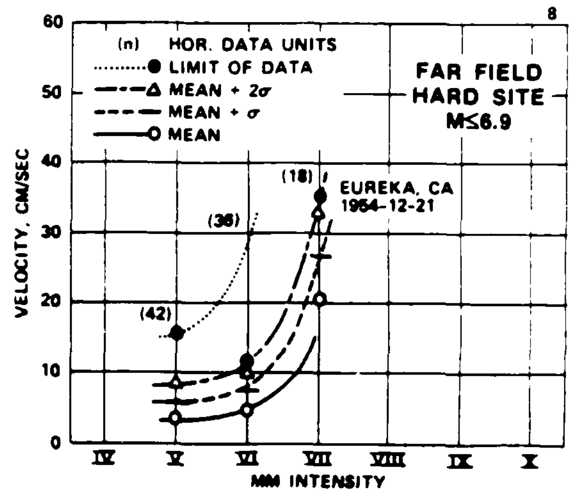


c. Duration versus MM intensity

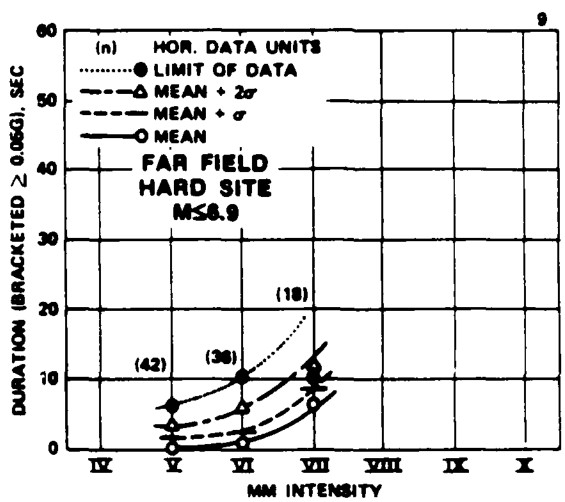
Figure 12. Ground motion data for a near field, hard site, all earthquakes



a. Accleration versus MM intensity

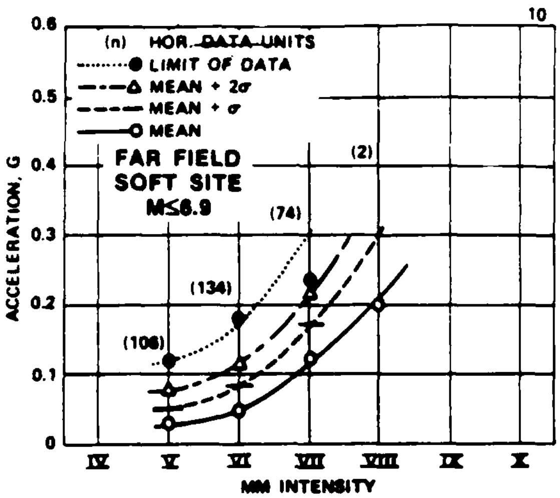


b. Velocity versus MM intensity

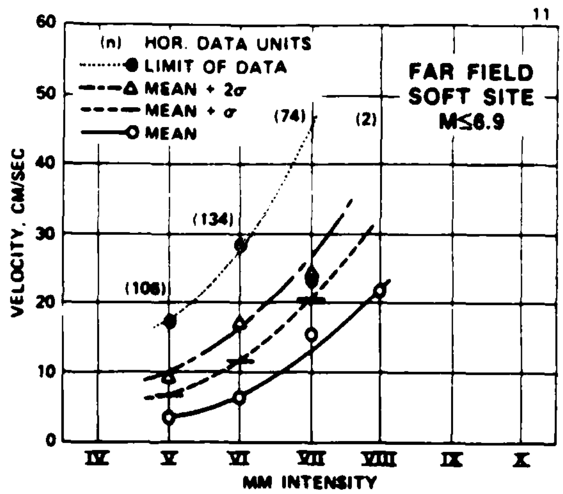


c. Duration versus MM intensity

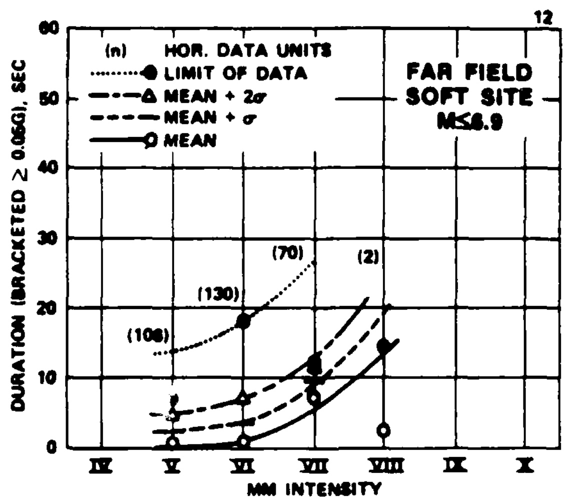
Figure 13. Ground motion data for a far field, hard site, $M \leq 6.9$



a. Acceleration versus MM intensity



b. Velocity versus MM intensity



c. Duration versus MM intensity

Figure 14. Ground motion data for a far field, soft site, M ≤ 6.9

evidence of causative faulting has been defined for the Franklin Falls damsite and vicinity.

77. Figure 12a has some very high values, over 0.5 g, for accelerations at Melendy Ranch and at the Franklin Falls Dam. These are high-frequency, high-spiked acceleration peaks with low energy. Nuttli (1979) defines criteria for measuring peak values and indicates that these values are not considered valid for design purposes unless the structural components have natural frequencies between 10 and 25 Hz.

78. The recommended values for mean plus one standard deviation for peak motions are as follows:

Earthquake Source	Acceleration G	Velocity cm/sec	Duration Sec, 0.05 g
Zone 1 (FF)	0.15	27	9
Ossipee (NF)	0.38	25	6

Recommended Accelerograms

79. Table 3 presents a selection of accelerograms and associated ground motion data interpreted for the Franklin Falls damsite. The selection of accelerograms includes two from a FF site (earthquake from Zone 1) and two from a NF site (earthquake from the Ossipee area). A scaling factor for each accelerogram is included in Table 3. The accelerograms are presented in Appendix D. The data for these accelerograms are derived from the following three sources: the California Institute of Technology (1971-1975), US Geological Survey (1983), and US Department of Conservation Division of Mines and Geology (1984).

80. The accelerograms are obtained from soft, intermediate, and hard sites that are identified in Table 3. The scaling factor for the four accelerograms ranges from 0.5 to 1.2. The distance from the source area to the site is representative of study area conditions which, for the FF, is nearly 40 km while the NF ranges from 14 to 25 km.

81. The records presented in Table 3 are by no means the only records that may be used. They are presented as appropriate accelerograms to be used in an engineering analysis of the damsite.

Motions for Nearby Nuclear Power Plants

82. Nuclear power plant locations for the northern New England region are presented in Figure 15. Design accelerations for the safe shutdown and operating basis earthquakes as indicated are included in Figure 15. Four nuclear power plants are located within a 200-km radius of the Franklin Falls damsite. These power plants are Seabrook 1 and 2, Vermont Yankee, Yankee,

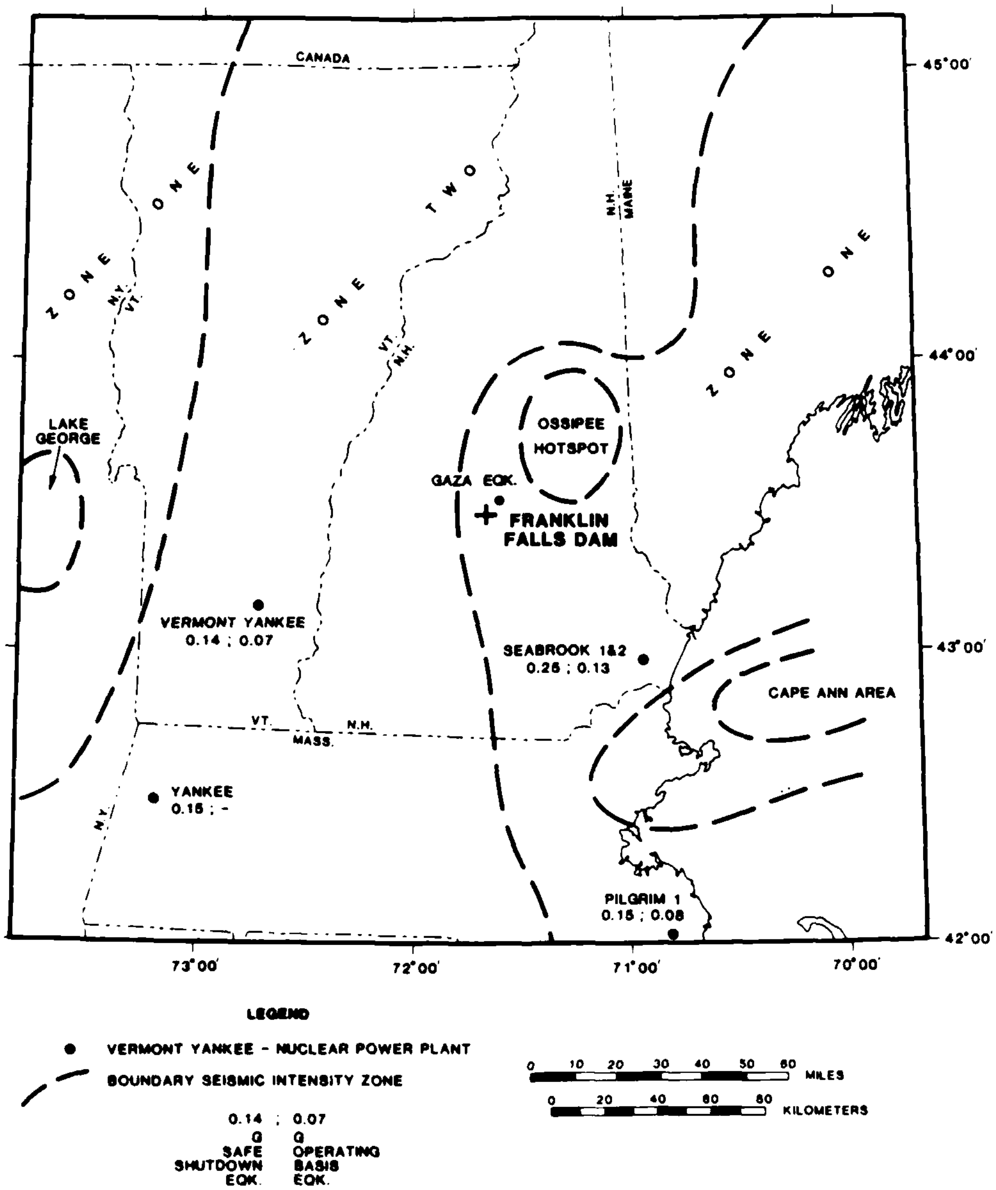


Figure 15. Locations of nuclear power plants for the northern New England region

and Pilgrim 1. Two nuclear power plants, Seabrook 1 and 2 and Pilgrim 1, are located in Zone 1. The Seabrook 1 and 2 power plant is located near the Cape Ann area.

83. Peak accelerations for Zone 1 nuclear power plants compare favorably with those selected for Zone 1 at the Franklin Falls damsite. Ground motion values for the Franklin Falls damsite originating from the Ossipee area are much higher than those accorded to the Seabrook 1 and 2 plant near the Cape Ann area as the Franklin Falls damsite is located along the margin of the Ossipee seismic hot spot.

84. The recommended ground motions for the Franklin Falls damsite are more conservative than the maximum peak accelerations assigned to the nuclear power plants. However, the Franklin Falls damsite is in closer proximity to an area of intense seismic activity than any of these New England power plants.

Amplification of Base Motions at the Dam Crest

85. The seismic stability of nonliquefiable embankment dams can be estimated by idealization of the potential slide mass as a sliding block on an inclined plane that undergoes earthquake-induced accelerations. The technique known as a pseudostatic stability analysis can serve as a useful screening procedure to distinguish between safe dams and those requiring more specialized evaluation techniques, such as a dynamic analysis.

86. A necessary step in a pseudostatic evaluation of embankment stability is to determine the amplification of the base motions into the dam or embankment. Amplification curves have been developed by Hynes-Griffin and Franklin (1984) for estimating the amplification factor provided that the area of concern is not subject to earthquakes of magnitude 8 or greater, materials in either the embankment or the foundation are not susceptible to liquefaction under the design cyclic loading, or the dam does not have safety-related features that are vulnerable to small displacements.

87. These amplification curves were derived from 27 strong motion earthquake records and from computed amplification values from numerous visco-elastic shear beam analyses. The curves for determining the estimated amplification of earthquake-generated motions at any point within the dam or embankment are shown in Figure 16 and consist of three curves representing the

mean, mean plus one standard deviation, and the upper bound of the peak amplifications observed from each record. To use the curves, simply calculate the ratio between the the depth of sliding (y) being investigated as compared with the total thickness of the embankment (h) and then find the corresponding amplification factor for this ratio. The amplification factor obtained is then multiplied by the peak bedrock acceleration value to estimate an upper-bound amplified acceleration at the depth of interest in the embankment.

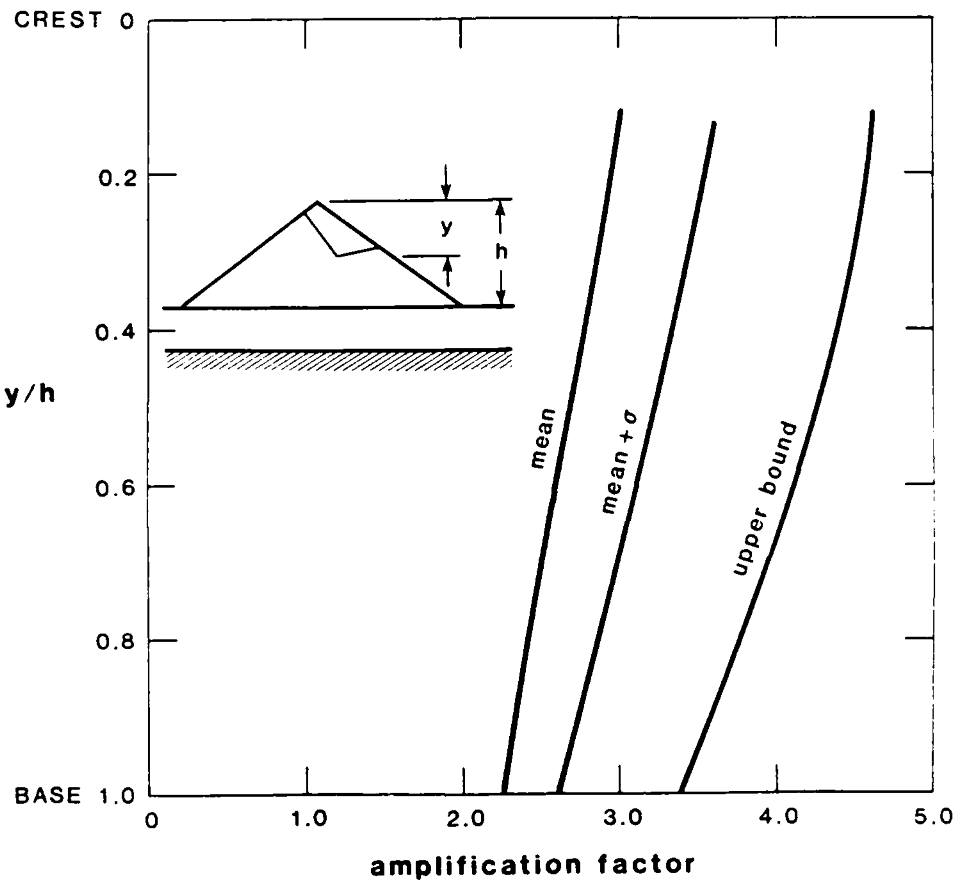


Figure 16. Amplification factor for embankment dams (from Hynes-Griffin and Franklin, 1984)

88. The amplification factor for the peak acceleration in an earth dam at the crest ranges from 3, 4, or 5 times depending on the degree of severity specified. Results of this study indicate the Franklin Falls damsite is susceptible to a maximum credible earthquake originating from the Ossipee area and having a peak bedrock acceleration of 0.38 G. As defined

by the Hynes-Griffin and Franklin curves, peak acceleration at the dam's crest using the maximum credible earthquake value would be less than 1.14 G, 1.52 G, or 1.9 G depending on the amplification curve specified. The mean plus one standard deviation value (1.52 G) is considered a reasonable estimate for the Franklin Falls damsite by this technique. The upper bound curve in Figure 16 would be extremely conservative since no known causative surface faulting is present in the study area; the assigned value for the maximum credible earthquake already has a conservative factor of safety built in; and, last, the historic record indicates no major earthquake activity is associated with the study area. Actual motions or motions found to occur by a more detailed analysis will probably be less.

PART VI: CONCLUSIONS

89. A seismic zoning was developed for the northern New England region based on the geology, historic seismicity, and geophysical data. The seismic zones include an interior stable zone, a narrow active coastal margin, and several seismic hot spots. The seismic hot spots are Ossipee, Cape Ann, and Lake George. Floating earthquakes were assigned to these seismic zones as no active faults have been identified for the northern New England region.

90. The Franklin Falls damsite is susceptible to a floating earthquake as follows:

Zone 1: Local source, MM VII, M = 5.5

Ossipee: Distance = 21 km, MM VIII, M = 6.0 to 6.3

Cape Ann: Distance = 110 km, MM VII, M = 5.5

91. Recommended peak motions based on the MM intensity and ground motion relationships of Krinitzsky and Chang (1977) are as follows:

Earthquake Source	Acceleration G, in m/sec^2	Velocity cm/sec	Duration sec, 0.05 g
Zone 1	0.15	27	9
Ossipee	0.38	25	6

Values for Zone 1 and the Cape Ann area are identical. Accelerograms and response spectra (Appendix D) for the recommended peak motions are included as representative of appropriate ground motions.

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Table 1

Earthquake Intensities (MM) at the

Franklin Falls Dam (Io = VI to XI)

Date	Latitude deg	Longitude deg	Location	MM*(Io)**	MM(Is)†	Distance km (miles)
1857 Dec 23	44.1	70.2	Lewiston, Maine	VI	IV	149 (93)
1904 Mar 21	45.0	67.2	Near Calais, Maine	VII	III	402 (250)
1905 Jul 15	44.2	70.0	Sabatus, Maine	VI	IV	149 (93)
1918 Aug 21	44.2	70.5	Bridgton, Maine	VI	IV	113 (70)
1949 Oct 05	44.8	70.6	Houghton, Maine	VI	II	433 (269)
1957 Apr 26	43.5	70.3	Portland, Maine	VI	IV	113 (70)
1627	42.6	70.8	Essex, Mass.	VI	IV	105 (65)
1727 Nov 10	42.8	70.6	Cape Ann, Mass.	VII	V	124 (77)
1727 Nov 17	42.8	70.6	Cape Ann, Mass.	VIII	VI	124 (77)
1727 Dec 29	42.8	70.6	Cape Ann, Mass.	VI	IV	124 (77)
1744 Jun 14	42.5	70.9	Cape Ann, Mass.	VI	IV	124 (77)
1755 Nov 18	42.7	70.3	Cape Ann, Mass.	VIII	VI	124 (77)
1817 Oct 05	42.5	70.2	Woburn, Mass.	VI	IV	113 (70)
1963 Oct 16	42.5	70.8	Cape Ann, Mass.	VI	IV	124 (77)
1884 Nov 23	43.2	71.7	Concord, N. H.	VI	VI	31 (19)
1925 Oct 09	43.7	71.1	Ossipee, N. H.	VI	V	56 (35)
1940 Dec 20	43.9	71.4	Ossipee, N. H.	VII	VI	56 (35)
1940 Dec 24	43.9	71.3	Ossipee, N. H.	VII	VI	56 (35)
1964 Jun 26	43.4	71.7	Concord, N. H.	VI	VI	31 (19)
1982 Jan 19	43.5	71.6	Near Laconia, N. H.	VI	VI	16 (10)
1855 Feb 07	42.0	74.0	Hudson Valley, N. Y.	VI	III	206 (128)
1897 May 28	44.5	73.5	Near Plattsburg, N. Y.	VI	IV	155 (96)
1931 Apr 20	43.5	73.8	Warrensburg, N. Y.	VII	V	164 (102)
1934 Apr 15	44.7	73.8	Dannemora, N. Y.	VI	III	222 (138)
1944 Sep 05	45.0	74.9	Massena, N. Y.	VIII	V	309 (192)
1952 Jan 29	44.5	73.2	Burlington, Vt.	VI	III	175 (109)
1638 Jun 11	47.6	70.1	Quebec, Canada	IX	IV	483 (300)
1663 Feb 05	47.6	70.1	Quebec, Canada	X	V	483 (300)
1732 Sep 16	45.5	73.6	Quebec, Canada	VIII	V	290 (180)
1860 Oct 17	47.5	70.1	Quebec, Canada	VIII-IX	V	418 (260)
1870 Oct 20	47.4	70.5	Quebec, Canada	IX	IV	459 (285)
1914 Feb 10	45.0	76.9	Quebec, Canada	VII	II	451 (180)
1925 Mar 01	47.6	70.1	Quebec, Canada	IX	IV	483 (300)
1929 Nov 18	44.5	55.0	Newfoundland, Canada	X	II	1320 (820)
1935 Nov 01	46.8	79.0	Ontario, Canada	VII	II	692 (430)
1811 Dec 11	36.6	89.6	New Madrid, Mo.	XI	III	1706 (1,060)
1812 Jan 23	36.6	89.6	New Madrid, Mo.	XI	III	1706 (1,060)
1812 Feb 07	36.6	89.6	New Madrid, Mo.	XI	III	1706 (1,606)
1886 Sep 01	32.9	80.0	Charleston, S.C.	X	II	1432 (890)

* MM = Modified Mercalli Intensity Scale.

** Io = intensity at the source.

† Is = intensity attenuated to the site.

Table 2

Summary of Ground Motions

Earthquake	Distance km	MM (Io)	MM (Is)	M		G	V	T
Zone 1 (NF)	--	VII	VII	5.5	Mean	0.14	10	3
(hard site)					Mean + 1sd	0.22	19	5
					Mean + 2sd	0.27	28	7
Zone 1 (FF)	+15	VII	VII	5.5	Mean	0.10	20	7
(hard site)					Mean + 1sd	0.15	27	9
					Mean + 2sd	0.20	32	13
Ossipee (NF)	--	VIII	VIII	6.0	Mean	0.24	20	4
(hard site)					Mean + 1sd	0.38	35	6
					Mean + 2sd	0.46	45	9
Ossipee (FF)	+25	VIII	VIII	6.0	Mean	*	*	*
(hard site)					Mean + 1sd	*	*	*
					Mean + 2sd	*	*	*
Ossipee (FF)	+25	VIII	VIII	6.0	Mean	0.20	22	15
(soft site)					Mean + 1sd	0.30	32	20
					Mean + 2sd	*	*	*

Note: MM = Modified Mercalli Intensity Scale, Io = intensity at source, Is = intensity at site, M = magnitude, G = acceleration where one G = 980 cm/sec^2, V = velocity in centimeter/second, T = duration in seconds, NF = near field, sd = standard deviation, FF = far field, * = no data.

Table 3

Selected Earthquake Records for Franklin Falls Dam

Earthquake	Record	Date	Focal Distance km	Component Degrees	Peak Acceleration cm/sec/sec	Peak Velocity cm/sec	Duration sec	M*	Site**	Scaling Factor
				Far Field						
San Fernando	S255	2/9/71	38.9	N 08 E	123.8	22.5	6.3	6.6	I	1.2
San Fernando	S255	2/9/71	38.9	N 82 W	-128.4	21.8	8.5	6.6	I	1.2
				Near Field						
Coalinga	Pleasant Valley Pumping Plant	5/2/83	14	135	514.4	39.2	7	6.5	S	0.65
Morgan Hill	Coyote Lake	4/24/84	25	195	639.7	-51.9	6	6.2	H	0.5

* M = Magnitude.
** Site type: I = intermediate, S = soft, H = hard.

APPENDIX A: STRATIGRAPHY OF FRANKLIN FALLS, DAMSITE AND VICINITY (TO ACCOMPANY FIGURE 1 IN MAIN TEXT)

METASEDIMENTARY, METAVOLCANIC AND VOLCANIC ROCKS

Mississippian (?)

Mm — Moat volcanics (Extrusive phase of White Mountain plutonic-volcanic series) - Flows, tuffs, and breccias composed chiefly of light-gray, bluish gray, and rhyolite, black basalt, and dark-gray andesite, but including some red trachyte.

Devonian

Littleton formation

DI (g) — Gray quartz-mica schist and gray mica schist, with such minerals as biotite, garnet, and/or staurolite.

DI (st) — Gray quartz-mica schist and gray mica schist, with such minerals as biotite, garnet, and/or staurolite.

DI (si) — Gray micaceous quartzite and gray coarse-grained mica schist, with such minerals as biotite, garnet sillimanite, and locally, andalusite.

DIv (si) — Dark-green medium-grained amphibolite and gray mica schist.

DIg (si) — Gray gneiss, much of it rusty brown.

DIi (si) — Schist and gneiss, respectively, injected by numerous dikes and sills of binary granite; many such injected areas have not been separately distinguished.

DIk (si) — Schist injected by numerous sills and dikes of kinsman quartz monzonite.

DIkg (si) — Schist injected by numerous sills and dikes of Kinsman quartz monzonite and Winnipesaukee quartz diorite.

Silurian

Sf (st) — White to buff marble, greenish-gray diopside-actinolite granulite, (st) greenish-gray actinolite marble, purplish-brown actinolite-biotite schist, purplish-brown biotite-calcite schist, light-gray arenaceous marble, white quartzite, and light-gray mica schist.

Sc (g) — Clough quartzite - White quartzite and quartz conglomerate, coarse crystalline, some mica schist with such minerals as biotite, garnet, and/or staurolite.

Sc (st) — Clough quartzite - White quartzite and quartz conglomerate, coarse crystalline, some mica schist with such minerals as biotite, garnet, and/or staurolite.

Sc (si)	Clough quartzite - rocks similar to those in zones g and st, except that schists contain sillimanite rather than staurolite.

Ordovician (?)

Oam (st)	Ammonoosuc volcanics - Light-gray fine-grained biotite gneiss, dark-green to black amphibolite and conglomeratic amphibolite, gray mica schist, and gray micaceous quartzite.
Oo (g)	Orfordville formation - Dark gray mica schist with porphyroblasts of garnet, staurolite, and/or kyanite; locally ottrelite schist; includes some volcanic rocks, chiefly amphibolite and fine-grained biotite gneiss.
Oop (g)	Orfordville formation - Post pond volcanic member; amphibolite and some fine-grained biotite gneiss.

PLUTONIC ROCKS
(Including a few dike rocks and shallow intrusive volcanic rocks)

Mississippian (?)

Volcanic rocks

v	Shallow intrusive rocks composed of tuff, breccia, rhyolite, quartz latite, keratophyre, andesite, and trachyte.
Cg	Conway granite - Coarse- to medium-grained biotite granite; includes fine-grained biotite granite on Red Hill.

Granite porphyry

gp	Pink, gray, green, and red medium-grained granite porphyry. Includes Mount Lafayette granite porphyry of Mount Lafayette region.
Pqs	Porphyritic quartz syenite - Pink, gray, and green medium- to coarse-grained porphyritic quartz syenite. (Albany and Mound Garfield porphyritic quartz syenite.) Includes some black fine-grained porphyritic quartz syenite.
qs	Quartz syenite - Gray, white, pink, and light-brown fine- to medium-grained quartz syenite, locally porphyritic.
ns	Nephelite-sodalite syenite - Light-gray medium- to coarse-grained nephelite-sodalite syenite.
Sy	Syenite - Dark green, light-gray, and pink coarse- to medium-grained syenite. Includes syenite porphyry.
qm	Quartz monzonite - Dark-gray fine- to coarse-grained quartz monzonite, locally porphyritic.
gd	Granodiorite - Gray to dark-gray fine-grained granodiorite.

m	Monzonite - Gray to pink fine- to medium-grained monzonite; includes dark-gray to light-gray medium-grained monzodiorite.
d	Diorite - Dark-gray to black fine- to coarse-grained diorite. Generally massive, but is foliated in Pawtuckaway Mountains Intruded and brecciated by Conway granite in Belknap Mountains. Includes quartz diorite 4 miles southeast of Franconia.
g	Gabbro - Dark-gray, medium- to coarse-grained gabbro, including some olivine gabbro and anorthosite. North of Union is gray to dark-gray fine- to medium-grained massive to foliated diorite-gabbro.

Devonian (?)

gqg	Granite, quartz monzonite, and granodiorite - Where mapped in detail, east of longitude 71°15', these rocks are pink to gray medium- to coarse-grained massive to foliated biotite granite, quartz monzonite, and granodiorite. West of longitude 71°15', where these rocks have not been mapped in detail, some areas of schist have not been separately distinguished. Continuous with Fitchburg granite of Massachusetts.
big	Binary granite - White to light-gray fine- to coarse-grained biotite-muscovite granite and quartz monzonite (Concord and Bickford granites).
kqm	Kinsman quartz monzonite - Dark-gray to light-gray medium- to coarse-grained biotite-quartz monzonite, in many places with phenocrysts of potash feldspar 1 to 3 inches long; massive to well foliated. Includes Meredith granite of Lake Winnipesaukee region.
bg	Bethlehem gneiss - Dark-gray to light-gray medium-grained biotite gneiss, strongly to weakly foliated, granoblastic texture common. Chiefly granodiorite, some quartz diorite and quartz monzonite.
qd	Quartz diorite - Dark-gray to gray medium-grained biotite-quartz diorite; massive to well foliated; includes some diorite, granodiorite, and quartz monzonite (Winnipesaukee quartz diorite of central part of State, Spaulding quartz diorite of southwestern part of State, Remick tonalite west of Littleton and Lisbon, and unnamed quartz diorite elsewhere.)
ol	Granite, quartz monzonite, and granodiorite - Pink to gray medium- to coarse-grained granite, quartz monzonite, and granodiorite; in many places foliated and granoblastic; elsewhere massive. Depending upon the ratio of potash feldspar to total feldspar, the rocks are granite, quartz monzonite, granodiorite, and rarely quartz diorite.
w	Water

Metamorphic Zonal Classification

(g)	garnet
(st)	staurolite
(si)	sillimanite

MAP REFERENCE

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APPENDIX B: EARTHQUAKES IN NORTHERN NEW ENGLAND

(Barosh, 1985; Chiburis, 1981; Nottis, 1983;
Nuttli, 1973; and Richter, 1935)

MAINE

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1766 Jan. 23	Portland	43	42	70	18	V	
1766 Jan. 24	Portland	43	42	70	18	F	
1769 Oct. 19	Portland	43	42	70	18	IV	
1769 Oct. 19	Portland	43	42	70	18	IV	
1805 Feb. 07	Augusta	44	18	69	48	F	
1806 Jun. 13	Kennebec River	44	00	69	54	F	
1807 Feb. 22	Windham	43	42	70	30	III	
1807 May 06	Saco River	43	30	70	30	IV	
1814 Nov. 29	Windham	43	42	70	18	V	4.0(B)
1821 Mar. 07	Brunswick	43	54	70	00	IV	
1828 Jul. 25	Brunswick	43	54	70	00	IV	
1829 Aug. 27	Brunswick	43	54	70	00	III	
1829 Aug. 27	Brunswick	43	54	70	00	III	
1829 Aug. 27	Gardiner	44	14	69	46	IV	
1847 Apr. 02	Limington	43	42	70	42	F	
1850 Jul. 20	Portland	43	42	70	18	III	
1853 Jun. 17	Portland	43	42	70	18	III	
1853 Jun. 20	Portland	43	42	70	00	III	
1853 Jul. 17	Portland	43	30	70	12	IV	
1853 Jul. 20	Portland	43	42	70	18	III	
1855 Jan. 16	Otisfield	44	00	71	00	V	5.0(B)
1855 Jan. 17	Otisfield	44	00	71	00	IV	
1855 Jan. 19	Portland	43	42	70	18	III	
1855 Jan. 20	Portland	43	42	70	18	III	
1857 Dec. 23	Lewiston	44	06	70	12	VI	4.0(B)
1857 Dec. 28	Lewiston	44	06	70	12	IV	
1868 Mar. 01	Augusta	44	18	69	42	III	
1870 Feb. 08	Gardiner	44	06	69	48	IV	
1873 Jan. 11	Brunswick	43	54	70	00	III	
1873 Apr. 17	Waterville	44	30	69	42	III	
1874 Feb. 12	Saco	43	30	70	30	II	
1877 Feb. 18	Portland	43	42	70	18	III	
1880 Mar. 29	Sanford	43	24	70	42	III	
1881 Jan. 21	Bath	44	00	70	00	V	
1881 Feb. 27	Augusta	44	18	69	48	III	
1888 Feb. 01	Industry	44	42	70	06	IV	
1888 Aug. 15	Wayne	44	18	70	00	IV	
1904 Mar. 21	Lubec	45	00	67	12	VII	
1905 Jul. 15	Sabbatus	44	12	70	00	VI	
1906 Oct. 19	Saco	43	30	70	30	IV	
1906 Oct. 20	Saco	43	30	70	30	IV	
1907 Jun. 29	Biddeford	43	30	70	50	III	
1910 Jan. 23	Windham	43	48	70	24	IV	
1914 Feb. 22	Rangeley Lake	45	00	70	30	V	
1914 Feb. 22	Rangeley Lake	45	00	70	30	V	
1914 Feb. 22	Rangeley Lake	45	00	70	30	V	
1918 Aug. 21	Bridgeton-Norway	44	12	70	30	VI	
1919 Jul. 11	Brunswick	43	54	70	00	IV	
1919 Jul. 23	Portland	43	42	70	18	IV	
1920 Jun. 07	Saco	43	30	70	30	IV	
1925 Oct. 18	Lewiston	44	06	70	12	IV	

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1926 May 15	Portland	43	42	70	12	III	
1926 Aug. 28	Farmington	44	48	70	24	V	
1929 Feb. 05	Auburn	44	00	70	18	V	
1929 Oct. 08	Lewiston	44	00	70	12	III	
1929 Dec. 05	Skowhegan	44	48	69	42	II	
1930 Mar. 11	Topsham	44	00	70	00	II	
1934 Aug. 02	Portland	43	42	70	18	IV	
1934 Aug. 02	Portland	43	42	70	18	III	
1934 Aug. 03	Portland	43	42	70	18	IV	
1935 Jan. 15	Lewiston	44	06	70	12	II	
1937 Oct. 12	Kennebunkport	43	18	70	30	II	
1940 Mar. 28	Stark	44	42	69	54	F	3.8(G)
1941 Jul. 01	Off Kennebunkport	43	24	70	12	--	2.0(G)
1942 Mar. 08	Lewiston	44	12	70	24	IV	
1943 Feb. 10	Portland	43	42	70	18	II	
1949 Oct. 05	Houghton	44	48	70	36	VI	4.4(C)
1951 Oct. 28	S. Paris	44	18	70	30	III	
1957 Apr. 26	Portland	43	30	70	18	VI	4.7(C)
1958 Sep. 19	Cape Elizabeth	43	36	70	12	V	
1967 Jul. 01	Augusta	44	24	69	54	V	3.2(G)
1967 Jul. 01	Augusta	44	24	69	54	III	
1967 Jul. 01	Augusta	44	24	69	54	IV	
1967 Jul. 01	Augusta	44	24	69	54	III	
1967 Jul. 01	Augusta	44	21	69	49	V	3.4(C)
1967 Jul. 01	Augusta	44	24	69	54	III	
1967 Jul. 01	Augusta	44	24	69	54	--	
1975 Oct. 10	Sabbatus	44	13	70	10	--	1.9(H)
1975 Oct. 10	Sabbatus	44	05	70	10	IV	2.2(H)
1976 Feb. 05	Lewiston	43	58	70	10	--	2.3(H)
1976 Apr. 15	North of Lewiston	44	14	70	08	III	2.4(H)
1976 Jul. 28	Off SW. Coast	43	10	70	14	--	2.3(H)
1977 Sep. 08	Little Ossipee Pond	43	34	70	41	--	1.8(H)
1978 Jan. 04	Otisfield	44	02	70	31	IV	3.2(H)
1978 Jan. 04	Otisfield	43	56	70	34	--	2.4(H)
1978 May 16	Livermore	44	23	70	14	--	2.5(H)
1978 Sep. 24	NE. of Dallas	44	59	70	25	--	2.2(H)
1978 Oct. 29	Crescent Lake	43	56	70	24	--	2.5(H)
1978 Oct. 30	Crescent Lake	43	58	70	25	--	1.6(H)
1978 Oct. 31	Crescent Lake	44	00	70	26	--	1.9(H)
1978 Oct. 31	Crescent Lake	43	59	70	25	--	2.0(H)
1978 Dec. 04	Blue Mountain	44	46	70	47	--	1.6(H)
1979 Feb. 21	Lewiston	44	05	70	11	--	1.9(H)
1979 Apr. 18	Bath	43	57	69	45	V	4.0(I)
1979 Jul. 28	So. of Kennebunkport	43	17	70	26	--	3.5(H)
1979 Aug. 24	Wayne	44	26	70	06	--	2.4(I)
1979 Sep. 22	East of Farmington	44	41	70	03	--	2.1(H)
1979 Nov. 13	SE. of Canton	44	23	70	20	--	2.1(H)
1980 Feb. 09	West of Biddeford	43	34	70	46	F	2.6(I)
1980 Feb. 25	N. of Pennesseewassee Lake	44	16	70	32	--	2.0(I)
1980 May 14	East of Speckled Mt.	44	18	70	43	--	2.1(I)
1980 Jul. 04	NW. of Augusta	44	27	69	52	--	2.4(I)
1980 Jul. 12	West of Auburn	44	07	70	31	--	2.0(I)
1980 Nov. 21	NE. of Rump Mt.	45	09	70	52	--	2.8(I)
1981 Jan. 04	Maine	43	53	70	01	F	2.6(*)

MASSACHUSETTS

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1627	Essex	42	36	70	48	VI	
1638 Jul. 01	Salem	42	30	70	54	III	
1639 Jan. 25	Lynn	42	30	70	54	III	
1643 Mar. 15	Newbury	42	48	70	48	V	
1643 Jun. 11	Newbury	42	48	70	48	IV	
1653 Nov. 08	Danvers	42	36	70	54	IV	
1658 Apr. 14	Lynn	42	30	70	54	V	
1668 Apr. 03	Boston	42	18	71	06	IV	
1668 Jun. 26	Roxbury	42	18	71	06	II	
1669 Nov. 30	Boston	42	18	71	06	II	
1670	Boston	42	18	71	06	II	
1685 Feb. 18	Danvers	42	42	70	48	IV	
1701 Feb. 10	Danvers	42	36	70	54	III	
1701 Mar. 08	Danvers	42	36	70	54	III	
1705 Jun. 27	Boston	42	24	71	06	IV	
1706	Boston	42	18	71	06	II	
1721 Jan. 19	Boston	42	18	71	06	II	
1727 Nov. 10	Cape Ann	42	48	70	36	VII	5.0(B)
1727 Nov. 10	Cape Ann	42	48	70	36	IV	
1727 Nov. 10	Cape Ann	42	48	70	36	IV	
1727 Nov. 14	Cape Ann	42	48	70	36	V	
1727 Nov. 17	Cape Ann	42	48	70	36	VIII	
1727 Nov. 18	Cape Ann	42	48	70	36	V	
1727 Dec. 01	Cape Ann	42	48	70	36	IV	
1727 Dec. 16	Cape Ann	42	48	70	36	IV	
1727 Dec. 19	Cape Ann	42	48	70	36	IV	
1727 Dec. 29	Cape Ann	42	48	70	36	VI	
1728 Jan. 05	Cape Ann	42	48	70	36	V	
1728 Feb. 05	Cape Ann	42	48	70	36	IV	
1728 Feb. 08	Cape Ann	42	48	70	36	IV	
1728 Feb. 10	Cape Ann	42	48	70	36	V	
1728 May 16	Cape Ann	42	48	70	36	IV	
1728 May 24	Cape Ann	42	48	70	36	IV	
1728 May 29	Cape Ann	42	48	70	36	IV	
1728 May 29	Cape Ann	42	48	70	36	IV	
1728 Jul. 30	Cape Ann	42	36	70	36	IV	
1728 Aug. 02	Cape Ann	42	48	70	36	IV	
1729 Feb. 10	Cape Ann	42	48	70	36	V	
1729 Mar. 30	Cape Ann	42	48	70	36	IV	
1729 Nov. 25	Cape Ann	42	48	70	36	IV	
1729 Dec. 09	Cape Ann	42	48	70	36	IV	
1730 Feb. 20	Cape Ann	42	48	70	36	V	
1730 Feb. 20	Cape Ann	42	48	70	36	V	
1730 Mar. 09	Cape Ann	42	48	70	36	IV	
1730 Apr. 24	Cape Ann	42	48	70	36	IV	
1730 Nov. 17	Cape Ann	42	48	70	36	IV	
1730 Dec. 07	Cape Ann	42	48	70	36	IV	
1730 Dec. 18	Cape Ann	42	48	70	36	IV	
1730 Dec. 22	Cape Ann	42	48	70	36	IV	
1730 Dec. 24	Cape Ann	42	48	70	36	IV	
1730 Dec. 30	Cape Ann	42	48	70	36	V	
1731 Jan. 12	Cape Ann	42	48	70	36	IV	

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1731 Oct. 13	Cape Ann	42	48	70	36	IV	
1732 Feb. 19	Cape Ann	42	48	70	36	V	
1734 Nov. 23	Cape Ann	42	48	70	36	V	
1734 Nov. 27	Cape Ann	42	48	70	36	IV	
1736 Oct. 12	Cape Ann	42	48	70	36	V	
1736 Nov. 23	Cape Ann	42	48	70	36	IV	
1737 Feb. 17	Cape Ann	42	48	70	36	V	
1737 Sep. 20	Cape Ann	42	48	70	36	IV	
1739 Aug. 13	Cape Ann	42	48	70	36	V	
1740 Dec. 25	Cape Ann	42	48	70	36	F	
1741 Jan. 29	Cape Ann	42	48	70	36	F	
1741 Feb. 05	Cape Ann	42	48	70	36	F	
1741 Jun. 24	Boston	42	12	71	12	V	
1741 Dec. 17	Boston	42	18	71	12	IV	
1744 Jun. 13	Cambridge	42	18	71	12	F	
1744 Jun. 14	Cape Ann	42	30	70	54	VI	4.7(B)
1744 Jun. 14	Salem	42	30	70	54	IV	
1744 Jun. 15	Salem	42	36	70	54	F	
1744 Jul. 01	Salem	42	30	70	54	V	
1744 Jul. 09	Salem	42	30	70	54	III	
1744 Dec. 23	Cape Ann	42	48	70	36	F	
1745 Jan. 03	Newbury	42	48	70	54	III	
1745 Jun. 12	Boston	42	18	71	06	F	
1746 Feb. 03	Boston	42	18	71	06	F	
1746 Feb. 14	Boston	42	18	71	06	F	
1746 Aug. 13	Newbury	42	48	70	54	F	
1747 Jan. 17	Newbury	42	48	70	54	F	
1747 Dec. 14	Newbury	42	48	70	54	F	
1747 Dec. 17	Newbury	42	48	70	54	F	
1748 Mar. 22	Newbury	42	48	70	54	F	
1755 Nov. 18	Cape Ann	42	42	70	18	VIII	6.0(B)
1755 Nov. 18	Cape Ann	42	42	70	18	IV	
1755 Nov. 23	Cape Ann	42	42	70	18	V	
1755 Dec. 20	Cape Ann	42	42	70	18	IV	
1756 Jan. 02	Boston	42	18	70	06	III	
1756 Mar. 11	Newbury	42	48	70	54	F	
1756 Nov. 16	Boston	42	18	71	06	III	
1756 Dec. 05	Boston	42	18	71	06	III	
1756 Dec. 19	Boston	42	18	71	06	F	
1757 Jul. 08	Boston	42	24	71	06	IV	
1758 Feb. 02	Boston	42	18	71	06	F	
1759 Feb. 02	Boston	42	18	71	06	IV	
1760 Feb. 03	Boston	42	18	71	06	II	
1760 Nov. 09	Boston	42	18	71	06	F	
1761 Feb.	Boston	42	18	71	06	F	
1761 Mar. 12	Boston	42	30	70	54	V	4.6(B)
1761 Mar. 16	Boston	42	18	71	06	IV	
1765 Jan. 05	Newbury	42	48	70	54	F	
1766 Jan. 09	Boston	42	18	71	06	V	
1766 Jun. 14	Essex	42	42	70	54	III	

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1768 Jan. 15	Newbury	42	48	70	54	F	
1768 Jun. 20	Newbury	42	48	70	54	F	
1769 Jul. 13	Newbury	42	48	70	54	F	
1770 Feb. 24	Newbury	42	48	70	54	F	
1771 Mar. 03	Salem	42	36	70	54	F	
1780 Nov. 29	Lynn	42	30	70	54	IV	
1785 Jan. 02	Dover	42	18	71	06	IV	
1786 Jan. 09	Cambridge	42	48	70	54	F	
1786 Nov. 29	Newbury	42	24	71	06	III	
1786 Dec. 06	Newbury	42	48	70	54	F	
1787 Feb. 25	Cambridge	42	24	71	06	III	
1792 Jan. 10	Salem	42	30	70	54	F	
1800 Nov. 11	Boston	42	18	71	06	F	
1803 Jan. 18	Salem	42	30	70	54	IV	
1804 Feb. 08	Salem	42	30	70	54	F	
1805 Apr. 06	Lynn	42	30	70	54	IV	
1805 Apr. 25	Salem	42	30	70	54	IV	
1805 May 12	Newbury	42	48	70	48	F	
1817 Sep. 07	Lynn	42	30	70	54	III	
1817 Oct. 05	Woburn	42	30	71	12	VI	4.0(B)
1830 Dec. 02	Lynn	42	30	70	54	III	
1837 Jan. 15	Lynn	42	30	70	54	IV	
1846 May 30	Cape Ann	42	42	70	18	IV	
1846 Aug. 25	Marblehead	42	30	70	48	V	5.0(B)
1849 Feb. 15	Springfield	42	06	72	36	III	
1849 Oct. 08	Middlesex Co.	42	30	71	24	IV	
1852 Nov. 27	Northeastern Mass.	42	48	71	00	V	
1854 Jan. 24	Palmer	42	12	72	18	III	
1854 Jan. 27	Palmer	42	12	72	18	III	
1854 Feb. 23	Reading	42	30	71	06	III	
1854 Dec. 10	Newburyport, Mass.	42	48	70	48	V	
1855 Jan. 23	Newbury	42	36	70	24	III	
1860 Mar. 17	Off Provincetown	42	12	70	30	V	
1860 Mar. 17	Off Provincetown	42	12	70	30	V	
1861 Mar. 01	Boston	42	24	71	06	III	
1862 Feb. 04	Cambridge	42	30	71	12	III	
1870 Oct. 23	Springfield	42	06	72	36	III	
1873 Jul. 16	Worchester	42	18	71	48	II	
1874 Jan. 25	Lowell	42	36	71	24	IV	
1874 Nov. 24	Salem-Newbury	42	42	70	54	IV	
1875 May 15	Cambridge	42	24	71	06	II	
1875 Nov. 01	Cambridge	42	24	71	06	II	
1876 Sep. 21	Southeastern Mass.	42	48	70	54	V	
1877 Sep. 10	Cambridge	42	24	71	06	III	
1880 May 12	Boxford	42	42	71	00	V	
1881 Feb. 02	Boston	42	18	70	06	II	
1881 Feb. 03	Plymouth	42	00	70	42	II	
1881 Jun. 19	Newburyport	42	48	70	54	IV	
1881 Dec. 16	Dorchester	42	18	71	06	III	
1884 Oct. 10	Roxbury	42	18	71	06	II	
1884 Dec. 04	Northampton	42	18	72	42	II	
1891 Jan. 15	Fitchburg	42	36	71	48	F	
1893 Mar. 14	Leeds	42	21	72	40	IV	
1903 Jan. 21	Eastern Mass.	42	06	70	54	V	

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1903 Apr. 24	Merrimac Valley	42	42	71	00	IV	
1907 Oct. 16	Newbury	42	48	71	00	V	
1908 Feb. 05	Needham	42	18	71	12	III	
1909 Aug. 16	Needham	42	18	71	12	III	
1910 Aug. 21	Merrimac Valley	42	42	71	06	IV	
1911 Feb. 06	Cambridge	42	24	71	06	II	
1913 Mar. 31	Worchester	42	18	71	48	II	
1914 Jan. 14	Needham	42	12	71	12	III	
1915 Feb. 21	Merrimac Valley	42	48	71	06	IV	
1921 Jul. 29	Cambridge	42	30	70	24	IV	
1923	Groveland	42	48	71	00	II	
1925 Jan. 07	Cape Ann	42	36	70	36	V	4.0(B)
1925 May 04	Lynn	42	30	70	54	IV	
1926 Jan. 22	Cambridge	42	24	71	06	III	
1926 Mar. 04	Lynn	42	30	70	54	II	
1926 Oct. 25	Brockton	42	06	71	00	III	
1927 Aug. 20	Quincy	42	18	71	00	IV	
1929 Sep. 17	Holbrook	42	12	71	00	II	
1930 Mar. 27	West Springfield	42	06	72	42	III	
1931 May 04	Amherst	42	24	72	30	III	
1932 Jul. 20	Lake Garfield	42	12	73	12	II	
1934 Aug. 02	Cape Ann	42	36	70	12	IV	
1935 Jan. 30	Billerica	42	36	71	18	II	
1935 Apr. 24	Off Cape Cod	42	12	70	12	IV	
1938 Jun. 23	Chelmsford	42	36	71	25	V	
1939 Feb. 01	Chelmsford	42	36	71	24	II	
1940 Jan. 02	Littleton	42	30	71	30	III	
1941 Oct. 11	Sturbridge	42	18	72	18	IV	3.0(G)
1943 Mar. 31	Northampton	42	18	72	36	II	
1951 Mar. 31	Palmer	42	12	72	12	IV	
1954 Jul. 29	Cape Ann	42	48	70	42	V	4.0(C)
1963 Oct. 16	Marble Head	42	24	70	24	--	3.8(C)
1963 Oct. 16	Near Coast of Mass.	42	30	70	48	VI	
1963 Oct. 17	Dunstable	42	42	71	30	III	
1963 Oct. 30	Off Cape Ann	42	42	70	48	VI	3.2(G)
1967 May 15	NE. of Provincetown	42	18	69	48	--	3.2(G)
1971 Oct. 21	Lawrence	42	42	71	12	V	
1975 Aug. 03	Ipswich	42	42	70	54	--	2.4(G)
1977 Jul. 01	Cape Ann	42	53	70	04	--	2.6(H)
1978 Aug. 06	Wakefield	42	27	71	04	--	1.6(H)
1978 Aug. 06	Wakefield	42	26	71	02	--	1.8(H)
1978 Sep. 01	Boxborough-Acton	42	29	71	28	II	2.0(H)
1979 Nov. 20	Quincy	42	13	71	02	--	2.2(H)
1980 Nov. 23	Lowell	42	38	71	22	IV	2.6(I)

New Hampshire

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1728 Jan. 12	New Hampton	43	36	71	42	III	
1747 Aug. 25	Dover	43	12	70	54	III	
1751 Jul. 21	Dover	43	12	70	54	III	
1761 Nov. 02	South of Concord	43	06	71	30	IV	
1766 Dec. 17	Portsmouth	43	06	70	48	IV	
1772 Aug. 15	Shelburne	44	24	71	06	F	
1777 Sep. 14	Manchester	43	00	71	30	F	

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1800 Dec. 20	NW. of Newport	43	42	72	18	IV	
1801 Mar. 01	Portsmouth	43	06	70	48	IV	
1801 Mar. 18	Portsmouth	43	06	70	48	F	
1807 Jan. 12	North Hampton	43	00	70	54	F	
1807 Jan. 14	Exeter	43	00	71	00	IV	
1810 Nov. 10	Portsmouth	43	00	70	48	V	4.0(B)
1823 Jul. 23	Off Hampton	42	54	70	36	V	4.0(B)
1829 Jan. 01	Portsmouth	43	06	70	48	IV	
1845 Nov.	Lebanon	43	36	72	18	IV	
1846 Jul. 10	Deerfield	43	06	71	18	III	
1846 Sep. 12	Deerfield	43	06	71	18	III	
1846 Oct. 30	Deerfield	43	06	71	18	III	
1846 Oct. 31	Deerfield	43	06	71	18	III	
1846 Nov. 13	Deerfield	43	06	71	18	III	
1846 Dec. 02	Deerfield	43	06	71	18	III	
1847 Feb. 02	Deerfield	43	06	71	18	III	
1847 Feb. 14	Deerfield	43	06	71	18	III	
1847 Feb. 21	Deerfield	43	06	71	18	III	
1851 Oct. 12	Deerfield	43	06	71	18	III	
1852 Jun. 30	Claremont	43	24	72	18	III	
1852 Aug. 11	Deerfield	43	06	71	18	III	
1852 Nov. 28	Exeter	43	00	70	54	V	
1853 Nov. 21	Antrim	43	00	71	54	III	
1853 Nov. 28	Antrim	43	00	71	54	IV	
1854 Oct. 01	Keene	42	54	72	18	F	
1854 Oct. 25	Keene	42	54	72	18	IV	
1854 Dec. 11	North Hampton	43	00	70	48	V	
1855 May 29	Coos Co.	44	42	71	36	IV	
1871 Jul. 20	Concord	43	12	71	30	IV	
1872 Nov. 18	Concord	43	12	71	36	V	
1873 Oct. 05	Derry	42	54	71	18	III	
1874 Jan. 06	Wolfeboro	43	36	71	12	II	
1874 Jan. 26	Manchester	43	00	71	30	IV	
1874 Jan. 26	Manchester	43	00	71	30	III	
1875 May 06	Wolfeboro	43	36	71	12	II	
1875 Dec. 01	Keene	42	54	72	18	IV	
1875 Dec. 01	Keene	42	54	72	18	II	
1877 Apr. 23	Auburn	43	00	71	18	II	
1879 Oct. 26	Manchester	43	00	71	30	IV	
1879 Nov. 03	Contoocook	43	12	71	42	II	
1880 Jul. 13	Concord	43	12	71	36	II	
1880 Jul. 21	Manchester	43	00	71	30	IV	
1880 Aug. 21	Barrington	43	12	71	06	II	
1881 Feb. 04	Greenland	43	00	70	48	II	
1881 Feb. 12	Portsmouth	43	00	70	48	II	
1881 Apr. 03	Antrim	43	00	71	54	III	
1881 May 18	Contoocook	43	12	71	42	III	
1881 May 18	Contoocook	43	12	71	42	III	
1881 Aug. 13	Contoocook	43	12	71	42	III	
1881 Oct. 06	Bristol	43	12	71	36	III	
1881 Oct. 31	Contoocook	43	12	71	42	II	
1882 Apr. 17	Hopkinton	43	12	71	42	IV	
1882 May 08	Concord	43	12	71	36	III	
1882 Dec. 19	Concord	43	12	71	24	IV	

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1883 Feb. 04	Wolfeboro	43	36	71	12	II	
1884 Jan. 18	Contoocook	43	12	71	42	IV	
1884 Oct. 27	Nashua	42	48	71	24	II	
1884 Nov. 13	Concord	43	12	71	36	II	
1884 Nov. 23	Concord	43	12	71	42	VI	4.0(B)
1884 Dec. 17	Center Harbor	43	42	71	30	III	
1885 Jan. 03	Laconia	43	30	71	30	II	
1885 Mar. 18	Contoocook	43	12	71	42	II	
1886 Jan. 06	Merrimack	42	54	71	30	IV	
1886 Jan. 17	Nashua	42	48	71	24	IV	
1887 Jul. 01	Concord	43	12	71	32	IV	
1889 Mar. 08	Franklin	43	30	71	36	IV	
1891 May 02	Near Concord	43	12	71	36	V	4.0(B)
1891 May 30	Near Concord	43	06	71	30	IV	
1892 Dec. 11	Bethlehem	44	18	71	42	IV	
1893 Jul. 02	Dublin	42	54	72	06	F	
1896 Oct. 22	Bethlehem	44	18	71	48	IV	
1897 Jul. 01	Meredith	43	42	71	36	IV	
1905 Mar. 05	Lebanon	43	36	72	18	V	
1905 Aug. 30	Rockingham Co.	43	06	70	42	V	
1908 Nov. 23	Franklin	43	30	71	42	IV	
1910 Aug. 30	Lake Sunaped	43	24	72	06	IV	
1911 Mar. 02	Concord	43	12	71	30	IV	
1920 May 23	Concord	43	06	71	30	IV	
1922 May 07	Pittsfield	43	24	71	24	IV	
1925 Mar. 09	Goff's Falls	42	54	71	30	IV	
1925 Oct. 09	Ossipee	43	42	71	06	VI	
1926 Mar. 18	New Ipswich	42	48	71	48	V	
1927 Mar. 09	Concord	43	18	71	24	V	
1928 Apr. 25	Berlin	44	30	71	12	V	4.0(B)
1928 Apr. 28	Concord	43	12	71	30	IV	
1928 May 22	Concord	43	12	71	30	II	
1928 May 26	Contoocook	43	12	71	42	II	
1928 Oct. 15	Pittsburg	45	06	71	24	II	
1928 Oct. 17	Wilton	42	48	71	36	III	
1928 Nov. 05	Rochester	43	18	71	18	II	
1928 Dec. 01	Rochester	43	18	71	00	II	
1929 Jan. 13	Rochester	43	18	71	00	II	
1929 Jan. 15	Rochester	43	18	71	00	III	
1929 Feb. 05	Weare	43	18	71	42	II	
1930 Feb. 14	Franklin	43	24	71	42	IV	
1930 Mar. 19	Concord	43	18	71	36	IV	
1932 Oct. 15	Meredith	43	36	71	30	III	
1932 Oct. 16	Keene	42	54	72	18	II	
1932 Nov. 04	Concord	43	12	71	30	II	
1935 Sep. 13	Concord	43	12	71	30	F	
1936 Jun. 14	Laconia	43	30	71	30	III	
1936 Jun. 15	Center Sandwich	43	48	71	24	III	
1936 Nov. 10	Laconia	43	36	71	24	V	
1938 Apr. 01	Rochester	43	18	71	00	III	
1938 Apr. 03	Rochester	43	18	71	00	II	
1939 Oct. 10	Tilton	43	24	71	36	III	
1939 Oct. 11	Derry	42	54	71	24	III	
1940 Dec. 20	Ossipee	43	54	71	24	VII	5.5(C)

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1940 Dec. 24	Ossipee	43	48	71	18	F	
1940 Dec. 24	Ossipee	43	54	71	18	VII	5.5(C)
1940 Dec. 24	Ossipee	43	48	71	18	F	2.8(C)
1940 Dec. 24	Ossipee	43	48	71	18	F	
1940 Dec. 25	Ossipee	43	48	71	18	F	3.7(C)
1940 Dec. 27	Ossipee	43	48	71	18	F	3.8(C)
1941 Jan. 02	Ossipee	43	48	71	18	F	
1941 Jan. 04	Ossipee	43	48	71	18	F	
1941 Jan. 18	Ossipee	43	48	71	18	F	
1941 Jan. 21	Ossipee	43	48	71	18	F	3.6(G)
1941 Jan. 23	Ossipee	43	48	71	18	F	2.9(C)
1941 Feb. 12	Ossipee	43	48	71	18	F	
1943 Mar. 14	Meredith	43	42	71	36	--	3.9(G)
1944 Mar. 06	Concord	43	12	71	36	II	
1944 Mar. 06	Concord	43	12	71	36	II	
1944 Apr. 11	Woodstock	44	00	71	42	III	
1945 Mar. 22	Concord	43	12	71	36	III	
1949 Sep. 02	S. Tanworth	43	48	71	18	III	
1950 Feb. 24	SW. of Concord	43	00	71	48	III	
1952 Oct. 26	Wolfeboro	43	36	71	12	II	
1953 May 11	Conway	44	00	71	06	IV	
1954 Oct. 07	Pelham	42	42	71	18	III	
1958 Nov. 21	Woodstock	44	00	71	42	IV	
1962 Dec. 29	Nashua	42	48	71	42	V	
1963 Dec. 04	Laconia	43	36	71	36	V	3.6(G)
1964 Apr. 01	Laconia	43	36	71	30	IV	2.4(G)
1964 Jun. 26	Concord	43	25	71	41	VI	3.2(D)
1965 Jan. 03	Laconia	43	31	71	47	IV	3.0(G)
1966 Apr. 28	Benton	44	06	71	54	IV	
1966 Oct. 23	Manchester	43	00	71	24	V	3.1(G)
1967 Jan. 26	North of Berlin	44	36	70	54	--	2.1(G)
1969 Aug. 06	Ossipee	43	48	71	24	F	2.6(G)
1976 Jun. 12	Franconia	44	14	71	37	--	2.4(H)
1976 Jun. 14	Franconia	44	17	71	41	--	2.0(H)
1976 Nov. 15	Laconia	43	34	71	37	--	1.5(H)
1976 Nov. 22	Laconia	43	32	71	36	--	1.8(H)
1977 Dec. 25	Hopkinton	43	11	71	39	V	3.2(H)
1978 Jan. 18	East of Keene	42	59	72	09	--	1.9(H)
1978 Mar. 20	NW. of Manchester	43	05	71	31	--	2.4(H)
1978 Mar. 31	Dunbarton	43	06	71	38	--	2.7(H)
1978 Jun. 21	Winnipesaukee	43	40	71	23	--	1.8(H)
1978 Aug. 17	Winnisquam Lake	43	31	71	34	--	1.9(H)
1978 Aug. 25	Seabrook	42	52	70	50	II	2.3(H)
1979 Jan. 01	SE. of Bristol	43	31	71	38	--	1.9(H)
1979 Jul. 09	South of Lanconia	43	23	71	27	--	2.4(H)
1980 Apr. 01	NE. of Squam Lake	43	50	71	24	--	2.0(I)
1980 Apr. 07	West of Highland Lake	43	08	72	13	--	2.8(I)
1980 May 21	NW. of Keene	43	01	72	24	--	1.8(I)
1980 Nov. 05	N. Lake Winnipesaukee	43	40	71	22	--	2.7(I)
1981 Jun. 28	New Hampshire	43	34	71	33	F	3.1(*)
1982 Jan. 19	West of Laconia	43	30	71	37	VI	4.7(I)
1982 Jan. 27	West of Laconia	43	32	71	37	V	2.9(H)
1982 Dec. 01	North of Laconia	43	37	71	31	F	2.2(H)

NEW YORK

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1847 Jan. 12	Albany	42	42	73	48	IV	
1847 Jul. 09	Glens Falls	43	24	73	42	III	
1855 Feb. 07	Hudson Valley	42	00	74	00	VI	
1855 Dec. 17	Warren Co.	43	30	73	48	IV	
1889 Aug. 10	Warrensburg	43	30	73	48	IV	
1894 Dec. 17	Coeymans	42	29	73	48	V	
1897 May 28	South of Plattsburg	44	30	73	30	VI	
1915 Feb. 21	Beekmantown	44	42	73	24	IV	
1916 Jan. 05	Chestertown	43	36	73	42	V	
1916 Nov. 02	Glens Falls	43	24	73	36	V	
1917 Oct. 02	Glens Falls	43	18	73	42	III	
1927 Oct. 24	Dannemora	44	42	73	48	IV	
1931 Apr. 20	Warrensburg	43	30	73	48	VII	3.7(J)
1934 Apr. 15	Dannemora	44	42	73	48	VI	4.5(G)
1939 Oct. 21	Glens Falls	43	18	73	18	II	
1940 Sep. 26	Plattsburg	44	42	73	30	--	2.9(G)
1941 Dec. 12	Dannemora	44	54	73	36	--	2.7(G)
1942 May 24	Dannemora	44	42	73	48	--	2.9(G)
1942 May 24	Dannemora	44	42	73	48	--	3.9(G)
1942 Oct. 01	Lake Champlain	44	00	73	36	--	2.5(G)
1942 Oct. 02	Albany	42	36	73	48	--	3.0(G)
1943 May 09	Dannemora	44	48	73	48	--	3.2(G)
1944 Sep. 05	Massena	44	59	74	54	VIII	
1948 Apr. 04	East of Lake Placid	44	12	73	36	--	2.5(G)
1951 Nov. 06	Rouses Pt.	44	54	73	42	IV	4.1(D)
1953 Apr. 26	Plattsburg	44	42	73	30	IV	2.6(G)
1954 Apr. 21	Plattsburg	44	42	73	30	IV	
1956 Jul. 27	Dannemora	44	42	73	48	--	3.4(G)
1963 Feb. 16	Rouses Pt.	44	54	73	42	--	2.6(G)
1963 Jul. 01	Albany	42	36	73	48	--	3.3(G)
1973 Mar. 30	Dannemora	44	42	73	48	--	1.7(H)
1974 Jun. 26	Cannon Corners	45	00	73	48	--	2.1(H)
1974 Sep. 18	SW. of Lake George	43	24	73	48	--	2.5(H)
1974 Nov. 23	Saranac	44	35	73	42	--	1.6(H)
1975 Jan. 27	Near Vt. Border	43	47	73	22	--	1.7(H)
1975 Jan. 28	Cannon Corners	44	58	73	47	--	2.6(H)
1975 Apr. 28	Lyon Mtn.	44	43	73	44	--	1.2(H)
1975 May 14	Blue Mtn. Lake	44	48	73	36	--	1.7(H)
1975 Jun. 09	Altona	44	52	73	39	V	3.5(C)
1975 Jun. 12	Altona	44	53	73	38	--	
1976 Feb. 13	SW. of Plattsburg	44	38	73	35	--	1.9(H)
1976 Dec. 16	Wilmington	44	24	73	48	--	1.8(H)
1977 Oct. 07	Dannemora	44	44	73	39	--	2.2(H)
1978 Jul. 13	Dannemora	44	44	73	40	--	2.5(H)

VERMONT

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1843 Mar. 14	North of Montpelier	44	24	72	30'	IV	
1851 Dec. 25	Bridgeport	44	00	73	18	III	
1856 Jun. 10	Bellows Falls	43	06	72	30	II	
1863 Jun. 09	East of Burlington	44	30	73	00	IV	
1867 Dec. 18	Vermont	44	00	73	00	V	
1873 Nov. 05	Burlington	44	30	73	12	III	
1873 Nov. 05	Burlington	44	30	73	12	III	
1878 Mar. 12	Milford	42	42	71	36	II	
1880 Sep. 23	Charlotte	44	18	73	18	II	
1895 May 28	Putney	43	00	72	30	III	
1898 Jun. 11	Brattleboro-Vernon	42	48	72	36	IV	
1905 Oct. 22	Newport	44	54	72	12	V	
1908 Aug. 16	Milton	44	36	73	06	III	
1934 Apr. 11	Rutland-Montpelier	44	00	72	42	III	
1934 Apr. 11	Rutland-Montpelier	44	00	72	42	III	
1935 Nov. 01	Montpelier	44	18	72	36	II	
1936 Nov. 10	Bloomfield	44	42	71	42	IV	
1937 Dec. 02	Burlington	44	30	73	12	II	
1938 Apr. 13	Manchester	43	12	73	06	II	
1941 May 19	North of Hanover, NH	43	48	72	18	--	2.0(G)
1943 Jul. 06	Swanton	44	48	73	00	IV	4.1(D)
1944 Jun. 04	Northfield	44	12	72	48	III	
1945 Aug. 05	Woodstock	43	36	72	30	III	
1948 Oct. 20	Burlington	44	30	73	12	F	
1952 Jan. 29	Burlington	44	30	73	12	VI	
1953 Mar. 31	Brandon	43	42	73	00	III	
1953 Mar. 31	Brandon	43	42	73	06	V	4.0(D)
1955 Feb. 02	Burlington	44	30	73	12	V	
1957 Apr. 24	St. Johnsbury	44	24	72	00	V	
1962 Apr. 10	Middlebury	44	06	73	00	V	4.2(D)
1967 Jan. 11	North of Montpelier	44	42	72	36	--	1.9(G)
1976 Dec. 29	Burlington	44	25	73	08	--	1.7(H)
1977 May 05	Lake Fairlee	43	52	72	16	--	2.1(H)
1978 Aug. 07	NW. of Montpelier	44	22	72	38	--	1.8(H)
1978 Sep. 27	East of Bristol	44	08	73	02	--	1.8(H)
1978 Oct. 24	SE. of Bristol	44	06	72	59	--	1.9(H)
1979 Jan. 29	North Hero	44	49	73	11	II	2.5(H)
1979 Jan. 31	Ludlow	43	23	72	38	--	1.5(H)
1979 May 04	North of Middlebury	44	04	73	14	--	1.3(I)
1979 May 15	North of Middlebury	44	05	73	13	--	1.4(I)
1980 Jun. 30	South of Montpelier	44	08	72	35	--	1.9(I)
1980 Dec. 25	NW. of Newbury	44	06	72	05	--	2.5(I)

QUEBEC CANADA

Date	Location	Lat. deg.	Lat. sec.	Long. deg.	Long. sec.	M.M. Int.	Mag.
1638 Jun. 11	LaMelbaie	47	36	70	06	IX	
1663 Feb. 05	LaMelbaie	47	36	70	06	X	
1732 Sep. 16	Montreal	45	30	73	36	VIII	
1860 Oct. 17	East of Montgomery	47	30	70	06	IX	
1870 Oct. 20	Baie St. Paul	47	24	70	30	IX	
1914 Feb. 10	West of Perth	45	00	76	54	VII	
1925 Mar. 01	LaMelbaie	47	36	70	06	IX	
1929 Nov. 18	S. of Newfoundland	44	30	55	00	X	
1935 Nov. 01	Temiscamina Station	46	48	79	00	VIII	
1971 May 14	Lacolle	45	06	73	24	IV	3.2(H)
1974 Aug. 12	SE. of Montreal	45	03	73	20	--	2.1(G)
1975 Sep. 19	St. Chrysostone	45	08	73	49	--	2.2(G)
1979 Mar. 14	Lake Ontario	43	32	73	20	--	2.4(G)
1980 Apr. 19	SE. of Montreal	45	08	73	02	--	2.6(H)
1980 Jun. 26	Stanbridge Station	45	07	70	02	--	1.9(I)
1980 Aug. 11	South of Montreal	45	08	73	38	--	2.0(G)

Note: Dates were based on Greenwich Mean Time.

B	Felt area magnitude based on M_{bLg} (Nuttli, 1973)
C	M_{bLg} (Nuttli, 1973) computed from seismograms
D	M_{bLg} (Nuttli, 1973) computed from seismograms
G	M_L (Richter, 1935 - computed from seismograms by the Earth Physics Branch, Ottawa, Canada
H	M_{bLg} (Nuttli, 1973) - computed from seismograms by data contributors to the Northeastern United States Seismic Network
I	Signal duration magnitude based on M_{bLg} (Nuttli, 1973), calculated by Weston Observatory, Boston College
J	Felt area magnitude based on M_L (Richter, 1935), and adjusted by Ebel (1982) for the seismic wave attenuation of the north eastern United States
*	Mag. not specified. Stover (1984). Stover, Carl W. (1984) United States Earthquakes, 1981. U.S.G.S. Special Publication. Washington, 136 pp.

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APPENDIX C: SUMMARY AND ANALYSIS OF THE 1982 GAZA, NEW HAMPSHIRE EARTHQUAKE

(Report by Patrick J. Barosh, 1985)

SUMMARY AND ANALYSIS OF THE 1982 GAZA, NEW HAMPSHIRE EARTHQUAKE

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INTRODUCTION

On January 18, 1982 EST a magnitude 4.7 Mc earthquake occurred near the village of Gaza, N.H., about 3.5 miles from the Franklin Falls dam on the Pemigewasset river (Fig. 1). The earthquake was widely felt and produced epicentral intensities of low VI, about the same as those from the much larger, magnitude 5.8 Mn Mirimachi earthquake in New Brunswick, nine days earlier. The Gaza earthquake also produced an unusually high acceleration and resulted in the first set of strong-motion records for the northeastern United States. The data from this earthquake, along with that from the improved seismic network, offers an opportunity to reassess the seismicity in central New Hampshire and its potential effect at the Franklin Falls Dam site..

In the following report the source parameters of the earthquake will be reviewed, the damage in the epicentral area described, and possible source zone and cause analyzed. The implications of this investigation to the Franklin Falls dam site are discussed.

SEISMICITY OF NEW HAMPSHIRE

New Hampshire experiences low to moderate seismic activity. Over 200 earthquakes are recorded from the state between 1728 and September 1983, disregarding the small aftershocks (Appendix) (Figs. 2 and 3). Most of these are felt, as non-felt earthquakes have only been adequately recorded since 1977. 23 earthquakes above magnitude 1.0 were recorded in the last full year of

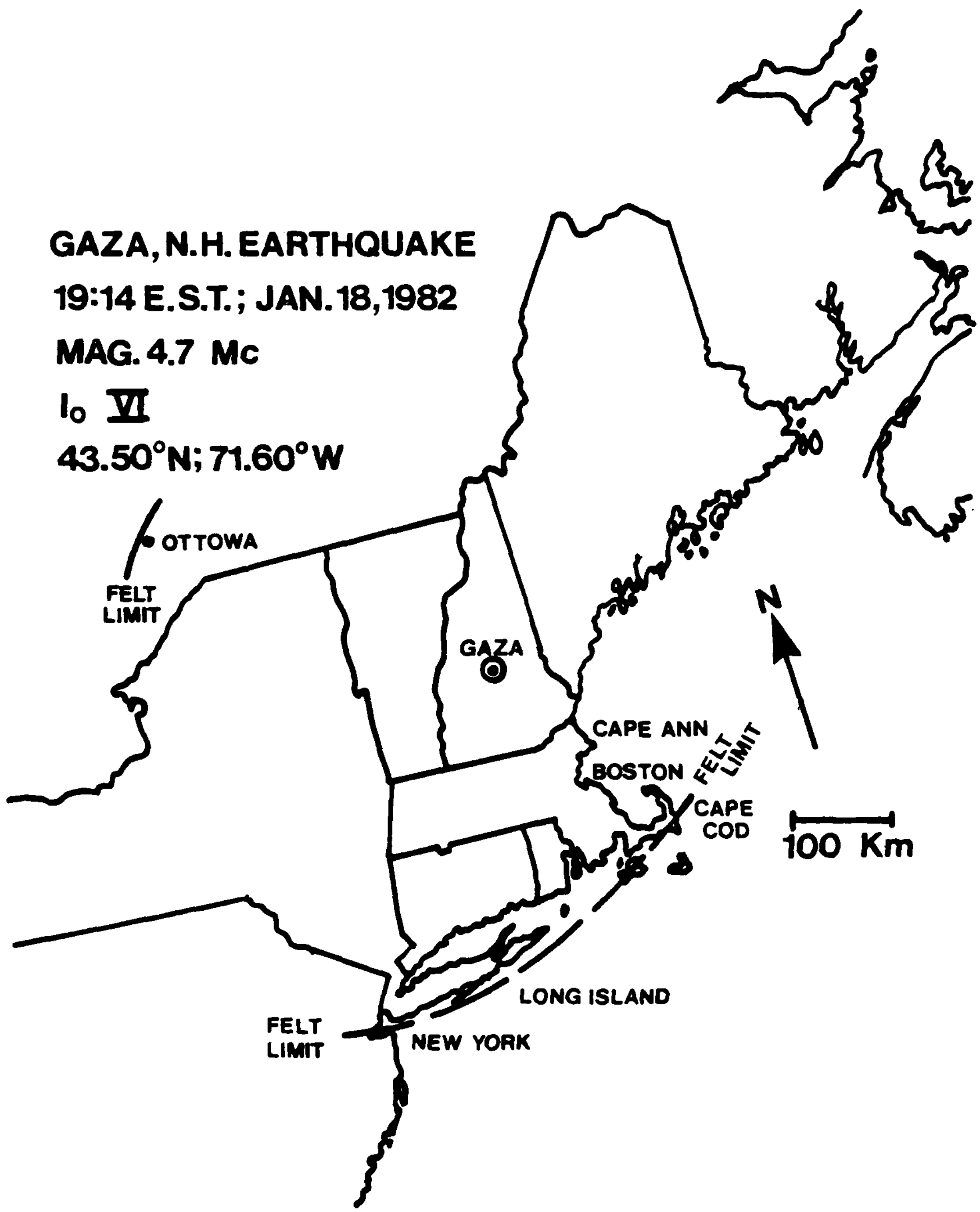


Figure 1. Index map showing the location of the Gaza earthquake and its felt limits.

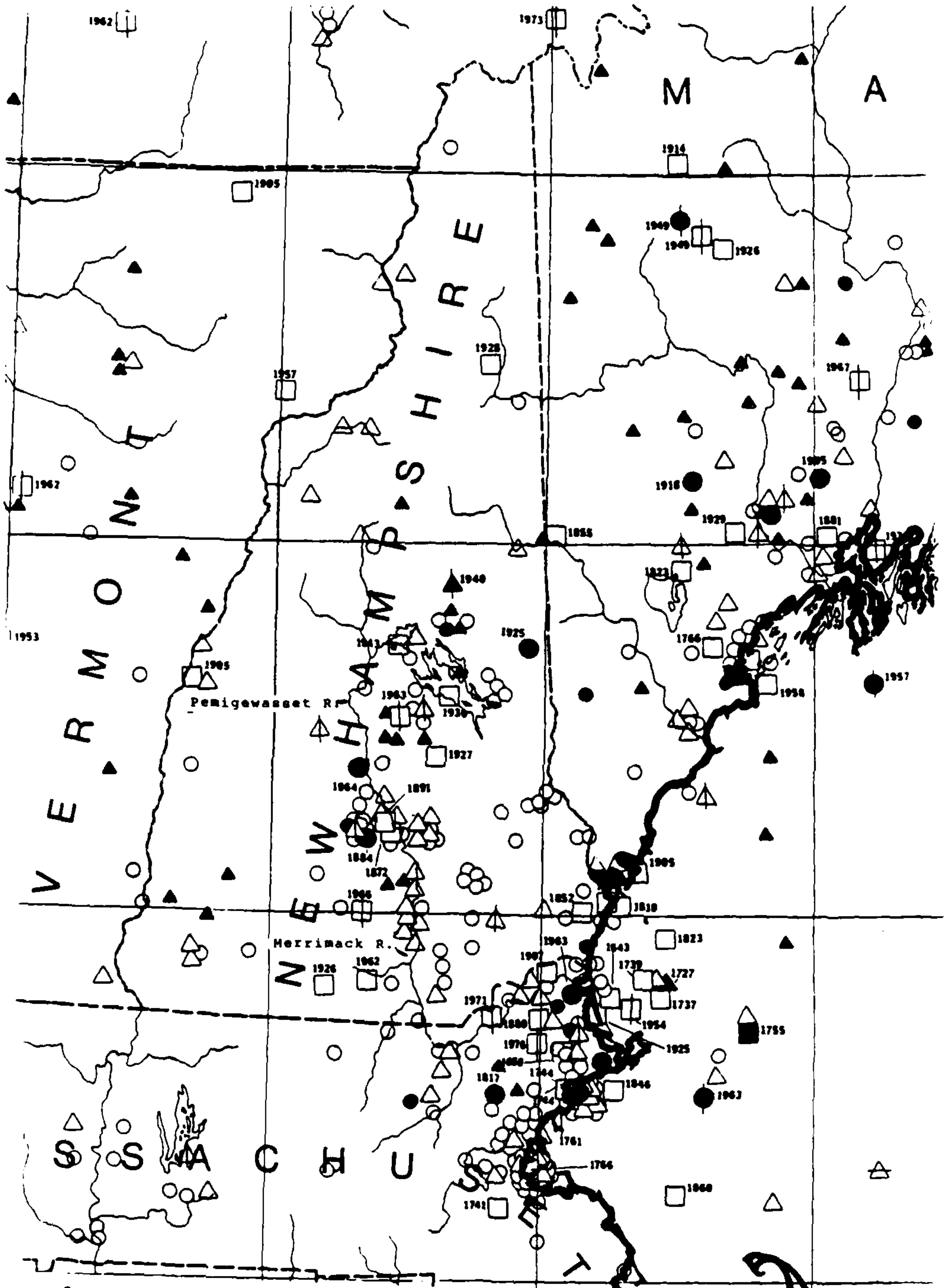
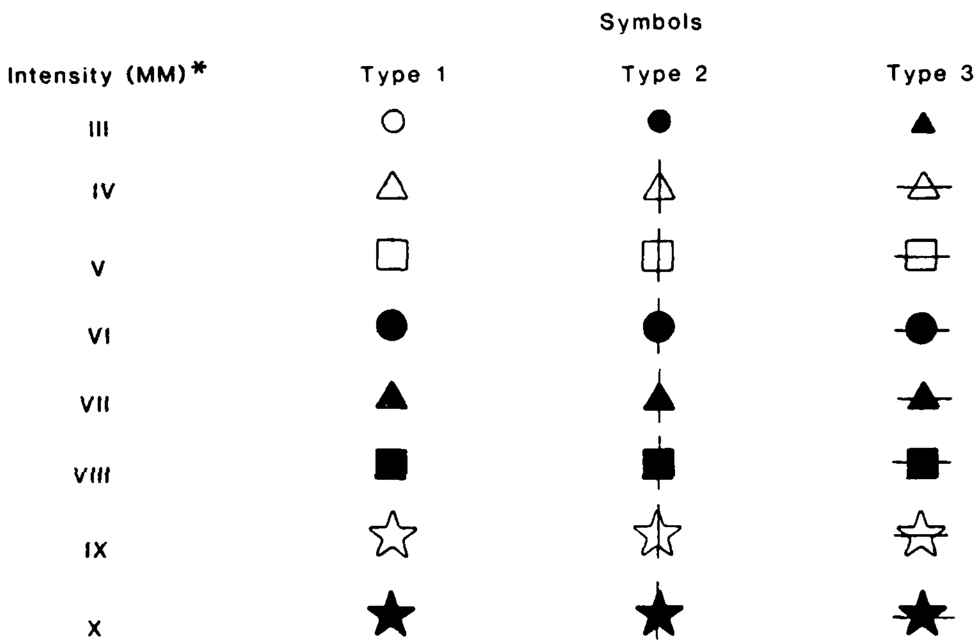


Figure 2. Epicentral map of New Hampshire and adjacent areas to 1980 (Nottis, 1983). Explanation on next page.

Figure 2. EXPLANATION

KEY TO EPICENTER SYMBOLS



Type 1 symbols indicate an epicenter that was determined from felt reports only and had an epicentral intensity (MM) as indicated.

Type 2 symbols indicate earthquakes detected by seismographs or an epicenter that was determined from seismogram analysis and had an epicentral intensity (MM) as indicated.

Type 3 symbols indicate an epicenter that was determined from seismogram analysis and that the earthquake was not felt. An intensity symbol is assigned to the earthquake using the I_0-M formula developed by Mitronovas (1981).

*Felt Intensity in Modified Mercalli Scale after Wood and Neumann (1931).

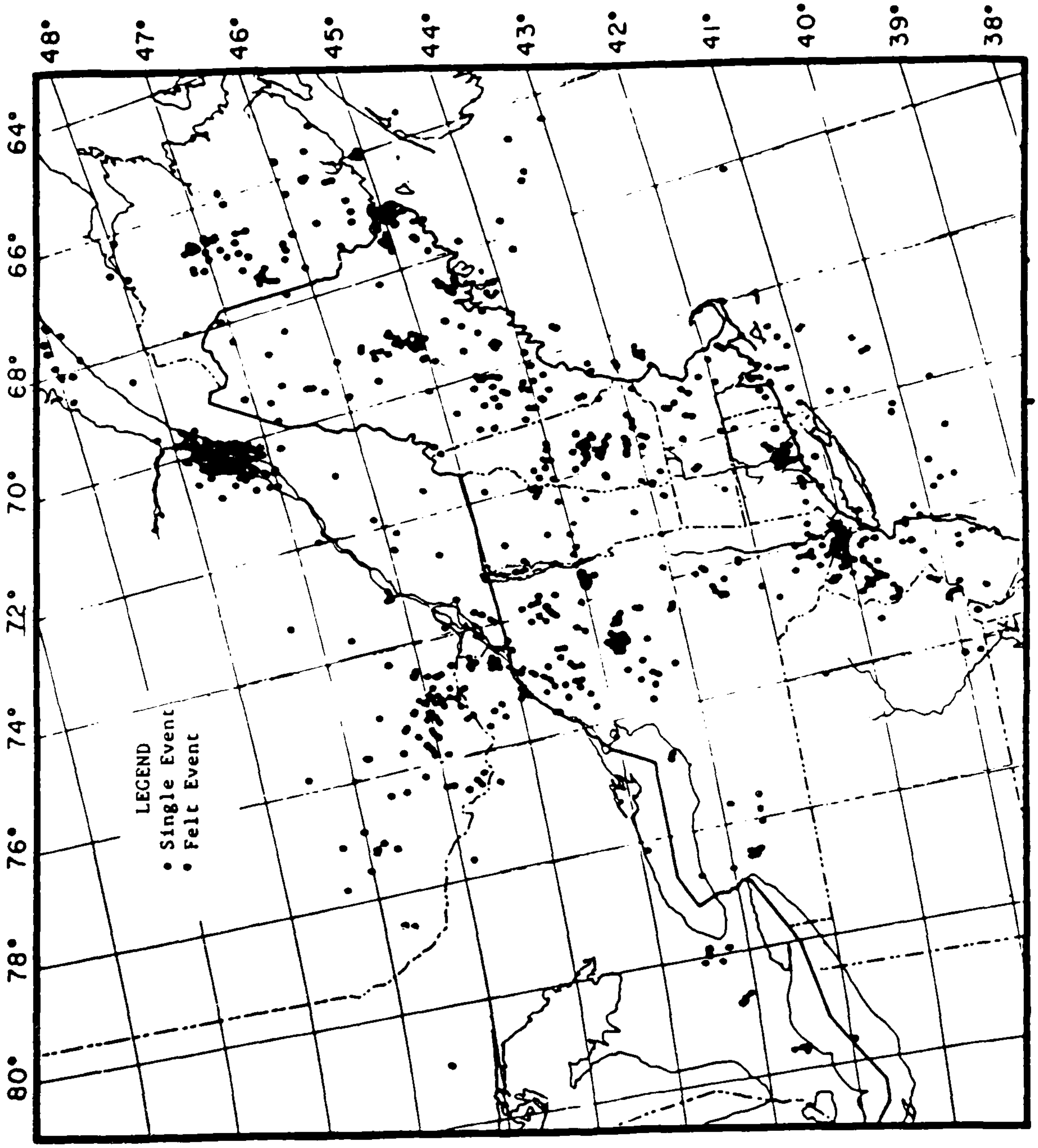


Figure 3. Epicentral map of the northeastern United States period October 1975 to September 1983 (Foley and others, 1984).

operation. The two Ossipee earthquakes of December 1940 with intensities of VII and magnitudes of 5.5 are the largest known. Four intensity VI earthquakes have occurred, including the Gaza event. An earthquake of V or greater occurs about every 8 years in the state.

Most of the earthquakes are clustered in a zone through the state along the Merrimack river valley and around Lake Winnipesaukee at the southern edge of the White Mountains. The largest earthquakes and the Gaza event are in the northern part of this cluster. Some earthquakes occur along the coast not far from Cape Ann, and a few along the Connecticut River.

The focal depths recorded show a range of 0.53 to 18.75 km with the great majority 10.0 km or less. The average depth is just over 7 km. Errors in depth of 2.0 to 2.5 are typical of recent years. The listed epicentral accuracies for 1983 are generally 0.9 to 1.9 km and the potential location error for earlier earthquakes increases with their age.

1940 Ossipee Earthquakes

Earthquakes of nearly equal strength occurred north of Lake Winnipesaukee on December 20 and 24, 1940. The first was located at approximately 43.87° N and 71.37° W at a depth of 10.0 km and the second slightly to the east at 7.6 km depth (Dewey, 1983). Both reached intensity VII. The Richter magnitudes were reported as about 6.0 and slightly higher, respectively by Leet and Linehan (1942) and reevaluated as 5.5 mbLg magnitude by Street and Turcotte (1977). 129 aftershocks were recorded through January 31, 1941 by one observer (Neumann, 1941), although only 10 were instrumentally recorded (Leet and Linehan, 1942). The

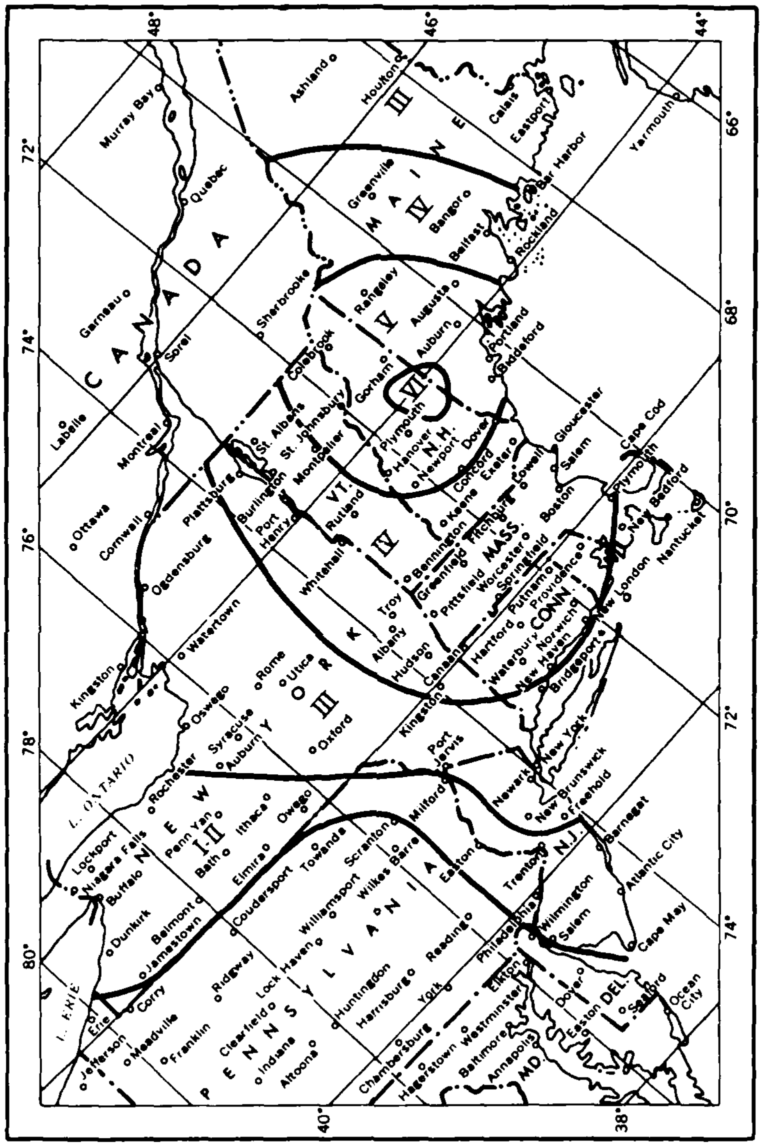


Figure 4. Isoseismal map of the 1940 Ossipee earthquakes (Neumann, 1942).

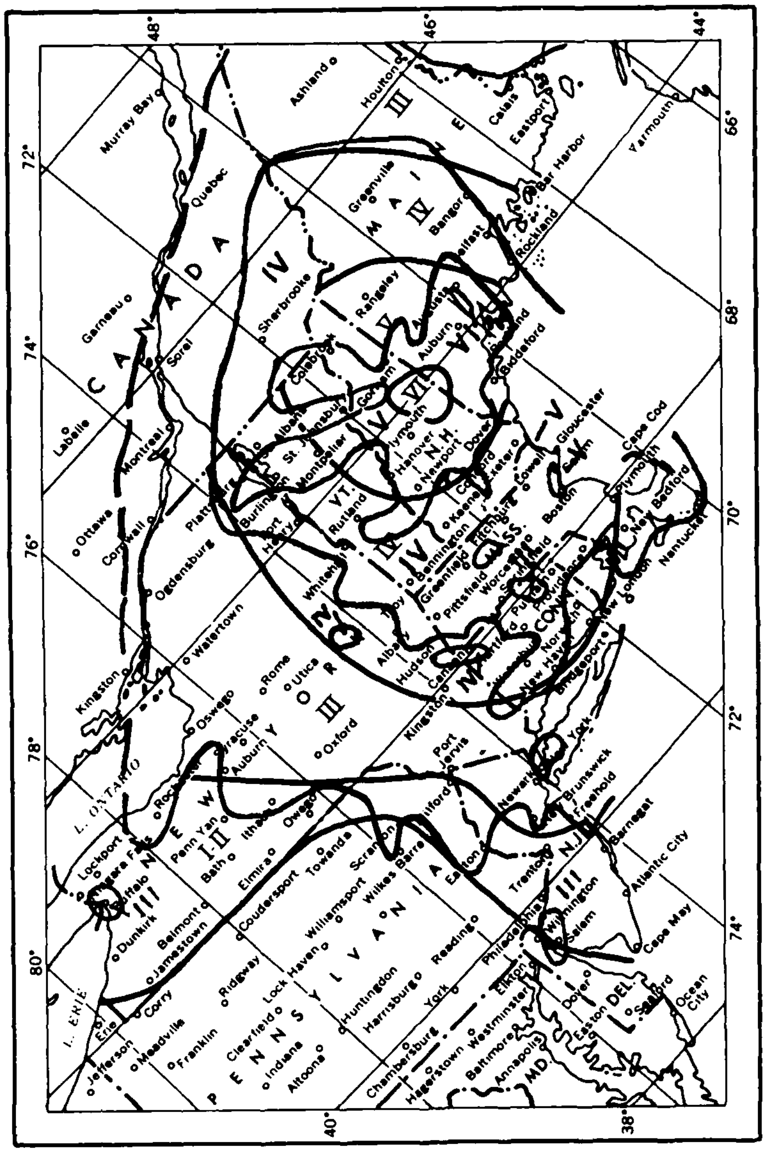


Figure 5. Detailed isoseismal map of the 1940 Ossipee earthquakes (data from Neumann, 1942, Smith, 1966).

earthquakes were first thought to be deep and deep crustal causes were sought (Billings, 1942; Leet, 1942), but the reevaluation by Dewey (1983) indicates they are shallow, despite the large felt area, and similar to other nearby earthquakes.

The earthquakes were very widely felt, especially to the southwest. The reported felt area extended from the New Brunswick border to southwest New Jersey and an isolated report from Shelby, North Carolina. Some tall buildings were shaken rather severely in Boston, Massachusetts and Albany, New York by the earlier shock (Neumann, 1942). The maximum effects were in the valley at Tamworth, New Hampshire, where 20 old chimneys were reported damaged, some being thrown down (Neumann, 1942). Ground cracks were seen, but the snow cover made an accurate appraisal difficult.

The reports of effects of the two earthquakes were hard to separate and they were, thus combined to make a single isoseismal map. The produced map has been generalized into a slightly irregular bulls eye pattern (Fig. 4), however, contouring of the reported effects with minimal generalization produces a highly complex pattern (Fig. 5) The high intensities in the epicentral area show a northwest-trend centered on the northwest-trending Wonalancet river valley. Large lobes in the isoseismal lines for intensity V also trend northwestward across New Hampshire and Vermont. Some relatively higher intensities appear to follow river valleys such as along the Merrimack river in southern New Hampshire, along the Hudson river in east-central New York, the Connecticut valley in Connecticut and along the Delaware river. There is also a slight extension to the southwest along the shore of the Great Lakes. A northeast-trending lobe of intensity V extends into southern Maine. Much of the irregularity in th data can thus be attributed to poor ground along major river valleys, but the strong northwest-trends nearer the center may represent structural and tectonic influence.

SEISMIC PARAMETERS OF THE GAZA EARTHQUAKE

An earthquake struck central New Hampshire January 18, 1982 at 7:14 p.m. EST and was felt over most of New England and New York (Fig. 1) (Table 1). It was centered about 1.5 miles (2.4 km) southwest of the village of Gaza in Sanbornton and 7.5 miles (12 km) west of Laconia, New Hampshire, at a depth of about 8 km according to Foley and others (1984) and 3 km according to Pulli and others (1983). The epicenter is located 3.5 ± .56 miles (5.6 ± .9 km) northeast of the Franklin Falls dam. The earthquake had mb and Mn magnitudes of 4.5 and a coda magnitude of 4.7 (Foley and others, 1984). The variation in parameters listed on Table 1 is one indication of the range of error involved and suggests that the present given accuracies for earthquakes in this region may be overstated.

The earthquake was accompanied by a great deal of noise in the epicentral region. Close to the epicenter the noise was described as resembling a plane crash or bomb and caused one person's ears to ring for a few hours afterwards.

TABLE 1

SEISMIC PARAMETERS OF THE GAZA NEW HAMPSHIRE, EARTHQUAKE

(compiled from Stover and others (1983) (USGS) and Foley and others (1984) (NEB) Pulli and others (1983) (MIT)

Origin Time:
January 19, 1982, 00 hrs. 14 min. 42.67 sec.
Universal Coordinated Time.
January 18, 1982, 7:14 p.m. Eastern Standard Time

Epicenter:
43.40° N, 71.60° W (USGS)
43° - 30.50', 71° - 37.13 W (NEB)
(43.508° N, 71.619° W)
43.52° N, 71.61° W (MIT)

30 stations recorded event in northeast US
Largest azimuthal separation between stations is 75°
30 phase arrivals used in epicenter location
Standard error of epicenter is 0.9 km

Depth:
7.41 km (NEB)
Fair solution quality
Standard error of depth 1.2 km
8 km (USGS) (Approximation of NEB)
3 km (MIT)

Magnitude:
4.5 mb (USGS source, Gutenberg and Richter (1956) modified by USGS)
4.6 mb (MIT)
4.5 Mn (VA Poly Inst. source, Nuttli (1973) calculated equivalent to Ml magnitude at Richter (1958).
4.7 Mc (NEB source, coda duration magnitude)

Maximum Intensity:
VI

Felt Area:
127,000 sq. km in U.S.

Strong-Motion Data

The earthquake triggered strong-motion instruments across the region. Eleven instruments at six stations operated by the U.S. Army Corps of Engineers and one at Seabrook Nuclear Power Plant responded (Fig. 6) (Table 2). These were set to trigger at a vertical acceleration of 0.01 g. The acceleration values from the Corps records have been analyzed by Chang (1983), Toksoz (1982) and Sauber (in press) (Table 3, Fig. 6). The instrument at Seabrook was just triggered and is about the threshold value 0.01g. The high acceleration values were very unusual for an earthquake of this magnitude; reaching 0.555g at the abutment of Franklin Falls Dam. The ground motion causing the acceleration decayed to the threshold value at approximately 100 km to the west-southwest and to the southeast (Fig. 7), but the decay rate was greater to the south and southwest. It appears to have decayed at at least twice the rate to the south (Fig. 6). No instruments were available for control to the north and northeast.

TABLE 2

STRONG-MOTION STATIONS RESPONDING TO THE GAZA EARTHQUAKE OF JANUARY 19, 1982 (modified from Chang, 1983)

Responding Site	Distance to Epicenter	Direction
Franklin Falls Dam, NH	6 km	SW
Union Village Dam, VT	60 km	NW
White River Junction, VT	60 km	W-NW
North Hartland Dam, VT	61 km	W
North Springfield Dam, VT	76 km	W-SW
Seabrook Nuclear Power Plant, NH	93 km	SE
Bald Mountain Dam, VT	103 km	SE

Non Responding Site	Distance to Epicenter	Direction
Manchester V.A. Hospital, NH	58 km	S-SW
Surry Mountain Dam, NH	78 km	SW
Townshend Dam, VT	99 km	SW

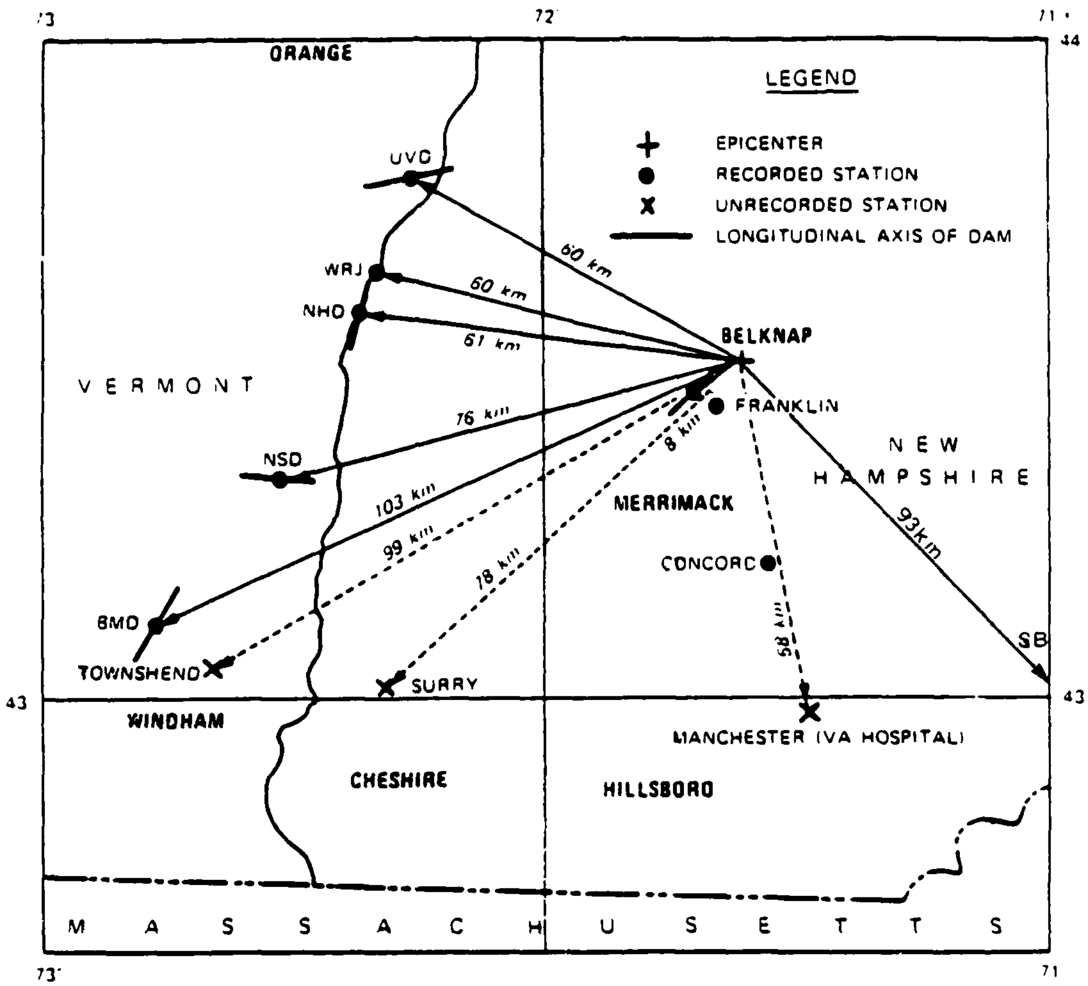


Figure 6. Index map showing location of strong-motion seismograph stations in New Hampshire and Vermont (modified from Chang, 1983).

TABLE 3
STRONG MOTION RECORDS FROM THE
GAZA, N.H. EARTHQUAKE
(Toksoz, 1982)

The Gaza, New Hampshire Earthquake of Jan, 19, 1982
Epicenter data: O.T. 00:14:41.5 UTC
Latitude 43.520
Longitude -71.610
Depth 5 km (approx)
Magnitude 4.7 (mb)

Strong Motion Data
Peak Acceleration Values

	L		V		T		Resolved horiz	
	g	cm/s2	g	cm/s2	g	cm/s2	g	cm/s2
Franklin Falls Dam, NH Distance - 7 km								
Abutment	0.22	218	0.14	136	0.56	544	0.60	586
Crest	0.10	100	0.10	101	0.24	238	0.26	258
Downstream	0.08	77	0.14	136	0.31	307	0.32	317
North Hartland Dam, VT Distance = 62 km								
Crest	0.02	23	0.02	17	0.02	22	0.03	32
Union Village Dam, VT Distance - 61 km								
Abutment	0.01	6	0.01	6	0.01	5	0.01	8
Crest	0.02	22	0.02	22	0.03	26	0.04	34
Downstream	0.03	34	0.03	34	0.03	26	0.04	43
White River Jtn., VT Distance - 61 km								
Basement	0.02	15	0.02	17	0.02	21	0.03	26
North Springfield Dam, VT Distance = 75 km								
Downstream	0.03	31	0.02	15	0.02	23	0.03	39
Crest	0.03	31	0.02	15	0.02	15	0.03	34
Ball Mountain Dam, VT Distance = 104 km								
Crest	0.01	11	0.02	15	0.01	12	0.02	16

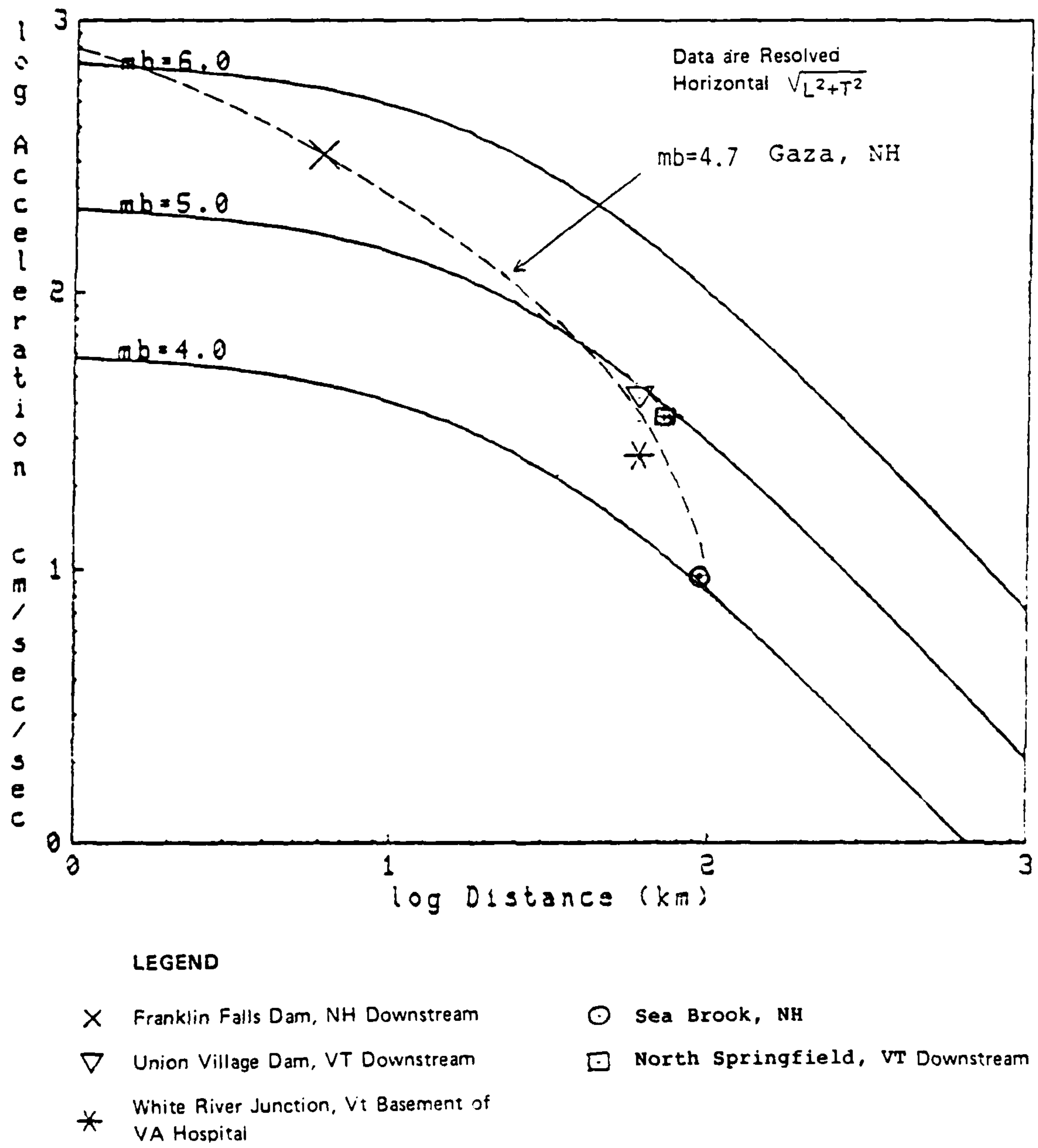


Figure 7. Chart showing attenuation of acceleration with distance from the Gaza earthquake.
The vector sum of the longitudinal and transverse components of peak horizontal acceleration form downstream stations are used. General curves for different magnitudes from Battis, (1981) (modified from Toksoz, 1982).

Aftershocks

Numerous small aftershocks occurred. Five were recorded by the existing seismic network within several hours following the earthquake (Table 4) and many others were later recorded by a portable seismic network deployed in the field by the Weston Observatory (Brown and Ebel, 1982) and M.I.T. (Pulli and others, 1983) staffs. The first two aftershocks in the half hour following the main event were felt widely in the epicentral region and had magnitudes of about 2.6 (Mc). Between January 20 and February 18, 1982, 58 aftershocks were recorded (Brown and Ebel, 1982). The largest aftershock occurred on January 27 and had a magnitude (Mn) of 2.8. It was felt over central New Hampshire and had a maximum intensity of V (Stover and others, 1983). The two groups studying the aftershocks obtained slightly different results. The aftershocks extended to the north or northeast of the mainshock for a couple of kilometers and had a focal depth of about 2 km, except that the two largest, including that of January 27, may (Brown and Ebel, 1982); or may not (Pulli and others, 1983) have been more than twice that depth.

TABLE 4

AFTERSHOCKS OF GAZA EARTHQUAKES

January 19, 1982 (UTC), in first 10 hours (V. Vudler, written commun.)

Hr.	Min.	Sec.	Epicenter	Depth	Intensity	Magnitude
00	31	7.5		12.5	F.	~2.6 Mc
00	55	27.95			F.	~2.6 Mc
01	16	20.00				trace
09	17	50.00				trace
10	05	19.50				~1.3 Mc

January 27, 1982 (UTC) (Foley and others. 1984)

Hr.	Min.	Sec.	Epicenter	Depth	Intensity	Magnitude
16	43	14.47	43.535°N, 71.612°W	8.2,	V	2.9 Mn 2.7 Mc

INTENSITY OF THE GAZA EARTHQUAKE AND AFTERSHOCK

Regional Intensities

The earthquake was widely felt in the northeast United States and the adjacent edge of Canada and had a felt area of 127,000 sq. km in the US (Fig. 8) It was felt to the southwest as far as New York City, but not felt in the Catskill Mountains and was felt to the northwest as far as Ottawa (Gary Nottis, oral commun.). The intensities distribution shows a regional pattern (Fig. 8) more complex than for 1940 Ossipee earthquakes, probable reflecting a greater density of reports. Nevertheless several features can be noted. The distribution of intensity V shows a irregular, but definite northwest-trend extending from Portsmouth, New Hampshire (V reported, but not shown on figure) to Burlington, Vermont. There is a sharp drop off of intensity V to the northeast and a moderately sharp, albeit irregular, drop off to the southwest as well. Northwest-trending lobes of intensity V also cross southwest Vermont and adjacent New York; echoing subtler lobes in the Ossipee earthquake data (Fig. 5). A northeast-trending lobe also extends into southern Maine. The Connecticut river valley shows a little correspondence with intensity distribution and perhaps the Mohawk river in New York, but otherwise river valley control is not obvious.

Epicentral Intensities

The intensity at several localities in the epicentral region reached a low VI (MM) and a few scattered VIs were also recorded in sensitive spots at more distant locations (Stover and others, 1983). The area of intensity VI damage in the epicentral region

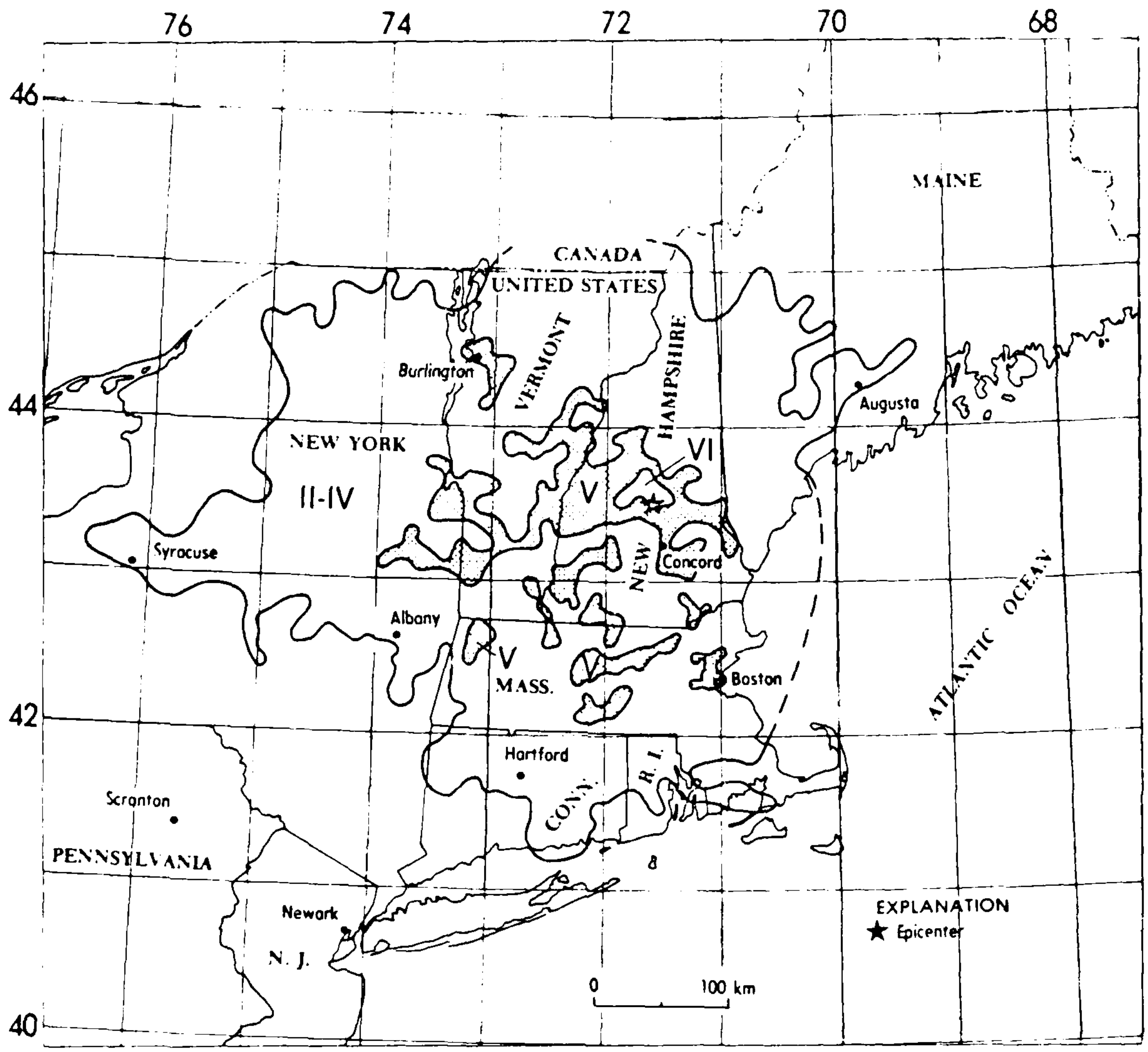


Figure 8. Isoseismal map of the Gaza earthquake (Stover and others, 1983).

AD-A173 230 GEOLOGICAL-SEISMOLOGICAL EVALUATION OF EARTHQUAKE HAZARDS AT FRANKLIN FAL..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS GEOTE.. 2/3

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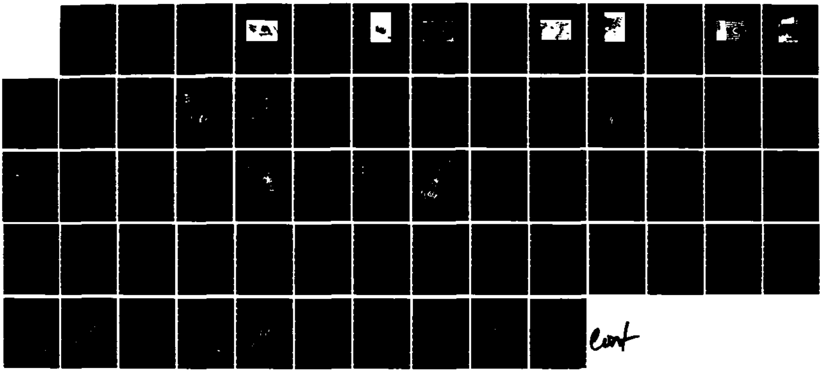

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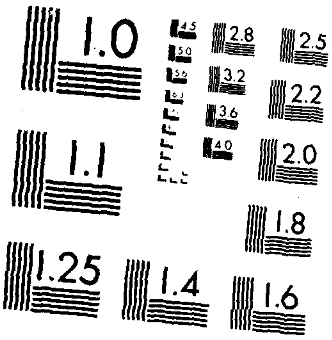


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

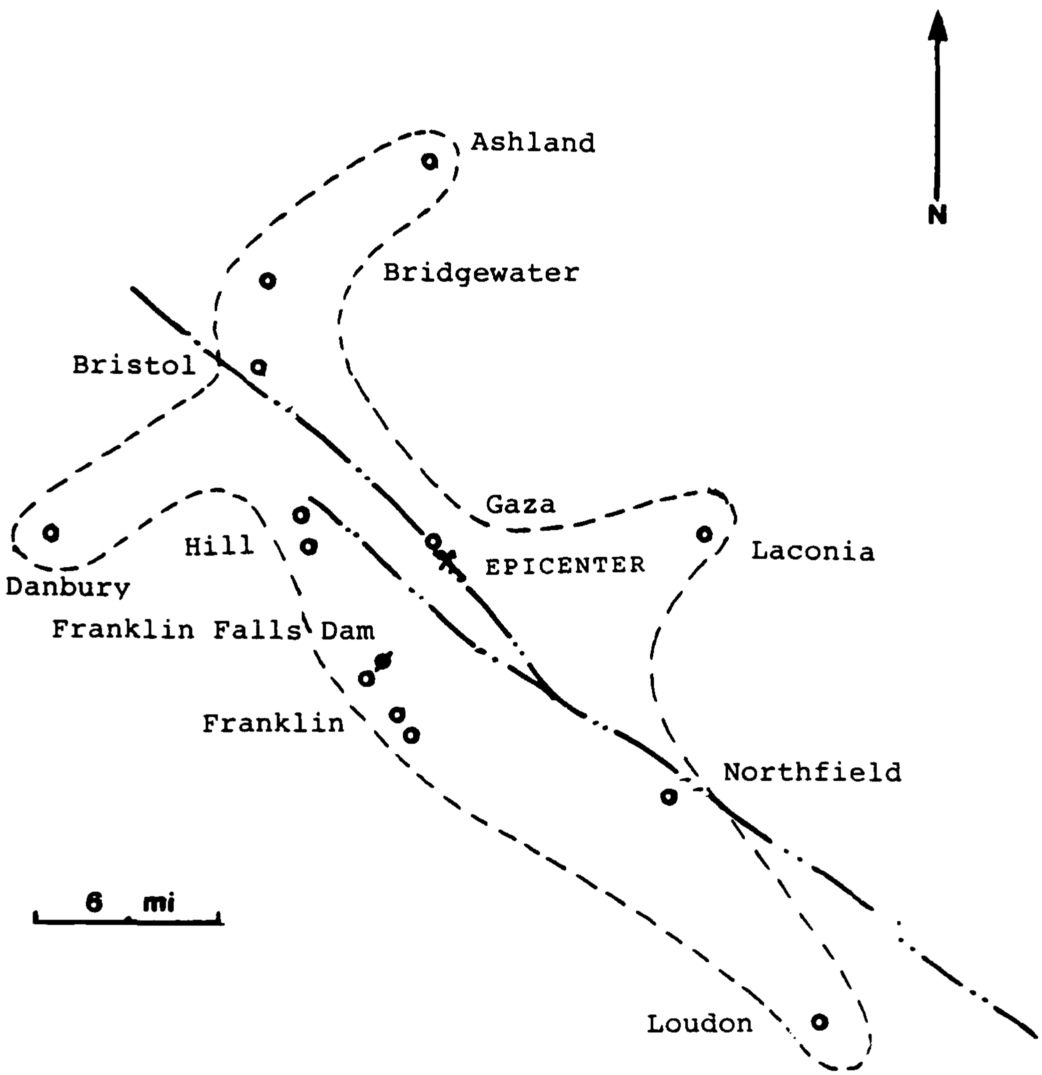


Figure 9. Map showing location of damage in the epicentral area of the Gaza earthquake.

extends from southern Loudon northwestward to southern Bridgewater (Fig. 9). The damaged area has a northwest elongation that widens abruptly at its northwest end to somewhat of a northeast-southwest trend; a shape reminescent of a hammerhead shark (Fig. 9). A northwest-trending topographic lineament, that passes through the epicenter, and a couple of others are placed on the map for comparison to northwest-trending topographic features.

Two days were spent in the field investigating the damage shortly after the earthquake by myself and M.H. Pease, Jr. Also numerous telephone calls concerning reports of damage were both received and made. A great many questionnaires on effects from this earthquake were received and reviewed by E. Schlesinger - Miller at Lamont-Doherty Geological Observatory and the U.S. Geological Survey. The following short descriptions of the damage in the epicentral region are those from the field investigation supplemented by reports listed by the U.S. Geological Survey (Stover and others, 1983).

Loudon

Pleasant View Garden, Pleasant Street, south of Loudon Center.

Steel posts, set in concrete, supporting northwest side of greenhouse raised six inches out of ground (Fig. 10) and a 36 inch high platform along the wall tilted away from it. A sliding door in the wall was also pulled away a little.

Figure 10. Photograph of greenhouse at Pleasant View Gardens, Loudon, New Hampshire showing concrete base of supporting steel pipe raised out of ground.

Northfield

Old Payson Road, south of Belmont Center.

New strongly built post and beam house had about 40 10x10 inch wooden beams cracked and split (Fig. 11) and pulled apart a quarter to a half inch at the joints. Several cracks formed in 10 inch thick poured concrete foundation (Fig. 12) and minor hair line cracks in a massive stone fireplace. One corner of foundation is just above rock and rest underlain by compacted glacial fill. Damage probably resulted from differential movement beneath foundation effecting very ridged structure. Several slender pieces of bric-a-brac resting on beams did not fall.

Laconia

2 Center Street.

Stones dislodged and fell from corner at cellar wall and vertical supports in cellar shifted laterally about one inch at juncture with floor beams they support (Fig. 13).

43 High Street

Items knocked off shelves

95 Massachusetts Avenue

Plaster and glass cracks

Elsewhere

Large cracks in plaster walls, few merchandise items thrown from store shelves, few glassware items broken, few small objects overturned and fell, and some windows broken.

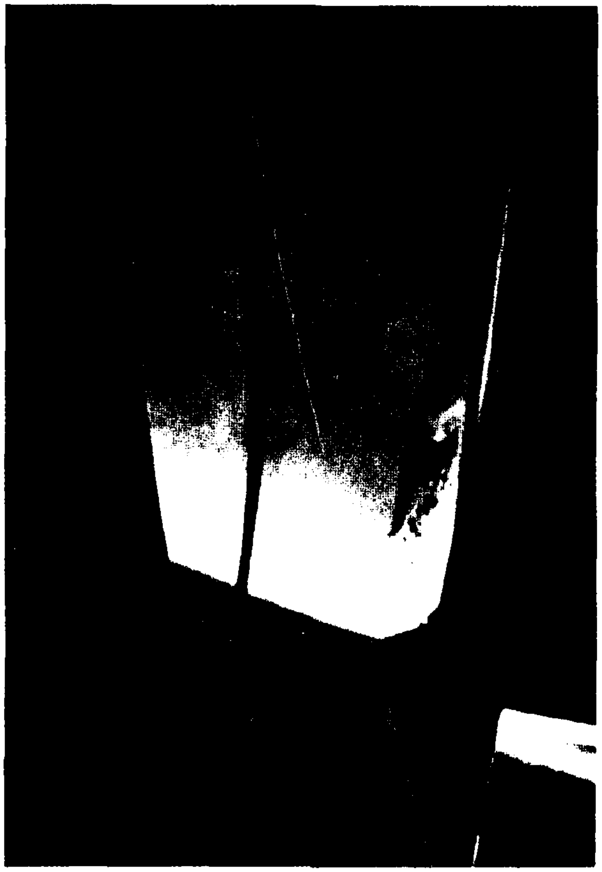


Figure 11. Photograph of interior of house on Old Payson Road, Northfield, New Hampshire showing split beam.

Figure 12. Photograph of cellar of house on Old Payson Road, Northfield, New Hampshire showing crack in poured concrete wall.

Franklin

380 Prospect Street, south of the center of town.

Brick house about 25 years old with many plaster cracks in house interior in walls, ceilings and near moldings. Doorway pulled away about one inch, formica split in kitchen, bathroom window sill dropped. Patio floor adjacent to swimming pool settled 2 to 3 inches. Water well beneath house muddied and much silt and fine sand came up. No cracks noticed in basement.

Franklin Center

Merchandise fell off store shelves, shelf fell out of cupboard.

Webster Lake Area

Crack in basement floor

Franklin Falls Dam

Window broke in tower.

Gaza (Sanbornton)

RFD 1, Morrison Road, about 1 mile from Gaza center.

Five foot section of a stone foundation of a 211 year old chimney fell causing floor to heave 2 inches and extensive cracking of plaster (Fig. 14). Window broken in shed.

Hill

Hill Country Store

Two windows cracked, some merchandise fell off shelves in wood clapboard building.

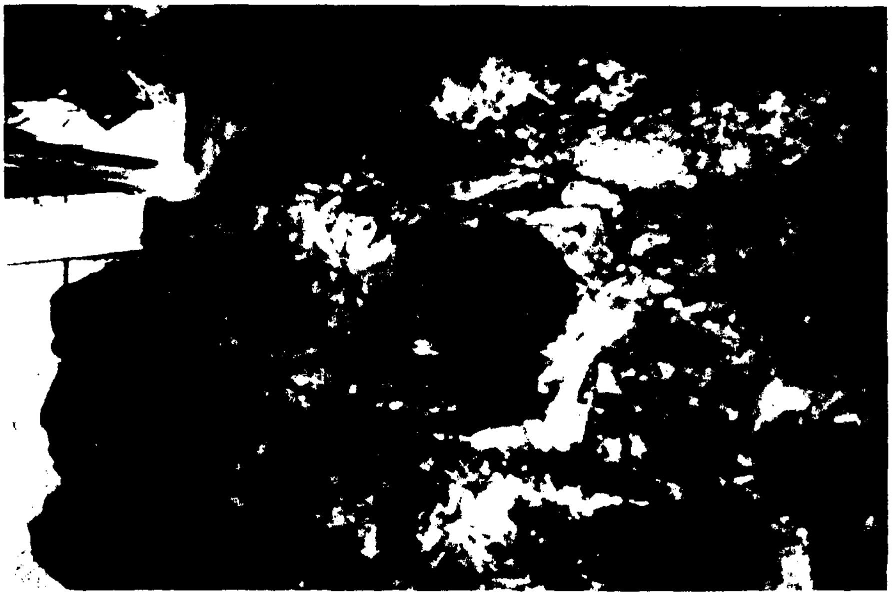


Figure 13. Photograph of cellar of house on Center Street, Laconia, New Hampshire showing cracks in stone cellar wall adjacent to collapsed corner.

Figure 14. Photograph of cellar of colonial house on Morrison Road, Gaza, New Hampshire showing collapsed chimney foundation.

Hill Fire Department

One story cement block building with fine cracks around and a few through the blocks, especially on south wall.

Trailer Park north of Hill

Brick stove chimney attached to trailer cracked near stove pipe hole (Fig. 15).

Bristol

Joe's Market, east side of center of town.

Large single story cement block building with cracks along mortar joints; mainly along seams, where no blocks overlap, in back wall, but a few elsewhere (Fig. 16). Leak in roof increased. Few merchandise items thrown from store shelves.

International Packing Corporation

Single story cement block building on concrete slab had few fine mortar cracks.

Elsewhere

Split interior walls, cracked plaster walls, few glassware items broken, few small objects overturned and fell.

Danbury

Few chimneys cracked. Interior walls had hairline cracks. Few merchandise items thrown from store shelves and few glassware items broken. Few small objects overturned and fell.

Bridgewater

92 Pine Street, east side of Newfound Lake.

Window broken.

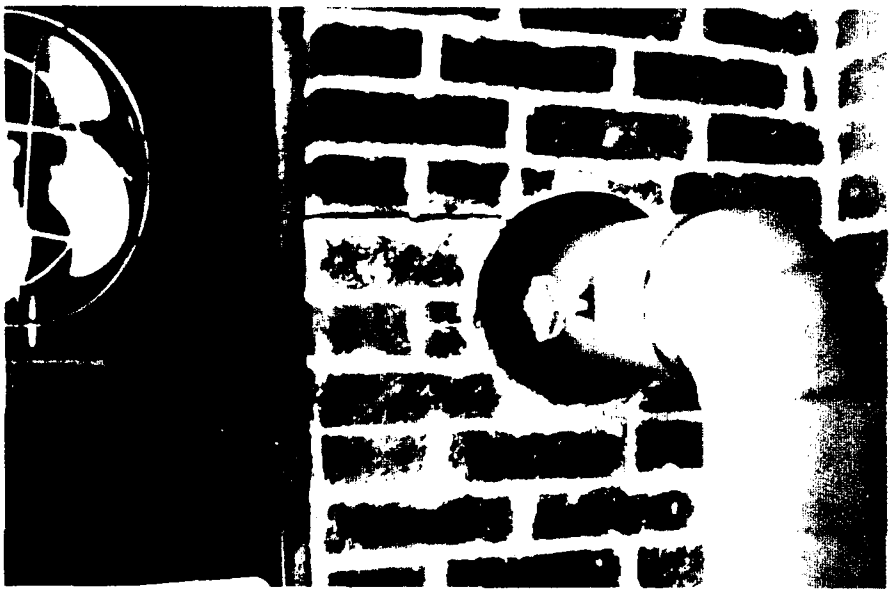


Figure 15. Photograph of cracks in brick chimney attached to trailer in Hill, New Hampshire.

Figure 16. Photograph of back wall of Joe's Market in Bristol, New Hampshire showing cracked mortar seam.

Ashland

Cracked chimneys, few merchandise items thrown from store shelves and few glassware items broken.

Aftershock Intensities

The largest aftershock in January 27, 1982 occurred slightly north-northwest of the main shock and produced a maximum intensity of V (Table 5). The pattern of intensity distribution is different from the main shock as it has a northeast-trend (Fig. 17). This may be due to under reporting or possibly due to adjustments along a fault of a different trend.

TABLE 5

INTENSITIES FOR JANUARY 27, 1982, Earthquake

(Stover and others, 1983)

Origin time:	16 43 14.5
Epicenter:	43.53°N., 71.61° W.
Depth:	2 km
Magnitude:	2.8Mn

Intensity V:

Laconia--hairline cracks in plaster walls, felt by many

Lochmere--few glassware broken, few small objects overturned and fell.

Weare--few glassware broken, few small objects overturned and fell

Intensity IV; Bristol, Center Harbor, Danbury, Hill, Sanbornton.

Intensity III: Alton, Belmont (press report), Contoocook, Franklin, Guild, Penacook, Wendell, West Ossipee.

Intensity II: Center Sandwich, New Durham.

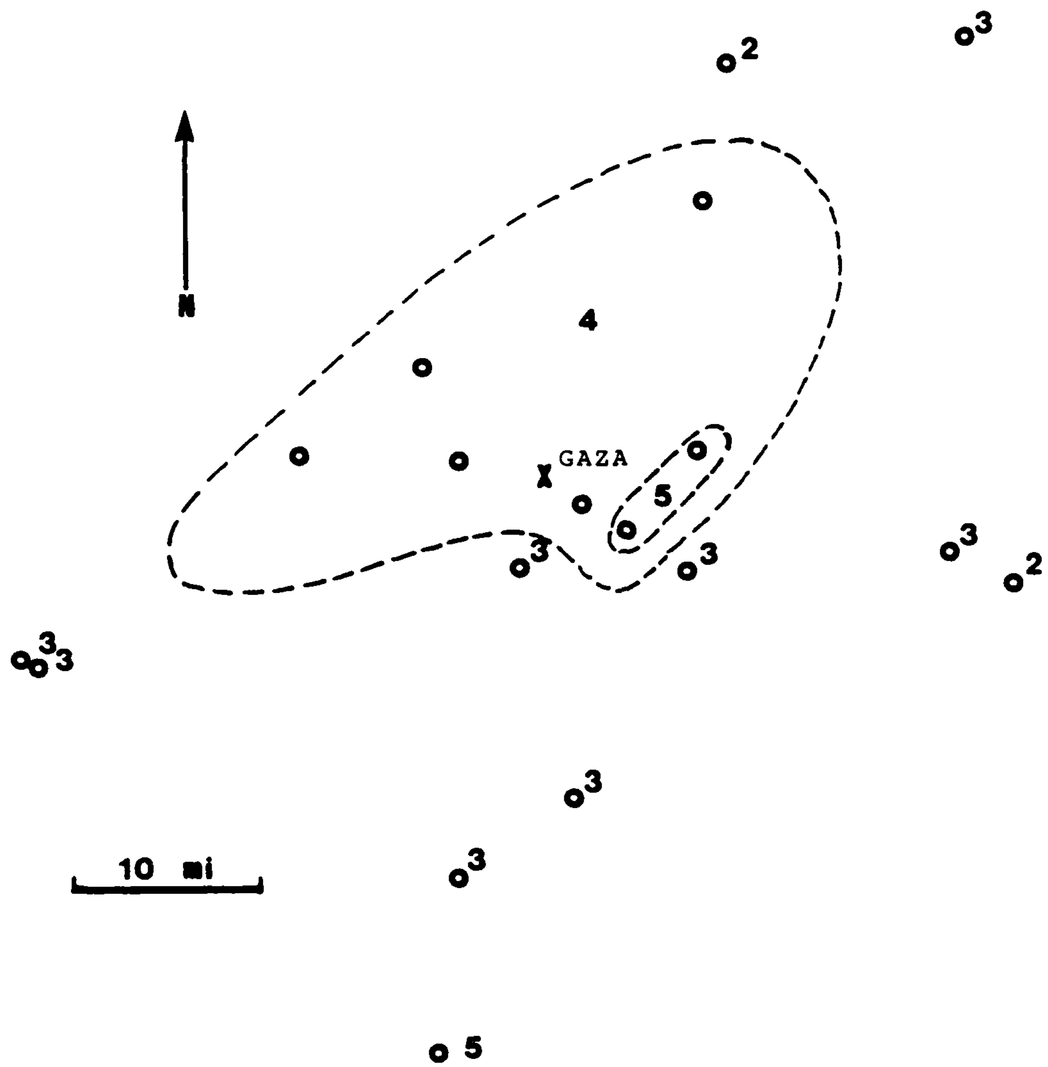


Figure 17. Map showing the intensities from the January 27, 1982 aftershock (data from Stover and others, 1983).

GEOLOGIC SETTING

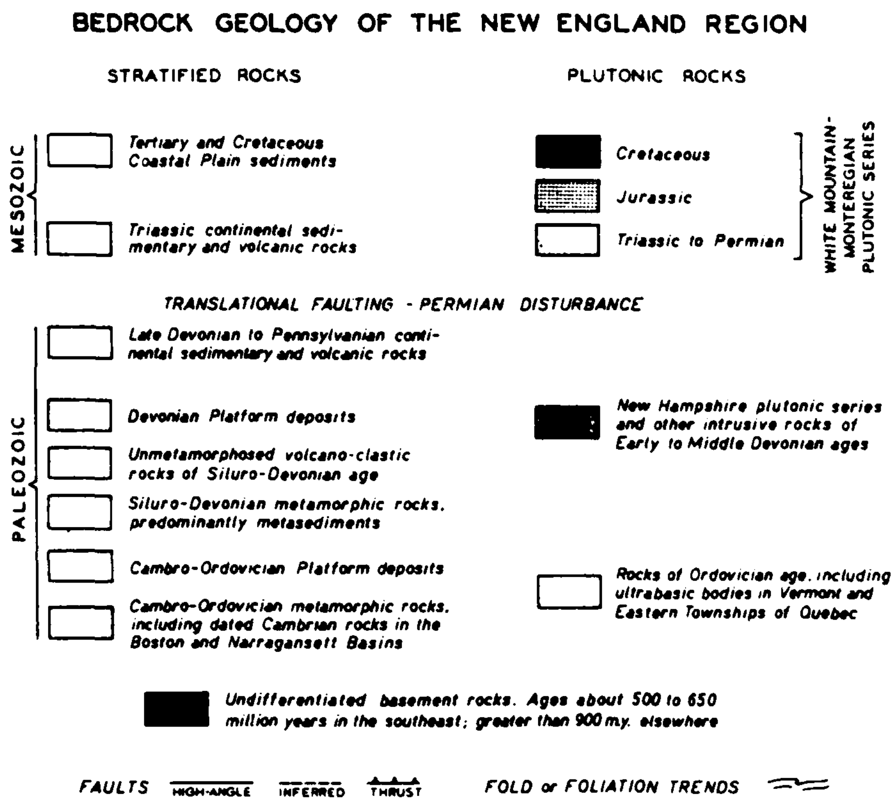
New Hampshire consists of slightly to highly metamorphosed pre-Mississippian sedimentary and volcanic rock of the eastern Appalachian organic belt cut by a great variety of pre-teritary intensive rock (Billings 1955). The principal structural elements are the north to north-east trending regional pre-Mesozoic structural trend, remnants of a north-trending chain of Mesozoic volcanos and a broad regional northwest-trending fracture zone that crosses the bend in the regional structure and has at least some post-Cretaceous movement. These three structural features cross in central New Hampshire.

Little structural information is directly available from the Gaza area in central New Hampshire, but the kinds of structures present can be inferred with some confidence from work in the bordering areas.

Central New Hampshire is shown as formed mainly of Devonian Littleton Formation folded into the northeast-trending Merrimack Synclinorium (Billings 1955); and little other structural information is present on the state geologic map (Fig. 18). It is now known to consist mainly of Schist and gneiss of the Pre-Ordovician, probably pre-Cambrian, Brimfield Group from detailed work in Connecticut, Massachusetts and reconnaissance along routes 93 and 3 in central New Hampshire (Peper and others, 1975; Barosh, 1984; M.H. Pease, Jr., oral commun.). There is no evidence for a synclinorium, instead the rock, by analogy for the south and geomorphic analysis is cut by a series of northeast-trending, west-dipping thrust-faults, that have served to control many later intrusive bodies (Fig. 19). Nearer the

Figure 18. Geologic map of New England and adjacent areas (Weston Geophys. Res., 1976).

Figure 18. Explanation



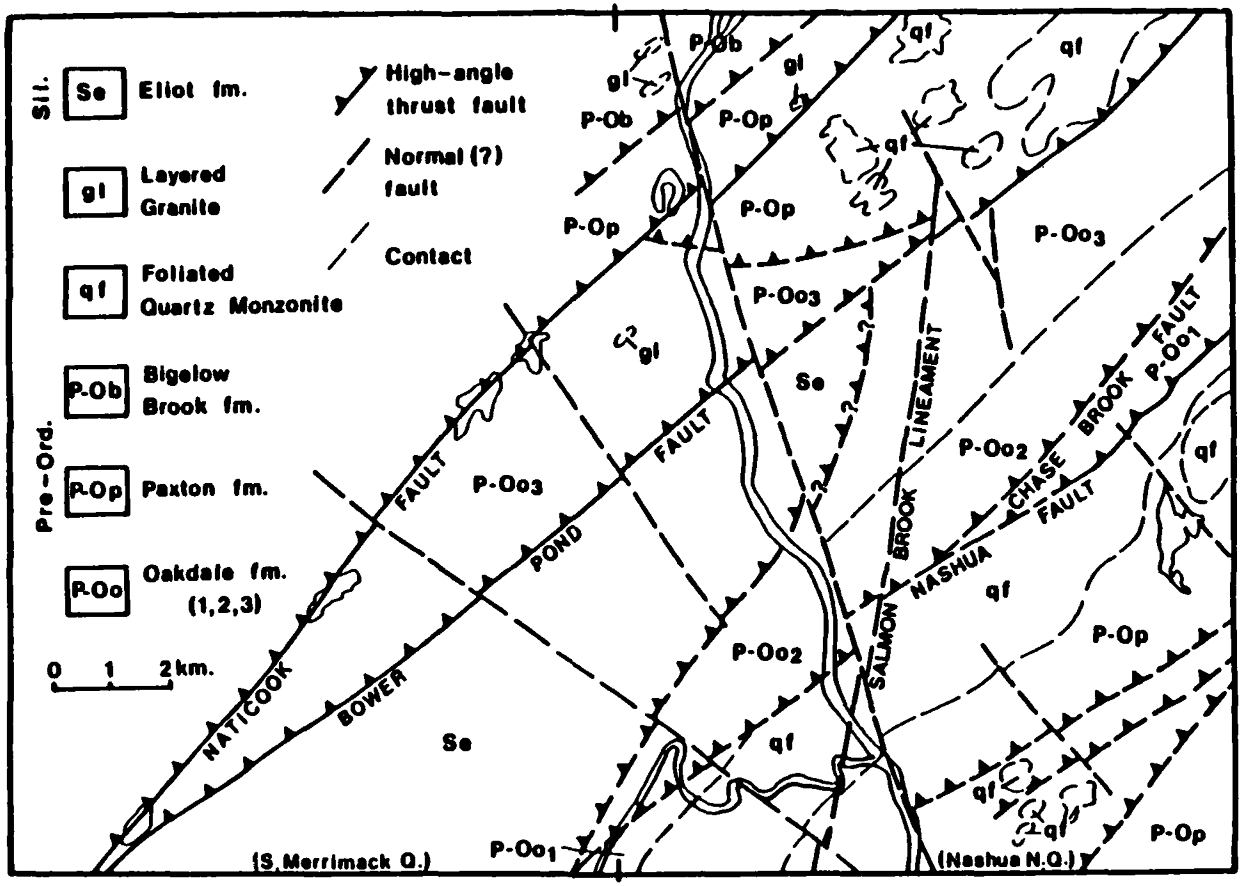


Figure 19. Geologic sketch map of the Nashua area, New Hampshire (Smith and Barosh, 1982, also in Barosh, 1984).

coast the thrust faults are near vertical and have repeated the rock units beneath the Brimfield (Barosh, 1984). Such thrust faults, where mapped, have west over east and right-lateral components of movement. The faults may have been initiated in the late Precambrian and are locally intruded Ordovician and Silurian intrusive rock. Some have been reactivated at times and slivers of younger rocks have been locally caught in these fault zones by later Paleozoic movement. The major Clinton-Newbury fault zone lies off shore.

Analysis of these early fault and joint patterns in southern New England suggest a maximum compressive stress with a general orientation of east-northeast-west-southwest, but with many local variations near major structures. The recorded strain measurements in rock in the region apparently represent residual strain from this stress. These thrust faults are cut by later northwest, north-northwest and north-trending faults in the Merrimack river valley south of Manchester and these cross faults are indicated by geomorphic analysis to occur further north as well (Fig. 19). The course of the Merrimack River in southern New Hampshire is closely controlled by these structures, the orientation of different stretches correspond to those of the local controlling fault.

Intrusive rock representing a chain of Mesozoic volcanos (part of the White Mountain plutonic series) extends northward through east-central New Hampshire and into adjacent southern Maine and northeast Massachusetts. At the Quebec border it meets another chain, the Monteregion Hills, that extends westward to Montreal (Fig. 18). The ages range from Triassic to Cretaceous and are mainly younger than mid-Jurassic. Mount Ossipee northeast of Gaza is one of the more prominent volcanic cores.

This volcanic chain may may have formed along a north-trending zone of extension in the crust following the northeast-trending one that parallels the coast and developed prior to the mid-Jurassic during the initial formation of the Atlantic basin. It may be similar to the extension along the north-trending Connecticut River valley and the Lake Champlain - Lake George region. The north-trending Merrimack and Pemigewasset river valleys could be similar.

The maximum compressive force is thus indicated to have a general northeast-southwest orientation in the early part of the Mesozoic and a north-south orientation later. Analysis of the widespread Misozoic dikes in the New Hampshire region suggest some local variations or changes in the stress orientation may have occurred (McHone, 1978).

A broad northwest-trending fracture zone crosses central New Hampshire, southernmost Maine and continues into east-central and northwestern Vermont., based on geomorphic analysis that has been field checked in adjacent areas (Fig. 20). The stream and small valleys across the entire region show a pronounced northwest-southeast orientation. Many streams are aligned over long distances as if along extensive fault zones, although many shorter alignments may be controlled by joint zones. Such geomorphic features also occur although in lessor concentration to the northeast and southwest and where mapped in Massachusetts, southern New Hampshire or western Maine are found to be faults. Hobbs (1907) indicated a general lineament through the region,

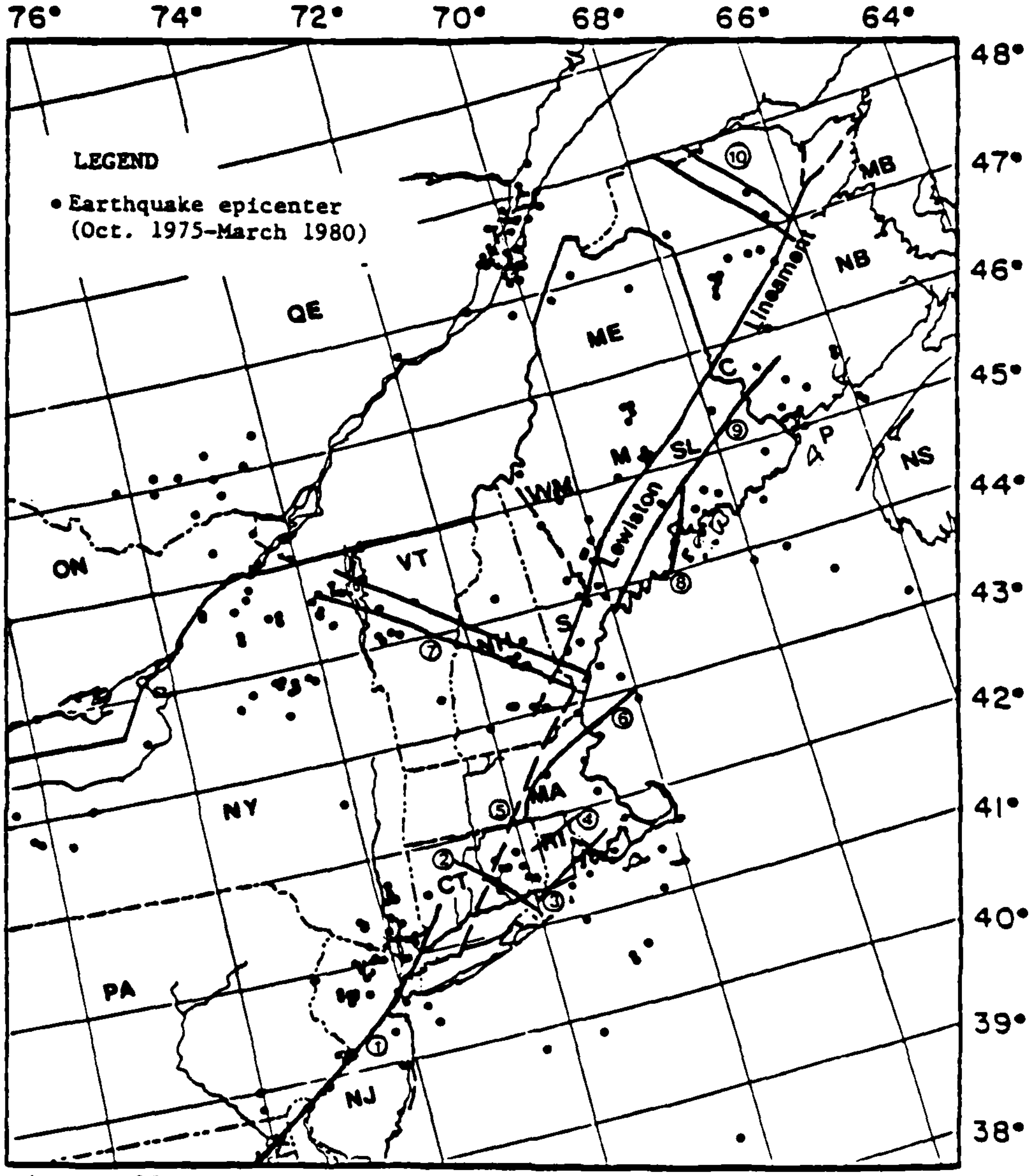


Figure 20.
Map of the northeastern United States and adjacent Canada showing recent earthquakes, the Winnipesaukee-Winooski lineament and other selected structures (Barosh, 1982, 1984). 1. Northern Fall Line; 2. Connecticut River lineament; 3. Watch Hill lineament; 4. North Scituate-Blackstone lineament zone; 5. Higganum dike system; 6. Clinton-Newbury fault zone; 7. Winnipesaukee-Winooski lineament zone; 8. Penobscot lineament; 9. Norumbega fault zone; and 10. Upsalquitch lineament zone. Some geographical locations are: S, Sebago Lake; L, Lewiston; M, Medford; SL, South Lincoln; P, Passamaquoddy Bay; C, Chiputneticook Lakes; MB, Miramichi Bay.

Barosh (1976) showed the most prominant lineament as representative of the group and later (1982, 1984) named the fracture zone the Winnipesaukee-Winooski lineament, Jones, 1979, compiled the lineaments along it in Vermont, Slemmons and others (1980), also indicated a general grouping of lineaments and later more detailed LANDSAT and SLAR have shown even more. A few northwest-trending faults have been mapped along the lineaments, mainly in southeast New Hampshire. The most significant ones of these cut the Mount Pawtuckaway Cretaceous volcanic plug (Freedman, 1950). The zone can be traced offshore in the Gulf of Maine, using bathymetric data, and is aligned with transform fracture zones farther offshore.

This fracture zone appears to be the youngest structural feature in the region. Elsewhere, in the relatively more active seismic areas in New England, northwest-trending faults, locally accompanied by north-trending ones are also the youngest. Many geologic contacts in central New Hampshire and adjacent southern Maine have local northwest-trends or disruptions in the mapped patterns along northwest-trending lines, that offer possible locations for such faults.

This zone of northwest-trending fractures coincides with a pronounced change in the pattern of Bouger gravity anomalies and is seen in the few available detailed aeromagnetic maps (Barosh 1982). It also coincides with a regional change in the metamorphic grade (Fig. 21).

Analysis of the small northwest-trending faults cutting an Early Jurassic dike system in south-central Connecticut indicates

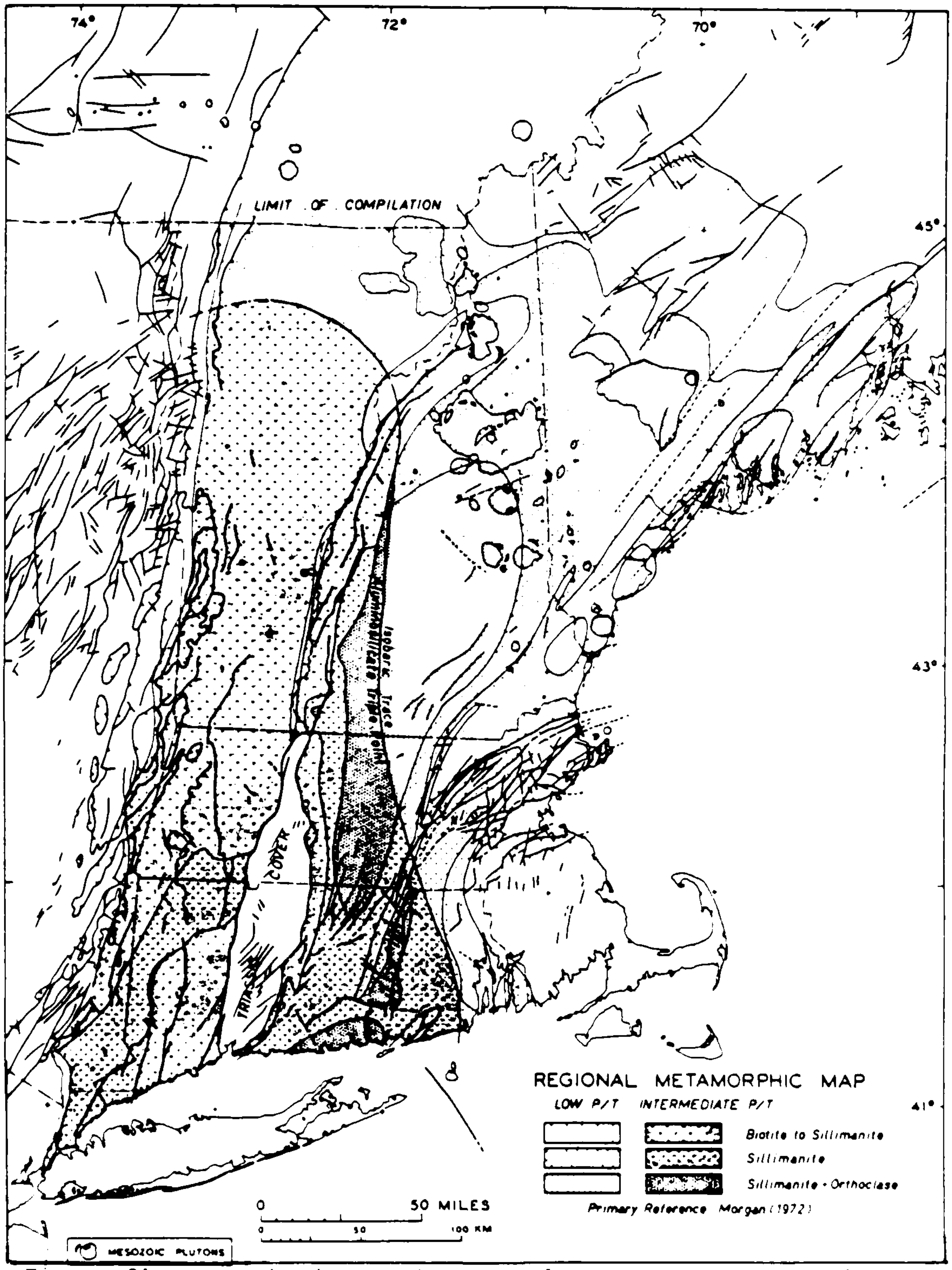


Figure 21. Map showing regional fault zones and metamorphic grade in New England (Weston Geophys. Res., 1976).

that, at least there, the principal compressive stress forming them was oriented north-northwest--south-southeast.

The fracture zone intersects the coastline at a pronounced embayment north of Cape Ann. The coast here is noted for its barrier bars and large estuaries in contrast to the more rocky coastline on either side. This coastal development may be influenced by greater subsidence here. Present day subsidence is indicated to increase along the coast south of Portland, Maine (Tyler and Ladd, 1981).

SEISMOTECTONIC SETTING

Active faults have yet to be mapped in New Hampshire and the correlation of earthquakes with tectonic structures is largely a function of matching the distribution of earthquakes with such structures. The perceived distribution of earthquakes in New Hampshire is greatly influenced by the scale of the map displaying the epicenters and the amount of information analyzed. Three different distributions can be seen that, non the less, may all have some tectonic implications.

Boston-Ottowa Seismic Belt

On a small scale regional map the earthquake appears to be part of a broad belt of earthquakes extending from near Timiskaming, Quebec to northeast Massachusetts and continuing off shore, referred to as the Boston-Ottowa seismic belt. It was first noted by Hobbs (1907), mentioned by Smith (1966), and discussed by others (Sbar and Sykes, 1973). It was the chief influence on the 1976 probabilistic map of the northeast (Algermissen and Perkins, 1976). It, however, is not a continuous zone of activity, as it crosses relatively quiet zones, and the concentrations of activity along it are best described separately (Barosh 1978). Most of the geologic freatures mentioned by Sbar and Sykes (1973) do not correlate well with it in distribution or trend, however, the broad northwest-trending Winnipesaukee-Winooski fracture zone described above does match it well in New England Fig. 20).

Merrimack - White Mountains Seismic Area

A closer analysis indicates that a distinct concentration of earthquakes across central New Hampshire can be distinguished as the north-trending Merrimack - White Mountains seismic area and those on the coast as belonging to the northwest edge of the Cape Ann seismic area (Fig. 22). These two areas appear to adjoin in Massachusetts, but mainly separated in southern New Hampshire by an area in which only small earthquakes have occurred. The largest earthquakes and a large part of the others occur in the northern part of the Merrimack - White Mountains seismic area.

The Merrimack Valley might be similar to the other north-trending extensional valleys in the region. Subsidence of the valley could be hypothesized to be occurring by means of the north- to northwest-trending faults known to be controlling the southern part of the valley, and thereby triggering earthquakes.

Seismic Source Zones

The more recent epicentral data suggests several northwest-trending alignments of epicenters may be present within the Merrimack - White Mountains seismic area. Three make credible alignments and two others are more diffuse and only suggest possible zones. The seismic data is displayed on two epicentral maps (Figs. 22 and 23) and both should be refered to

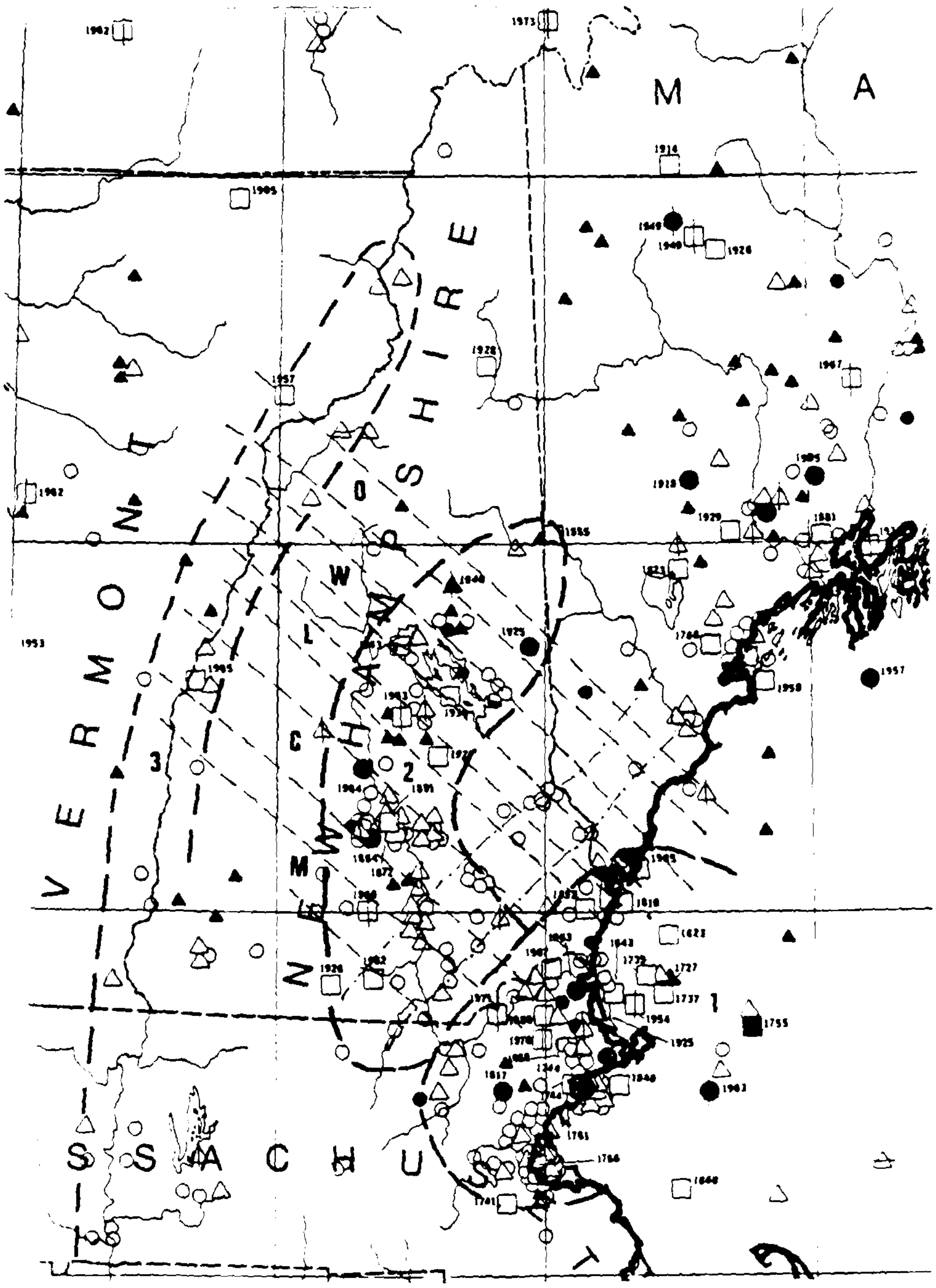


Figure 22.
Epicentral map of New Hampshire and adjacent areas to 1980 (Nottis, 1983) showing seismic zones.
Explanation: Heavy dashed lines = seismic areas. 1, Cape Ann; 2, Merrimack Valley-White Mountains; 3, Connecticut River. Fine dashed lines = seismic zones. O, Ossipee; W, Winnipesaukee; L, Laconia; C, Concord; M, Manchester. Fine dot-dashed lines = fault zones.

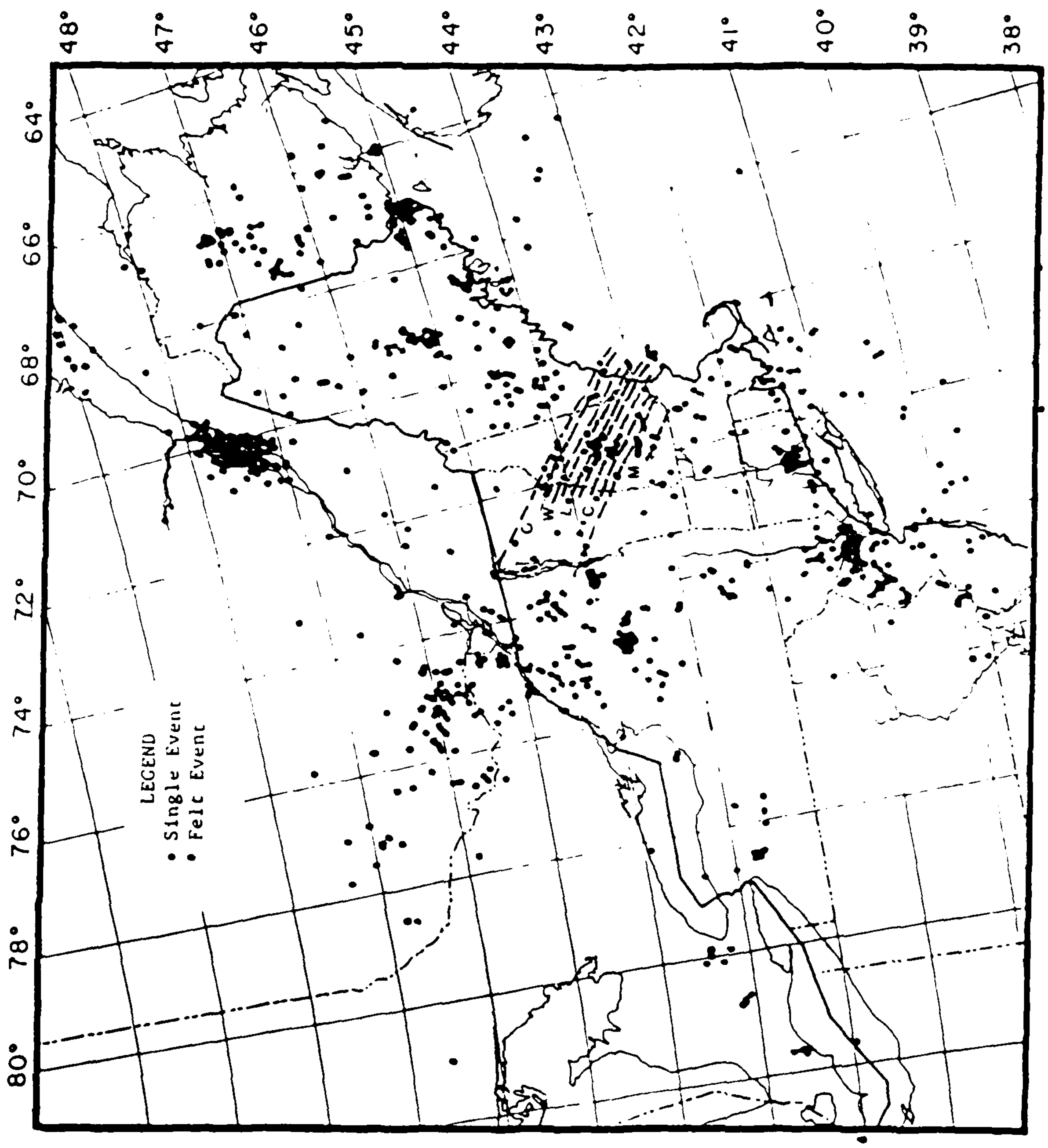


Figure 23. Epicentral map of the northeastern United States period October 1975 to September 1983 (Foley and others, 1984) showing seismic zones in New Hampshire.
Explanation same as Figure 22

to see their zones. These zones are aligned parallel with the northwest-trending post-Cretaceous fracture and geomorphic trend and cross rivers at bends. This apparent geologic correlation suggests they may represent actual seismic source zones. If so, any actual structural zone would be narrower than these zones that encompass earthquake locations of varying accuracies.

Ossipee Zone

The Ossipee zone passes northeast of Lake Winnipesaukee through Lake Ossipee, the Wonalancet river valley and the bend in the Connecticut river west of Littleton, New Hampshire. It is defined by the 1940 earthquakes, a 1925 intensity VI event, an intensity V earthquake in Vermont near the river bend and over 20 smaller events (Figs. 22 and 23). The elongated epicentral isoseismal pattern for the 1940 Ossipee earthquake extends along it (Fig. 5).

Winnipesaukee Zone

The broad Winnipesaukee zone passes through the Lake and southeastward along the bend and northwest-trending stretch in the Salmon Falls river at the Maine-New Hampshire border. To the northwest it passes through short northeast-trending river segments, between north-trending ones on both the Pemigewasset (north of Plymouth, N.H.) and Connecticut rivers (north of Bradford, VT). It is defined by a somewhat diffuse zone of activity of mainly intensity III or lower, but includes two intensity V earthquakes in Lake Winnipesaukee area and a couple on the coast (Figs. 22 and 23).

Laconia Zone

The Laconia zone passes along the southwest side of Laconia, N.H., through the sharp bend in the Pemigewasset river, east of Bristol, through Newfound Lake and a short northeast-trending stretch of the Connecticut River near Oxford, N.H. It is defined by the Gaza earthquake, two intensity V earthquakes near Laconia and others near the coast and a number of recent small earthquakes (Fig. 22 and 23).

Concord Zone

The Concord zone extends along the northwest-trending stretch of the Merrimack River near Concord and through the bend of the Connecticut River near Hanover, N.H. and the bend in the coastline near the mouth of the Merrimack River (Fig. 22 and 23). The zone is defined by a cluster of activity, including two intensity VI events along the Merrimack River, intensity V earthquakes at both the Connecticut River and shore and numerous small events.

Manchester Zone

The Manchester zone represents a diffuse cluster of earthquakes in southern New Hampshire, that only vaguely form a northwest-trending group passing through the bend in the Merrimack River south of Manchester. Intensity V earthquakes have occurred in this cluster.

Relations of the Seismic Zones to Geology

The seismic zones appear to correspond to some geologic changes and trends in the available geologic data despite its limited nature. The Ossipee zone crosses the bend in the regional geologic structure from north-northeast to northeast of the western edge of New Hampshire, lies along the southwest edge of the White Mountain botholith, the northeast side of the Winnipesaukee pluton and extends into southern Maine along a line where contacts change from predominantly northeast-trending on the southwest to northwest-trending on the northeast (Fig. 24). The Winnipesaukee zone extends along a line of abrupt changes in contact direction and termination of units in western New Hampshire. Through the southwest margin of the Winnipesaukee pluton and a northwest-trending aeromagnetic lineament along Salmon Falls River where the Fitchburg and Exeter plutons end. (Fig. 24). The Laconia zone also lies along a line of changes in contacts and ends of units in western New Hampshire, along the southwesternmost edge of the Winnipesaukee pluton and an inferred fault (Fig. 21) and crosses the Fitchburg pluton at a zone of disruption and some known northwest-trending faults and crosses the Exeter pluton where it changes widtn (Fig. 24). Geologic changes along the Concord zone are a little less pronounced, but again include changes in contact trends and termination of units along it in western and central New Hampshire and an abrupt bend in the contact of the Fitchburg pluton (Fig. 24). The Manchester zone has only slight changes in trend of geologic contacts across it and a couple of terminations of units against it. Where the units mapped along the western edge of New Hampshire, the Oliverian dames and Ammonoosuc Volcanics are crossed by the zones they step to the east north of each zone crossing suggesting right-lateral movement along the zones (Fig. 24).

The four zones show a correspondence with the broad north-west-trending disruption of the gravity pattern in New Hampshire

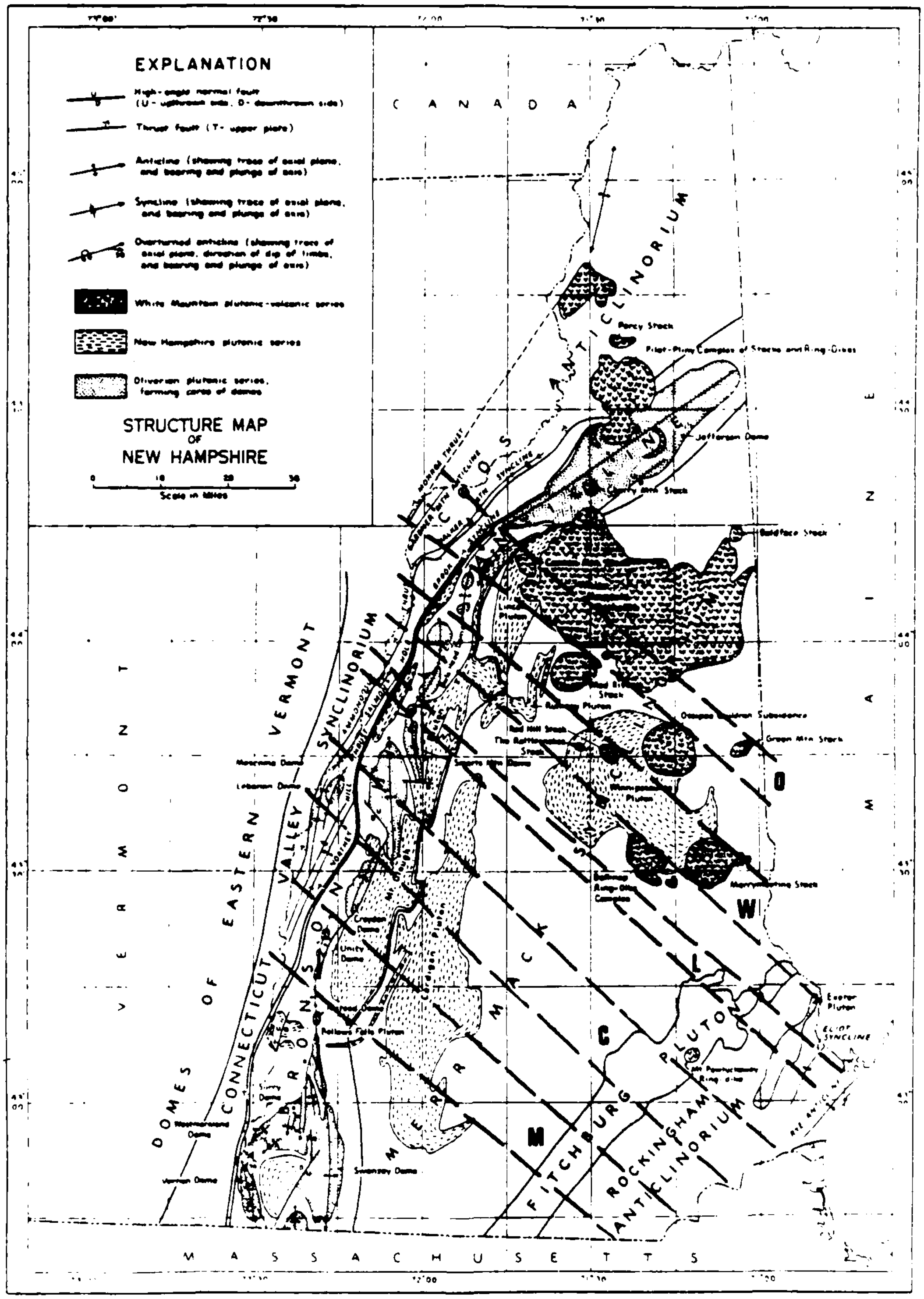


Figure 24. Structure map of New Hampshire (Billings, 1955) showing seismic zones.
Explanation, O, Ossipee; W, Winnipesaukee; L, Laconia; C, Concord; M, Manchester

and Vermont. The Ossipee and Manchester zones lie close to the border of the disruption and the other two along some changes within it (Fig. 25). Slightly more detailed gravity information in central New Hampshire shows a good correspondence of the trend of the gravity changes and the Laconia and Concord zones (Fig. 26).

Focal Plane Solutions

The interpretation of compressional or dilational movement from seismograms have been used to construct hypothetical fault plane attitudes for the fault movement producing the earthquake. The focal or fault plane solutions that have been interpreted for several New Hampshire earthquakes vary greatly in orientation (Graham and Chiburis 1980) and are of no apparent use in regional tectonic interpretation.

A focal plane solution was constructed for the earthquake using 24 reliable P-wave first motions (Pulli and others, 1983, Sauber, in press). A strike-slip motion was interpreted from the data, although two stations did not fit. The attitudes given by Puli and others (1983) are N 20°E, 80°E dip and N 100°E (N80°W), 75° N dip. However, attitudes calculated from the figure showing the data for the two possible solutions given by Sauber (in press) and using her dips are north 23° east, 68° southeast dip, left-lateral motion and north 70° west, 75° northeast dip, right-lateral. The interpreted northwest striking plane is roughly in line with the north 45 to 55 west-trending topographic lineaments near the epicenter and the approximately north 40° west trend of the damage.

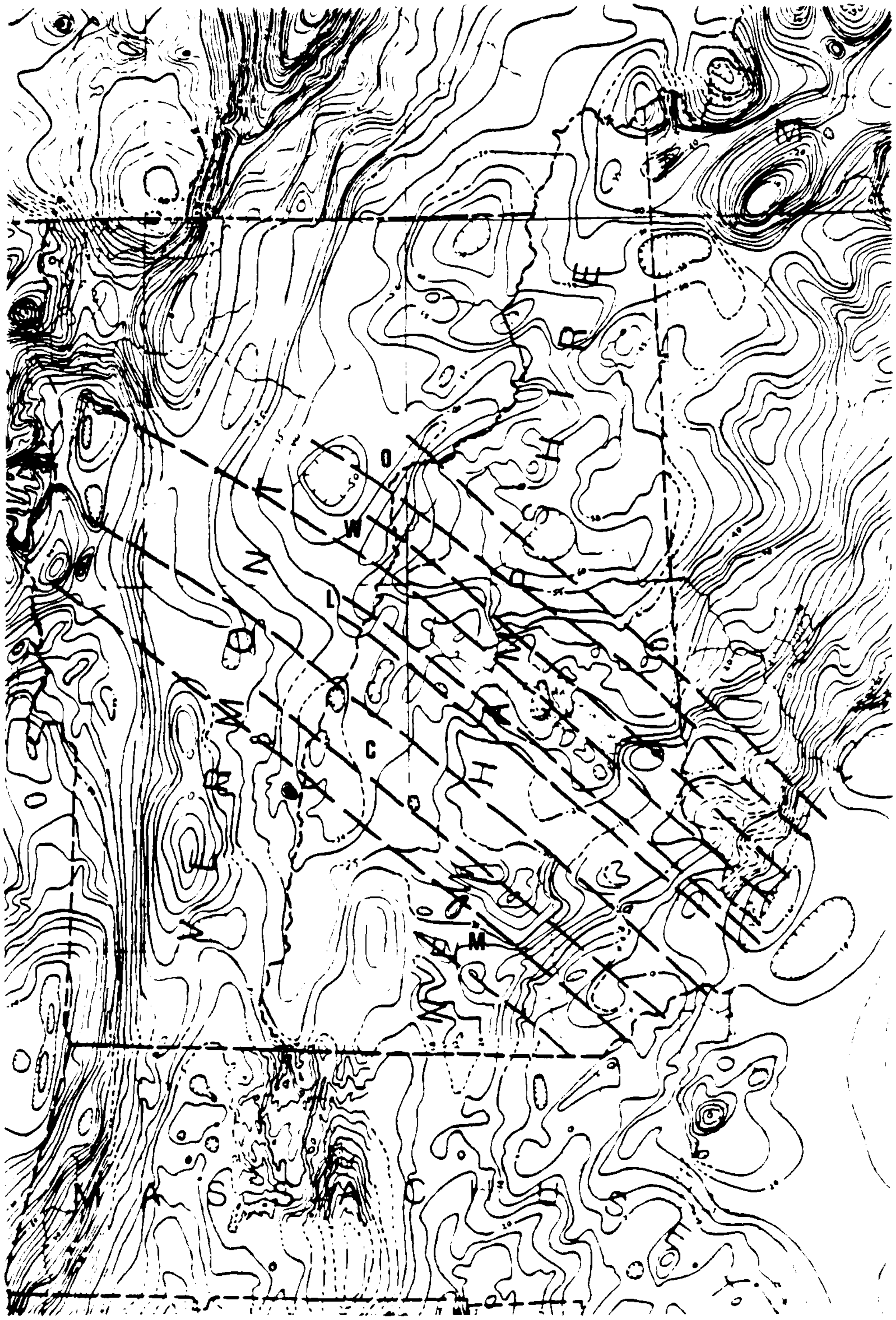


Figure 25. Gravity map of New Hampshire and Vermont (Hildreth, 1979) showing seismic zones.
Explanation, O, Ossipee; W, Winnipesaukee; L, Laconia; C, Concord; M, Manchester

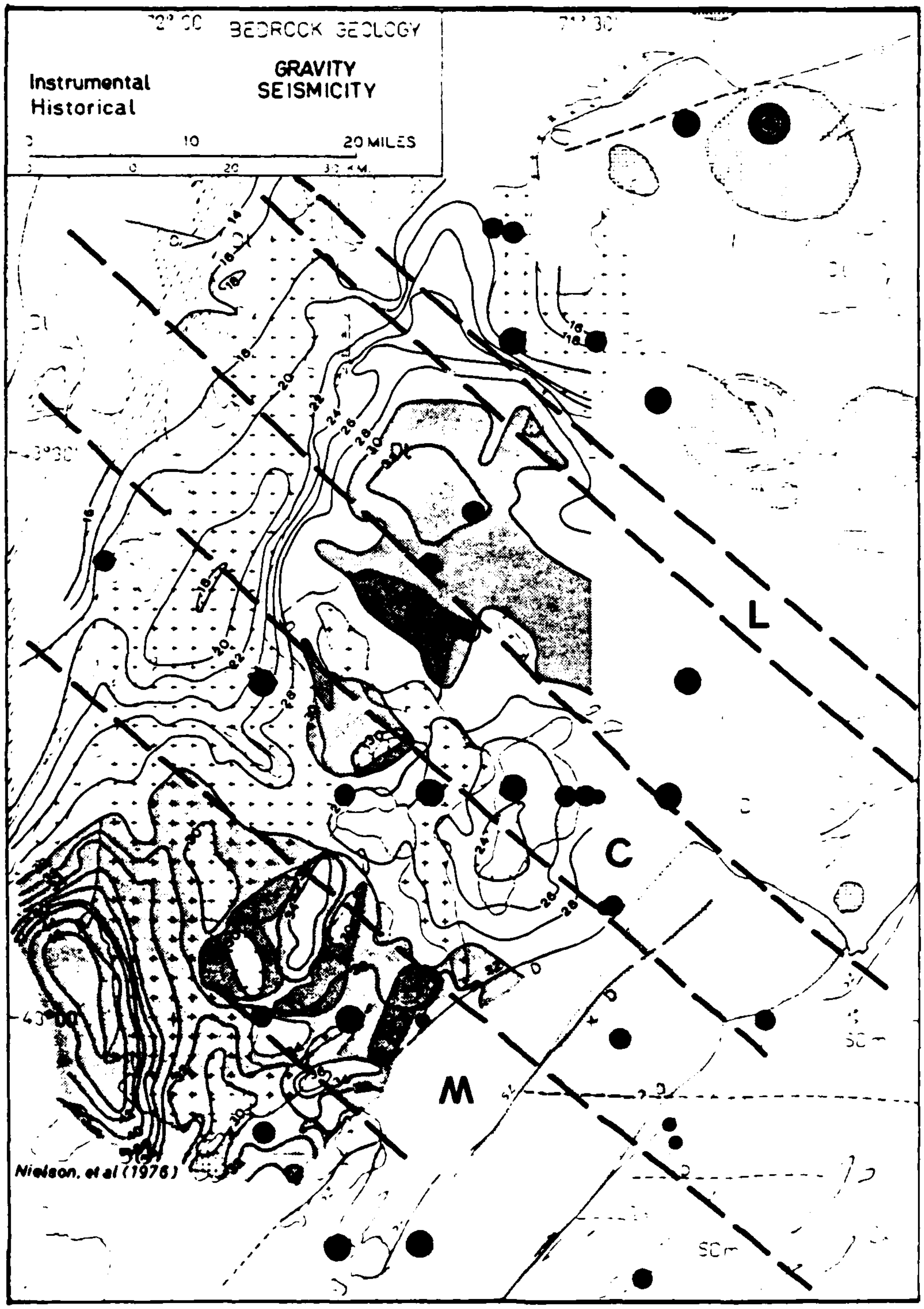


Figure 26. Gravity map of central New Hampshire (Weston Geophys. Res., 1976) showing seismic zones. Explanation: L, Laconia; C, Concord; M, Manchester. (Note, epicentral locations are incorrect.)

Figure 26. Explanation

GENERALIZED BEDROCK GEOLOGY

MESOZOIC		WHITE MOUNTAIN PLUTONIC SERIES
MIDDLE PALEOZOIC		GRANITE
		KINSMAN QUARTZ MONZONITE
		QUARTZ MONZONITE
		BETHLEHEM GNEISS
		DIORITE-QUARTZ DIORITE
	Dt	LITTLETON FORMATION
	SDm	MERRIMACK GROUP
LOWER PALEOZOIC		ORDOVICIAN-UNDIFFERENTIATED
PRECAMBRIAN		MASSABESIC GNEISS

Sz	Silicified Fault Zones
	High-Angle Fault - Arrows show sense of displacement
D	"D" on inferred down-dropped block
--?--	Fault inferred from aeromagnetic anomalies

PRIMARY SOURCES: Billings 1956; Nielson, et al, 1976; Weston Geophysical Research, 1976

BOUGUER GRAVITY ANOMALY MAP

2 MILLIGAL CONTOUR INTERVAL

SOURCE: —— Nielson, et al, 1976;

PROBABLE CAUSE OF EARTHQUAKES IN CENTRAL NEW HAMPSHIRE

The seismicity in the eastern United States appears to be due to a combination of factors related to movements generated by the continued opening of the North Atlantic basin. Earthquakes appear to occur in areas of vertical movement along northwest-trending fracture zones, related to the off shore transform fracture zones, and associated north-trending extensional fault zones (Barosh, 1981, in press). Other faults may be locally reactivated where they are intersected. The activity in central New Hampshire fits with this theory, although lacking information on vertical movement.

Possible subsidence in the Merrimack-White Mountains seismic area may localize movement along several zones where it is crossed by the Winnipesaukee-Winooski fracture zone. This fracture zone is probably also controlling seismicity where it crosses the apparently downwarping coast near Cape Ann and the St. Lawrence lowland. Epicentral data now suggest the activity is concentrated mainly along four zones within the fracture zone. The northwest-trending isoseismal pattern in the epicentral areas of the Ossipee and Gaza earthquakes and the rapid dropoff of the strong motions to the south are consistent with northwest-trending source zones.

Some minor activity between the Merrimack Valley and Cape Ann seismic areas appears to be spatially associated with a northeast-trending fault zone along either side of the Fitchburg pluton where crossed by the fracture zone (Fig. 22). Such an intersection with extensional faults near the Connecticut River may also account for the activity there (Fig. 22).

The Gaza earthquake is suggested to have occurred along a broad northwest-trending fault zone and to have had some component of right-lateral movement. The movement might possibly have occurred along a topographic lineament that extends north 45° west from the epicenter through Bristol to the northwest and south 50° east through "The Gulf," on the west side of Sanbornton, and along the Belknap-Merrimack county line to the southeast (Figs. 9, 27 and 28). A splay extends off this lineament west of "The Plains" and extends into the Pemigewasset river east of Hill. The aftershock of January 27 may have been due to adjustments along an intersected northeast-trending fault. Salmon brook, that extends north-northeast from near the epicenter, lies approximately along the trend and extent of the aftershocks and could be the location for such fault (Fig. 27).

The Ossipee earthquakes probably had a similar cause. However, the distribution of seismicity and epicentral intensity data both indicate that the Gaza and Ossipee earthquakes occurred on different northwest-trending structural zones.

A working hypothesis for the local cause of the Gaza earthquake and other earthquakes in central New Hampshire would be right-lateral movement along a series of northwest-trending fault zones and related extensional movement along north to northeast-trending faults between them (Fig. 29)

IMPLICATIONS TO THE FRANKLIN FALLS DAM SITE

The 1982 Gaza earthquake occurred about 3.5 miles (5.6 km) northeast of the dam site, but does not greatly change the known seismic hazard at the site as another intensity VI earthquake, with a slightly less magnitude, 3.2, had occurred 4 miles

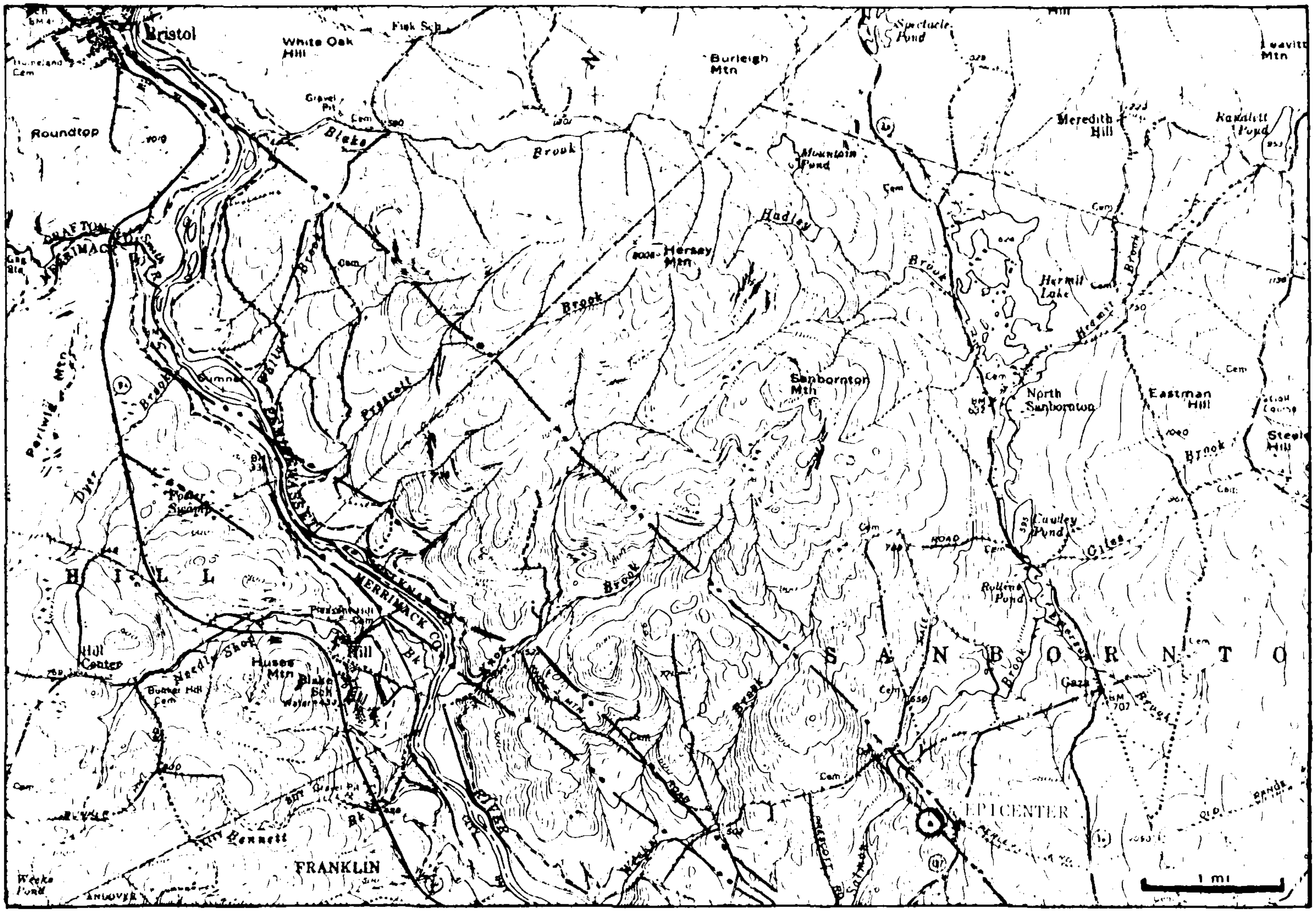


Figure 27. Map of the northwestern part of the epicentral area of the 1982 Gaza earthquake showing epicenter and selected lineaments.

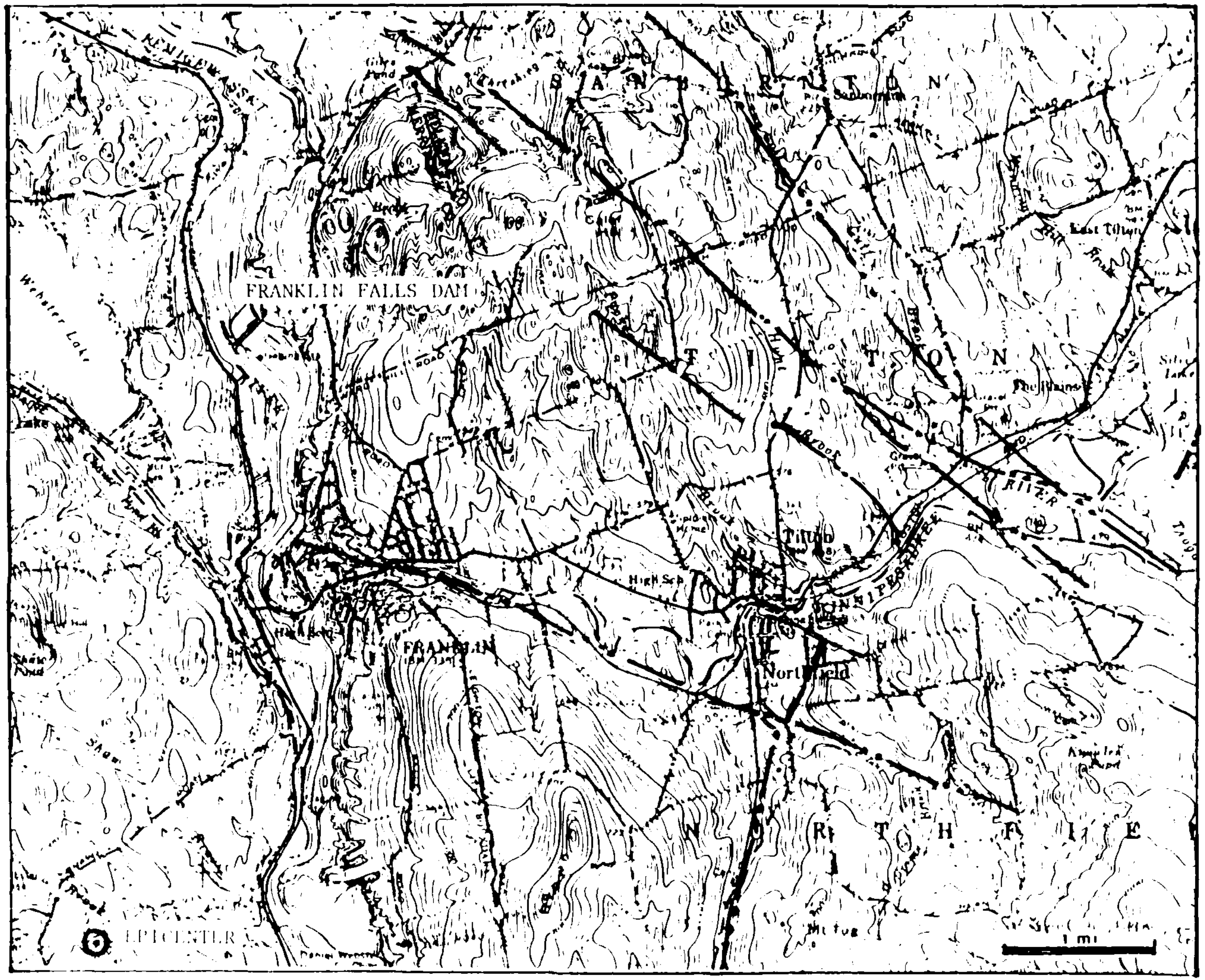
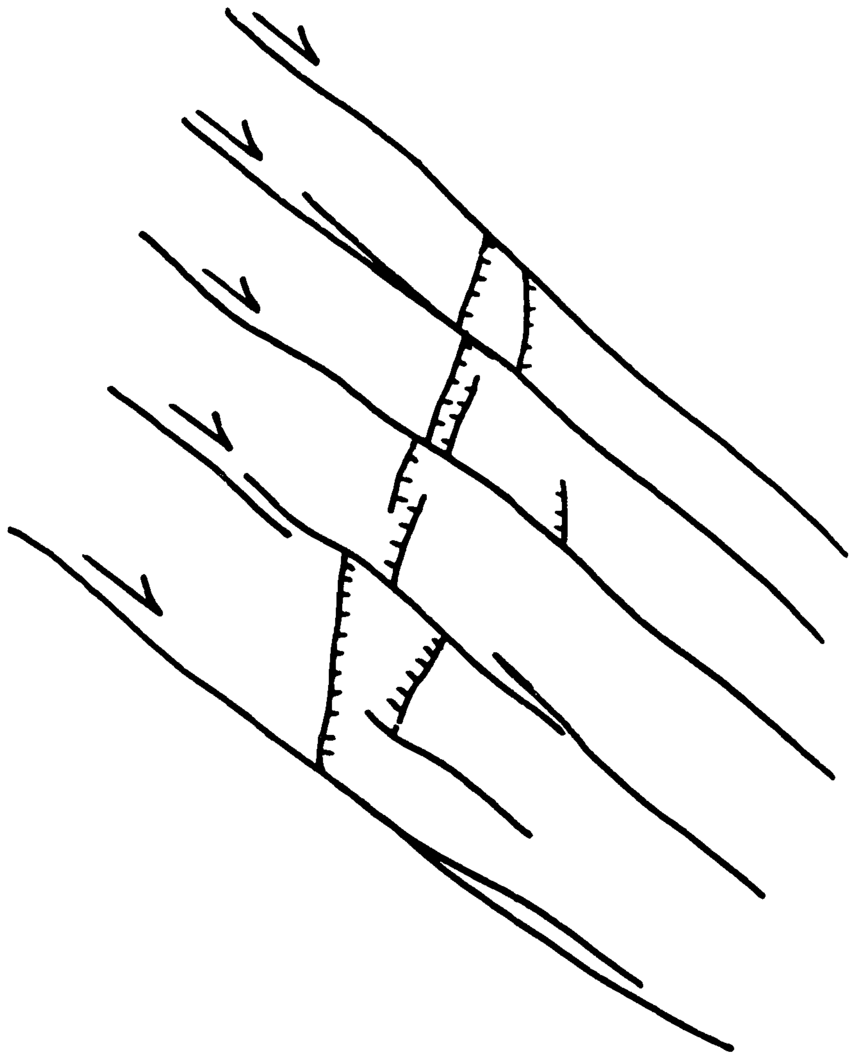


Figure 28. Map of the southern part of the epicentral area of the 1982 Gaza earthquake showing epicenter of the 1964 intensity VI earthquake and selected lineaments.



29. Sketch map showing possible fault configuration and movements to account for the seismic activity in central New Hampshire.

(6.4 km) to the south-southwest in 1964. The high accelerations recorded from the earthquake were a surprise, but this very short period movement produced no damage at the dam site. A previous study on earthquake zonation placed the site on the border of a zone with a maximum credible local earthquake of intensity VIII (Barosh, in press) and this study does not change this value.

The analysis of the data, however, does clarify possible earthquake controls in the region. The data suggests there are northwest-trending seismic source zones in the area. The Laconia zone, containing the Gaza event, and the Concord zone; each passing about 3 miles on either side of the dam site. No indication of an active zone through the dam itself is suggested, although some structure is probable controlling the position of the Pemigewasset river there. There is also the suggestion that sections of north- to northeast-trending structures may have moved or at least greatly transmitted the seismic force. One passes through Bristol to the north and possibly through Northfield to the southwest, but none are indicated at the dam site.

The analysis indicates that the 1940 Ossipee and Gaza earthquakes are not on some northeast-trending structure that would project very close to the dam, but are on separate northwest-trending ones.

SUMMARY

The Gaza earthquake, like the 1940 Ossipee earthquake, was a shallow event with about a normal magnitude-epicentral intensity relation. The depth was 3-8 km and the epicentral intensity relation. 4.7 Mc magnitude produced a low VI epicentral intensity. The shallowness may have been responsible for the recorded very high acceleration values and high noise level, yet did not limit the very widespread effects. The distribution pattern for intensities in the epicentral region for the Gaza and Ossipee events showed a definite northwest trend as did the lessor intensities in Vermont. The drop off of values to the northeast and southwest is more abrupt, although the decrease to the southwest is very irregular, due in part to more sensitive habitats along river valleys. The acceleration values also decreased at over twice the rate to the south as to the west, west-soutwest and southeast. The aftershock sequence and intensities displayed a more north to northeast trend for these shallow, mostly 2 km, earthquakes

The distribution of seismicity and earthquake intensity and available geologic information are used to produce working hypothesis, that apears to satisfy the present data, to explain the crustal movements in central New Hampshire. A broad northwest-trending fracture zone with known post-Cretaceous movement, that crosses New England and extends into Canada is locally active where critical structure is crossed and perhaps subsidence is taking place. Central New Hampshire forms one of these active areas, where a north- to north-northeast-trending area of seismicity lies mainly along a fault controlled river

valley and is parallel to extensional Mesozoic faulting along the Connecticut river valley to the west. Within this seismic area there are suggestions of separate northwest-trending zones of epicenters. These apparent zones parallel the geomorphic expression of the regional fracture zone. The Gaza earthquake occurred on one of these zones and produced an elongated pattern of intensity VI in the epicentral area that coincided with the zone. The aftershocks, however display a north to northeast trend and could be due to adjustments along a fault of this trend north of the epicenter. The 1940 Ossipee earthquakes lie on a different zone, but showed a similar relation of intensities in the epicentral region to that zone. Changes in geologic pattern suggest that right-lateral movement may occur along these zones. If so, a working hypothesis to account for the seismicity would be minor right-lateral movement occuring along zones within the broad fracture zone resulting in some extensional movement along north to north-northeast-trending faults adjacent to the zones. The Franklin Falls dam lies close to and between two zones, that have experienced intensity VI earthquakes, but no zone is indicated to pass through the site. The dam site is at the edge of an earthquake zone with a maximum credible earthquake of VIII for a local earthquake.

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APPENDIX

EARTHQUAKE CATALOG OF NEW HAMPSHIRE
January 1978 - September 1983

Sources and References (REF.)
Nottis (1983), (numbers refer to sources in this text)
U.S. Seismic Network Bulletins 22 to 32, (NEB)
Dewey (1983), (D)
Stover and others (1983), (GS)

Magnitude Type (from Nottis, 1983)

TYPE	DESCRIPTION
B	Felt area magnitude based on M_{bLg} (Nuttli, 1973)
C	M_{bLg} (Nuttli, 1973) computed from seismograms
D	M_{bLg} (Nuttli, 1973) computed from seismograms
G	M_L (Richter, 1935) - computed from sesmograms by the Earth Physics Branch, Ottawa, Canada
H	M_{bLg} (Nuttli, 1973) - computed from seismograms by data contributors to the Northeastern United Stated Seismic Network
I	Signal duration magnitued based on M_{bLg} (Nuttli, 1973), calculated by Weston Observatory, Boston College.
J	Felt area magnitude based on M_L (Richter, 1935), and adjusted by Ebel (1982) for the seismic wave attenuation of the northeastern United States.

APPENDIX

EARTHQUAKE CATALOG OF NEW HAMPSHIRE, 1728 - September 1983

	DATE		ORIGIN TIME (GMT)			EPICENTER		DEPTH		MAGNITUDE		INTENSITY		
YEAR	MONTH	DAY	HR.	MIN.	SEC.	N. LAT.	W. LONG.	(KM.)	REF	VAL.	TYPE	(MM)	REF.	LOCALITY
1728	JAN	12	--	--	-----	43.60	71.70	----	101	---	-	3	101	NEW HAMPTON
1747	AUG	25	--	--	-----	43.20	70.90	----	101	---	-	3	101	DOVER
1751	JUL	21	--	--	-----	43.20	70.90	----	101	---	-	3	101	DOVER
1761	NOV	02	01	--	-----	43.10	71.50	----	10	---	-	4	79	S. OF CONCORD
1766	DEC	17	11	48	-----	43.10	70.80	----	101	---	-	4	101	PORTSMOUTH
1772	AUG	15	--	--	-----	44.40	71.10	----	118	---	-	F	118	SHELBURNE
1777	SEP	14	--	--	-----	43.00	71.50	----	118	---	-	F	118	MANCHESTER
1800	DEC	20	--	--	-----	43.70	72.30	----	79	---	-	4	79	NW. OF NEWPORT
1801	MAR	01	20	30	-----	43.10	70.80	----	79	---	-	4	79	PORTSOMOUTH
1801	MAR	18	07	00	-----	43.10	70.80	----	118	---	-	F	118	PORTSMOUTH
1807	JAN	12	--	--	-----	43.00	70.90	----	118	---	-	F	118	NORTH HAMPTON
1807	JAN	14	04	00	-----	43.00	71.00	----	79	---	-	4	79	EXETER
1810	NOV	10	02	15	-----	43.00	70.80	----	116	4.0	B	5	116	PORTSMOUTH
1823	JUL	23	11	55	-----	42.90	70.60	----	116	4.0	B	4-5	116	OFF HAMPTON
1829	JAN	01	--	--	-----	43.10	70.80	----	101	---	-	4	101	PORTSMOUTH
1845	NOV	--	--	--	-----	43.60	72.30	----	101	---	-	4	101	LEBANON
1846	JUL	10	--	--	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1846	SEP	12	23	30	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1846	OCT	30	02	00	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1846	OCT	31	--	--	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1846	NOV	13	00	40	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1846	DEC	02	--	--	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1847	FEB	02	--	--	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1847	FEB	14	--	--	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1847	FEB	21	--	--	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1851	OCT	12	02	30	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1852	JUN	30	--	--	-----	43.40	72.30	----	101	---	-	3	101	CLAREMONT
1852	AUG	11	--	--	-----	43.10	71.30	----	101	---	-	3	101	DEERFIELD
1852	NOV	28	04	45	-----	43.00	70.90	----	116	---	-	5	79	EXETER
1853	NOV	21	--	--	-----	43.00	71.90	----	101	---	-	3	101	ANTRIM
1853	NOV	28	--	--	-----	43.00	71.90	----	101	---	-	4	101	ANTRIM
1854	OCT	01	--	--	-----	42.90	72.30	----	84	---	-	F	84	KEENE
1854	OCT	25	03	00	-----	42.90	72.30	----	101	---	-	4	101	KEENE
1854	DEC	11	15	30	-----	43.00	70.80	----	10	---	-	4-5	116	NORTH HAMPTON
1855	MAY	29	10	00	-----	44.70	71.60	----	101	---	-	4	101	COOS CO.
1871	JUL	20	--	--	-----	43.20	71.50	----	79	---	-	4	79	CONCORD
1872	NOV	18	19	00	-----	43.20	71.60	----	10	---	-	4-5	79	CONCORD
1873	OCT	05	07	30	-----	42.90	71.30	----	101	---	-	3	101	DERRY
1874	JAN	06	--	--	-----	43.60	71.20	----	101	---	-	2	101	WOLFEBORO
1874	JAN	26	07	00	-----X	43.00	71.50	----	101	---	-	4	101	MANCHESTER
1874	JAN	26	10	00	-----	43.00	71.50	----	101	---	-	3	101	MANCHESTER
1875	MAY	06	--	--	-----	43.60	71.20	----	101	---	-	2	101	WOLFEBORO
1875	DEC	01	09	00	-----	42.90	72.30	----	101	---	-	4	79	KEENE
1875	DEC	01	11	00	-----X	42.90	72.30	----	101	---	-	2	101	KEENE
1877	APR	23	16	00	-----	43.00	71.30	----	101	---	-	2	101	AUBURN
1879	OCT	26	03	30	-----	43.00	71.50	----	79	---	-	4	101	MANCHESTER
1879	NOV	03	12	15	-----	43.20	71.70	----	101	---	-	2	101	CONTOOCOOK

	DATE		ORIGIN TIME (GMT)			EPICENTER		DEPTH		MAGNITUDE		INTENSITY		
YEAR	MONTH	DAY	HR.	MIN.	SEC.	N. LAT.	W. LONG.	(KM.)	REF	VAL.	TYPE	(MM)	REF.	LOCALITY
1880	JUL	13	04	00	-----	43.20	71.60	----	101	---	-	2	101	CONCORD
1880	JUL	21	00	00	-----	43.00	71.50	----	79	---	-	4	101	MANCHESTER
1880	AUG	21	--	--	-----	43.20	71.10	----	101	---	-	2	101	BARRINGTON
1881	FEB	04	--	--	-----	43.00	70.80	----	101	---	-	2	101	GREENLAND
1881	FEB	12	--	--	-----	43.00	70.80	----	101	---	-	2	101	PORTSMOUTH
1881	APR	03	09	25	-----	43.00	71.90	----	101	---	-	3	101	ANTRIM
1881	MAY	18	05	20	-----	43.20	71.70	----	101	---	-	3	101	CONTOOCOOK
1881	MAY	18	08	30	-----	43.20	71.70	----	101	---	-	3	101	CONTOOCOOK
1881	AUG	13	--	--	-----	43.20	71.70	----	101	---	-	3	101	CONTOOCOOK
1881	OCT	06	05	03	-----	43.20	71.60	----	101	---	-	3	101	BRISTOL
1881	OCT	31	06	40	-----	43.20	71.70	----	101	---	-	2	101	CONTOOCOOK
1882	APR	17	19	00	-----	43.20	71.70	----	101	---	-	4	101	HOPKINTON
1882	MAY	08	09	00	-----	43.20	71.60	----	101	---	-	3	101	CONCORD
1882	DEC	19	22	20	-----	43.20	71.40	----	10	---	-	4	10	CONCORD
1883	FEB	04	20	05	-----	43.60	71.20	----	101	---	-	2	101	WOLFEBORO
1884	JAN	18	07	00	-----	43.20	71.70	----	101	---	-	4	101	CONTOOCOOK
1884	OCT	27	01	00	-----	42.80	71.40	----	101	---	-	2	101	NASHUA
1884	NOV	13	00	50	-----	43.20	71.60	----	101	---	-	2	101	CONCORD
1884	NOV	23	05	30	-----	43.20	71.70	----	10	4.0	B	5-6	101	CONCORD
1884	DEC	17	07	00	-----	43.70	71.50	----	101	---	-	3	101	CENTER HARBOR
1885	JAN	03	07	00	-----	43.50	71.50	----	10	---	-	2	101	LACONIA
1885	MAR	18	17	00	-----	43.20	71.70	----	101	---	-	2	101	CONTOOCOOK
1886	JAN	06	00	10	-----	42.90	71.50	----	79	---	-	4	79	MERRIMACK
1886	JAN	17	22	14	-----	42.80	71.40	----	79	---	-	4	79	NASHUA
1887	JUL	01	02	00	-----	43.20	71.53	----	79	---	-	4	79	CONCORD
1889	MAR	08	--	--	-----	43.50	71.60	----	79	---	-	4	79	FRANKLIN
1891	MAY	02	00	10	-----	43.20	71.60	----	10	4.0	B	5	10	NEAR CONCORD
1891	MAY	30	00	00	-----	43.10	71.50	----	101	---	-	4	101	NEAR CONCORD
1892	DEC	11	16	30	-----	44.30	71.70	----	79	---	-	4	79	BETHLEHEM
1893	JUL	02	--	--	-----	42.90	72.10	----	84	---	-	F	84	DUBLIN
1896	OCT	22	10	30	-----	44.30	71.80	----	79	---	-	4	79	BETHLEHEM
1897	JUL	01	09	20	-----	43.70	71.60	----	101	---	-	4	101	MEREDITH
1905	MAR	05	02	25	-----	43.60	72.30	----	116	---	-	4-5	116	LEBANON
1905	AUG	30	10	40	-----	43.10	70.70	----	116	---	-	5	116	ROCKINGHAM CO.
1908	NOV	23	13	00	-----	43.50	71.70	----	79	---	-	4	79	FRANKLIN
1910	AUG	30	14	30	-----	43.40	72.10	----	10	---	-	4	10	LAKE SUNAPEE
1911	MAR	02	21	30	-----	43.20	71.50	----	79	---	-	4	79	CONCORD
1920	MAY	23	08	00	-----	43.10	71.50	----	101	---	-	4	101	CONCORD
1922	MAY	07	22	40	-----	43.40	71.40	----	101	---	-	4	101	PITTSFIELD
1925	MAR	09	--	--	-----	42.90	71.50	----	101	---	-	4	101	GOFF'S FALLS
1925	OCT	09	14	00	-----	43.70	73.10	----	79	---	-	6	116	OSSIPEE
1926	MAR	18	21	09	-----	42.80	71.80	----	116	---	-	5	116	NEW IPSWICH
1927	MAR	09	04	08	-----	43.30	71.40	----	10	---	-	4-5	116	CONCORD
1928	APR	25	23	38	-----	44.50	71.20	----	37	4.0	B	5	102	BERLIN
1928	APR	28	22	07	-----	43.20	71.50	----	37	---	-	4	102	CONCORD
1928	MAY	22	00	24	-----	43.20	71.50	----	37	---	-	2	102	CONCORD
1928	MAY	26	--	--	-----	43.20	71.70	----	37	---	-	2	102	CONTOOCOOK
1928	OCT	15	--	--	-----	45.10	71.40	----	37	---	-	2	102	PITTSBURG
1928	OCT	17	00	30	-----	42.80	71.60	----	37	---	-	3	102	WILTON
1928	NOV	05	04	00	-----	43.30	71.30	----	37	---	-	2	102	ROCHESTER
1928	DEC	01	--	--	-----	43.30	71.00	----	37	---	-	2	102	ROCHESTER

	DATE		ORIGIN TIME (GMT)			EPICENTER		DEPTH		MAGNITUDE		INTENSITY		
YEAR	MONTH	DAY	HR.	MIN.	SEC.	N. LAT.	W. LONG.	(KM.)	REF	VAL.	TYPE	(MM)	REF.	LOCALITY
1929	JAN	13	--	--	-----	43.30	71.00	----	38	---	-	2	102	ROCHESTER
1929	JAN	15	02	45	-----	43.30	71.00	----	38	---	-	3	102	ROCHESTER
1929	FEB	05	17	10	-----	43.30	71.70	----	38	---	-	2	102	WEARE
1930	FEB	14	06	15	-----	43.40	71.70	----	65	---	-	3-4	102	FRANKLIN
1930	MAR	19	00	15	-----	43.30	71.60	----	65	---	-	4	102	CONCORD
1932	OCT	15	03	10	-----	43.60	71.50	----	67	---	-	3	102	MEREDITH
1932	OCT	16	19	12	-----	42.90	72.30	----	67	---	-	2	102	KEENE
1932	NOV	04	05	00	-----	43.20	71.50	----	67	---	-	2	102	CONCORD
1935	SEP	13	03	49	-----	43.20	71.50	----	70	---	-	F	70	CONCORD
1936	JUN	14	05	40	-----	43.50	71.50	----	71	---	-	3	102	LACONIA
1936	JUN	15	00	49	-----	43.80	71.40	----	102	---	-	3	102	CENTER SANDWICH
1936	NOV	10	02	46	-----	43.60	71.40	----	102	---	-	5	79	LACONIA
1938	APR	01	22	15	-----	43.30	71.00	----	73	---	-	3	73	ROCHESTER
1938	APR	03	--	--	-----	43.30	71.00	----	102	---	-	2	102	ROCHESTER
1939	OCT	10	--	--	-----	43.40	71.60	----	102	---	-	3	102	TILTON
1939	OCT	11	18	49	-----	42.90	71.40	----	102	---	-	3	102	DERRY
1940	DEC	20	07	27	26.20	43.87	71.37	10.0	32D	5.5	C	7	74	OSSIPEE
1940	DEC	24	13	00	-----X	43.80	71.30	----	74	---	-	F	74	OSSIPEE
1940	DEC	24	13	43	45.00X	43.90	71.28	7.6	32D	5.5	C	7	74	OSSIPEE
1940	DEC	24	14	33	-----X	43.80	71.30	----	74	2.8	C	F	74	OSSIPEE
1940	DEC	24	18	12	-----X	43.80	71.30	----	74	---	-	F	74	OSSIPEE
1940	DEC	25	05	04	-----X	43.80	71.30	----	74	3.7	C	F	74	OSSIPEE
1940	DEC	27	19	56	-----X	43.80	71.30	----	102	3.8	C	F	102	OSSIPEE
1941	JAN	02	03	43	-----X	43.80	71.30	----	74	---	-	F	74	OSSIPEE
1941	JAN	04	11	10	-----X	43.80	71.30	----	74	---	-	F	74	OSSIPEE
1941	JAN	18	23	25	-----X	43.80	71.30	----	74	---	-	F	74	OSSIPEE
1941	JAN	21	02	28	-----X	43.80	71.30	----	74	3.6	G	F	74	OSSIPEE
1941	JAN	23	00	15	-----X	43.80	71.30	----	74	2.9	C	F	74	OSSIPEE
1941	FEB	12	22	24	-----X	43.80	71.30	----	74	---	-	F	74	OSSIPEE
1943	MAR	14	14	02	-----	43.70	71.60	----	102	3.9	G	-	-	MEREDITH
1944	MAR	06	05	46	-----	43.20	71.60	----	6	---	-	2	102	CONCORD
1944	MAR	06	12	15	-----	43.20	71.60	----	6	---	-	2	102	CONCORD
1944	APR	11	20	25	-----	44.00	71.70	----	6	---	-	3	102	WOODSTOCK
1945	MAR	22	08	04	-----	43.20	71.60	----	7	---	-	3	102	CONCORD
1949	SEP	02	05	48	-----	43.80	71.30	----	10	---	-	3	102	S. TAMWORTH
1950	FEB	24	13	04	-----	43.00	71.80	----	102	---	-	3	102	SW. OF CONCORD
1952	OCT	26	09	05	-----	43.60	71.20	----	10	---	-	2	102	WOLFEBORO
1953	MAY	11	06	13	-----	44.00	71.10	----	102	---	-	4	102	CONWAY
1954	OCT	07	--	--	-----	42.70	71.30	----	102	---	-	3	102	PELHAM
1958	NOV	21	23	30	-----	44.00	71.70	----	102	---	-	4	102	WOODSTOCK
1962	DEC	29	06	19	-----	42.80	71.70	----	79	---	-	5	79	NASHUA
1963	DEC	04	21	32	34.80	43.60	71.60	8.6	32D	3.6	G	5	106	LACONIA
1964	APR	01	11	21	-----	43.60	71.50	----	79	2.4	G	4	107	LACONIA
1964	JUN	26	11	04	49.00	43.41	71.68	1.0	32D	3.2	D	6	107	N. of CONCORD
1965	JAN	03	17	05	02.50	43.52	71.78	----	32	3.0	G	4	108	LACONIA
1966	APR	28	12	02	-----	44.10	71.90	----	109	---	-	4	109	BENTON
1966	OCT	23	23	05	-----	43.00	71.40	----	109	3.1	G	5	109	MANCHESTER
1967	JAN	26	04	10	-----	44.60	70.90	----	122	2.1	G	-	-	N. OF BERLIN
1969	AUG	06	16	02	-----	43.80	71.40	----	124	2.6	G	F	124	OSSIPEE
1976	JUN	12	21	00	59.00	44.24	71.61	----	13	2.4	H	-	-	FRANCONIA
1976	JUN	14	05	31	49.80	44.29	71.69	----	13	2.0	H	-	-	FRANCONIA

	DATE		ORIGIN TIME (GMT)			EPICENTER		DEPTH		MAGNITUDE		INTENSITY		
YEAR	MONTH	DAY	HR.	MIN.	SEC.	N. LAT.	W. LONG.	(KM.)	REF	VAL.	TYPE	(MM)	REF.	LOCALITY
1976	NOV	15	15	20	32.50	43.56	71.62	----	15	1.5	H	-	-	LACONIA
1976	NOV	22	22	49	38.00	43.54	71.60*	----	15	1.8	H	-	-	LACONIA
1977	DEC	25	15	35	54.00	43.19	71.66	12.3	19D	3.2	H	5	145	HOPKINTON
1978	JAN	18	00	28	57.30	42.98	72.15	----	20	1.9	H	-	-	E. OF KEENE
1978	MAR	20	08	16	54.10	43.09	71.52	----	20	2.4	H	-	-	NW. OF MANCHESTER
1978	MAR	31	14	27	57.00	43.10	71.63	----	20	2.7	H	-	-	DUNBARTON
1978	JUN	21	18	31	10.00	43.66	71.38	----	21	1.8	H	-	-	WINNIPESAUKEE
1978	AUG	17	21	41	08.10	43.52	71.56*	----	22	1.9	H	-	-	WINNISQUAM LAKE
1978	AUG	25	20	01	30.50	42.87	70.83	----	22	2.3	H	2	22	SEABROOK
1979	JAN	01	04	13	47.40	43.52	71.63	----	24	1.9	H	-	-	SE. OF BRISTOL
1979	APR	23	00	05	45.70	43.04	71.24	----	25	3.1	H	3-4	25	CANDIA
1979	JUL	09	05	42	32.20	43.39	71.45*	----	26	2.4	H	-	-	S. OF LACONIA
1980	APR	01	04	48	36.40	43.84	71.40	----	113	2.0	I	-	-	NE. OF SQUAM LAKE
1980	APR	07	09	36	00.40	43.13	72.22	----	113	2.8	I	-	-	W. OF HIGHLAND LAKE
1980	MAY	21	19	22	17.90	43.01	72.40	----	113	1.8	I	-	-	NW. OF KEANE
1980	NOV	05	22	40	01.40	43.66	71.36	----	137	2.7	I	-	-	N. LAKE WINNIPESAUKEE
1981	FEB	09	03	14	10.42	43.22	71.58	4.4	NEB	1.9	H	-	-	NW OF CONCORD
										1.7	I			
1981	JUN	28	22	42	35.10	43.57	71.55	0R	NEB	3.1	H	F	NEB	W OF LACONIA
										3.0	I			
1981	SEP	04	06	59	54.70	43.33	71.69	10.0	NEB	1.9	H	-	-	NW OF CONCORD
										1.9	I			
1981	OCT	28	00	27	29.63	44.174	71.446	5.00	NEB	2.3	H	-	-	WHITE MOUNTAINS
										2.0	I			
1982	JAN	19	00	14	42.67	43.508	71.619	7.41	NEB	4.7	I	6	GS	W OF LACONIA
1982	JAN	27	16	43	14.47	43.535	71.612	8.82	NEB	2.9	H	5	GS	W OF LACONIA
										2.7	I			
1982	FEB	15	20	13	46.48	43.091	71.493	2.48	NEB	2.1	H	-	-	SE OF CONCORD
										1.9	I			
1982	FEB	26	22	04	46.98	43.093	71.496	8.51	NEB	1.9	H	-	-	S OF CONCORD
										1.7	I			
1982	MAR	05	02	15	30.27	43.281	71.619	5.00	NEB	1.7	H	-	-	NEAR CONCORD
										1.5	I			
1982	MAR	10	18	40	07.72	43.779	71.438	14.20	NEB	1.0	H	-	-	W OF OSSIPEE
										1.6	I			
1982	AUG	04	21	33	10.11	42.989	71.581	5.00	NEB	2.1	H	-	-	NW OF MANCHESTER
										1.8	I			
1982	AUG	09	15	05	03.35	43.564	71.999	14.81	NEB	2.4	H	-	-	N OF NEW LONDON
										1.9	I			
1982	AUG	12	16	59	43.15	43.535	71.932	13.28	NEB	2.6	H	-	-	W OF DANBURY
										2.4	I			
1982	AUG	30	01	47	25.40	43.467	71.624	14.54	NEB	2.0	I	-	-	SW OF LACONIA
1982	SEP	11	05	28	02.67	43.475	71.534	9.82	NEB	1.9	H	-	-	W OF LACONIA
										1.6	I			
1982	SEP	14	22	33	03.56	44.325	71.902	1.43	NEB	2.4	H	-	-	NW OF FRANCONIA
										2.3	I			
1982	SEP	14	23	37	07.15	44.401	71.939	9.69	NEB	2.1	I	-	-	NW OF FRANCONIA
1982	SEP	21	21	37	41.20	44.365	71.802	11.34	NEB	1.9	I	-	-	SW OF LANCASTER

YEAR	DATE MONTH	DAY	ORIGIN TIME (GMT) HR.	MIN.	SEC.	EPICENTER N. LAT.	W. LONG.	DEPTH (KM.)	REF	MAGNITUDE VAL.	TYPE	INTENSITY (MM)	REF.	LOCALITY
1982	OCT	07	09	36	42.22	43.406	71.418	0.53	NEB	1.9	H	-	-	SSE OF LACONIA
										1.9	I			
1982	NOV	21	01	13	19.73	43.142	72.119	1.00	NEB	1.8	H	-	-	NW OF HIGHLAND LAKE
										1.5	I			
1982	DEC	01	22	52	22.91	43.616	71.516	6.00	NEB	3.0	H	-	-	N OF LACONIA
										3.0	I			
1982	DEC	01	23	05	01.61	43.611	71.526	2.10	NEB	2.2	H	F	-	N OF LACONIA
										2.4	I			
1982	DEC	02	20	36	38.64	44.170	71.420	18.75	NEB	1.7	I	-	-	E OF FRANCONIA NOTCH
1982	DEC	03	02	58	52.69	43.616	71.510	10.00	NEB	1.8	I	-	-	N OF LACONIA
1982	DEC	03	03	00	23.61	43.607	71.528	7.31	NEB	1.7	I	-	-	N OF LACONIA
1982	DEC	03	19	41	10.76	44.214	71.664	1.45	NEB	1.8	I	-	-	MT. LAFAYETTE (poss. blast)
1982	DEC	06	23	36	32.39	43.608	71.531	7.02	NEB	2.0	H	-	-	NW OF LACONIA
										2.2	I			
1983	FEB	08	11	10	54.91	43.272	71.898	7.40	NEB	2.0	H	-	-	W OF CONCORD
										1.7	I			
1983	FEB	14	04	29	57.05	44.097	71.351	3.17	NEB	2.1	H	-	-	SE OF WOODSVILLE
										2.3	I			
1983	FEB	16	16	19	40.29	44.064	71.366	2.77	NEB	1.9	I	-	-	SE OF WOODSVILLE
1983	MAR	13	13	03	11.64	43.697	71.331	1.62	NEB	2.9	H	-	-	LAKE WINNIPESAUKEE
										2.8	I			
1983	MAR	24	14	27	20.43	42.962	71.715	1.07	NEB	2.9	H	-	-	W OF MANCHESTER
										2.9	I			
										3.4	C			
1983	APR	03	05	26	36.36	43.900	71.536	8.67	NEB	1.4	I	-	-	NW OF SANDWICH
1983	APR	06	04	20	48.39	44.243	72.000	9.84	NEB	1.4	I	-	-	E OF MONROE
1983	JUL	16	06	19	22.05	43.562	71.580	3.45	NEB	1.4	H	-	-	W OF LACONIA
										1.6	I			
1983	AUG	06	05	24	57.51	43.039	70.134	7.33	NEB	2.7	H	-	-	OFF PORTSMOUTH
										2.4	I			
1983	AUG	10	23	52	32.95	43.046	70.224	6.87	NEB	2.6	H	-	-	OFF PORTSMOUTH
										2.3	I			
1983	AUG	16	09	11	47.92	43.474	71.632	2.52	NEB	2.1	H	-	-	SW OF LACONIA
										1.9	I			
1983	SEP	27	23	36	24.78	44.366	71.744	11.99	NEB	1.7	I	-	-	E OF WHITEFIELD

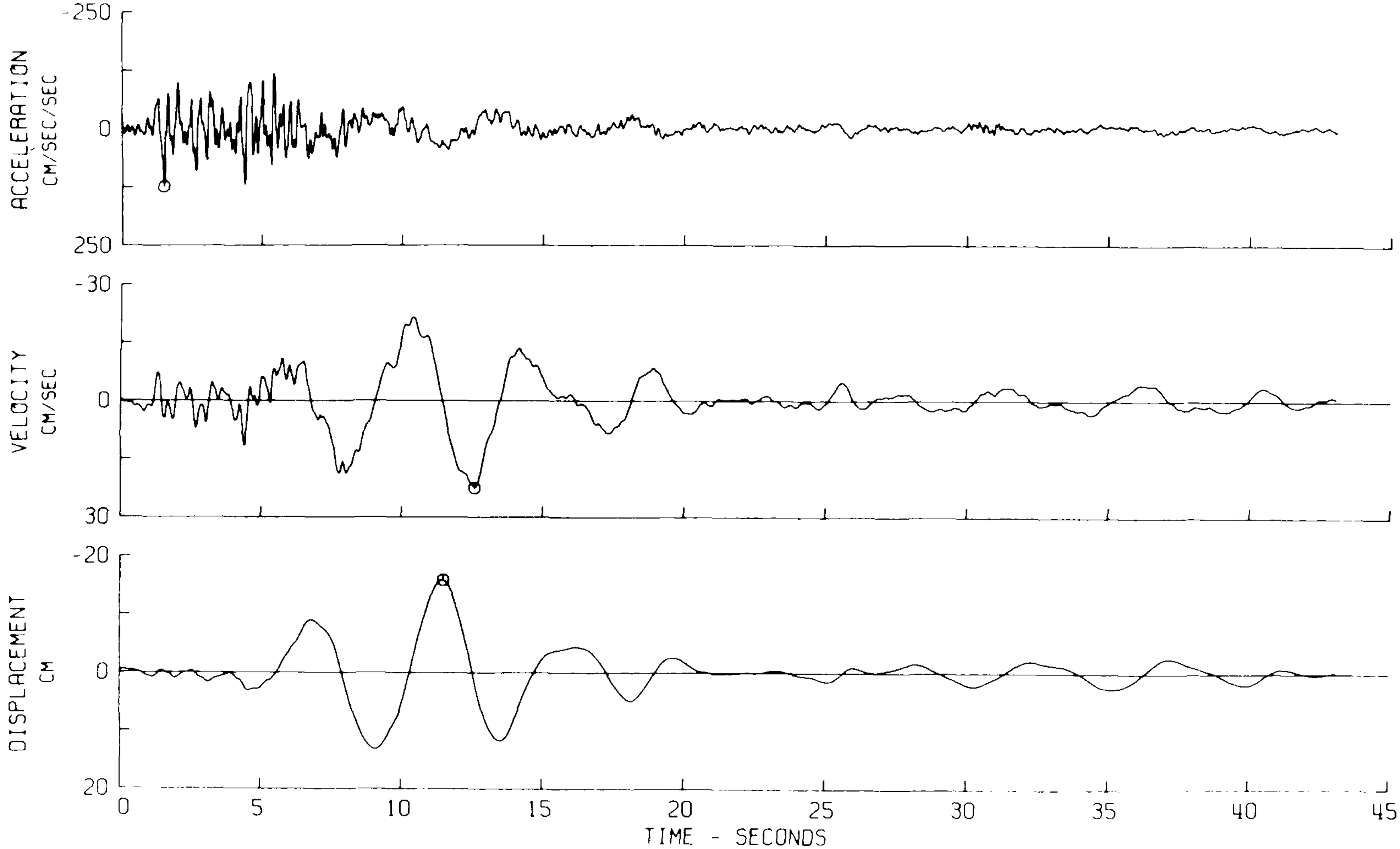
APPENDIX D: SELECTED ACCELEROGRAMS, RELATIVE VELOCITY RESPONSE SPECTRA, AND QUADRIPARTITE RESPONSE SPECTRA

(from California Institute of Technology, 1971-1975; USGS, 1983; and US Department of Conservation, Bureau of Mines and Geology, 1984)

SAN FERNANDO EARTHQUAKE   FEB 9, 1971 - 0600 PST

IIS255   71.178.0   6200 WILSHIRE BOULEVARD, GROUND FLOOR, LOS ANGELES, CAL.   COMP N08E

⊙ PEAK VALUES :   ACCEL = 123.8 CM/SEC/SEC   VELOCITY = 22.5 CM/SEC   DISPL = -15.8 CM

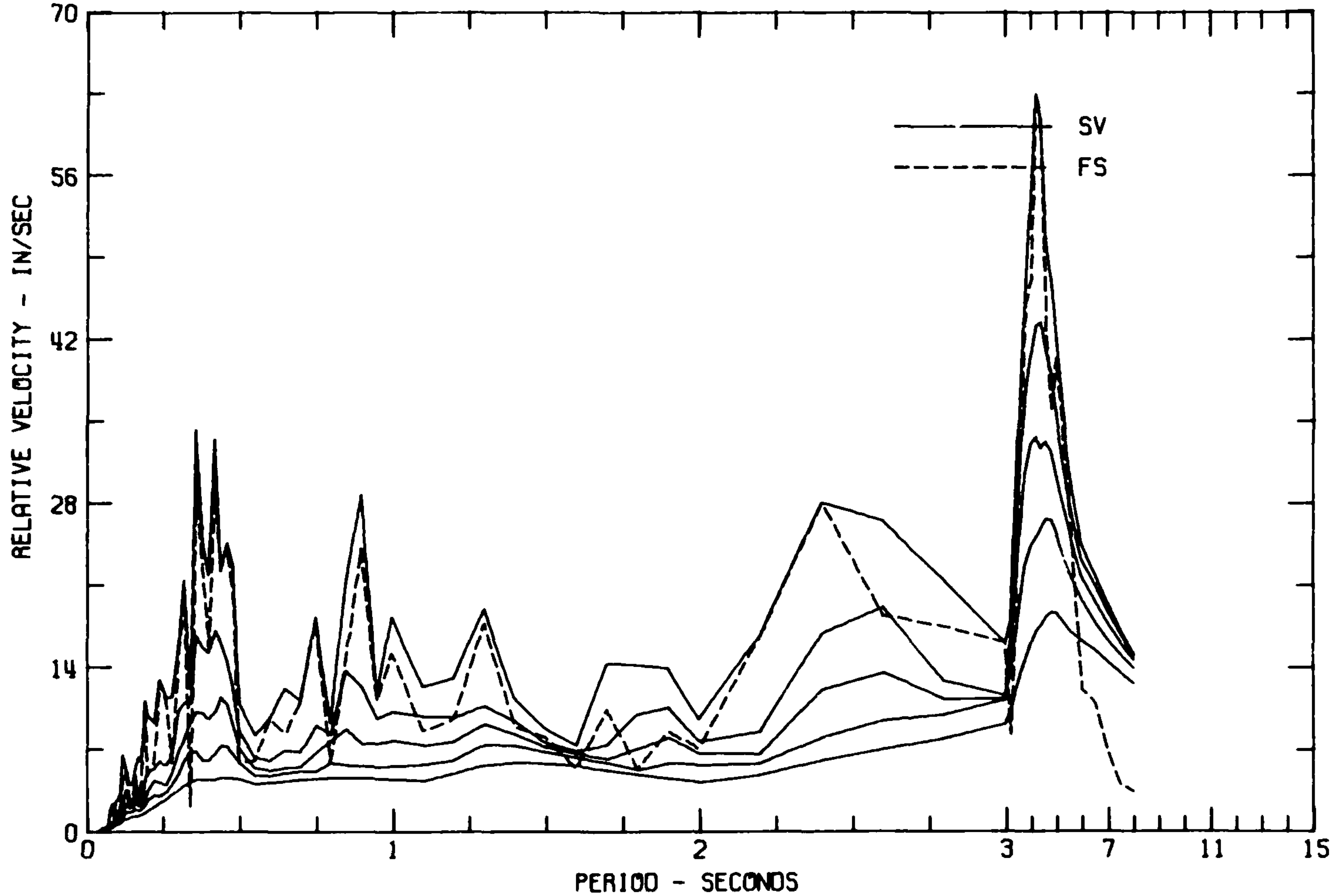


RELATIVE VELOCITY RESPONSE SPECTRUM

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIS255 71.178.0 6200 WILSHIRE BOULEVARD, GROUND FLOOR, LOS ANGELES, CAL. COMP N08E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

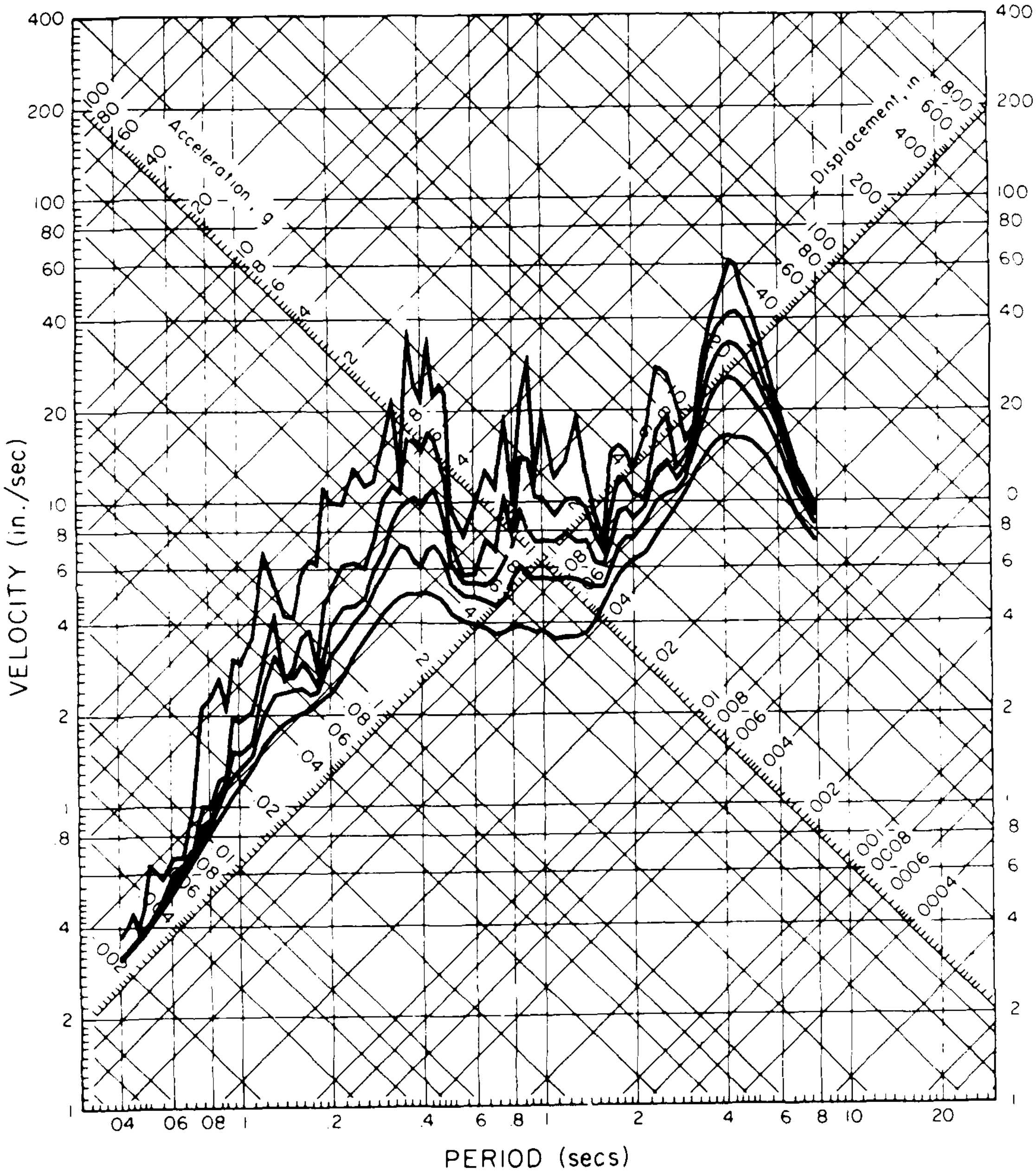


RESPONSE SPECTRUM

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIS255 71.178.0 6200 WILSHIRE BOULEVARD, GROUND FLOOR, LOS ANGELES, CAL. COMP NOBE

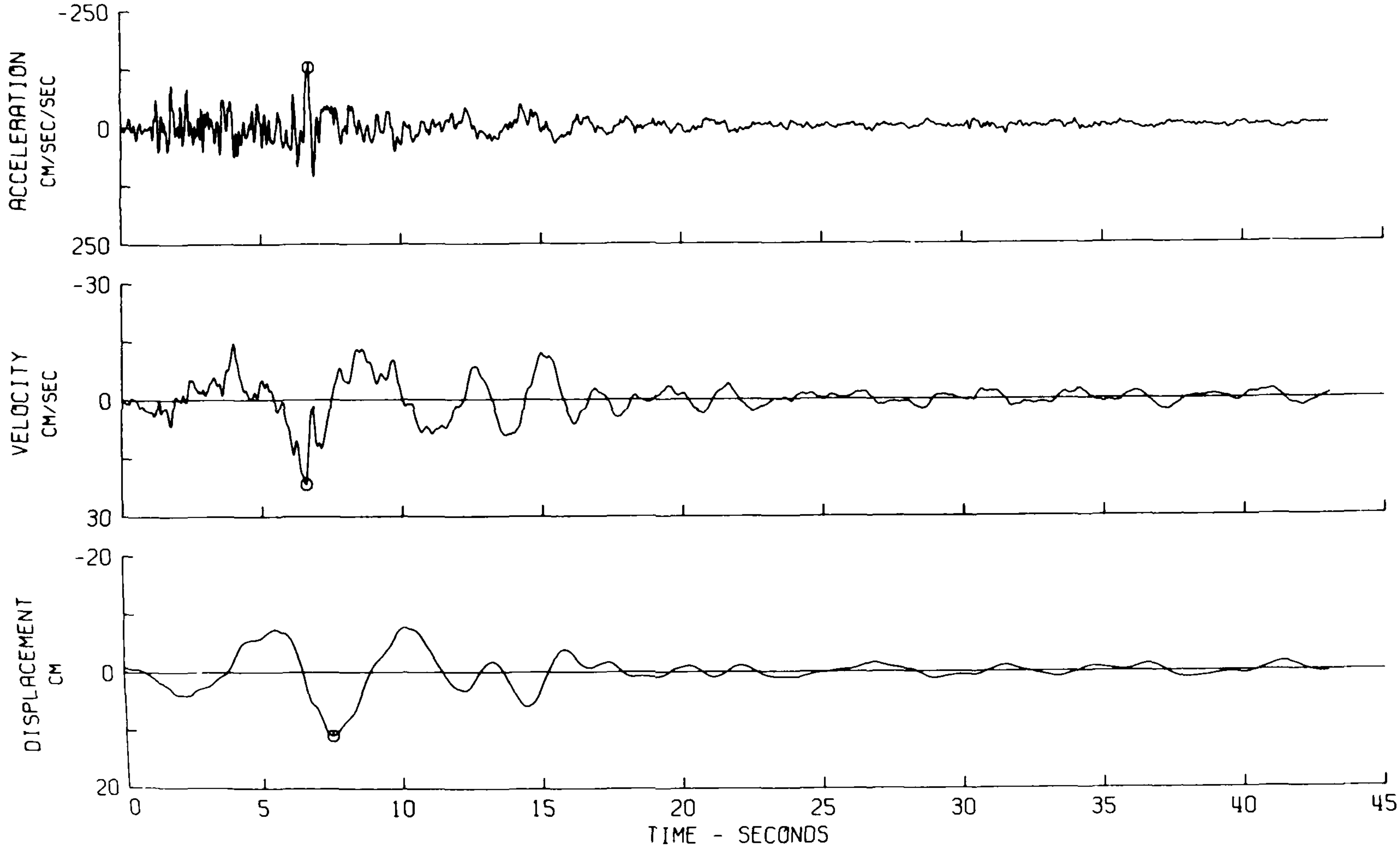
DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



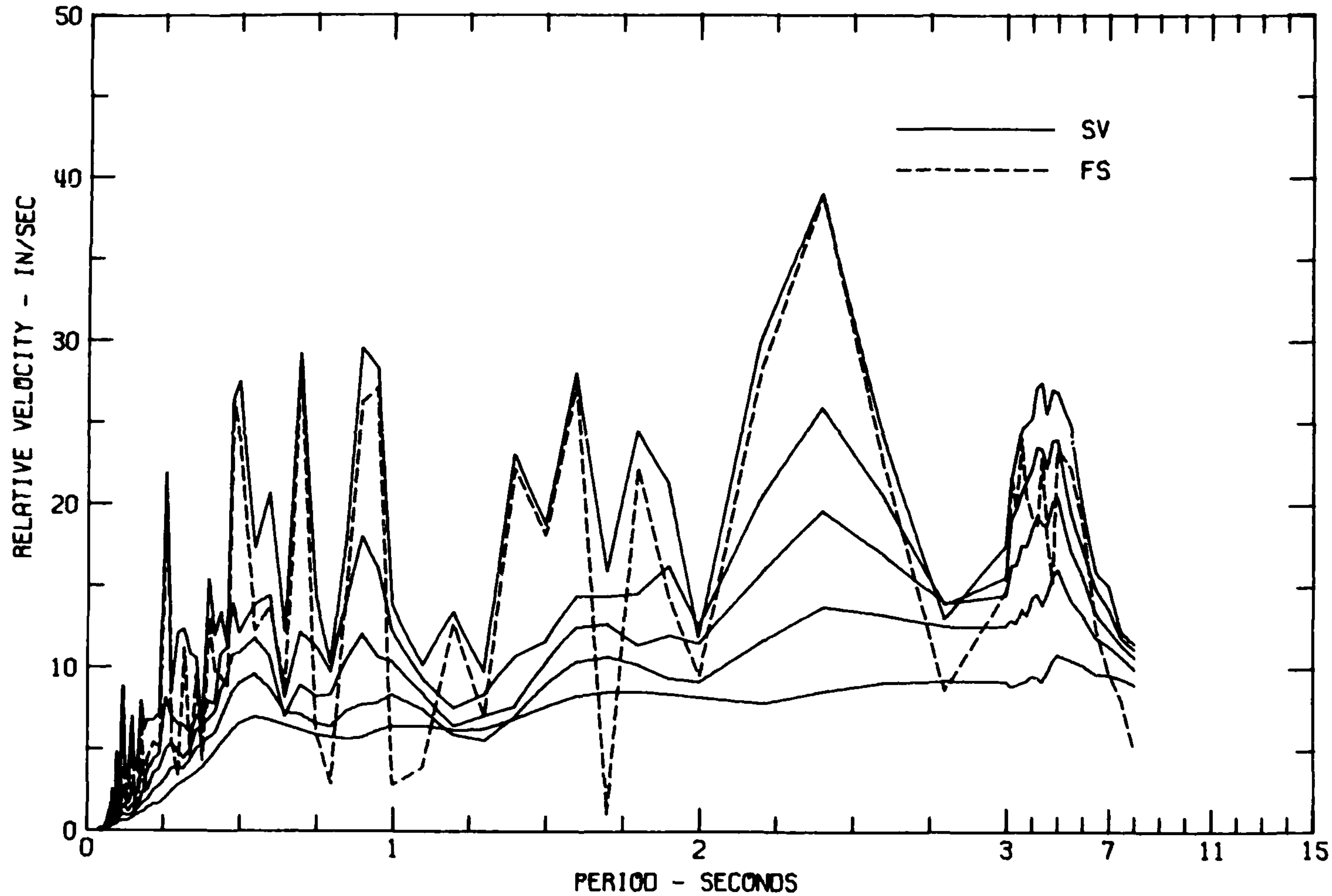
SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIS255 71.178.0 6200 WILSHIRE BOULEVARD, GROUND FLOOR, LOS ANGELES, CAL. COMP N82W

⊙ PEAK VALUES : ACCEL = -128.4 CM/SEC/SEC VELOCITY = 21.8 CM/SEC DISPL = 10.9 CM



RELATIVE VELOCITY RESPONSE SPECTRUM
SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST
IIIS255 71.178.0 6200 WILSHIRE BOULEVARD, GROUND FLOOR, LOS ANGELES, CAL. COMP N82W
DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

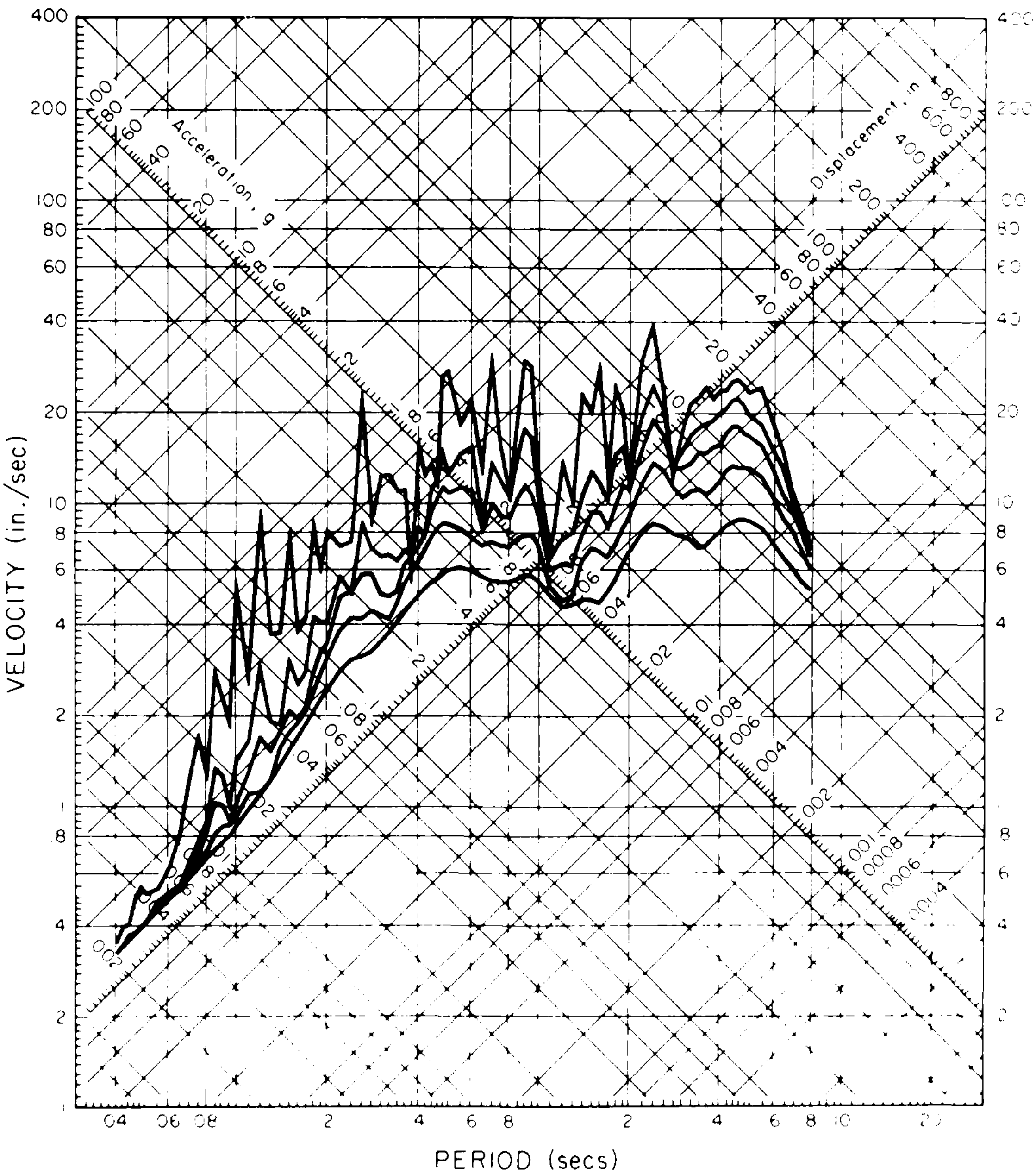


RESPONSE SPECTRUM

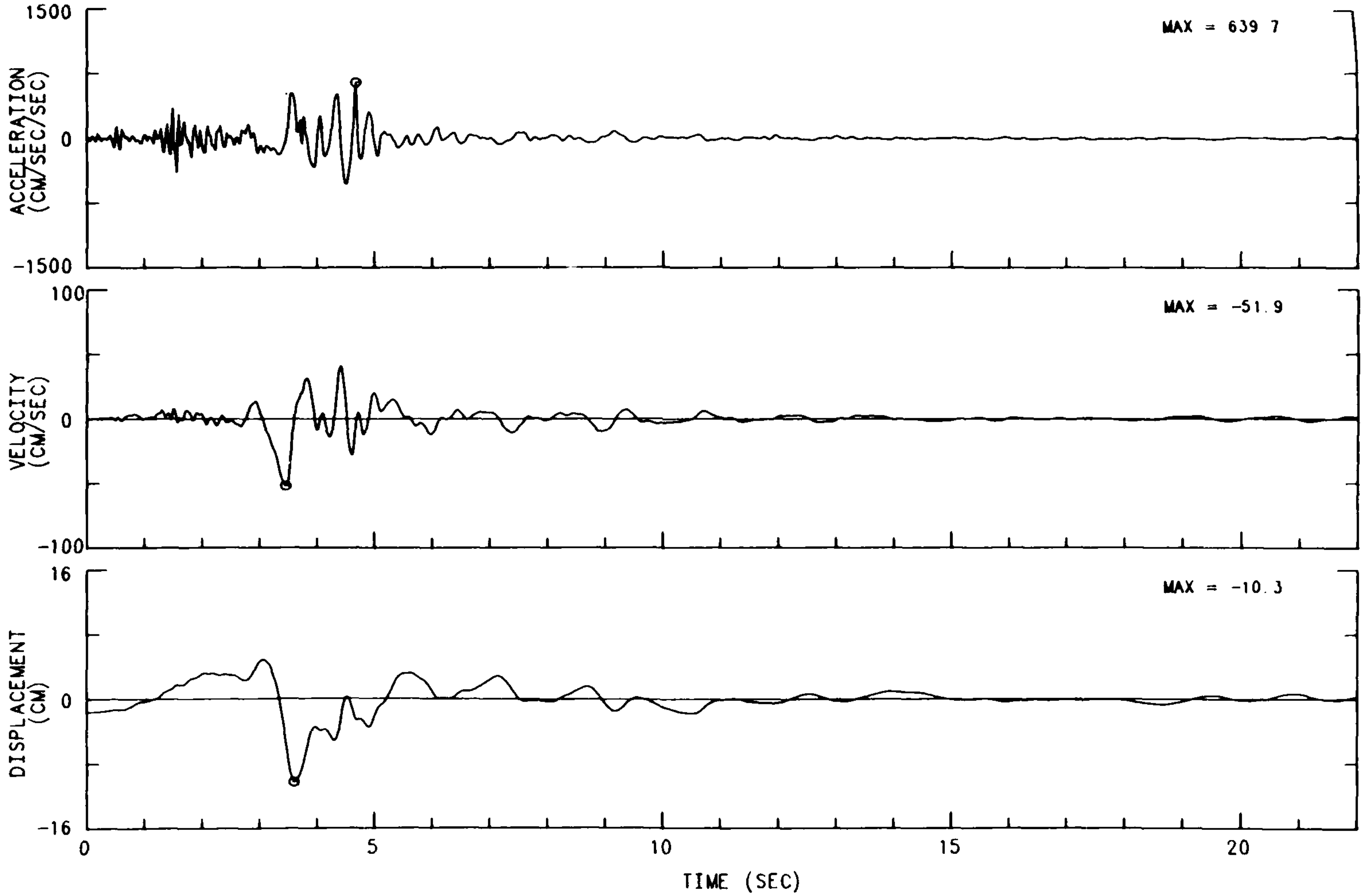
SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIS255 71.178.0 6200 WILSHIRE BOULEVARD, GROUND FLOOR, LOS ANGELES, CAL. COMP N82W

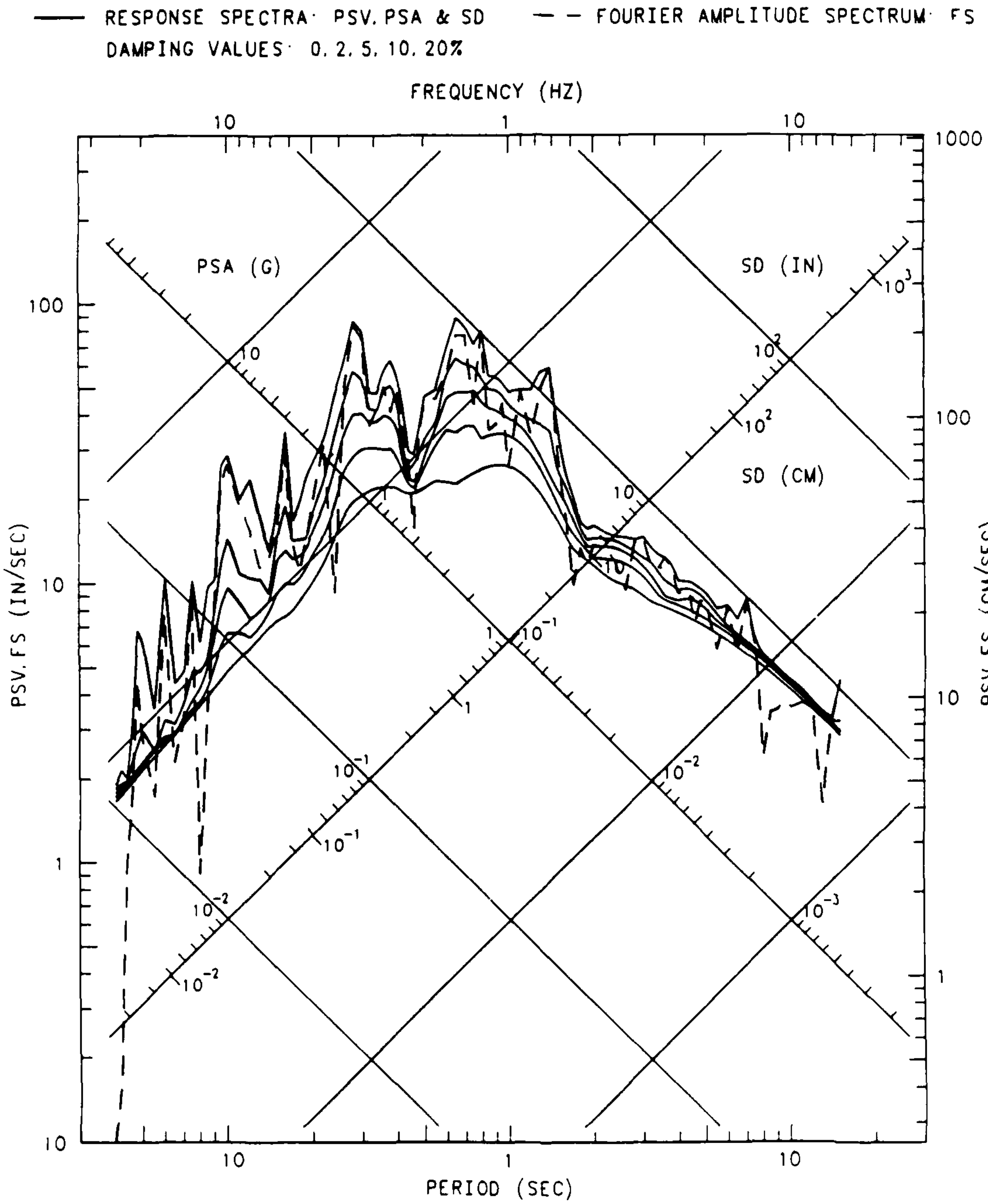
DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

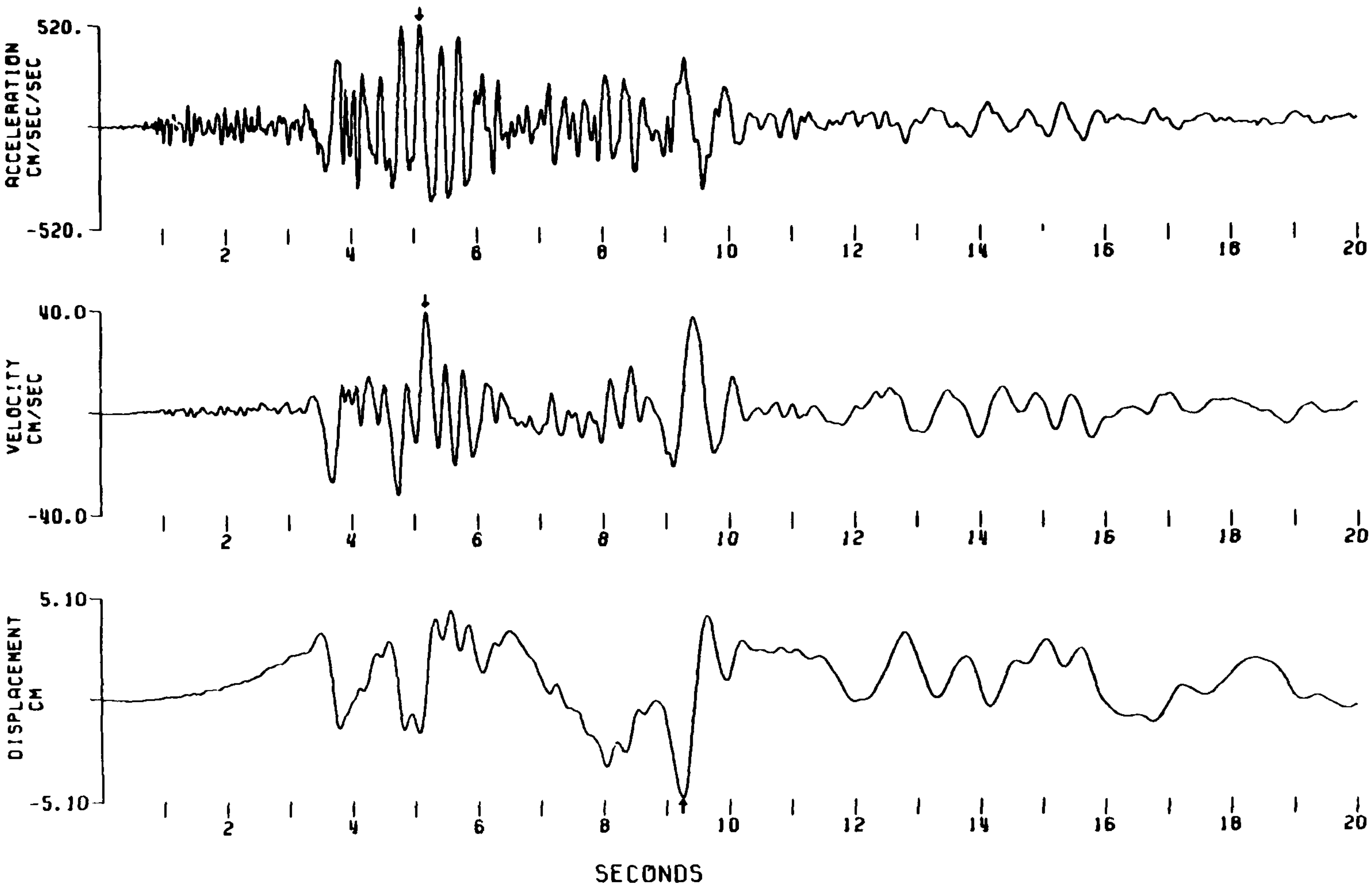


MORGAN HILL EARTHQUAKE APRIL 24, 1984 13 15 PST
COYOTE LAKE DAM (SAN MARTIN) CHN 3 195 DEG
INSTRUMENT-CORRECTED AND BANDPASS-FILTERED ACCELERATION, VELOCITY AND DISPLACEMENT
FILTER BAND 08-.16 TO 23.0-25.0 HZ. 57217-S2494-84116.01 061684.0949-QM84A217

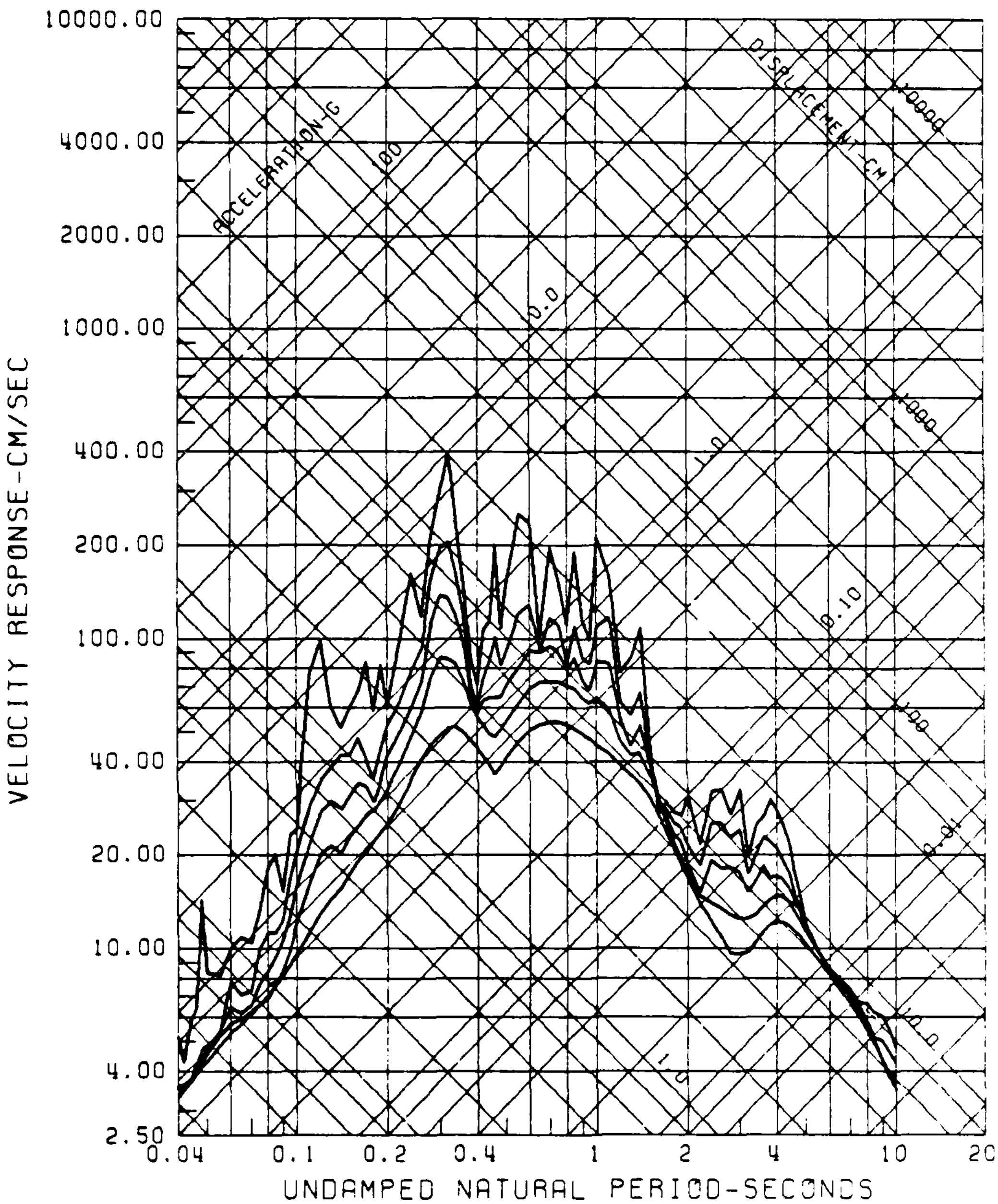


MORGAN HILL EARTHQUAKE APRIL 24, 1984 13:15 PST
COYOTE LAKE DAM (SAN MARTIN)
CHN 3: 195 DEG
ACCELEROGRAM BANDPASS-FILTERED WITH RAMPS AT .05-.07 TO 23.0-25.0 HZ.
57217-S2494-84116.01 061484.1641-QM84A217





Corrected acceleration, velocity and displacement time histories (200 sps) for earthquake of 2 May 1983, (2342 UTC) as recorded on 135^0 horizontal component at Pleasant Valley pumping plant (switchyard). Peak values are: acceleration = 514.43 cm/s^2, velocity = 39.22 cm/s, displacement = 5.05 cm (band pass filtered 0.1 to 50 Hz, Butterworth order 8 lowcut, cosine taper 50 Hz highcut).



Pseudo-velocity response curves (0, 2, 5, 10, 20 percent critical damping) computed for earthquake of 2 May 1983 (2342 UTC) as recorded on 135^{0} horizontal component at Pleasant Valley pumping plant (switchyard). (Band pass filtered 0.1 to 50 Hz, Butterworth order 8 lowcut, cosine taper 50 Hz highcut, U.S. National Strong-Motion Data Center).

END

12-86

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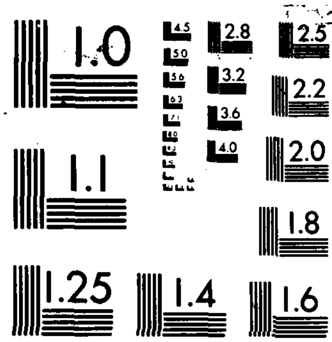
cont

AD-A173 230 GEOLOGICAL-SEISMOLOGICAL EVALUATION OF EARTHQUAKE HAZARDS AT FRANKLIN FAL (U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS GEOTE 3/3

UNCLASSIFIED E L KRINITZSKY ET AL SEP 86 F/G 8/11 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SUPPLEMENTARY

INFORMATION

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P.O. BOX 631
VICKSBURG, MISSISSIPPI 39180-0631

REPLY TO
ATTENTION OF

WESGR-GR

19 December 1986

Errata Sheet

No. 1

GEOLOGICAL-SEISMOLOGICAL EVALUATION OF EARTHQUAKE HAZARDS AT FRANKLIN FALLS DAMSITE, NEW HAMPSHIRE

Technical Report GL-86-16

September 1986

1. DD Form 1473, Block 19, Abstract, Line 6: Change

   velocity 25 cm/sec, to velocity 35 cm/sec,

2. Page 39, paragraph 78: Change second reading in third column of tabulation to

   35

3. Page 44, paragraph 91: Change second reading in third column of tabulation to

   35

END
3-87
DTIC