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GEOLOGICAL-SEISMOLOGICAL EVALUATION OF EARTHQUAKE HAZARDS AT PROMPTON AND FRANCIS E. WALTER DAMSITES, PENNSYLVANIA

by

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A seismic zoning was developed for eastern Pennsylvania and adjacent states based on the geology and the historic seismicity. Floating earthquakes were assigned to those zones in the absence of identifiable active faults. At the Prompton and Francis E. Walter Damsites, motions were far field, MM VI, acceleration 0.12g, velocity 7 cm/sec, and 3 sec bracketed duration $\geq$ 0.05g. Accelerograms and response spectra appropriate to these parameters were selected.

PREFACE

The US Army Engineer Waterways Experiment Station (WES) was authorized to conduct this study by the US Army Engineer District, Philadelphia, on 2 February 1984 by appropriation order FY84-1A0 No. NAPEN-84-20.

The study was conducted and the report was written by Dr. E. L. Krinitzsky, Engineering Geology and Rock Mechanics Division (EGRMD), Geotechnical Laboratory (GL). Dr. O. W. Nuttli, St. Louis University, reviewed the study with Dr. Krinitzsky and concurred with the motions that were selected. Mr. F. K. Chang, Earthquake Engineering and Geophysics Division, selected the earthquake accelerograms to accompany the recommended peak motions. Mr. D. Barefoot, EGRMD, assisted in compiling data and in the preparation of illustrative material. The project was under the general supervision of Dr. D. C. Banks, Chief, EGRMD, and Dr. W. F. Marcuson III, Chief, GL. The report was edited by Ms. Odell F. Allen, Information Technology Laboratory, Information Products Division.

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

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per mile	0.1893935	metres per kilometre
miles (US statute)	1.609347	kilometres

GEOLOGICAL-SEISMOLOGICAL EVALUATION OF EARTHQUAKE HAZARDS AT PROMPTON AND FRANCIS E. WALTER DAMSITES, PENNSYLVANIA

PART I: INTRODUCTION

Background

1. This study was made in order to determine the maximum potential for earthquake shaking at the Prompton and Francis E. Walter damsites in northeastern Pennsylvania. Prompton is an earth and rock-fill dam with a height of 140 ft* above its stream bed and is situated 34 km northeast of Scranton. Francis E. Walter is constructed of earth and rock fill with a height of 234 ft above the stream bed and is 34 km south of Scranton.

2. The investigation provides earthquake ground motions at these damsites as required in ER 1110-2-1806 of 30 April 1977 and ETL 1110-2-301 of 29 April 1983.

Regional Geology

3. The study area is located approximately in the northern terminus of the folded Paleozoic sedimentary deposits known as the Appalachian folded belt. The deformation that produced these folds and the major faults that accompany them came at the end of the Paleozoic about 250 million years ago. The next major disturbance saw a reactivation of faulting and the deposition of continental deposits in small, restricted basins during Triassic-Jurassic time about 180 million years ago. Since then the area has not undergone any deformations. There was a glacial advance into the area during late Wisconsin time in the Pleistocene and a retreat of the glaciers that began about 18,000 years ago.

4. The region has been subject to intermittent stages of slow, relatively uniform uplift which permitted erosion of the ancient deposits; however, there has been no tectonic deformation affecting the rocks since the Jurassic, or about 135 million years ago.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Local and Site Geology

5. The detailed surface geology with its stratigraphic relationships is shown in Figure 1. Explanatory notes on the stratigraphic section and the lithology are provided in Appendix A.

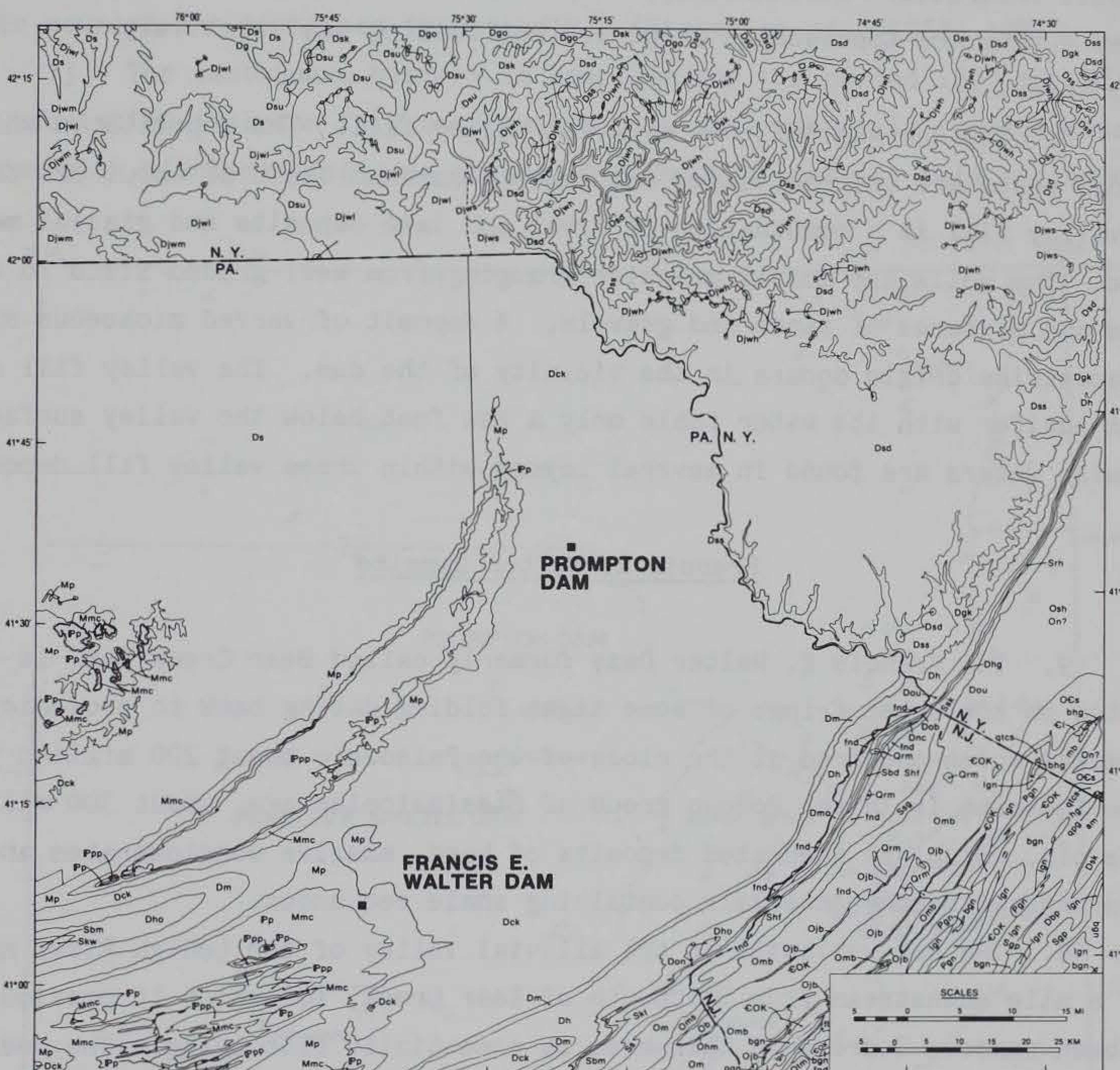

Figure 1. Surface geology in the region of Prompton and Francis E. Walter damsites (see Appendix A)

6. The stratigraphic column is composed principally of ancient sedimentary deposits from the lower Paleozoic. These rest on more limited exposures of Cambrian and pre-Cambrian crystalline and metamorphic rocks with some greatly indurated sedimentary rocks, notably marbles and quartzites.

Prompton Damsite

7. Prompton Dam is set in an area where there is a wide expanse of massive deposits of the Catskill formation of Devonian age, about 350 million years old. These deposits are shales and silty shales and sandstones which are well indurated. Structurally, they are in a zone where uplift has occurred during the Appalachian orogenies but folding was relatively unpronounced.

8. The dam was built on alluvial valley fill. The deposits on which the dam rests are unconsolidated and reach a maximum depth of about 120 ft. The valley fill is a combination of river and lake deposits and glacial moraine. The soils are mostly granular, ranging from well graded silts to clean sands and mixtures of sands and gravels. A deposit of varved micaceous silt of lacustrine origin occurs in the vicinity of the dam. The valley fill acts as an aquifer with its water table only a few feet below the valley surface. Artesian waters are found in several layers within these valley fill deposits.

Francis E. Walter Damsite

9. The Francis E. Walter Dam, formerly called Bear Creek Dam, is located on the outer fringe of some tight folding dating back to orogenic movements which occurred at the close of the Paleozoic about 200 million years ago. The site is in the Pocono group of Mississippian age, about 300 million years old, which are indurated deposits of hard, massive conglomerates and sandstones with some intervals containing shale sequences.

10. The dam was built in the alluvial valley of the Lehigh River about half a mile downstream from the mouth of Bear Creek, for which it previously had been named. Bedrock in this area is essentially flat lying. The bedrock at the damsite is hard, mostly unweathered silica-cemented gray sandstone and quartz conglomerates with discontinuous shale and siltstone layers. Valley fill deposits attain a maximum thickness of about 100 ft. These are unconsolidated granular deposits of silty sands, sands, and sands with gravel and boulders. They are both fluvial and glacial in origin.

11. In the areas of both damsites, there are irregular surficial veneers of glacial deposits that date from the last glacial retreat which began about 18,000 years ago.

PART II: SEISMIC HISTORY

Distribution of Earthquakes

12. The historic earthquakes in the study area are shown in Figure 2. A tabulation of the data assembled for these earthquakes and references to their sources are contained in Appendix B (Stover et al., 1980, 1981).

13. The earthquake history is complete for the period 1677 to 1981. The tabulation includes felt earthquakes plus instrumentally recorded earthquakes with Richter magnitudes above 2.0. Compilations for this region more

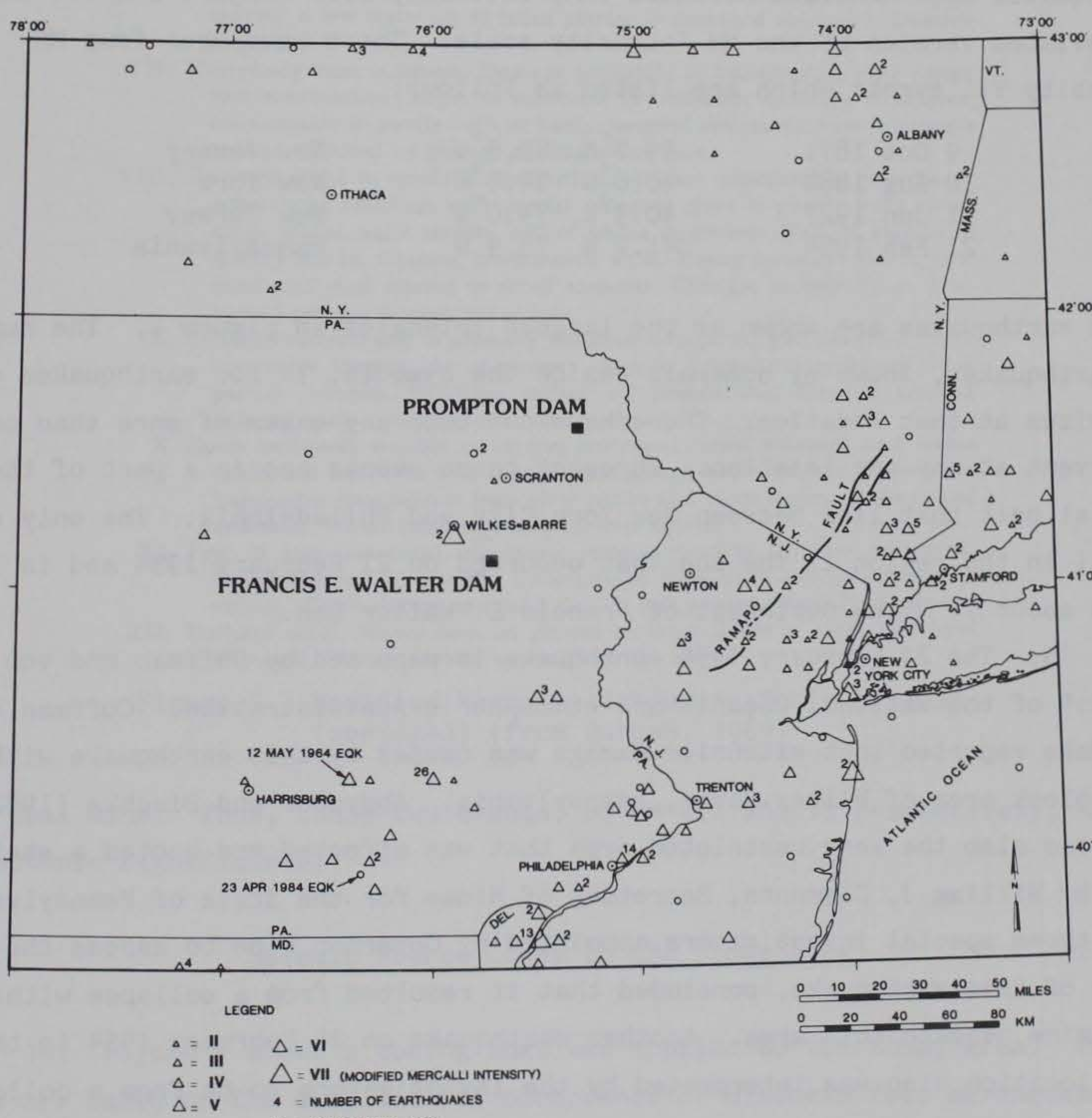

Figure 2. Distribution of historic felt earthquakes in eastern Pennsylvania and adjacent areas (see Appendix B)

recent than 1981 are not available, however, data on a well-monitored earthquake that occurred on 23 April 1984 have been included (Alexander and Stockar, 1984).

14. Reference to the plot of historic seismicity in Figure 2 shows a dispersion of earthquake events throughout the region but with a concentration along a very broad zone, about 75 miles in width, that borders the Atlantic coastline. A separate center occurs to the north in New York. Within the coastal belt, there is a concentration of earthquake activity from the area around New York City to Trenton and Philadelphia. Within the latter area, the largest earthquakes in this region have occurred. Since 1677, the severest earthquakes were Modified Mercalli (MM) Intensity VII. Figure 3 shows an abbreviated version of the MM Intensity scale. There have been four MM Intensity VII events which are listed as follows:

9 Oct 1871	39.7°N	75.5°W	New Jersey
10 Aug 1884	40.6°N	74.0°W	New York
1 Jun 1927	40.3°N	74.0°W	New Jersey
21 Feb 1954	41.2°N	75.9°W	Pennsylvania

These earthquakes are shown as the largest triangles in Figure 2. The number of earthquakes, shown by numerals beside the symbols, is for earthquakes of all sizes at that location. There have not been any cases of more than one MM VII event at any one location. Three of these events are in a part of the coastal belt that lies between New York City and Philadelphia. The only other MM VII in the region is the one that occurred on 21 February 1954 and is located about 12 miles northwest of Francis E. Walter Dam.

15. The 21 February 1954 earthquake is reported by Coffman and von Hake (1973)* of the National Oceanic and Atmospheric Administration. Coffman and von Hake reported that extensive damage was caused by this earthquake within a five-block area of Wilkes-Barre, Pennsylvania. Abdypoor and Bischke (1982) reported also the very restricted area that was affected and quoted a statement by William J. Clements, Secretary of Mines for the State of Pennsylvania, that three special investigators appointed by Governor Fine to assess the cause of this earthquake, concluded that it resulted from a collapse within a coal mine beneath this area. Another earthquake on 24 February 1954 in the same location also was interpreted by the investigators to be from a collapse

* In Appendix B.

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

in a coal mine. Thus, these two events, of MM VII and VI respectively, have no tectonic significance.

Seismic Source Zones in the Study Area

16. Figure 4 shows a zoning that was applied to the study area. The zones are based on the densities of occurrence of historic felt earthquakes and on the intensity levels of these earthquakes. A Lake George Zone takes in the seismicity in the area near Albany, New York. The Atlantic Coastal Zone

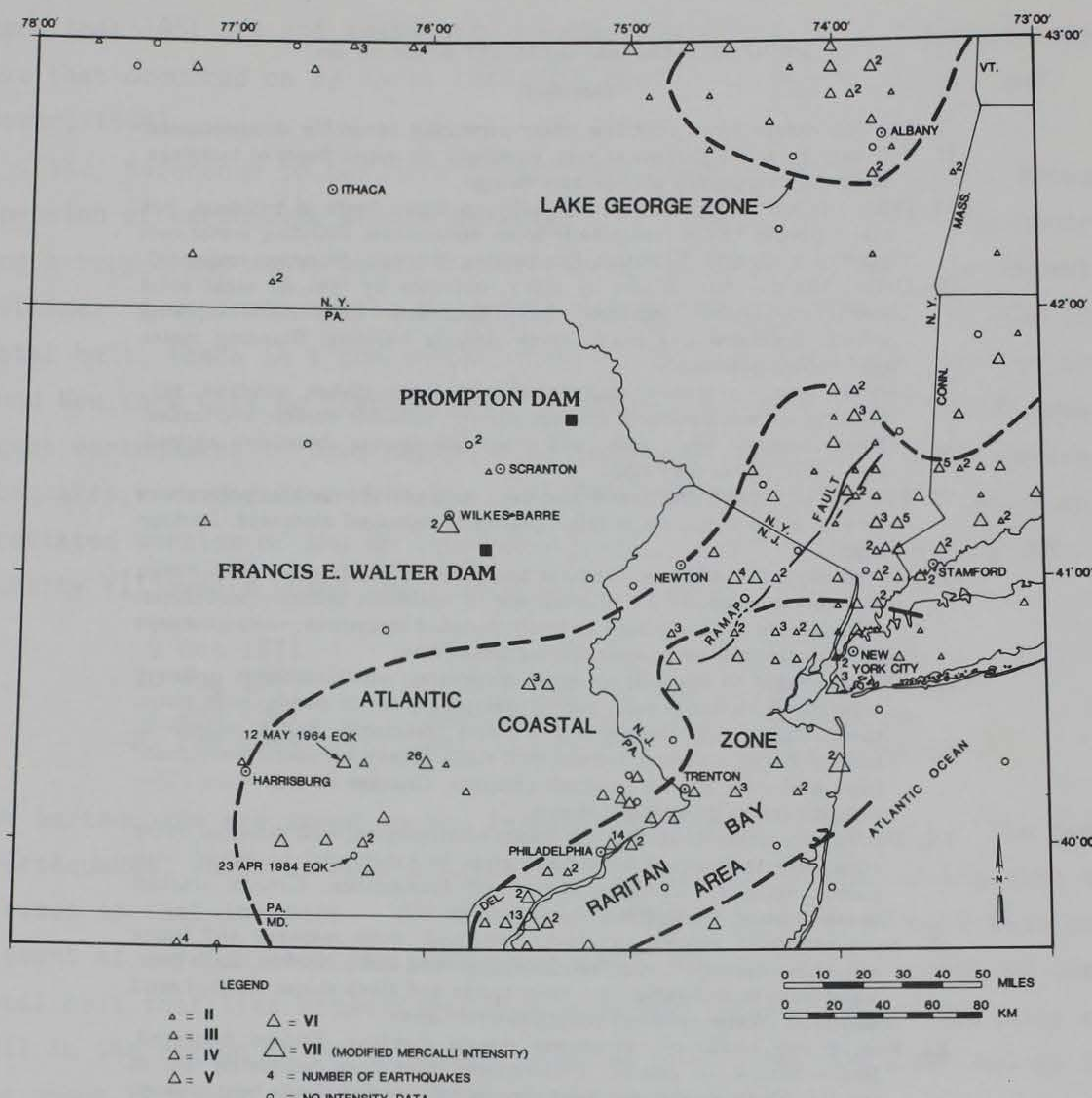

Figure 4. Boundaries of seismic source zones interpreted for the study area

takes in the wide and irregular seismic band that borders the coastline. Within the Atlantic Coastal Zone there is a Raritan Bay Area.

17. The Raritan Bay area is not only designated chiefly on the basis of its seismic history which includes the three MM VII events of tectonic origin in the region but also because the seismicity is structurally coincident with a plunging Cretaceous-Tertiary trough.

18. Figure 5, prepared by Barosh (In press) from work by Wentworth and Mergner-Keefer (1981), shows the location of early Mesozoic basins and related fracture zones in the Raritan Bay region. These ancient structures are experiencing a low level of activation which accounts for the concentration of

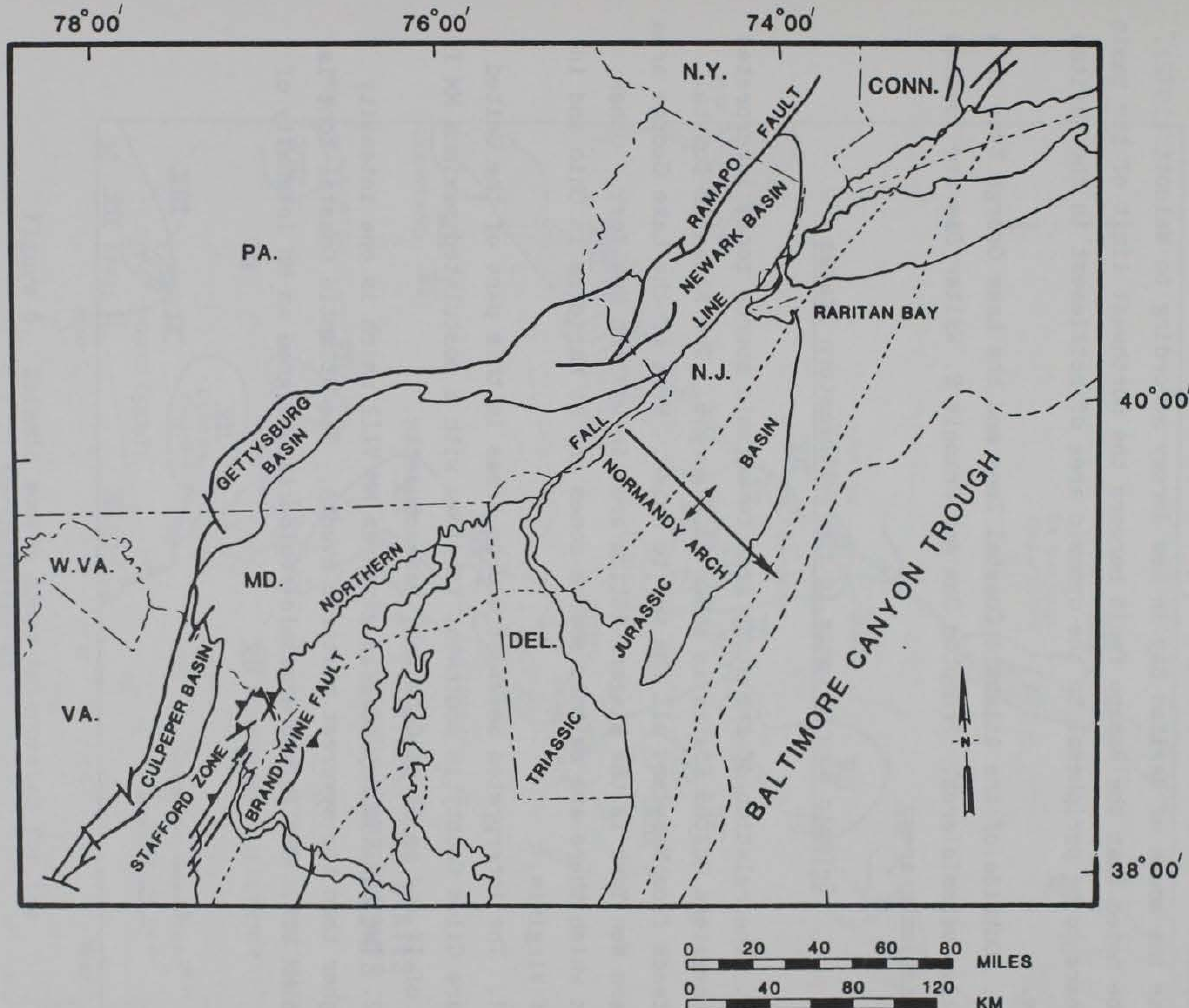

Figure 5. Map of Raritan Embayment and surrounding region showing location of early Mesozoic basins, oceanic fracture zones, and select geologic features (from Wentworth and Mergner-Keefer, 1983)

seismic activity within the broad coastal band that has been indicated. The Mesozoic basins have a southeast to northwest trend. At Raritan Bay, an area of coastal settlement conducts the Hudson River through an estuary to the sea. The embayment in this area is subsiding according to tidal gauge measurements made near the mouth of Raritan Bay in New Jersey according to Walcott (1972). It may be noted that the Ramapo fault borders the northwest limit of the basin and appears to be peripheral to the dynamic area of settlement in the Raritan Bay zone.

19. Outside of the Atlantic Coastal Zone and the Lake George Zone is a relatively aseismic area. Prompton Dam and Francis E. Walter Dam are located in this aseismic area.

Seismic Source Zones in the Northeastern States

20. The relation of the study area to seismic source zones interpreted for northeastern United States is shown in Figure 6. The Atlantic Coastal Zone extends from Maryland all the way to Maine. West of the Lake George area in eastern New York is the Niagara-Attica area in western New York. Other areas in which there are seismic source zones are at Marietta in Ohio and in parts of Virginia.

21. The interpreted severest source areas in this part of the United States are Giles County in southwest Virginia with a postulated maximum MM Intensity of IX and an IX at Cape Ann, Massachusetts.

22. The Raritan Bay zone is given an MM VIII which is one intensity unit higher than the severest historic events. The Atlantic Coastal Zone is given an MM VII. The inland aseismic region is assigned an MM Intensity of VI.

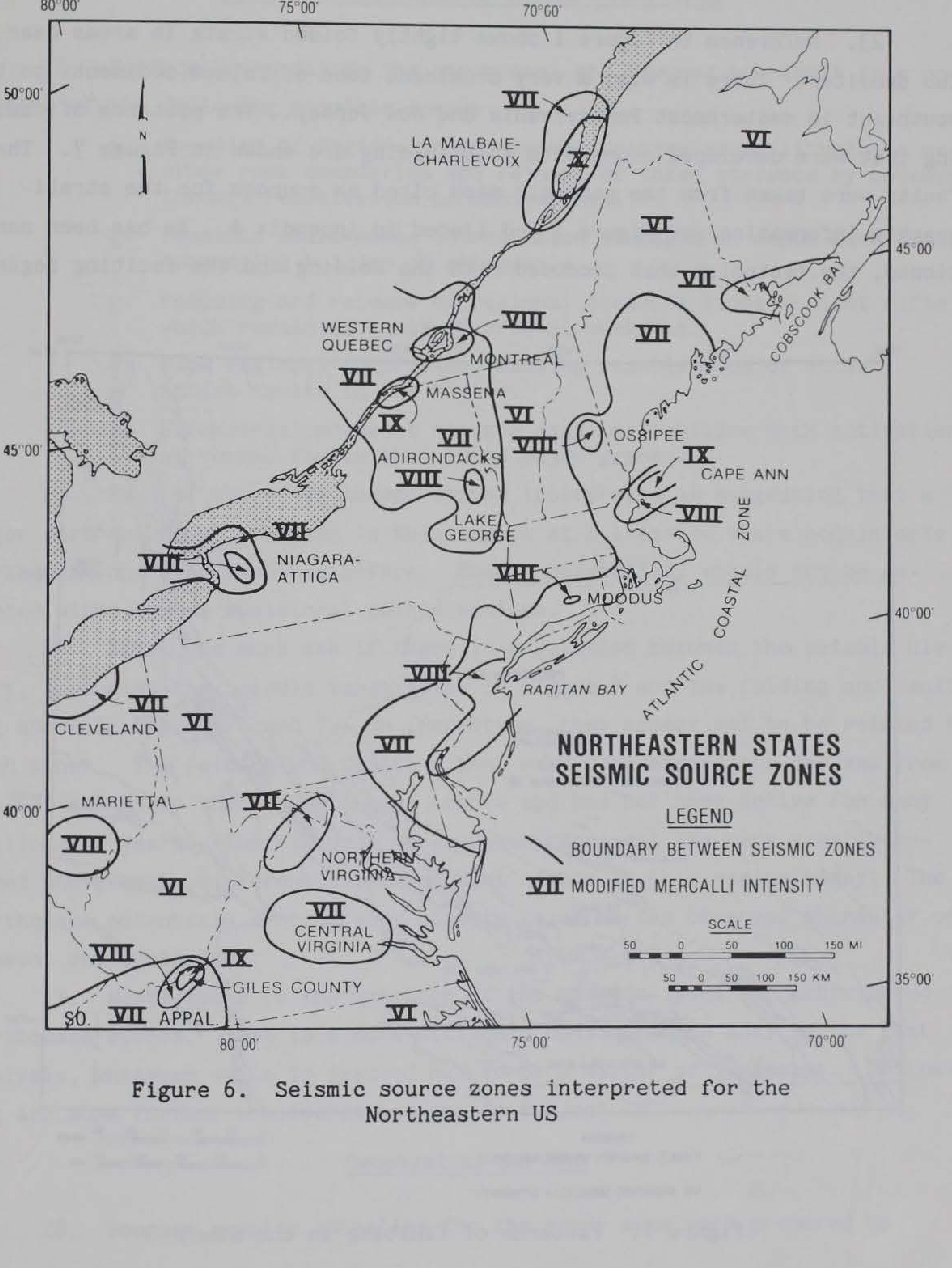

Figure 6. Seismic source zones interpreted for the Northeastern US

PART III: RELATION OF EARTHQUAKES TO GEOLOGIC STRUCTURE

General

23. Reference to Figure 1 shows tightly folded strata in areas near the two damsites. There is also a very prominent zone of folded sediments to the southeast in easternmost Pennsylvania and New Jersey. The patterns of faulting that were developed along with this folding are shown in Figure 7. These faults were taken from the geologic maps cited as sources for the stratigraphic information for Figure 1 and listed in Appendix A. As has been mentioned, the tectonism that produced both the folding and the faulting began at

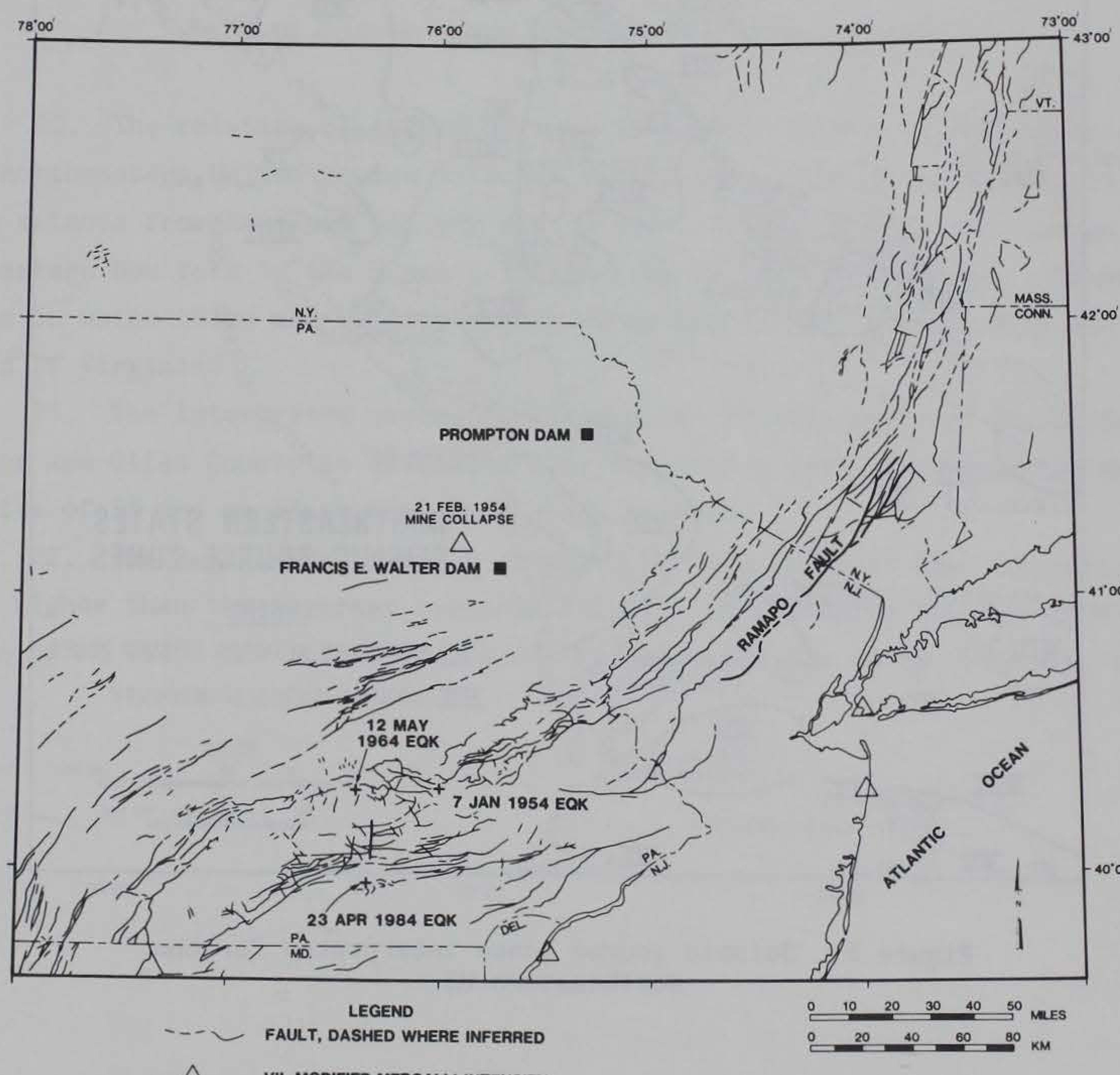

Figure 7. Patterns of faulting in the study

the end of the Palezoic and was active during the Mesozoic until about 100 million years ago.

Causes of Earthquakes in the Study Area

24. Earthquakes today in the study area are assumed to result from one or more of the following possible causes:

- a. Focusing of regional compressive stresses along lithologic or other rock boundaries and release of these stresses by movement through reactivation of ancient faults.
- b. Possible small-scale introduction of magma at depth with an accompanying buildup of stresses.
- c. Focusing and release of regional stresses along ancient rifts which remain as zones of crustal weakness.
- d. Slow regional compression causing reactivation of ancient thrust faults in the region.
- e. Extensional movement along a sagging coastline with activation of normal faults that bound major grabens.

25. Each of these hypotheses can be interpreted as suggesting that a major earthquake could happen in this region at a location where no historic earthquake has ever happened before. Such a possibility should not be accepted without some additional considerations.

26. First, we must ask if there is a relation between the seismic history, including the seismic zones shown in Figure 4 and the folding and faulting shown in Figures 1 and 7. On inspection, they appear not to be related to each other. The folding and faulting that have been mapped are derived from ancient tectonism that is no longer active and has not been active for many millions of years. The historic earthquakes represent the very greatly reduced and greatly different tectonism that occurs in this region today. The earthquake potentials must be very closely keyed to the observed character of present day tectonism.

27. Next, there is the question of the maximum level for anticipated earthquake events. That is a more difficult consideration and, in the last analysis, whatever value is assumed has to be a matter of judgement. Following are some further considerations on the subject.

Geophysical Surveys

28. Bouguer gravity anomalies for the study area were prepared by

Hildreth (1979) and are shown in Figure 8. Magnetic anomalies for the study area are from Zietz, Gilbert, and Kirby (1980) and are shown in Figure 9. In both figures, the seismic source zones interpreted for this study have been added. Also shown in the geophysical maps are the Ramapo Fault and the location of the 23 April 1984 Pennsylvania earthquake.

29. Both the gravity and the magnetic anomalies reflect the patterns of the folded strata and the associated faulting. The magnetic anomalies are indicative of deep seated lithologic features, and the gravity contours reflect

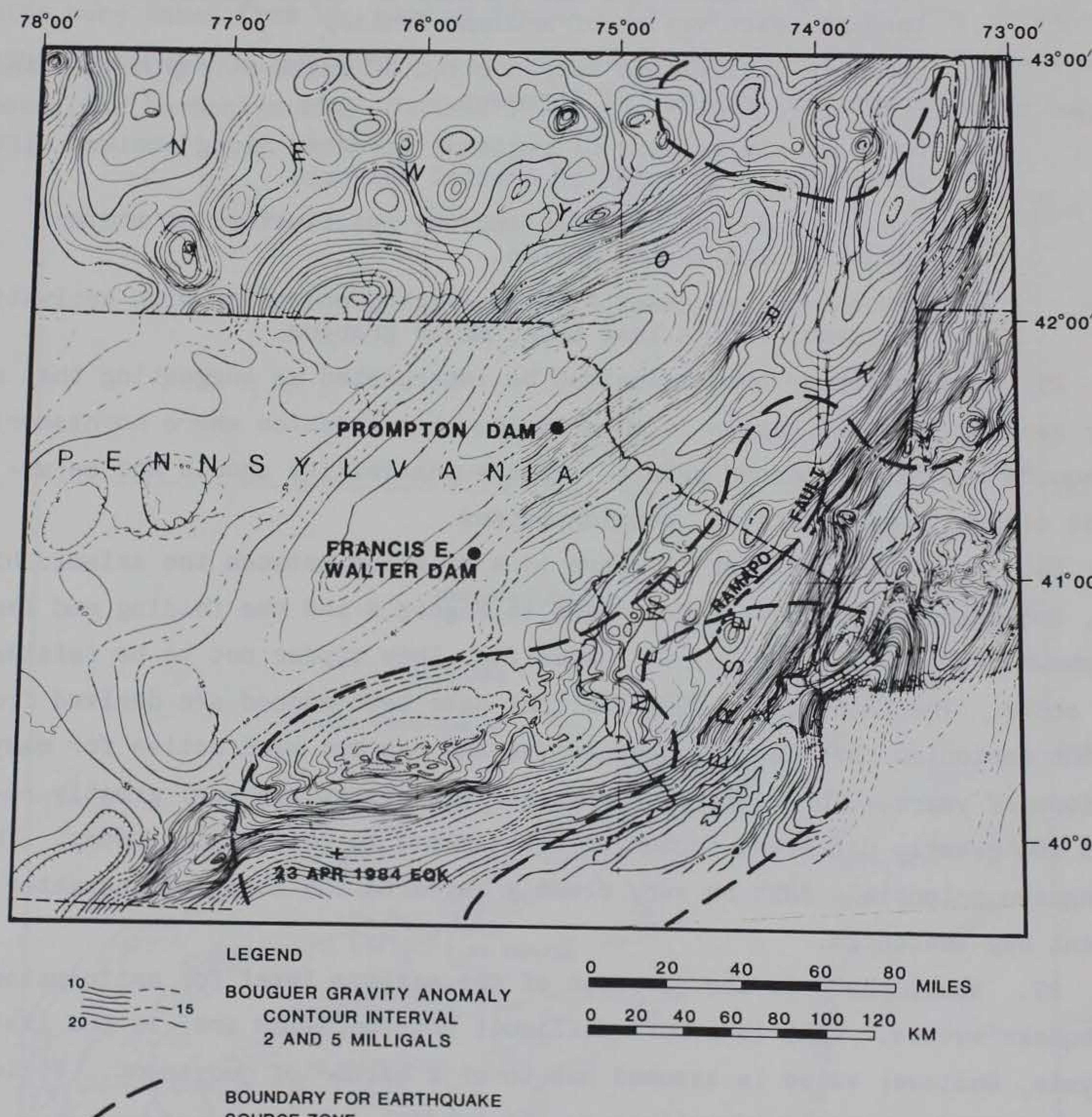

Figure 8. Bouguer gravity anomalies in the study area with boundaries for earthquake source zones (Gravity contours from Hildreth, 1979)

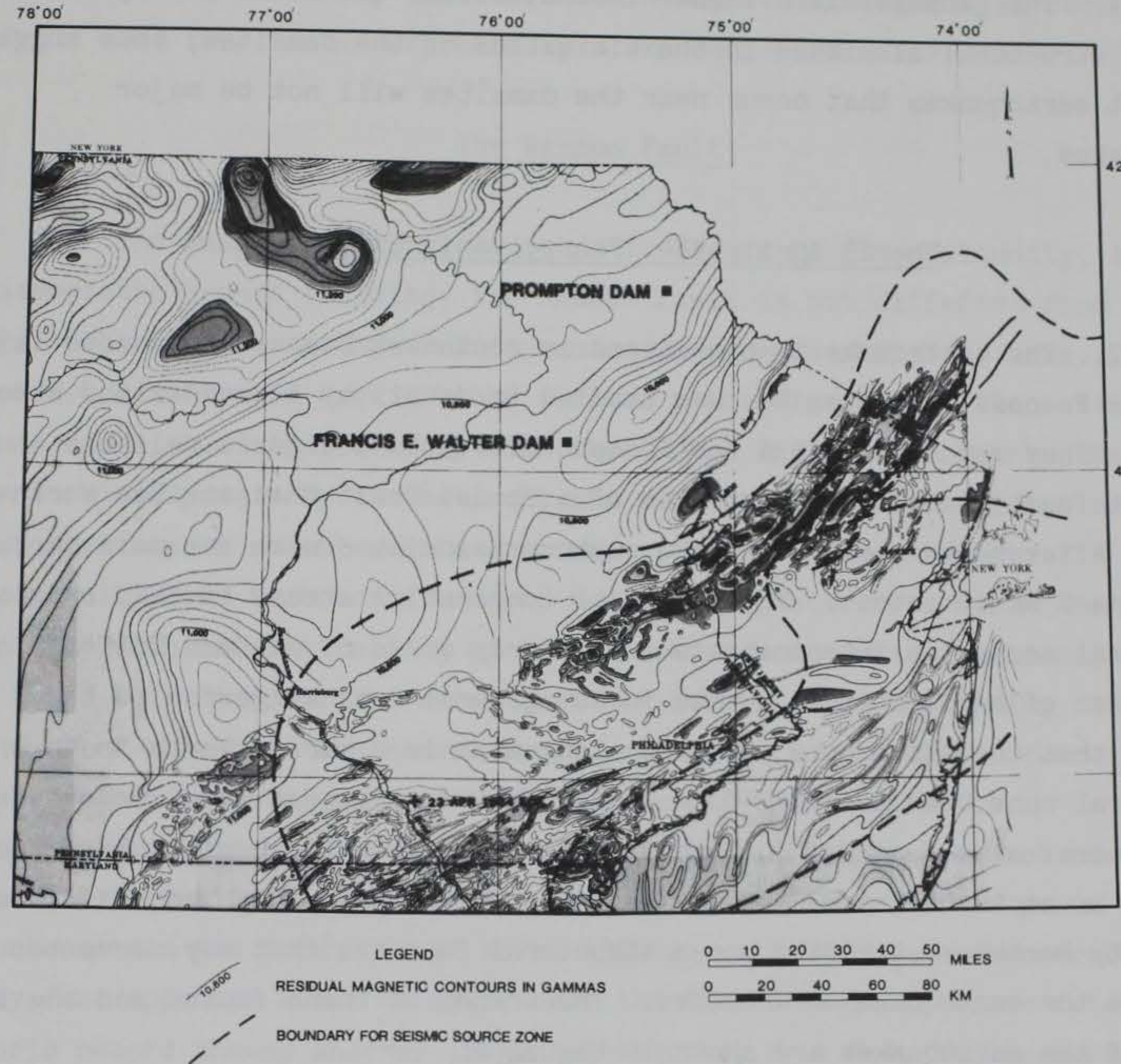

Figure 9. Magnetic anomalies in the study area with boundaries for earthquake source zones (Magnetic anamolies from Zietz, 1980)

the effects of shallower crustal layering. Both confirm that the Prompton Dam and the Francis E. Walter Dam do not have any significant crustal anomaly in the subsurface at or near their sites.

30. The relation of the geophysical anomalies to the seismic source zones is more ambiguous. The Atlantic Coastal Zone takes in a belt of tightly folded strata with corresponding geophysical characteristics, but the zone is not inclusive of all of the folded belt. In addition the zone extends into the much less deformed area near the Francis E. Walter Dam. The Raritan Bay area also takes in a mixture of structural effects. These associations confirm that the levels of present day tectonism cannot be defined by the boundaries of the ancient tectonic features.

31. The geophysical evidence indicates that there are no major or notable structural blemishes in the vicinities of the damsites, thus suggesting that earthquakes that occur near the damsites will not be major earthquakes.

The 23 April 1984, Pennsylvania Earthquake

32. The earthquake that occurred in southeast Pennsylvania about 130 km from the Francis E. Walter Dam was studied in detail by Alexander and Stockar (1984). They reported that a focal depth of 4.5 to 5.0 km is reliable and that the focal mechanism is movement of a thrust fault that strikes North-South. Aftershocks showed that the rupture associated with the main shock was less than 2 km in extent. The principal compressive stress is ENE, consistent with focal mechanism interpretations in nearby areas of eastern United States. Relocation of earlier small events in the general area suggested to the authors that the earthquake occurred along what is a narrow North-South cross structural zone that is over 40 km in length. The largest event recorded in this general area occurred on 12 May 1964 near a Triassic basin border fault some 40 km north of the 23 April 1984 event. The North-South zone is intersected by Northeast-trending cross structural features that may serve to localize the earthquake occurrences. The trends of these faults and the locations of the earthquakes are shown in Figure 7.

33. The above interpretations by Alexander and Stockar (1984) are subject to several cautions. Their use of several earthquakes which occurred over a period of 20 years to define a fault zone 40 km in length may carry a totally erroneous connotation that this length of fault can rupture at one time. If a rupture 40 km in length were to occur, it would generate a more powerful earthquake than has ever happened in this part of the United States. If there were any potential for such a major earthquake along the cited fault trend, there should be some evidence that shows the trend behaving as a seismic hot spot. Such evidence could be intense microearthquake activity along the trend of the fault zone, as it does at New Madrid, Missouri, or a pocket of continuous seismic excitation, as is the case near Charleston, South Carolina. Either would be indicative of a potential for a larger earthquake. Some historic large earthquakes, as have occurred at New Madrid and Charleston, would be even more compelling evidence. The absence of such

evidence makes it extremely unlikely that a major earthquake will occur along the fault zone that was interpreted by Alexander and Stockar.

The Ramapo Fault

34. The Ramapo Fault may be noted in Figure 7. In continuity, length, and associated branch faulting, the Ramapo fault is not different from any of several other faults in the vicinity and elsewhere in the study area. Earthquakes are distributed over a broad coastal belt (Figure 2). The earthquakes are not associated significantly with the Ramapo fault. The events that do occur in close proximity to the fault are very small, MM Intensities of II and III, but with some nearby events that are as large as MM Intensity V. The Ramapo fault seems to bound a zone of possible magmatic intrusions which are associated with intense folding of the Paleozoic sedimentary section (Figures 8 and 9). It should be noted that the belt of intense folding extends much further than does the Ramapo fault and, in fact, there are other intensely folded belts with comparable geophysical characteristics.

35. What, then, is special about the Ramapo fault? A branch of the Ramapo fault lies in close proximity to the Indian Point nuclear power plant in southeastern New York. On 11 March 1976 a small earthquake occurred in New Jersey (see Appendix B for details) near the Ramapo fault. A look into the historic record showed another larger earthquake, $M_L = 4.4$, had occurred near the fault at a location in New York on 3 September 1951. The question was whether or not these earthquakes indicated that the Ramapo fault was an active fault. As mentioned, there are many other earthquakes and numerous other major faults. However, none of those are near a nuclear power plant, and the nuclear power plant is only about 30 km from New York City. As a result, the Ramapo fault has been studied in far greater detail than any other fault in this region, or along the entire East Coast for that matter. Also, conclusions that can be drawn concerning activity of the Ramapo fault are instructive for the entire study area.

36. A major investigation of the Ramapo fault was made by Dames and Moore (1977). Their objective was to determine the nature and character of the youngest movement on the Ramapo fault and to establish whether or not the fault is, at present, capable of generating earthquakes of concern to engineering. The study included detailed studies performed under the following headings:

a. Geomorphology

b. Fault mapping

c. Seismic history

d. Petrography

e. Magnetometer profiles

f. Aeromagnetism

g. Bathymetry of the Hudson River

h. Radiometric age dating

i. In situ stress measurements

37. Trenching was done in the northern portion of the Ramapo fault in New York state. Oriented rock samples were taken along shear planes within the fault zone. Figure 10 is a representative illustration which shows the appearance of shear planes associated with the Ramapo fault and shows how samples were taken. These samples were sliced into petrographic thin sections and were observed using a petrographic microscope. The objective was to determine if there was any evidence of recent fault movement. Secondary mineralizations were recognized. They were analyzed to determine when these minerals were deposited, if they have been disturbed at any time since they

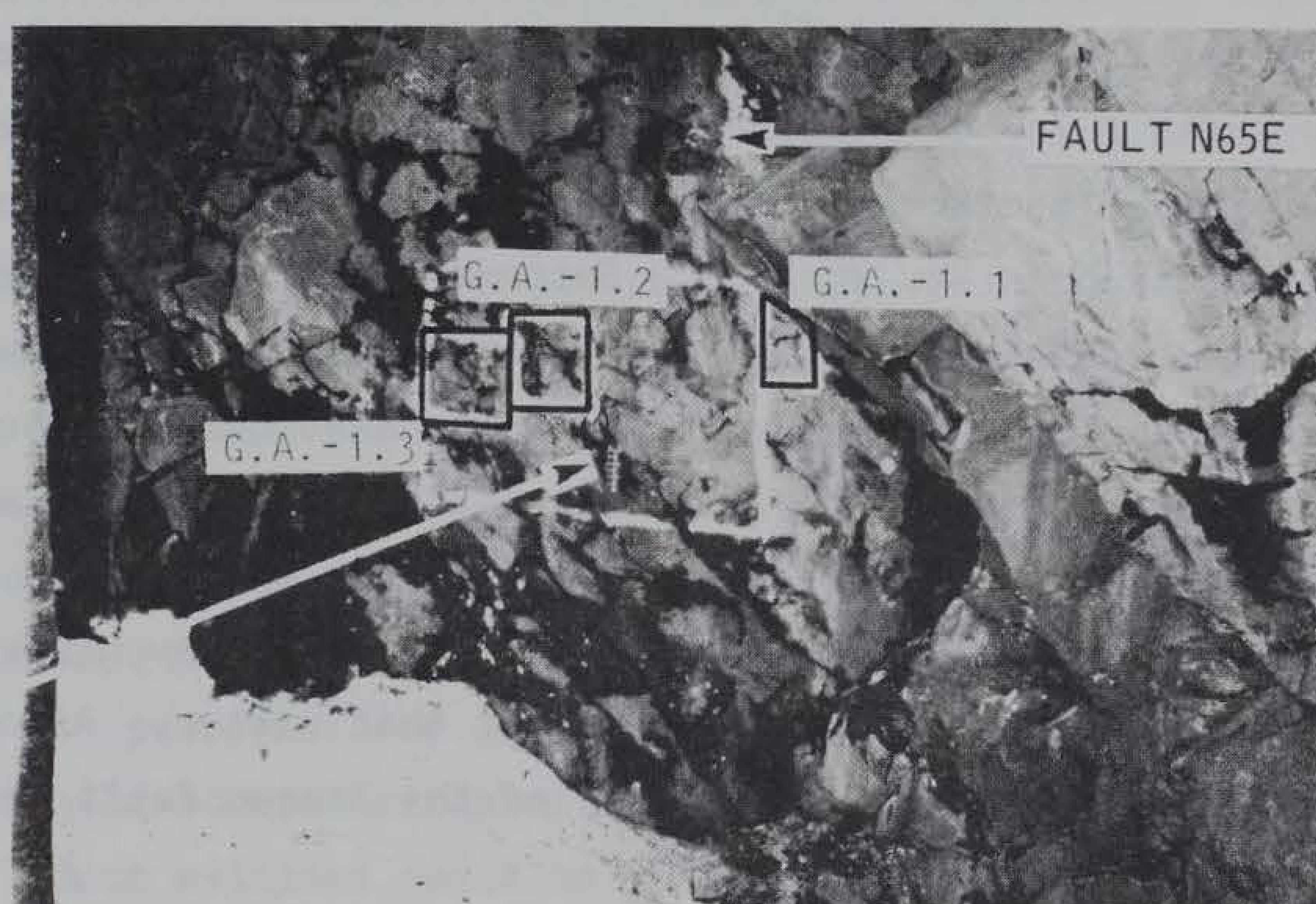

Figure 10. Fault planes revealed in trenching across the Ramapo fault zone near its northern end in New York (Rectangles show the positions where oriented, undisturbed samples were taken for petrographic analysis) (from Dames and Moore, 1977)

were deposited, and what can we tell about subsequent reactivation of movement along the fault plane. The petrographic studies were brilliantly successful in providing answers to all three of these questions.

38. In Figure 10, it may be noted that there are small open spaces or vugs along the shear planes. A vug may result from selective solution by ground water after the shear plane has formed. It may be the result also of heterogeneous materials being torn by the shearing process with the production of small cavities. It is likely that the vugs which occur here result from some combination of these processes.

39. Figure 11 shows the appearance in thin section of calcite crystals that were generated within a vug. The crystals are both euhedral, meaning they have their own normal faces that developed by growth into a free space, and are massed as they have grown to fill the space that was available. Twinning is noted in calcite resulting from the last period of crystal growth. Thus the deposition of the calcite occurred progressively through a period of time which cannot be specified but is more than just recent. Calcite is susceptible to deformation and would show physical movement by slippage and distortion of its crystals. In this case no movement has occurred.

40. Figure 12 shows undisturbed calcite crystals with euhedral forms. The shear planes, shown as striped lines, bound the void in which the crystals grew. The country rock shows deformation. These relationships indicate that no movement has occurred since the crystals were grown, and it may be inferred that no movement has occurred since the Ramapo fault moved last, probably in Triassic time. Certainly there has been no recent movement.

41. The same relationships between fault trace, deformed country rock, and various states of calcite crystals can be seen in Figure 13. Additionally, there are secondary crystals of the mineral stilbite present. Stilbite is a zeolite which is produced by crystallization from vapors given off by intrusions of molten rock, or magma, at great depth. The last such intrusion is believed to have occurred during Cretaceous time, about 100 million years ago. All of the secondary minerals are undeformed. Thus, it is inferred that no reactivation of the Ramapo fault has occurred since that distant period of geologic time.

42. For today, the mineralogical evidence confirms that the Ramapo fault is a dead fault and is not capable of generating earthquakes of concern to engineering. The latter is taken as at least a Richter magnitude 6.

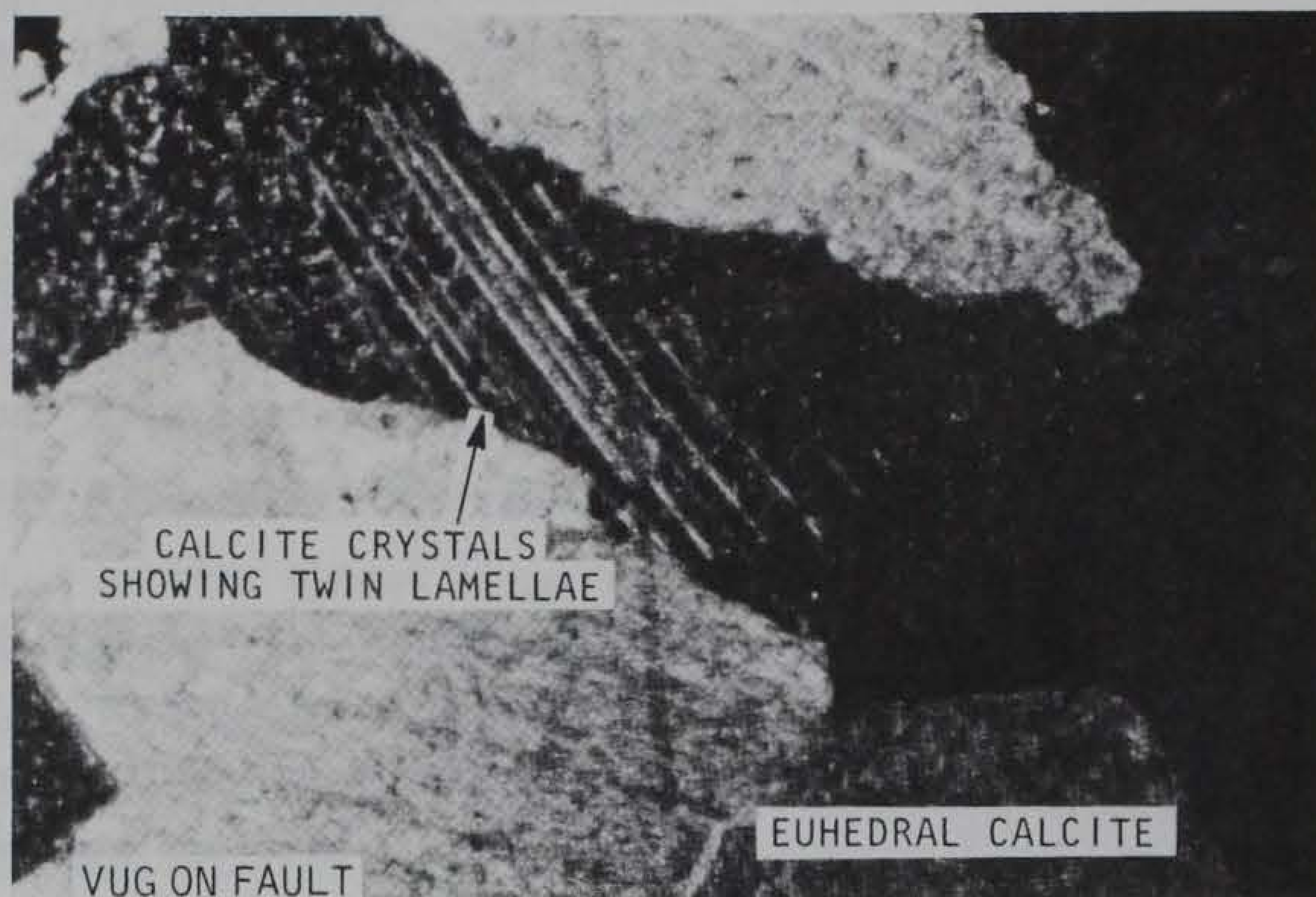

Figure 11. Petrographic thin section of secondary minerals in a vug on a plane of the Ramapo fault (calcite crystals are undisturbed) (from Dames and Moore, 1977)

Figure 12. Petrographic thin section of secondary minerals along shear planes (striped lines) of the Ramapo fault (calcite crystals show undeformed growth) (from Dames and Moore, 1977)

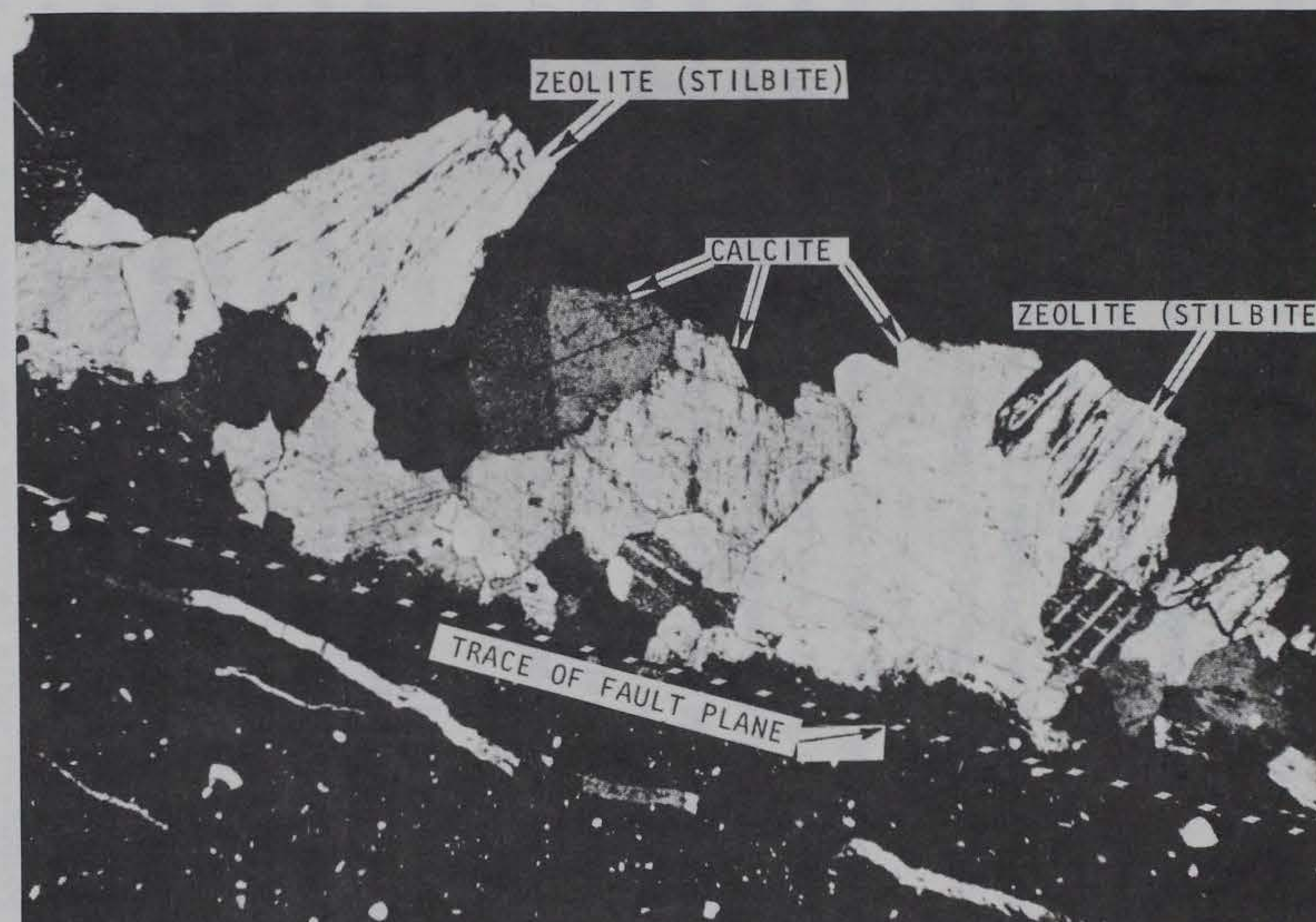

Figure 13. Petrographic thin section of secondary minerals along a shear plane (striped line) of the Ramapo fault (the calcite and zeolite crystals are interrelated and are both undeformed by movement) (from Dames and Moore, 1977)

43. Radiometric age dating minerals, mostly of the stilbite in these fault zones, were made. They also confirm that the faults have not been disturbed since the minerals were deposited. Their ages range from 73.3 ± 5.1 million years to 2.1 ± 0.5 million years. Because it has an open crystallographic structure and is subject to the effects of cation exchange, stilbite is susceptible to argon leakage and potassium concentration, features that produce anomalously young ages. The youngest age is probably the 73 million years that was measured.

44. A survey of the proglacial Lake Hudson's former shoreline in the Hudson River valley indicates that the shoreline is uniformly upwarped to the north at the rate of 4.17 ft/mile. This dimension is in accord with postglacial regional uplift and local rebound in this general area. Where the shoreline crosses fault zones, no offsets were noted in the elevations of the shorelines.

45. It was confirmed that the distribution of earthquake epicenters in the vicinity of the Ramapo fault is irregular and shows no significant concentration of earthquakes over the mapped extent of the fault. No earthquake was specifically associated with the fault. Further, the fault has never shown any displacement that can be identified to be in association with any historic earthquake. Fault plane solutions for earthquakes near the fault zone show ranges that vary widely from the pattern of the fault. It was concluded that correlation between individual focal mechanisms and fault geometry is inconclusive at best.

46. The conclusion is that the Ramapo fault zone shows no evidence of fault movement and is not capable of generating earthquakes that are of concern to engineering.

47. Shortly after the above study was completed, Aggarwal and Sykes (1978) published a paper to the effect that their studies of the seismic data showed that the Ramapo fault is indeed an active fault and that it is the most active of the faults in the northeast-southeast trend of the folded belt that the Ramapo fault bounds.

48. If the Ramapo fault is as active as Aggarwal and Sykes claimed, they did not give it a very high potential. They indicated an MM Intensity of VII with a recurrence time between 300 and 2,240 years, and an MM Intensity of VIII with a recurrence of 1,050 to 7,080 years. They indicated that the historic record was too short to establish an upper bound for the potential

earthquakes. The activity of the fault is inferred from taking the felt reports of earthquakes going back to 1793 and relating all events within the general vicinities of the fault to the fault itself. The inexactness of epicentral locating of historic felt earthquakes was taken as a basis for relocating the earthquakes to the Ramapo fault. In addition, Aggarwal and Sykes felt that the focal plane solutions for small earthquakes have a uniformity of pattern that argues for a continuity in the mechanism along the length of the Ramapo fault. More recently Yang and Aggarwal (1981) have shown that additional focal plane solutions for small earthquakes along the Ramapo fault show a unity in the mechanism of faulting and an inferred behavior that we may associate with that of the fault. Along the eastern margin of the Appalachians, earthquakes are generated by the reactivation of the older existing faults. The maximum compressive stress trends W to WNW and appears to be localized where little or no metamorphic or igneous activity postdating the youngest faulting has occurred. Apparently, unfaulted igneous intrusives inhibit rather than facilitate the occurrence of earthquakes. A largely aseismic area extends from the central fold belt in central Pennsylvania through the Catskill region of southern New York. That area is the interior aseismic area west of the Atlantic Coastal Zone designated in this study.

The 7 June 1974, Wappingers Fall, New York, Earthquake

49. In Appendix B an earthquake of 7 June 1974 with a magnitude of 3.3 and an Intensity of VI is shown. This earthquake occurred at Wappingers Falls, New York, and was studied intensively by Pomeroy, Simpson, and Sbar (1976). The location of this earthquake is seen as the MM VI event between the two forks of the Ramapo fault in New York.

50. Pomeroy, Simpson, and Sbar assigned an MM V to the event. Regardless, the earthquake had a radius of perceptibility of only 10 km. The high intensity and rapid fall off is presumed to be associated with a very shallow focal depth. Microearthquakes were monitored after the event. These recorded focal depths from 0 to 1-1/2 km. A composite fault plane solution derived from the microearthquakes supports a north-northeast trending compression. The authors interpreted the Wappingers Falls, New York, earthquake as related to quarrying operations in the presence of high horizontal compressive stresses. Quarrying, which began in the 1900's, is continuing today and is

expanding. The product is a crushed Wappinger group dolomitic limestone and limestone which is used as a concrete aggregate and as a base course for road construction. The aftershocks are clustered in an area of 1 km^2 in the same area that has been most recently quarried. The quarry is about 50 m deep.

51. The above mechanism of surficial stress release may account as well for other historic earthquakes along the Ramapo fault and in the Atlantic Coastal Zone. The mechanism has a potential for causing other earthquakes, but these will be low energy events and of no concern to engineering. Also, they are not indicative of any potential for the occurrence of larger earthquakes. Specifically, they do not have the focal depth necessary for the buildup of stresses that when relieved would produce a substantial earthquake.

Imagery

52. An inspection was made of ERTS imagery for the study area. The structural grain that was recognized in the geological and geophysical mapping was observed in the imagery. Of particular interest was the appearance of faulting. The imagery showed what is called a "dead" look, meaning there was no evidence of recent activation of faults.

Summary

53. In the study area there are wide bands of intensely folded sedimentary rocks and intervening areas where deformation was not pronounced. The folding was accompanied by major faults. These were produced at the end of the Paleozoic and were reactivated in the Triassic. There was also some igneous intrusion at depth during the Cretaceous. There have been no major tectonic effects, other than uplift and erosion, since the Cretaceous or about 100 million years ago.

54. The damsites are in areas that were relatively undisturbed by the intense folding and the igneous intrusions that were cited. There is no major faulting, ancient or otherwise, near the dams.

55. Historic earthquakes occur in a broad belt paralleling the Atlantic coast. This belt cuts across the trends of folds and faults and extends into some of the relatively undeformed tectonism. The latter does not coincide with ancient tectonism.

56. The Ramapo fault has been intensively studied. These studies were made because the fault is near the Indian Point Nuclear Power Plant, not because the fault is unique in any way. The fault is like many others in the zones of tight folding. The studies of the Ramapo fault show that it has not moved at least since Cretaceous time and show no capability for generating earthquakes of concern to engineering. One of the earthquakes felt along the Ramapo fault is believed to be from unloading by quarrying operations. The maximum earthquakes that have been postulated for the Ramapo fault are of MM Intensities VII or VIII.

57. Study of a 23 April 1984 earthquake in the folded belt of Pennsylvania has been interpreted as part of a 40 km North-South cross fault. However, there is no evidence that this North-South trend can be activated to produce anything more than minor earthquakes such as have already occurred.

PART IV: SEISMIC ZONES AND FLOATING EARTHQUAKES

58. Seismic zone boundaries based on the historic seismicity are shown in Figures 4, 6, 8, and 9. These boundaries include, but are independent of, the ancient tectonism of this region. The historic seismicity defines the present-day tectonism. Since there is no evidence of recent fault movement, and there are no seismic "hot spots" (a hot spot is where a major earthquake, M=6.0 or greater, has occurred, or where intense lesser seismicity is occurring), it was concluded that no major earthquake is to be expected anywhere in this region. To be expected are randomly occurring earthquakes of about the sizes of those which already have occurred.

59. Figure 14 shows the earthquake zones with interpreted maximum earthquakes. These are floating earthquakes, meaning that each earthquake should be moved everywhere over its respective zone. The maximum intensity is, in each case, either the historic maximum intensity or one unit higher than the maximum historic intensity. Thus in the Raritan Bay area, the MM=VIII was assigned as a conservative measure because three intensity VII's were recorded. The Richter magnitude (M) equivalents are interpreted for the intensities since no magnitudes of any of the levels shown have ever been recorded.

60. The values for floating maximum earthquakes in the study area are:

Area	MM Intensity	Richter Magnitude (M)
Zone 1	VI	5.0
Lake George Zone	VII	5.5
Atlantic Coastal Zone	VII	5.5
Raritan Bay Area	VIII	6.0

61. In addition, values are shown for Niagara-Attica sources in northwest New York state. These areas are designated in Figure 6. They are 250 km or more from the damsites and are therefore less likely to affect the dams than are the nearer sources for which there is comparable severity.

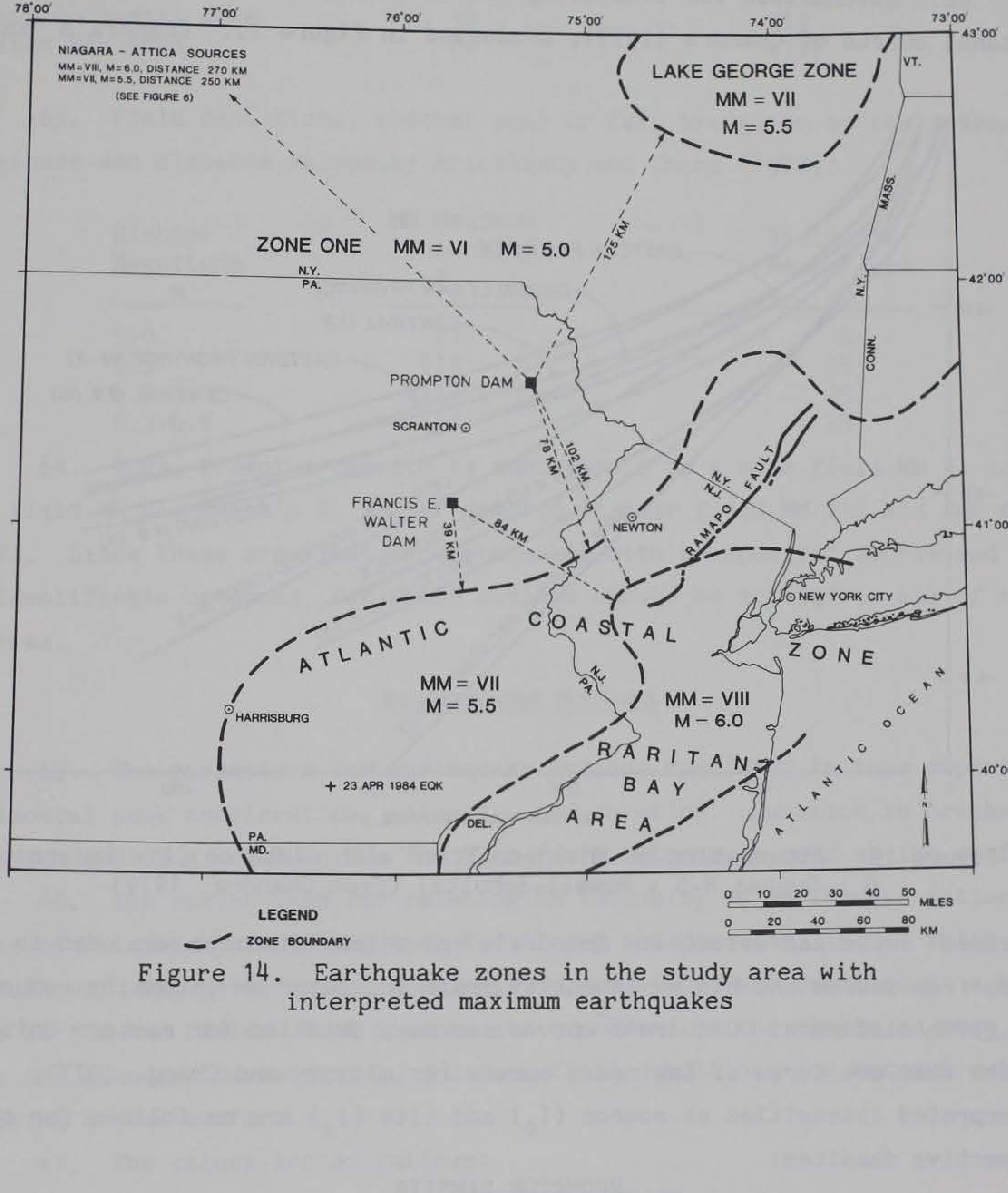

Figure 14. Earthquake zones in the study area with interpreted maximum earthquakes

PART V: EARTHQUAKE MOTIONS AT THE DAMSITES

62. Attenuation for this study uses the intensity versus epicentral distance charts of Chandra (1979), presented in Figure 15. Chandra's "Eastern

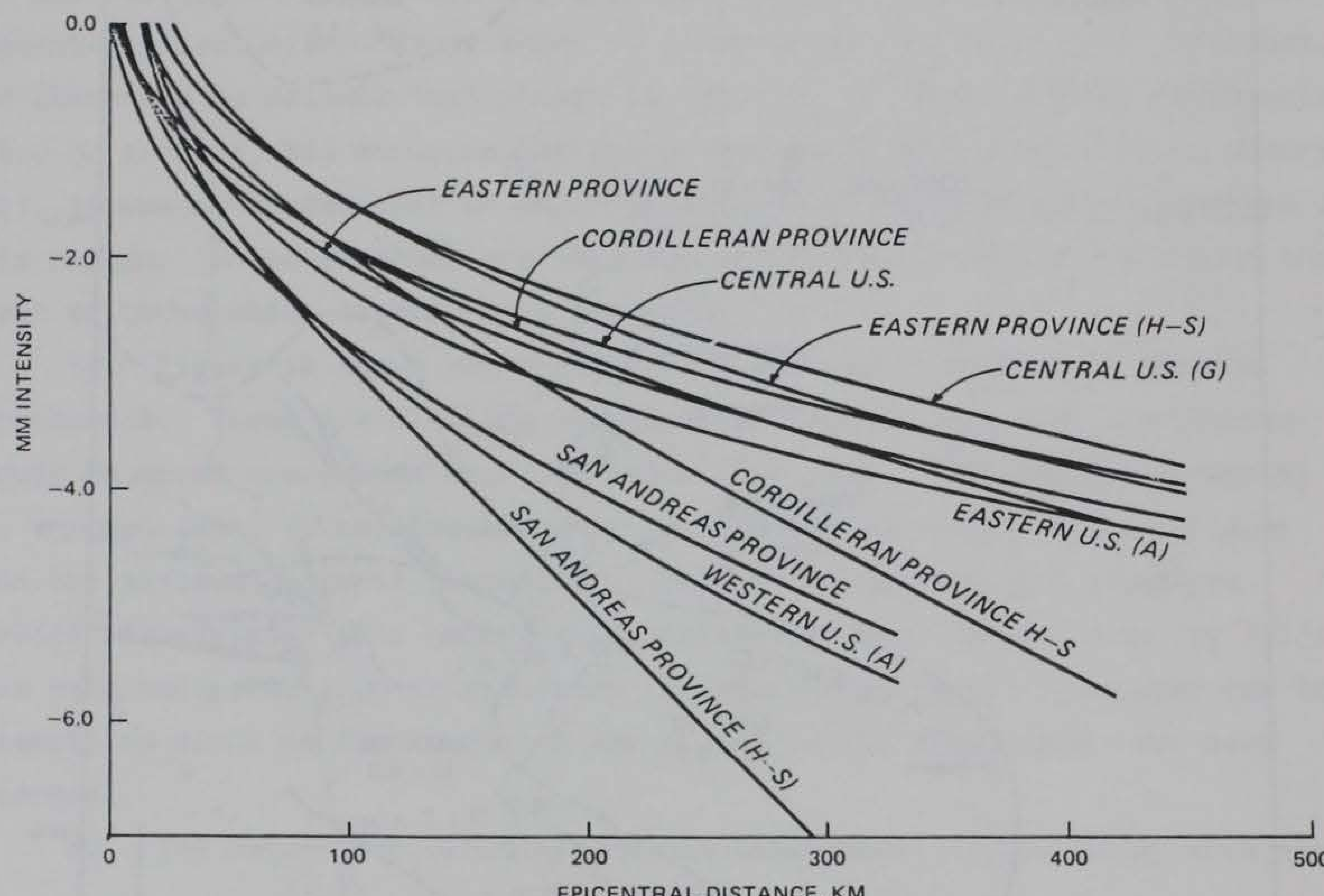

Figure 15. Attenuation of MM Intensities with distance (A = Anderson; G = Gupta; H-S = Howell-Schultz) (from Chandra, 1979)

Province" curve was selected. Chandra's epicentral distance was used as distance from source and his MM Intensity scale indicated MM Intensity reductions for given distances. Chandra's curves are more detailed for eastern United States than are Corps of Engineers curves (Krinitzsky and Chang, 1977). Interpreted intensities at source (I_o) and site (I_s) are as follows for the respective damsites:

PROMPTON DAMSITE

Source	Distance km	MM I_o	MM I_s
Zone 1	--	VI	VI
Atlantic Coastal Zone	78	VII	V
Raritan Bay Area	102	VIII	VI

(Continued)

FRANCIS E. WALTER DAMSITE

Source	Distance km	MM I_o	MM I_s
Atlantic Coastal Zone	39	VII	VI
Raritan Bay Area	84	VIII	VI

63. Field conditions, whether near or far, are given by the following magnitude and distance values by Krinitzsky and Chang (1977):

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

64. Thus, Prompton damsite is susceptible to a near field MM VI and a far field MM VI; Francis E. Walter damsite is near field MM VII and far field MM VI. Since these are floating earthquakes with no specific source and with no identifiable hotspots, far field motions should be applied to all of the sources.

Recommended Motions

65. The parameters for earthquake motions specified in this report are horizontal peak acceleration, velocity, and duration. Duration is bracketed duration $\geq$ 0.05 g. Values are for free-field motions on rock at the surface.

66. The curves used for relating MM Intensity to earthquake motions are those of Krinitzsky and Chang (see Krinitzsky and Marcuson, 1983), which are as follows: Figure 16 is for acceleration, velocity, and duration at a hard site in the far field. Peak motions are expressed in the charts as mean, mean plus one standard deviation(σ), and free-field conditions for bedrock outcropping at the surface.

67. The values are as follows:

PROMPTON DAMSITE

			Acceleration g	Velocity cm/sec	Duration 0.05g sec
Far Field	VI	Mean	0.07	4	2
		Mean + σ	0.12	7	3
		Mean + 2σ	0.14	9	6

(Continued)

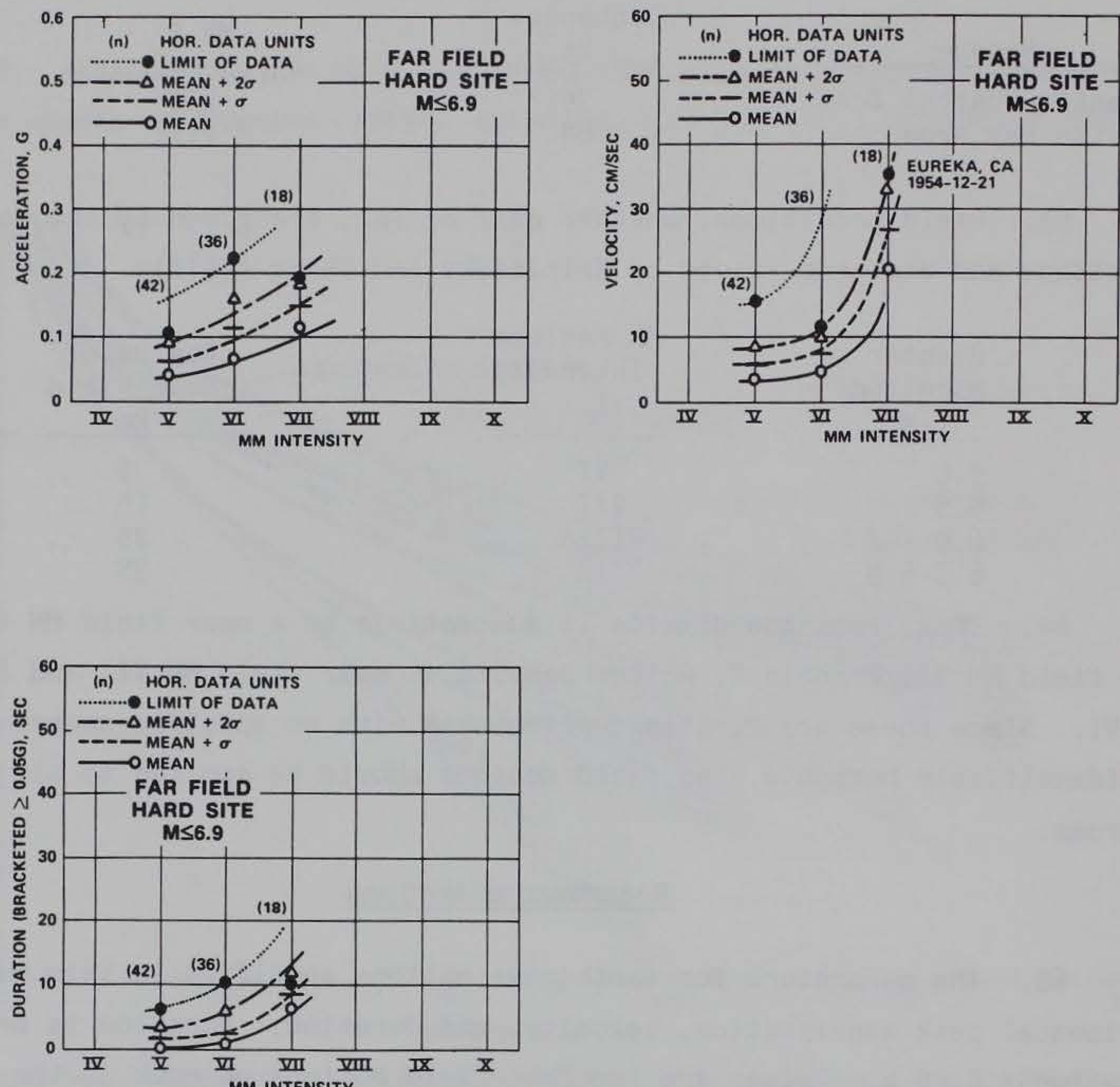

Figure 16. Krinitzsky-Chang charts for acceleration, velocity, and duration versus MM Intensity: far field, hard site (from Krinitzsky and Marcuson, 1983)

FRANCIS E. WALTER DAMSITE

			Acceleration g	Velocity cm/sec	Duration 0.05g sec
Far Field	VI	Mean	0.07	4	2
		Mean + σ	0.12	7	3
		Mean + 2σ	0.14	9	6

68. Peak motions that are recommended in this investigation are the far field values for mean + σ, or 84 percentile, should a time history be used in an analysis that will allow the embankment to undergo linear and nonlinear response. The level of motions (whether mean, mean + σ, or other) needs to be considered further where the design input is to be for appurtenant structures.

Recommended Accelerograms

69. Two accelerograms are recommended for the Francis E. Walter and Prompton Damsites as follows:

Far Field MM VI

(1) L166, N 00°E component

164.2 cm/sec^2, acceleration

12.3 cm/sec, velocity (scale to 7 cm/sec)

5.4 sec, duration

31 km, distance

(2) P221, N 87°W component

165.0 cm/sec^2, acceleration

6.7 cm/sec, velocity

5.8 sec, duration

43 km, distance

70. The accelerograms, velocity response spectra, and quadripartite response spectra for the above time histories are contained in Appendix C. They are from the California Institute of Technology (1971-1975) catalogue of uniformly processed motions.

71. The records require either no scaling or scaling as indicated. The actual distances of the records, source to site, are not those that are specified. Records for the specified distances and with the same attenuations do not exist. However, the recommended records represent the specified motions and are close enough to their sources to provide proper field conditions.

72. The records that are recommended are by no means the only records that may be used, but they are presented as appropriate accelerograms. If a single most appropriate record is to be specified, P221 is recommended.

Comparison of Motions with Those for Nuclear Power Plants in the Study Area

73. Table 1 and its corresponding figure (Figure 17) show the locations of nuclear power plants in the study area and values for the accelerations assigned to the safe shutdown earthquakes (SSE's) and the operating basis earthquakes (OBE's).

74. The OBE's represent an engineering decision based on cost-risk considerations where there are no hazards involved. Thus, the OBE's have no equivalents to values in this report. In practice, the OBE is about half the acceleration value for the SSE. If an OBE is desired for the Prompton and Francis E. Walter damsites, it may be obtained by taking half of the recommended values for accelerations.

75. The SSE's are the mean values for accelerations and are equivalent to the mean values specified for Prompton and Francis E. Walter damsites. However, the values must be compared for the same zones for which the motions are specified and for equivalent distances from other sources outside of the zones. The accelerations assigned at Prompton and Francis E. Walter damsites are for a less sensitive seismic area than that for the nuclear power plants except for Susquehanna 1 and 2 as compared below.

Nuclear Power Plant	SSE
Indian Point	0.15g
Limerick	0.15
Peach Bottom	0.12
Susquehanna	0.10
Three Mile Island	0.12

The acceleration derived in this report for the Prompton and Francis E. Walter sites is 0.12g, compared with 0.10 for Susquehanna. Considering that the values were derived by different methods, and at different times over the past decade, they agree reasonably well.

Recurrence of Earthquake Motions

76. For the purposes of this report, the rate of recurrence was not used. A deterministic method was followed whereby the assigned earthquakes were determined for the sources regardless of time. These earthquakes are the

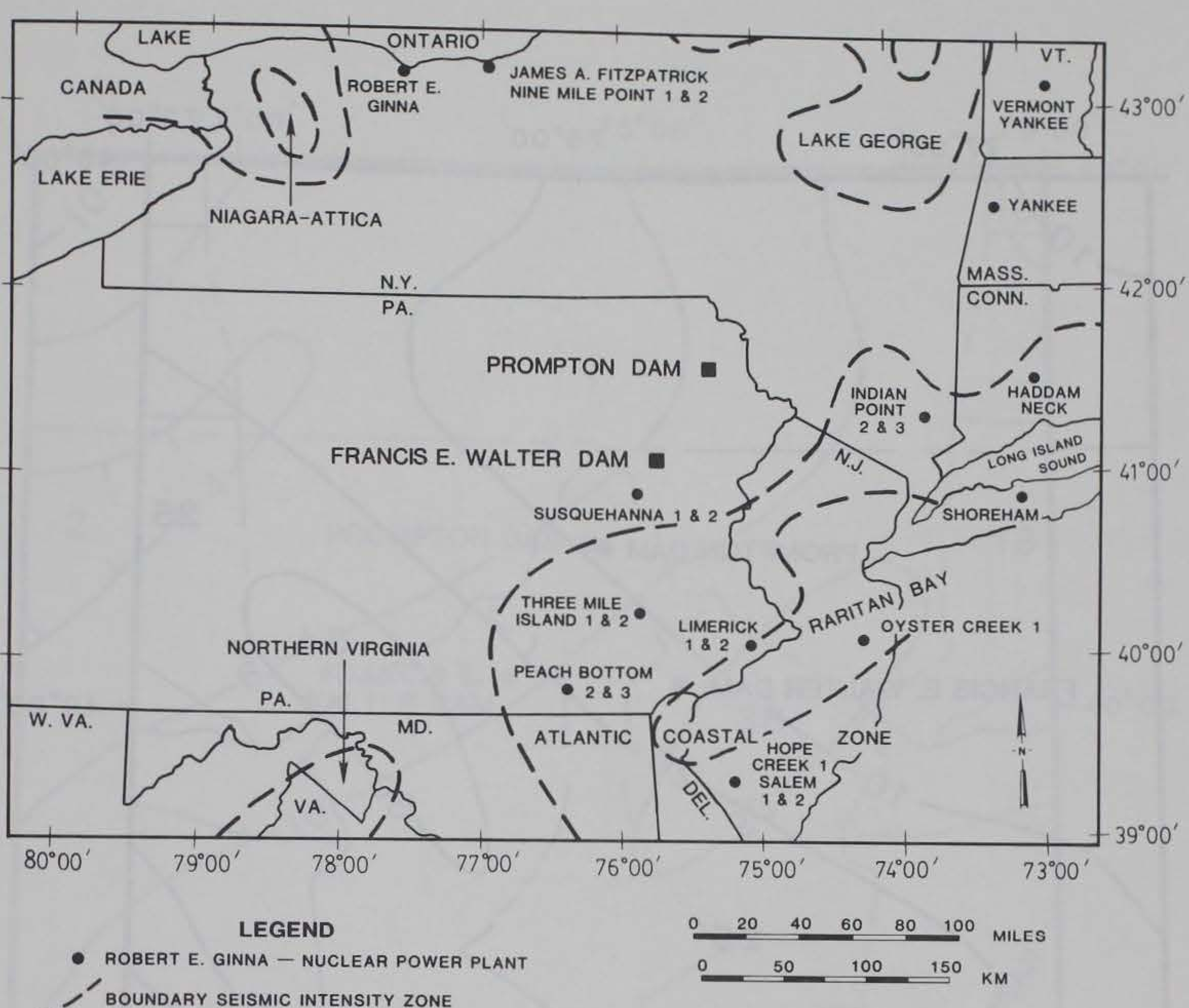

Figure 17. Locations of nuclear power plants and their design accelerations

severest that can be reasonably expected to occur. Since there can be no certainty as to when they will occur, the dams must be designed in anticipation.

77. A comparison can be made with recurrence estimated for this area. Probabilistic values were calculated for acceleration and velocity by Algermissen et al. (1982). These are shown in Figures 18 and 19, respectively. First, one must note that Algermissen takes an area which includes the Ramapo fault as a major source zone. We believe, as has been shown, that this is erroneous. But its effect is conservative. It gives a value of 0.54g mean acceleration, in an area where our mean acceleration is 0.13g, and a velocity of 38 cm/sec, where our velocity is 10 cm/sec. At the damsites, Algermissen's accelerations are about 0.1g, and the velocities are about 8 cm/sec. These compare with our range of mean accelerations of 0.07 to 0.08g and mean velocities of 4 to 7 cm/sec.

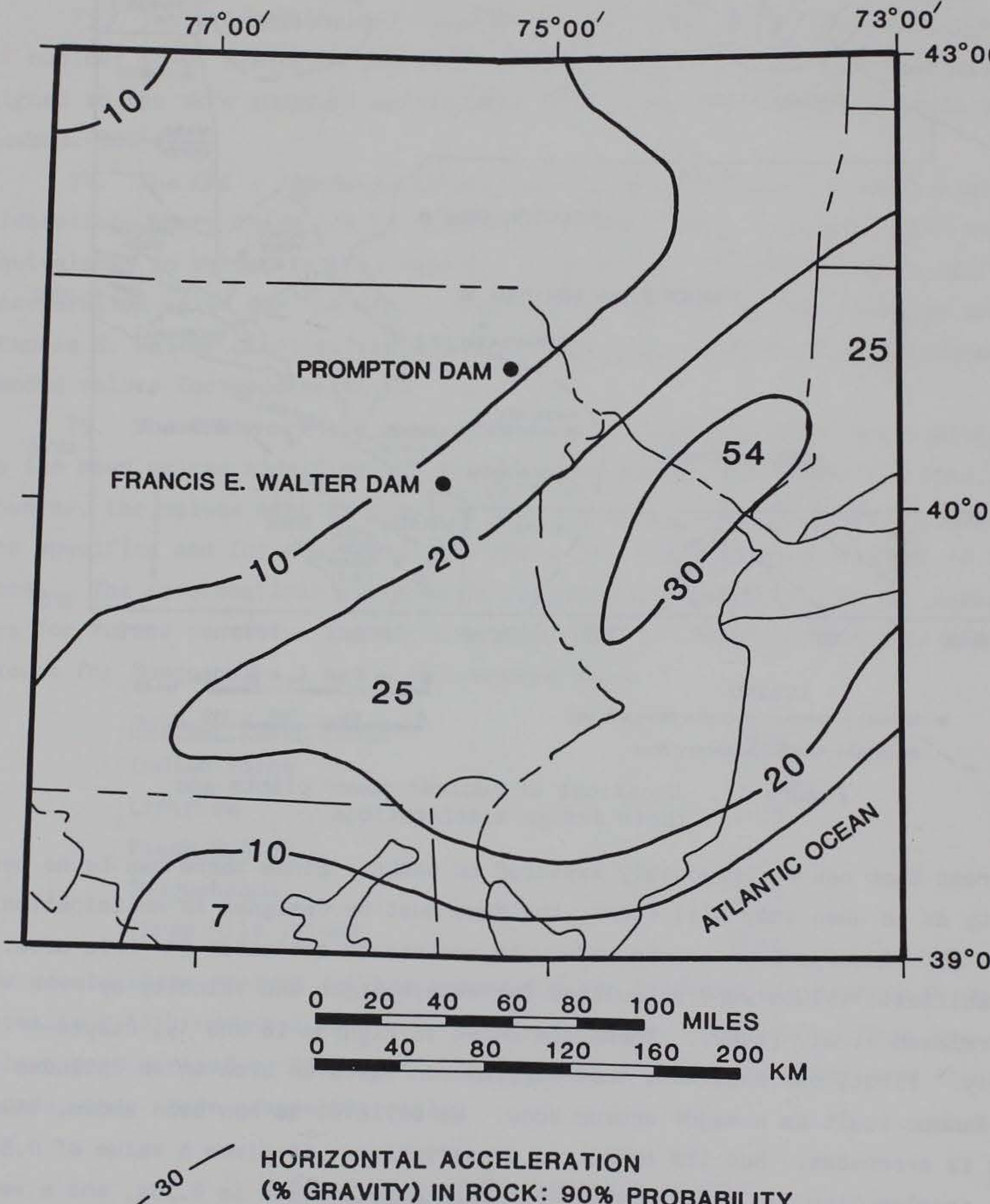

Figure 18. Mean acceleration, 90 percent probability of not being exceeded in 250 years (from Algermissen et al., 1982)

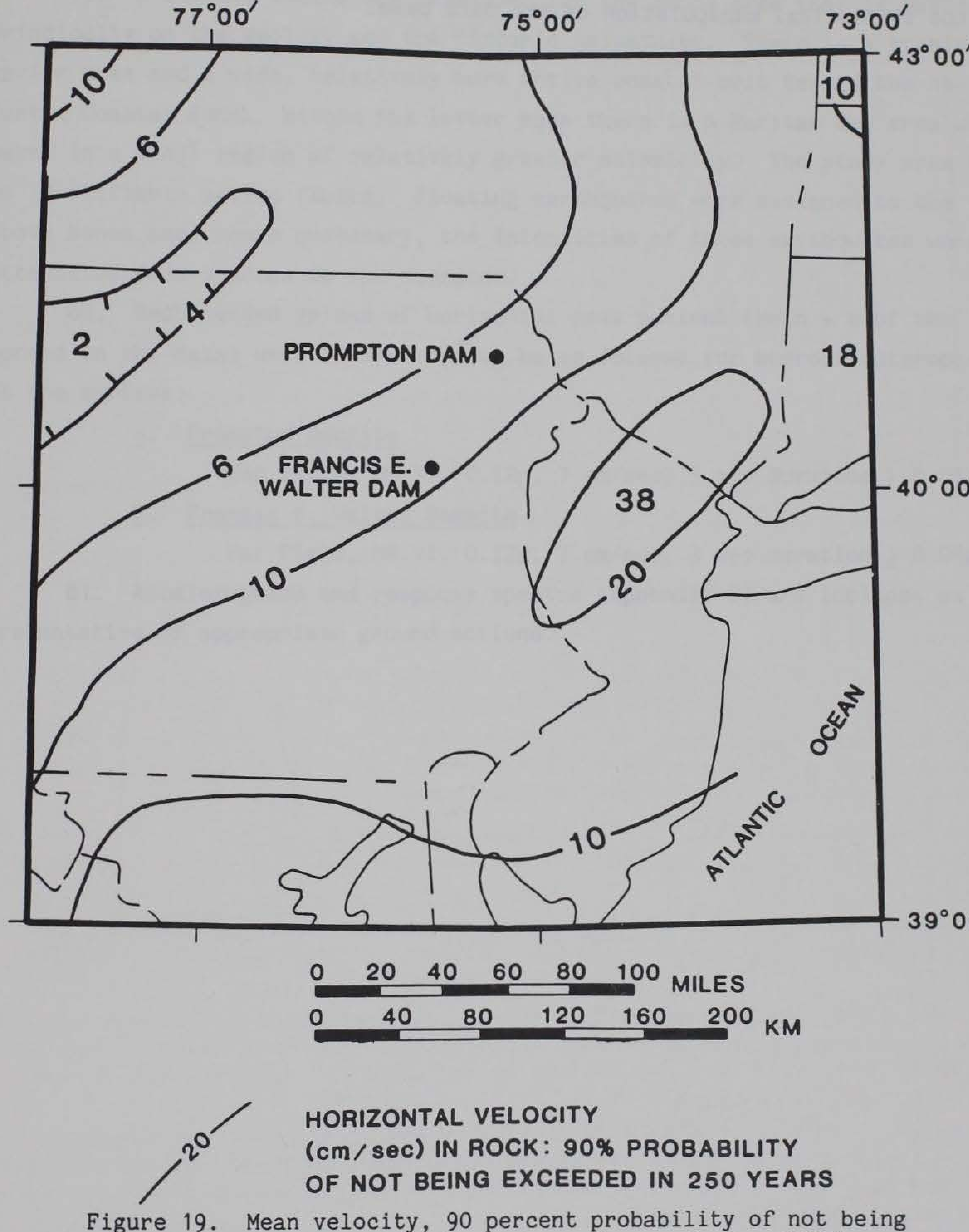

Figure 19. Mean velocity, 90 percent probability of not being exceeded in 250 years (from Algermissen et al., 1982)

78. The differences are regarded as resulting from the assumptions that are made in the probabilistic analysis and on the errors that are introduced in the statistical manipulation of the data base.

PART VI: CONCLUSIONS

79. A seismic zoning was developed for the study area that is based principally on the geology and the historic seismicity. There is a stable interior area and a wide, relatively more active coastal belt termed the Atlantic Coastal Zone. Within the latter zone there is a Raritan Bay area which takes in a small region of relatively greater seismicity. The study area has no identifiable active faults. Floating earthquakes were assigned to the above zones and, where necessary, the intensities of these earthquakes were attenuated from sources to the damsites.

80. Recommended values of horizontal peak motions (Mean + σ of the spread in the data) were interpreted to be as follows for bedrock outcropping at the surface:

a. Prompton Damsite

Far Field, MM VI, 0.12g, 7 cm/sec, 3 sec duration $\geq$ 0.05g.

b. Francis E. Walter Damsite

Far Field, MM VI, 0.12g, 7 cm/sec, 3 sec duration $\geq$ 0.05g.

81. Accelerograms and response spectra (Appendix C) are included as representative of appropriate ground motions.

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Table 1

Nuclear Power Plants in the Study Area (see Figure 18 for Locations) with Accelerations for Safe Shutdown Earthquakes and Operating Basis Earthquakes

Plant Name, Location	Date of Commercial Operation	SSE Acceleration g	OBE Acceleration g	Foundation
Haddam Neck (Haddam Neck, Conn.)	1-68	0.17	0.09	Bedrock
Hope Creek 1 (Salem, N. J.)	12-86	0.20	0.10	Soil
Indian Point 2 (Indian Point, N. Y.)	7-74	0.15	0.10	Bedrock
Indian Point 3 (Indian Point, N. Y.)	8-76	0.15	0.10	Bedrock
James A. Fitzpatrick (Scriba, N. Y.)	7-75	0.15	0.08	Soil
Limerick 1 (Pottstown, PA.)	4-85	0.15	0.075	Bedrock
Limerick 2 (Pottstown, PA.)	10-87	0.15	0.075	Bedrock
Nine Mile Point 1 (Scriba, N. Y.)	12-69	0.15	0.08	Bedrock
Nine Mile Point 2 (Scriba, N. Y.)	10-86	0.15	0.08	Bedrock
Oyster Creek 1 (Forked River, N. J.)	12-69	0.22	0.11	Soil
Peach Bottom 2 (Peach Bottom, PA.)	7-74	0.12	0.05	Bedrock
Peach Bottom 3 (Peach Bottom, PA.)	12-74	0.12	0.05	Bedrock
Robert E. Ginna (Ontario, N. Y.)	3-70	0.20	0.08	Soil
Salem 1 (Salem, N. J.)	6-77	0.20	0.10	Soil
Salem 2 (Salem, N. J.)	10-81	0.20	0.10	Soil
Shoreham (Brookhaven, N. Y.)	3-83	0.20	0.10	Soil
Susquehanna 1 (Berwick, PA.)	5-83	0.10	0.05	Soil
Susquehanna 2 (Berwick, PA.)	Late 84	0.10	0.05	Soil

(Continued)

Table 1 (Concluded)

Plant Name, Location	Date of Commercial Operation	SSE Acceleration g	OBE Acceleration g	Foundation
Three Mile Island (Londonderry TWP., PA.)	9-74	0.12	0.06	Soil
Three Mile Island (Londonderry TWP., PA.)	12-78	0.12	0.06	Soil
Vermont Yankee (Vernon, VT.)	11-72	0.14	0.07	Bedrock
Yankee (Rowe, Mass.)	6-61	0.15	--	Soil

APPENDIX A

STRATIGRAPHIC SECTIONS TO ACCOMPANY FIGURE 1

New Jersey

Quaternary

Surface covering of variable thickness, generally unconsolidated.

Glacial

Note. A sheet of stony or sandy clay of variable thickness (till, unstratified drift, or boulder clay) covers much of the surface north of the terminal moraine, but is not represented on the map.

Terminal Moraines of the last (Wisconsin) glacial epoch

Qtm — A belt of irregular hummocky accumulations of clay, sand, gravel, and boulders, in confused mixture.

Recessional Moraine (Wisconsin)

Qrm — Smaller moranic accumulations north of the terminal moraine, including some stratified drift of kamelike habit, and marking pauses in the recession of the last ice sheet.

(Unconformity)

Devonian

Skunnemunk Conglomerate

Dsk — Coarse white quartz pebbles in purple-red matrix with frequent beds of red sandstone.

Bellvale Sandstone and Pequanac Shale

Dbp — Gray sandstone and sandy shale (Bellvale) overlying dark slaty shale.

Marcellus Shale and Onondaga Limestone

Dmo — Fissile black shale overlying thin-bedded cherty limestone.

Esopus Grit

Des — Dark coarse sandstone with strong cleavage.

Oriskany and Becraft Limestones (including Port Ewen beds)

Dob — Siliceous Oriskany limestone with sandstone coming in southward, separated from the gray cherty Becraft limestone below by a formation (presumably Port Ewen shale) which is everywhere concealed by heavy glacial drift.

New Scotland, Stormville and Coeymans Formations

Dnc — Hard cherty limestone and limy shale (New Scotland) overlying light-gray limestone (Coeymans) and separated southward by a thin sandy bed (Stormville).

(Continued)

Silurian

Late Silurian Formations

Sbd — Including, from the top downward, (Northwestern area) dark thin-bedded limestone (Manlius), earthly shale and limestone (Roundout), thin beds of limestone and shale, becoming sandy southward (Decker), banded bluish-gray limestone (Bossardville), and buff or greenish limy shale.

High Falls Formation

Shf — Hard red sandstone and soft red shale, the latter more abundant near the top.

Shawangunk Conglomerate

Ssg — Conglomerate of white quartz pebbles in hard bluish matrix, red toward the top, with beds of coarse hard sandstone.

Green Pond Conglomerate

Sgp — Conglomerate of white quartz pebbles in hard reddish-brown matrix, with beds of coarse hard sandstone.

(Unconformity)

Ordovician

Martinsburg Shale
("Hudson River")

Omb — Black slaty shale (roofing slate in places) with thin beds of sandstone (flagstone), especially in upper parts.

(Unconformity)

Jacksonburg Limestone ("Trenton")

Ojb — Black or dark blue limestone often with limestone conglomerate at the base and limy shale ("cement rock") at the top.

(Unconformity)

Cambro-Ordovician

"Kittatinny" Limestone

Upper - Thin and thick, gray or blue cherty magnesian limestone (Beekmantown); unconformity.

εOk — Middle - Light and dark, medium bedded limestones with cryptozoon heads (Upper Cambrian); unconformity.

Lower - Massive blue, blue-gray limestone with yellowish or silvery shale.

Cambrian

E — Hardyston Sandstone

Variable hard sandstone usually containing feldspar; local beds of conglomerate and slate.

(Continued)

(Unconformity)

Pre-Cambrian-Metamorphic

Franklin Limestone

fl Coarse white marble, magnesian in part, containing graphite, chrondodite, pyrozene, and other minerals. Contains zinc ores in Sussex County.

Pre-Cambrian

Granite

gr Coarse-grained, rudely foliated hornblende granite, rich in zircon, titanite, and allanite.

Gabbro

Including hypersthene gabbro and norite.

Losee Gneiss

lgn White granitoid gneiss composed of oligoclase, quartz, and occasionally orthoclase, pyroxene, hornblende, and biotite.

Byram Gneiss

bgn Gray granitoid gneiss composed of microcline, microperthite, quartz, hornblende or pyroxene, and sometimes mica.

Metamorphic Rocks of Unknown Origin

Wissahickon Mica Gneiss

A banded quartz-feldspar rock with an excess of biotite.

Pochuck Gneiss

pgn Dark granular gneiss composed of pyroxene, hornblende, oligoclase, and magnetite. Probably igneous in part.

Unknown

Formation not determined

fnd Drift cover thick and continuous; bed rock unknown.

New York

Upper Devonian

Java and West Falls Groups

Djws Slide Mountain Formation - red shale, sandstone, conglomerate.
Djwh upper Katsberg Formation - red shale, sandstone, conglomerate.
Djwm middle West Falls Group - shale, siltstone, sandstone (Wellsburg?).
Djwl lower West Falls Group - shale, siltstone, sandstone (Cayuta?).

(Continued)

Sonyea Group

Ds Cashaqua Shale, replaced eastwardly by Enfield Formation - shale, siltstone, sandstone; Middlesex Shale.

Dsu upper Sonyea Group - shale, siltstone, sandstone.

Dsk Kattel Formation - shale, siltstone, sandstone.

Dsd lower Katsberg Formation - sandstone, red shale, siltstone.

Dss Stony Clove Formation - sandstone, conglomerate, shale.

Genesee Group and Tully Limestone

Dg West River Shale; Genundewa Limestone: Penn Yan and Geneseo Shales; all except Geneseo replaced eastwardly by Ithaca Formation-shale, siltstone and Sherburne Sandstone.

Dgo Oneonta Formation - red shale, sandstone.

Dgu Unadilla, Laurens, New Lisbon and Gilboa Formations - shale, siltstone, sandstone.

Dgk Oneonta Formation - red shale, sandstone; Kaaterskill Sandstone.

Middle Devonian

Hamilton Group

Dh undifferentiated Hamilton Group - shale, siltstone, includes Schunemunk Formation - sandstone, conglomerate and Bellvale Formation - shale, sandstone in eastern Orange County.

Lower Devonian

Onondaga Limestone and Ulster Group

Dou Onondaga Limestone; Schoharie Formation - shale, limestone, sandstone; Esopus Shale.

Helderberg Group

Dhg West of Albany: Alsen, Becraft, New Scotland, Kalkberg, Coeymans and Manlius Limestones; Rondout Dolomite.
South of Albany: Port Ewen, Alsen thru Manlius Limestones.

Upper Silurian

Srh Rondout Formation - dolomite, limestone; Decker Ferry Limestone; Binnewater Sandstone; High Falls Shale.

Middle Silurian

Shawangunk Formation

Ssk Sandstone, conglomerate.

Middle Ordovician

Trenton Group (black shales)

Osh Snake Hill Shale.

(Continued)

Trenton Group - Taconic Area

On — Normanskill Formation; Austin Glen Member - gray-wacke, black and gray shales; Mount Merino Member - black shale and chert; Indian River Member - red and green slate.

Upper Cambrian and Lower Ordovician

Stockbridge Group

Oεs — Undifferentiated carbonates.

Lower Cambrian

Lower Cambrian Carbonates and Quartzites

El — Stissing Limestone. In Vermont: Winooski, Mallett and Dunham Dolomites; Monkton quartzite.

Pre-Cambrian

am — Hornblende gneiss, amphibolite, pyroxenic amphibolite, biotite granitic gneiss, migmatite, subordinate calc-silicate rock.

bhg — Biotite hornblende granite.

hg — Hornblende granite and granitic gneiss, with subordinate leucogranite.

mb — Calcitic and dolomitic marble, variably siliceous; in part with calc-silicate rock and amphibolite.

qpg — Quartz plagioclase gneiss; may contain pyroxene, hornblende, biotite; locally interlayered with amphibolite.

qtcs — Non-rusty paragneiss; includes garnet-biotite-quartz-feldspar gneiss, quartzite, quartz-feldspar gneiss, calc-silicate rock.

Pennsylvania

Pennsylvanian

Pottsville Group

Pp — Predominantly sandstones and conglomerates with thin shales and coals; some coals mineable locally.

Anthracite Region

Post-Pottsville Formations

Ppp — Brown or gray sandstones and shales with some conglomerate and numerous mineable coals.

Pottsville Group

Pp — Light gray to white, coarse grained sandstones and conglomerates with some mineable coal.

(Continued)

Mississippian

Mauch Chunk Formation

Mmc — Red shales with brown to greenish gray flaggy sandstones; includes limestone.

Pocono Group

Mp — Predominantly gray, hard, massive, cross-bedded conglomerate and sandstone with some shale.

Upper Devonian

Catskill Formation

Dck — Chiefly red to brownish shales and sandstones; includes gray and greenish sandstone tongues.

Marine beds

Dm — Gray to olive brown shales, graywackes, and sandstones.

Susquehanna Group

Ds — Shales and sandstones.

Middle and Lower Devonian

Mahantango Formation

Dh (Dho) — Brown to olive shale with interbedded sandstones which are dominant in places, highly fissiliferous in upper part.

Marcellus Formation

Black, fissile, carbonaceous shale with thick, brown sandstone.

Onondaga Formation

Don (Dho) — Greenish blue, thin bedded shale and dark blue to black, medium bedded limestone with shale predominant in most places.

Oriskany Formation

Doh — White to brown, fine to coarse grained, partly calcareous, locally conglomeratic, fossiliferous sandstone.

Helderberg Formation

Doh — Dark gray, calcareous, thin bedded shale at the top, dark gray, cherty, thin bedded, fossiliferous limestone with some local sandstones in the middle; and, at the base, dark gray, medium to thick bedded, crystalline limestone.

Silurian

Keyser Formation

Skt (Skw) — Dark gray, highly fossiliferous, thick bedded, crystalline to nodular limestone.

(Continued)

Tonoloway Formation

Skt (Skw) Gray, highly laminated, thin bedded, argillaceous limestone.

Bloomsburg Formation

Sbm Red, thin, and thick bedded shale and siltstone with local units of sandstone and thin impure limestone, some green shale.

McKenzie Formation

Sbm Greenish gray, thin bedded shale interbedded with gray, thin bedded, fossiliferous limestone; shale predominant at the base; intraformational breccia in the lower part.

Ordovician

Martinsburg Formation

Oms / Om Gray to dark gray, light gray to olive weathering shale Om with thick sandstone interbeds Oms; east of Susquehanna River contains interbedded red shale, gray to brown sandstone, and thin bedded limestone.

Chambersburg Formation

Ohm Dark gray, thin bedded limestone at the top; gray, argillaceous limestone in the middle; dark gray, cobbly and thin, irregularly bedded limestone below.

Hershey and Myerstown Formations

Hershey-Dark gray to black, thin bedded, argillaceous limestone.

Beekmantown Group

Ob Dolomite and limestone, with nodular dark cherts in irregular beds and stringers.

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APPENDIX B

HISTORIC FELT EARTHQUAKES IN EASTERN PENNSYLVANIA AND ADJACENT AREAS, 1677 to 1984 (FOR LOCATIONS OF EARTHQUAKES, SEE FIGURE 2)

Year	Date Month	Day	Origin Time (Universal) hr	min	sec	Latitude (n)	Longitude (w)	Depth (km)	Magnitude	Intensity mm	Reference	State
1677	Dec	13	--	--	--	41.1	73.5	--	--	IV	8	CT
1698	--	--	--	--	--	41.4	73.5	--	--	IV	5,8	CT
1702	--	--	--	--	--	41.4	73.5	--	--	IV	5,8	CT
1711	--	--	--	--	--	41.4	73.5	--	--	IV	5,8	CT
1729	Mar	30	--	--	--	41.4	73.5	--	--	II	8	CT
1729	Aug	06	--	--	--	41.4	73.5	--	--	IV	5	CT
1737	Dec	08	03	58	--	39.9	75.4*	--	--	IV*	77	PA
1755	Nov	27	01	00	--	40.0	75.1*	--	--	III*	66	PA
1758	Mar	23	03	30	--	40.0	75.1*	--	--	III*	77	PA
1763	Mar	22	--	--	--	39.9	75.3*	--	--	III*	66	PA
1763	Oct	30	21	15	--	40.0	75.1*	--	--	IV*	67	PA
1772	Apr	25	13	00	--	40.0	75.1*	--	--	II*	77	PA
1777	Nov	22	--	--	--	40.0	75.1*	--	--	III*	66	PA
1777	Nov	23	--	--	--	39.9	75.3*	--	--	III*	66	PA
1780	Nov	29	--	--	--	40.0	75.1*	--	--	III*	76	PA
1780	Nov	29	--	--	--	40.0	75.1*	--	--	III*	76	PA
1783	Nov	24	--	--	--	41.0	74.5	--	--	IV	33	NJ
1783	Nov	30	02	00	--	41.0	74.5	--	--	IV	30,33	NJ
1783	Nov	30	03	50	--	41.0	74.5	--	--	VI	30	NJ
1783	Nov	30	07	00	--	41.0	74.5	--	--	IV	30,33	NJ
1800	Mar	17	--	--	--	40.0	75.1*	--	--	II	67,72	PA
1800	Nov	29	--	--	--	40.0	75.1*	--	--	--	67	PA
1801	Nov	12	--	--	--	40.0	75.1*	--	--	III*	66	PA
1804	May	18	--	--	--	40.7	74.0	--	--	III	49,53	NY
1811	Dec	09	01	00	--	40.0	75.1*	--	--	III*	77	PA
1811	Dec	16	08	00	--	40.0	75.1*	--	--	III*	77	PA
1840	Jan	16	20	00	--	43.0	75.0	--	--	VI	52	NY
1840	Nov	11	--	--	--	40.0	75.1*	--	--	V	67,74	PA
1840	Nov	14	--	--	--	40.0	75.1*	--	--	--	67	PA

(Continued)

* Estimated by the US Geological Survey.

Year	Date Month	Day	Origin Time (Universal) hr	min	sec	Latitude (n)	Longitude (w)	Depth (km)	Magnitude	Intensity mm	Reference	State
1841	Jan	25	--	--	--	40.7	74.0	--	--	III	49,53	NY
1845	Oct	26	23	15	--	41.2	73.3	--	--	VI	5,7	CT
1847	Jan	12	04	30	--	42.6	73.7	--	--	II	52	NY
1855	Jan	17	--	--	--	40.8	73.6	--	--	II	49	NY
1858	Jul	01	03	45	--	41.3	73.0	--	--	V	4	CT
1861	Mar	05	17	00	--	40.7	74.2	--	--	III	30,33	NJ
1871	Oct	09	14	40	--	39.7	75.5	--	--	VII	24	NJ
1871	Oct	10	05	08	--	39.6	75.5	--	--	IV*	36	NJ
1872	Jul	11	10	25	--	40.9	73.8	--	--	V	44,49	NY
1874	Dec	11	03	25	--	40.9	73.8	--	--	V	44,49	NY
1874	Dec	13	04	--	--	41.4	73.9*	--	--	II*	47	NY
1875	Jul	28	09	10	--	41.8	73.2	--	--	V	4	CT
1875	Sep	26	02	00	--	41.3	73.3	--	--	II	5,8	CT
1877	May	11	--	--	--	42.8	73.7*	--	--	II*	47	NY
1877	May	14	--	--	--	42.8	73.9	--	--	II	49	NY
1877	Sep	10	14	59	--	40.1	74.8	--	--	IV	30	NJ
1878	Feb	05	16	20	--	40.8	73.9	--	--	V	49,53	NY
1878	Oct	04	07	30	--	41.5	74.0	--	--	V	49	NY
1878	Dec	25	02	--	--	40.8	73.8	--	--	II	49,53	NY
1878	Dec	29	02	32	--	42.7	74.3	--	--	III	49,53	NY
1880	Aug	10	17	15	--	40.8	74.5*	--	--	III*	34	NJ
1880	Sep	01	10	10	--	40.8	74.5*	--	--	III*	34	NJ
1881	Mar	19	02	30	--	42.8	73.9	--	--	III	49,53	NY
1881	Apr	21	16	30	--	40.9	73.1	--	--	III	49,53	NY
1881	Sep	25	--	--	--	42.1	76.8	--	--	II	49,53	NY
1882	Apr	02	--	--	--	42.9	74.2	--	--	II	49	NY
1882	Sep	13	--	--	--	43.0	77.7*	--	--	II*	47	NY
1884	May	31	--	--	--	40.6	75.5	--	--	V	64	PA
1884	Aug	10	19	07	--	40.6	74.0	--	--	VII	49	NY

(Continued)

* Estimated by the US Geological Survey.

Year	Date Month	Day	Origin Time (Universal) hr	min	sec	Latitude (n)	Longitude (w)	Depth (km)	Magnitude	Intensity mm	Reference	State
1884	Aug	11	--	--	--	40.6	74.0	--	--	V	52	NY
1885	Jan	04	11	06	--	41.3	73.9	--	--	III	49,53	NY
1885	Jan	15	09	10	--	40.3	76.3	--	--	III	68,70	PA
1885	Jan	31	10	05	--	41.3	73.8	--	--	III	49,53	NY
1885	Mar	09	01	--	--	40.0	76.3*	--	--	IV	70,73	PA
1886	Jan	09	21	15	--	41.9	73.1	--	--	II	8	CT
1886	Jan	25	00	04	--	41.6	73.8	--	--	IV	52	NY
1886	Feb	03	--	--	--	41.2	73.2	--	--	II	8	CT
1886	Sep	03	--	--	--	42.5	73.4	--	--	II	52	NY
1886	Sep	09	--	--	--	42.5	73.4	--	--	II	52	NY
1889	Mar	08	23	40	--	40.0	76.7	--	--	VI	74,75	PA
1893	Mar	09	05	30	--	40.6	74.0	--	--	V	49	NY
1894	Dec	17	--	--	--	42.5	73.8	--	--	IV	52	NY
1895	Sep	01	11	09	--	40.7	74.8	--	--	VI	24	NJ
1899	May	16	--	--	--	40.9	74.0	--	--	II	33	NJ
1902	Mar	10	05	--	--	39.6	77.2	--	--	III*	16	MD
1902	Mar	11	10	30	--	39.6	77.2	--	--	III*	16	MD
1902	May	27	--	--	--	40.8	74.2	--	--	II	33	NJ
1902	Aug	11	--	--	--	40.8	74.2	--	--	II	33	NJ
1903	Jan	01	17	30	--	39.6	77.2	--	--	III*	16	MD
1903	Jan	01	22	45	--	39.6	77.2	--	--	II*	16	MD
1906	May	14	--	--	--	41.2	73.2	--	--	II	8	CT
1906	May	28	22	30	--	40.2	75.8*	--	--	III	70	PA
1907	Jan	10	09	45	--	41.2	77.1	--	--	IV	68	PA
1907	Jan	24	11	30	--	42.8	74.0	--	--	IV	49	NY
1908	Feb	05	08	20	--	41.4	73.2	--	--	IV	5	CT
1908	May	31	17	42	--	40.6	75.5	--	--	VI	64	PA
1910	Jan	24	02	20	--	39.6	77.0	--	--	II	16,17	MD
1910	May	01	20	--	--	40.7	73.5	--	--	II	49	NY

(Continued)

* Estimated by the US Geological Survey.

Year	Date Month	Day	Origin Time (Universal) hr	min	sec	Latitude (n)	Longitude (w)	Depth (km)	Magnitude	Intensity mm	Reference	State
1916	Feb	02	16	26	--	42.9	74.0	--	--	V	44,53	NY
1916	Feb	03	04	20	--	43.0	74.0	--	--	V	52	NY
1916	Jun	08	21	15	--	41.0	73.8	--	--	IV	49	NY
1921	Jan	26	23	40	--	40.0	75.0	--	--	V	24	NJ
1925	Apr	07	20	18	--	43.0	76.1	--	--	III	49,53	NY
1925	Oct	24	01	30	--	41.4	73.3	--	--	III	5	CT
1926	Jan	26	23	40	--	40.0	75.0	--	--	V	30	NJ
1926	May	12	03	30	--	40.9	73.9	--	--	V	44	NY
1926	May	22	--	--	--	41.7	73.9	--	--	II	49,53	NY
1927	Mar	29	20	30	--	43.0	76.1	--	--	III	49,53	NY
1927	Mar	31	21	00	--	43.0	76.1	--	--	III	49,53	NY
1927	Mar	31	21	30	--	43.0	76.1	--	--	III	49	NY
1927	Jun	01	12	20	--	40.3	74.0	--	--	VII	24	NJ
1929	Aug	12	06	--	--	42.2	77.2	--	--	III	50	NY
1931	Jul	01	02	45	--	41.6	73.4	--	--	IV	6	CT
1932	Jul	20	23	30	--	42.2	73.2	--	--	II	18	MA
1933	Jan	25	02	--	--	40.2	74.7	--	--	V	24	NJ
1933	Jun	26	14	10	--	41.0	73.8	--	--	III	50,53	NY
1933	Oct	29	--	--	--	43.0	74.7	--	--	IV	44	NY
1935	Nov	01	06	30	--	42.6	74.6	--	--	II	50	NY
1937	Feb	21	12	--	--	42.1	76.8	--	--	II	50	NY
1937	Jun	09	00	04	--	40.3	75.9	--	--	II	69	PA
1937	Jul	19	03	51	--	40.7	73.7	--	--	IV	39	NY
1937	Sep	30	22	08	22	40.8	74.3	--	--	III	31	NJ
1937	Oct	12	03	--	--	41.2	73.8	--	--	II	50	NY
1937	Oct	12	06	--	--	41.2	73.8	--	--	II	50	NY
1938	May	16	19	25	--	40.8	74.3	--	--	II	31,33	NJ
1938	Jun	14	04	02	--	41.4	73.4	--	--	II	6	CT
1938	Jun	14	19	30	--	41.4	73.4	--	--	II*	1,6	CT

(Continued)

* Estimated by the US Geological Survey.

Year	Date Month	Day	Origin Time (Universal) hr	min	sec	Latitude (n)	Longitude (w)	Depth (km)	Magnitude	Intensity mm	Reference	State
1938	Jul	29	07	44	07	41.0	73.7	--	--	III	50	NY
1938	Aug	02	09	02	30	41.1	73.7	--	--	V*	1,6	CT
1938	Aug	23	03	36	34	40.2	74.5	--	4.6	V	19,31	NJ
1938	Aug	23	05	04	55	40.2	74.5	--	4.8	--	31	NJ
1938	Aug	23	05	18	23	41.2	73.7	--	--	III	50	NY
1938	Aug	23	07	03	29	40.2	74.5	--	4.6	IV	31,33	NJ
1938	Aug	23	07	11	46	41.2	73.7	--	--	III	50	NY
1938	Aug	23	11	11	08	40.2	74.2	--	--	III	31	NJ
1938	Aug	27	22	36	25	40.2	74.2	--	--	III	31	NJ
1938	Oct	21	07	18	55	41.2	73.7	--	--	II	50	NY
1938	Dec	06	19	38	--	40.8	74.3	--	--	III	31	NJ
1939	Feb	09	23	50	--	41.4	75.7*	--	--	II*	58	PA
1939	Apr	02	03	00	--	40.0	76.3*	--	--	II*	58	PA
1939	Sep	13	01	22	04	40.8	74.0	--	--	II	31	NJ
1939	Sep	21	20	30	01	41.4	74.1	--	--	II	50	NY
1939	Oct	25	14	46	39	42.2	73.8	--	--	II	50	NY
1939	Nov	15	02	53	48.0	39.6	75.2	16	--	V	20	NJ
1940	Apr	12	01	58	10	42.8	74.6	--	--	II	50	NY
1940	May	28	20	06	--	40.3	76.9*	--	--	III*	59	PA
1941	Jul	29	00	24	--	41.1	73.8	--	--	III	52	NY
1942	Oct	24	17	27	04	41.0	75.2	--	3.4	--	69	PA
1944	Jan	08	--	--	--	39.8	75.5	--	--	V*	9	DE
1944	Feb	05	16	22	01	40.8	76.2	--	3.7	--	69	PA
1945	Apr	15	13	15	--	43.0	76.4	--	--	III	50	NY
1945	Apr	15	14	20	--	43.0	76.4	--	--	III	50	NY
1945	Apr	15	15	30	--	43.0	76.4	--	--	III	50	NY
1946	Oct	28	20	36	06	41.5	76.6	--	3.6	--	69	PA
1946	Nov	10	11	41	23	42.9	77.5	--	3.1	--	50	NY
1947	Jan	04	18	51	04	41.0	73.6	--	--	V	6	CT

(Continued)

* Estimated by the US Geological Survey.

(Sheet 5 of 10)

Year	Date Month	Day	Origin Time (Universal) hr	min	sec	Latitude (n)	Longitude (w)	Depth (km)	Magnitude	Intensity mm	Reference	State
1947	Apr	01	13	25	54	41.0	74.3	--	--	III	31,35	NJ
1949	Oct	16	23	33	44.8	40.4	74.8	--	--	--	29	NJ
1950	Mar	20	22	55	12	41.5	75.8	--	3.3	--	69	PA
1950	Mar	29	14	43	02	41.0	73.6	--	--	IV	2,6	CT
1951	Sep	03	21	26	25	41.3	74.3	--	4.4	V	40,50	NY
1951	Nov	23	06	45	36	40.6	75.5	--	--	IV	69	PA
1951	Dec	08	04	37	--	41.7	73.9	--	--	III	40,50	NY
1952	Aug	25	00	07	--	43.0	74.5	--	--	V	50	NY
1952	Oct	08	21	40	--	41.7	74.0	--	--	V	50	NY
1952	Nov	20	--	--	--	42.9	76.6	--	--	III	50	NY
1953	Mar	27	08	50	--	41.1	73.5	--	--	V	3,6	CT
1953	Aug	17	04	22	50.0	41.0	74.0	--	--	IV	21,31	NJ
1954	Jan	07	07	25	--	40.3	76.0	--	--	VI	64	PA
1954	Jan	07	08	00	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	07	08	30	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	07	10	45	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	08	01	25	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	08	01	30	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	08	18	00	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	08	21	45	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	09	07	00	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	09	08	00	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	09	14	00	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	09	16	30	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	09	18	25	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	09	20	00	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	09	21	30	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	10	04	00	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	10	22	00	--	40.3	76.0	--	--	II*	60,69	PA

(Continued)

* Estimated by the US Geological Survey.

Year	Date Month	Day	Origin Time (Universal) hr	min	sec	Latitude (n)	Longitude (w)	Depth (km)	Magnitude	Intensity mm	Reference	State
1954	Jan	13	21	00	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	14	03	30	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	15	19	40	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	17	02	54	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	17	03	32	--	40.3	76.0	--	--	II*	60,69	PA
1954	Jan	24	03	30	--	40.3	76.0	--	--	III	69	PA
1954	Jan	31	12	30	--	42.9	77.2*	--	--	IV	41	NY
1954	Feb	01	00	37	50	43.0	76.7	--	3.3	--	50	NY
1954	Feb	21	20	00	--	41.2	75.9	--	--	VII	64	PA
1954	Feb	24	03	55	--	41.2	75.9	--	--	VI	64	PA
1954	Mar	31	21	25	--	40.3	74.0	--	--	IV	22,31	NJ
1954	Aug	11	03	40	--	40.3	76.0	--	--	IV	69	PA
1954	Sep	24	11	00	--	40.3	76.0	--	--	IV	71	PA
1955	Jan	20	03	00	--	40.3	76.0	--	--	IV	61,69	PA
1955	Jan	21	08	40	--	42.9	73.8	--	--	V	50	NY
1955	Jan	21	12	20	--	42.9	73.8	--	--	III	42,50	NY
1957	Mar	23	19	02	31	40.6	74.8	10	4.8	VI	23,31	NJ
1958	May	06	19	00	--	42.7	73.8	--	--	IV	50	NY
1959	Apr	13	21	20	19	41.92	73.27	--	3.4	--	6	CT
1961	Sep	15	02	16	56	40.6	75.4	--	--	V	62,74	PA
1961	Dec	27	17	06	--	40.1	74.9*	--	--	V	62	PA
1962	Oct	13	--	--	--	41.0	74.3	--	--	II	33	NJ
1962	Nov	27	04	14	50	41.5	73.8	--	1.7	II	52	NY
1963	Mar	02	20	24	32.0	41.5	75.8	--	3.4	--	74	PA
1964	May	12	06	45	10.7	40.30	76.41	1	4.5	VI	63,78	PA
1964	Sep	29	00	16	27.5	41.2	73.7	--	--	III*	43,53	NY
1964	Nov	17	17	08	--	41.2	73.7	--	--	V	44	NY
1964	Nov	30	00	34	55	42.8	74.9	--	2.6	II	52,53	NY
1964	Nov	30	10	47	32.4	41.3	73.9	--	--	II	52,53	NY

(Continued)

* Estimated by the US Geological Survey.

Year	Date Month	Day	Origin Time (Universal) hr	min	sec	Latitude (n)	Longitude (w)	Depth (km)	Magnitude	Intensity mm	Reference	State
1965	Sep	29	20	57	39.5	41.4	74.4	--	--	IV	48,53	NY
1966	May	21	07	30	55.0	41.2	74.0	--	--	II	52,53	NY
1967	Nov	22	21	10	--	41.2	73.8	--	--	V	44,53	NY
1968	Dec	10	09	12	44.9	39.7	74.6	--	2.5	V	25	NJ
1969	Apr	25	00	14	41.4	40.7	74.3	--	--	III*	26	NJ
1969	Oct	06	--	--	--	41.1	74.6	--	--	IV	33	NJ
1971	Jul	14	--	--	--	39.7	75.6*	--	--	IV*	14	DE
1971	Dec	29	--	--	--	39.7	75.6*	--	--	IV*	14	DE
1972	Jan	02	07	08	--	39.7	75.6*	--	--	IV*	14	DE
1972	Jan	03	00	--	--	39.7	75.6*	--	--	IV*	14	DE
1972	Jan	07	03	45	--	39.7	75.6*	--	--	IV*	14	DE
1972	Jan	22	06	40	--	39.7	75.6*	--	--	IV*	14	DE
1972	Jan	23	01	35	--	39.7	75.6*	--	--	IV*	14	DE
1972	Jan	23	07	22	--	39.7	75.6*	--	--	IV*	14	DE
1972	Feb	11	00	16	30	39.7	75.6*	--	--	V*	14	DE
1972	Feb	11	15	30	--	39.7	75.6*	--	--	--	14	DE
1972	Feb	15	23	53	14.4	41.3	73.6	--	2.6	IV*	45,53	NY
1972	Aug	14	01	09	--	39.7	75.6*	--	--	IV	13	DE
1972	Aug	14	01	55	--	39.7	75.6*	--	--	--	13	DE
1972	Dec	08	03	00	33.3	40.14	76.24	2	3.5	V	65,78	PA
1973	Feb	28	08	21	32.3	39.72	75.44	14	3.8	V	27	NJ
1973	Jul	10	04	38	02	39.7	75.4	--	--	IV	27,33	NJ
1973	Jul	10	04	38	02	39.7	75.7	--	--	IV	15	DE
1974	Apr	28	14	19	20	39.7	75.6*	--	--	IV	10	DE
1974	Jun	07	19	45	35.7	41.60	73.95	3	3.3	VI	46,56	NY
1975	Feb	20	08	06	--	40.3	73.2	--	2.9	--	52	NY
1975	Jul	19	20	59	32.0	41.43	73.79	5	2.3	III	51,56	NY
1975	Oct	24	07	08	46.4	41.62	73.98	5	2.0	II	52,57	NY
1975	Oct	24	07	43	12.4	41.59	73.93	3	2.2	II	52,57	NY

(Continued)

* Estimated by the US Geological Survey.

	Date		Origin Time (Universal)			Lati- tude	Longi- tude	Depth		Intensity		
Year	Month	Day	hr	min	sec	(n)	(w)	(km)	Magnitude	mm	Reference	State
1975	Oct	28	21	45	--	41.57	73.93	--	--	II	52,57	NY
1976	Mar	11	21	07	20.4	40.96	74.37	4	2.4	VI	28	NJ
1976	Apr	13	15	39	13.2	40.84	74.05	2	3.1	VI	32	NJ
1976	May	11	13	18	14.4	40.48	73.80	1	2.8	--	52	NY
1976	Aug	20	22	08	14.3	41.11	73.75	6	2.5	--	54	NY
1976	Dec	05	13	00	--	40.8	74.8*	--	--	III	37	NJ
1976	Dec	05	16	32	06.9	40.77	74.76	3	1.8	III	37,38	NJ
1976	Dec	07	04	55	07.2	40.77	74.76	5	1.7	III	37,38	NJ
1977	Jan	21	20	50	44.5	39.97	74.32	0	2.7	--	33	NJ
1977	Feb	10	19	14	25	39.8	75.5	--	2.0	VI	11,12	DE
1977	Dec	15	08	55	24.5	43.03	77.44	5	2.6	--	55	NY
1978	Jul	16	06	40	--	39.9	76.3	--	3.1	V	79	PA
1978	Oct	06	19	26	--	40.0	76.5	--	3.0	V	79	PA
1979	Jan	30	16	31	--	40.3	74.3	--	3.0	V	79	NJ
1979	Mar	10	04	50	--	40.7	74.5	--	2.2	V	79	NJ
1980	Jan	17	10	13	--	41.31	73.93	3	2.9	V	80	NY
1980	Feb	29	05	53	--	42.58	74.20	12	3.1	--	80	NY
1980	Mar	02	11	54	--	40.21	75.08	0	2.8	--	80	PA
1980	Mar	05	17	06	--	40.19	75.16	5	3.5	V	80	PA
1980	Mar	05	17	20	--	40.18	75.07	5	3.1	V	80	PA
1980	Mar	11	06	00	--	40.16	75.10	5	3.7	V	80	PA
1980	Mar	11	16	16	--	40.25	74.99	2	2.8	V	80	NJ
1980	Mar	25	18	54	--	40.98	75.01	5	2.8	--	80	NJ
1980	Apr	05	11	49	--	39.83	74.05	6	2.9	--	80	NJ
1980	May	02	15	23	--	40.16	74.99	5	2.8	--	80	PA
1980	May	02	19	02	--	40.26	75.03	0	3.0	--	80	NJ
1980	May	07	04	32	--	41.02	73.87	0	2.6	--	80	NJ
1980	May	20	21	33	--	41.35	74.37	2	2.6	--	80	NY
1980	Aug	02	17	20	--	40.43	74.15	8	3.1	--	80	NJ

(Continued)

* Estimated by the US Geological Survey.

Year	Date Month	Day	Origin Time (Universal) hr	min	sec	Latitude (n)	Longitude (w)	Depth (km)	Magnitude	Intensity mm	Reference	State
1980	Aug	30	09	19	--	39.84	74.86	2	3.0	--	80	NJ
1980	Sep	04	04	30	--	41.11	73.78	13	3.2	IV	80	CN
1980	Sep	27	00	48	--	41.54	73.69	6	2.5	--	80	NY
1981	May	18	07	22	--	41.10	74.20	--	2.2	--	81	NJ
1981	Aug	18	00	25	--	42.31	74.27	--	2.1	--	81	NY
1984	Apr	23	01	36	--	39.94	76.33	5	4.1	--	82	PA

(Sheet 10 of 10)

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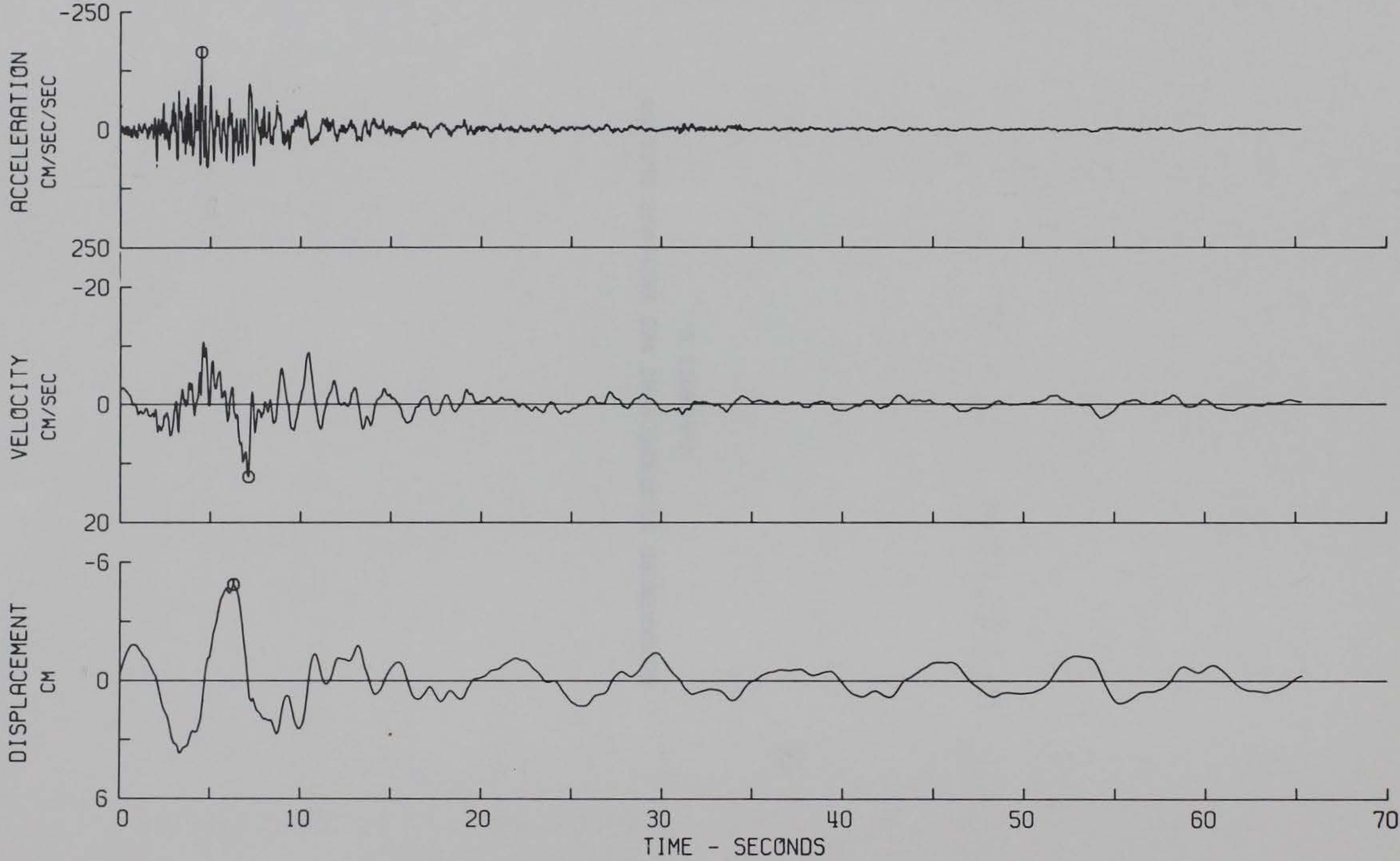
APPENDIX C

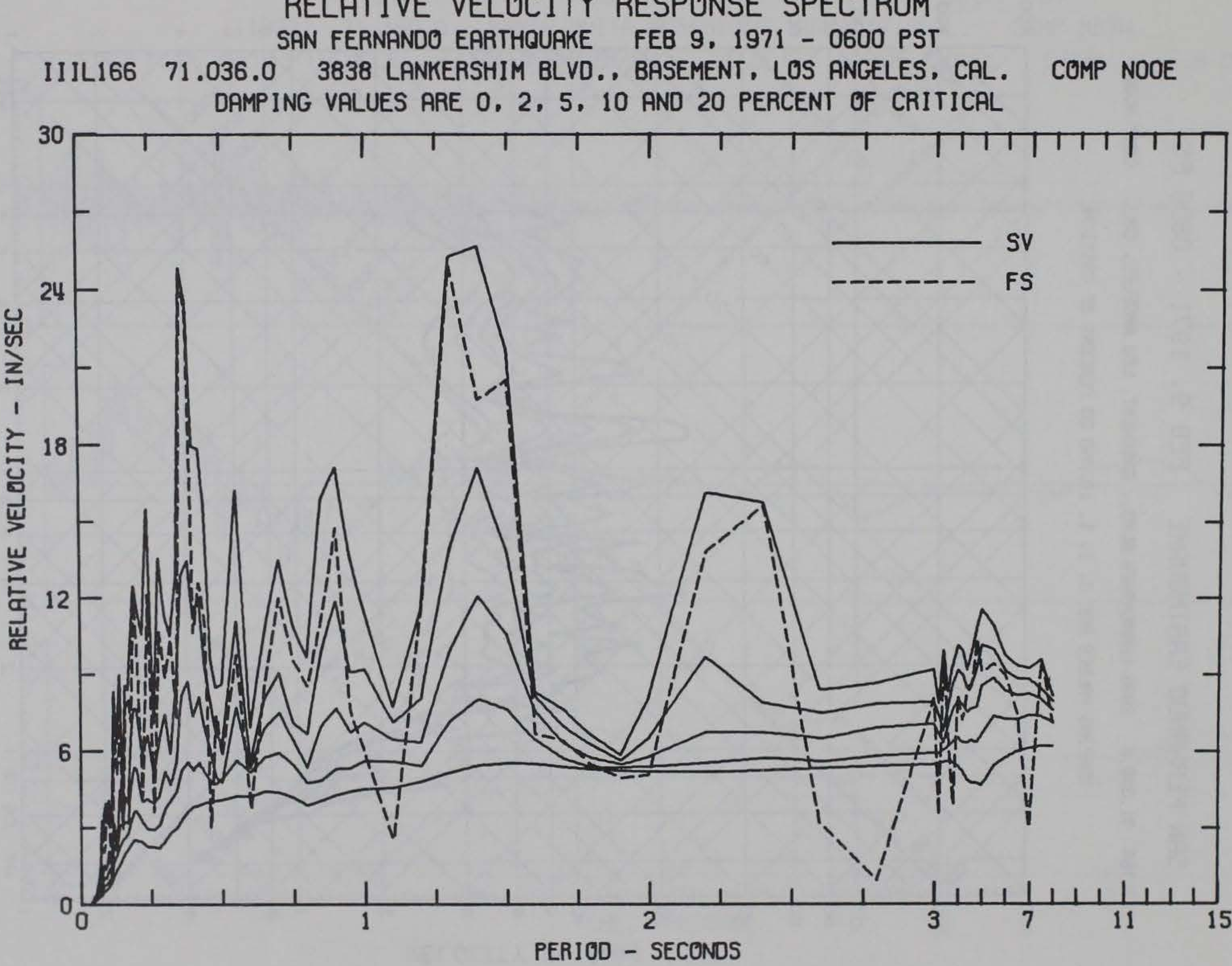
RECOMMENDED ACCELEROGRAMS AND RESPONSE SPECTRA

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIL166 71.036.0 3838 LANKERSHIM BLVD., BASEMENT, LOS ANGELES, CAL. COMP N00E

⊕ PEAK VALUES : ACCEL = -164.2 CM/SEC/SEC VELOCITY = 12.3 CM/SEC DISPL = -4.9 CM



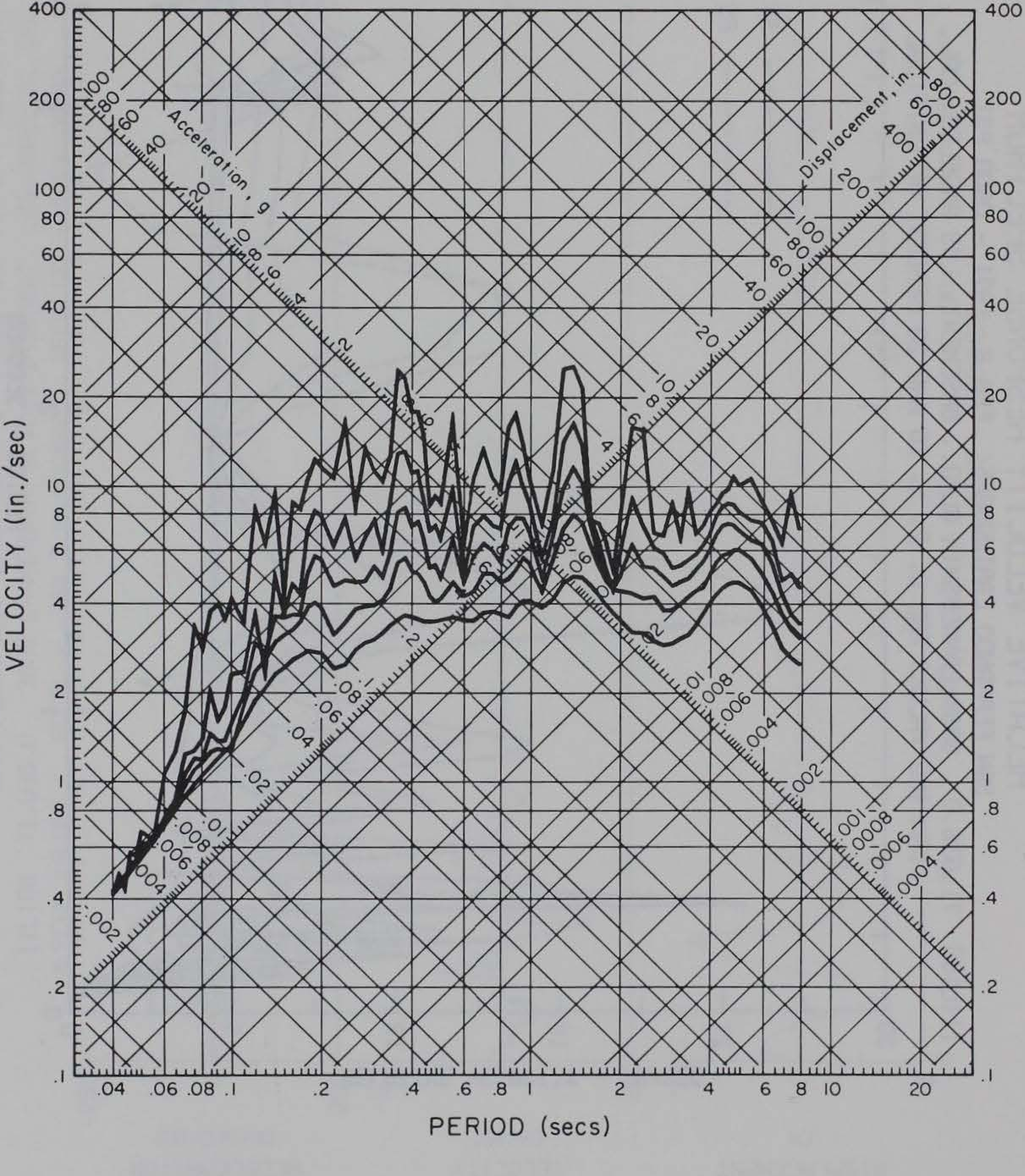

RELATIVE VELOCITY RESPONSE SPECTRUM
SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST
IIIL166 71.036.0 3838 LANKERSHIM BLVD., BASEMENT, LOS ANGELES, CAL. COMP NOOE
DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL
SV
FS
RELATIVE VELOCITY - IN/SEC
PERIOD - SECONDS
0
6
12
18
24
30
0
1
2
3
7
11
15

RESPONSE SPECTRUM

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIL166 71.036.0 3838 LANKERSHIM BLVD., BASEMENT, LOS ANGELES, CAL. COMP NOOE

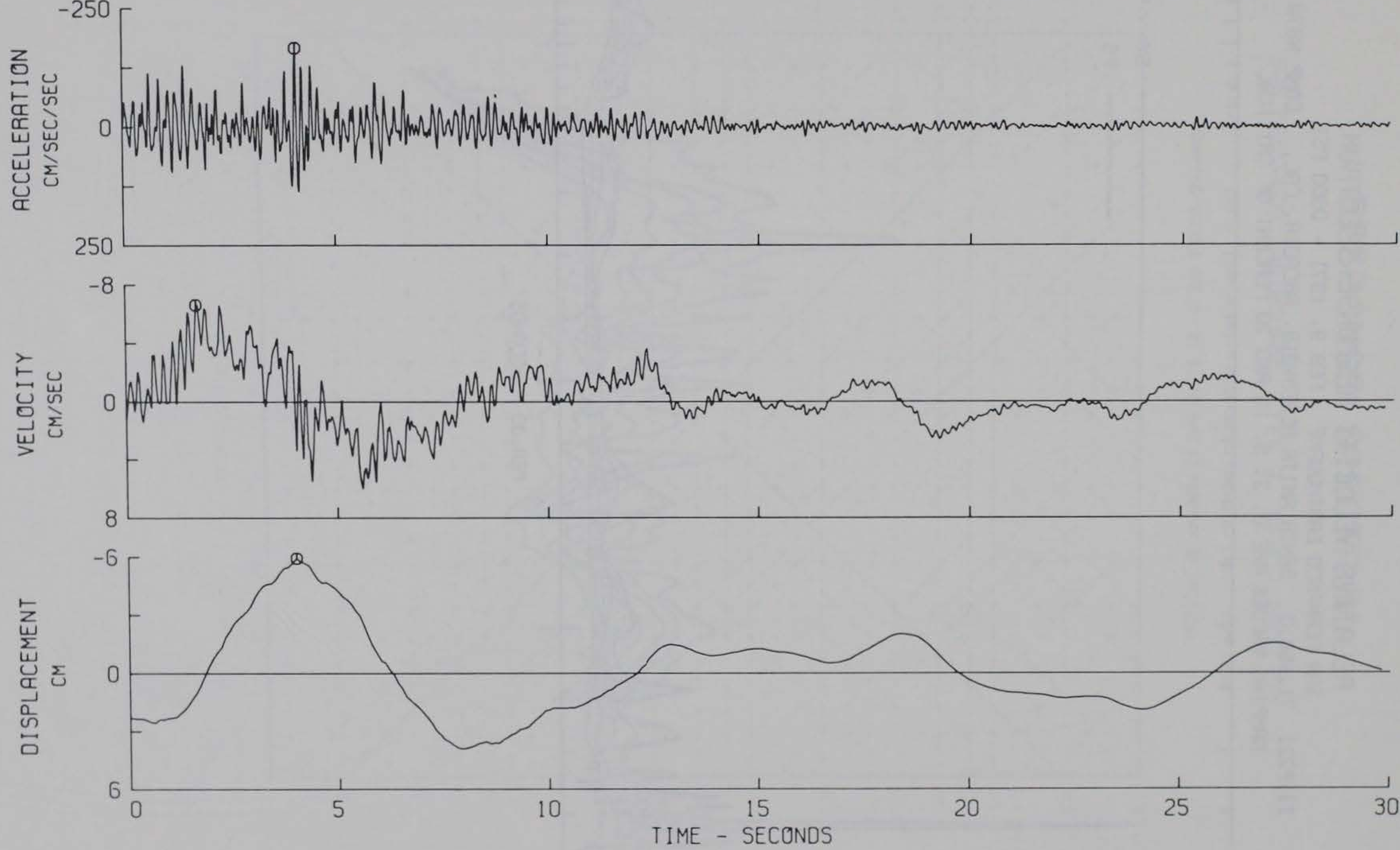
DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

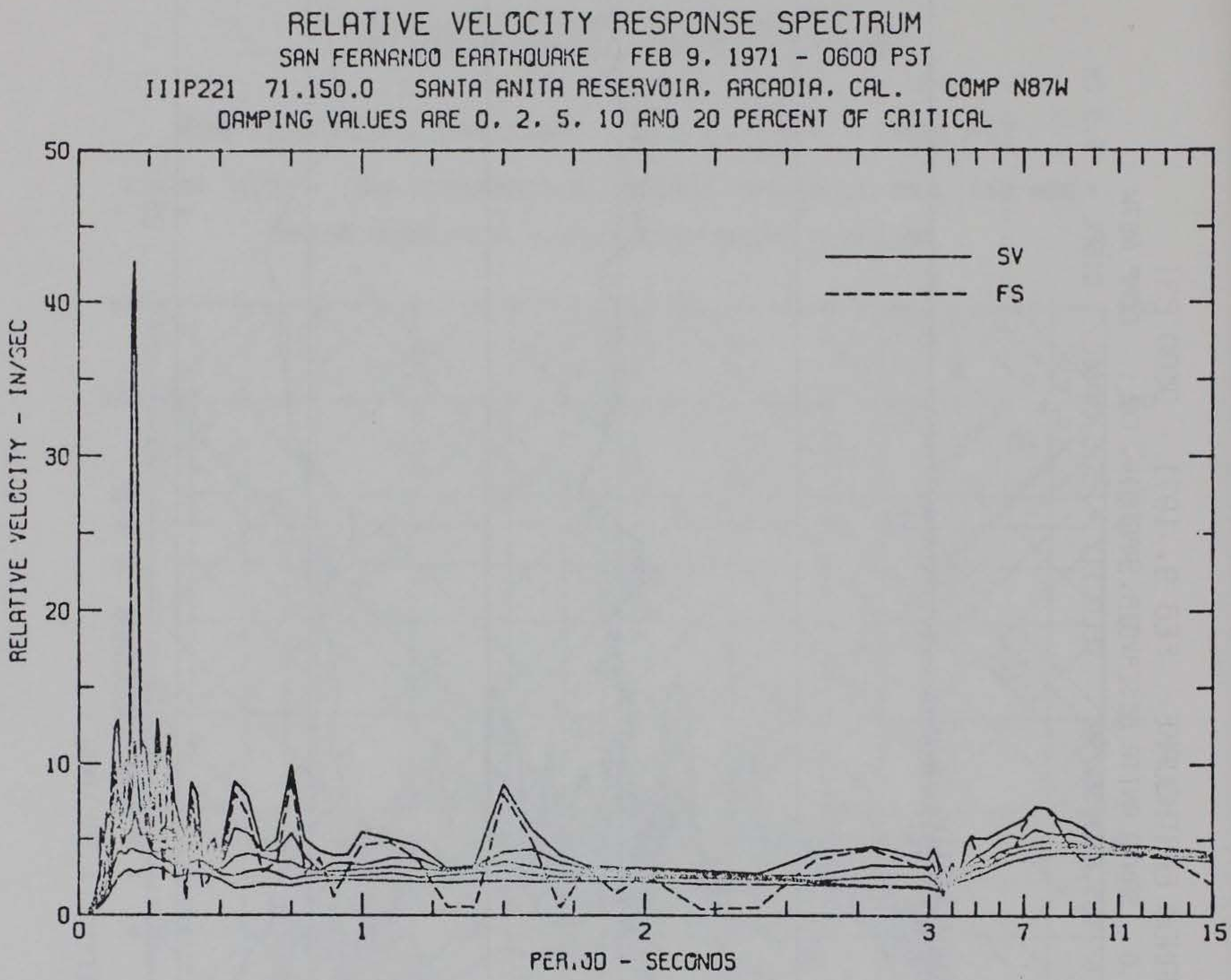


SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIP221 71.150.0 SANTA ANITA RESERVOIR, ARCADIA, CAL. COMP N87W

⊕ PEAK VALUES : ACCEL = -165.8 CM/SEC/SEC VELOCITY = -6.6 CM/SEC DISPL = -5.9 CM



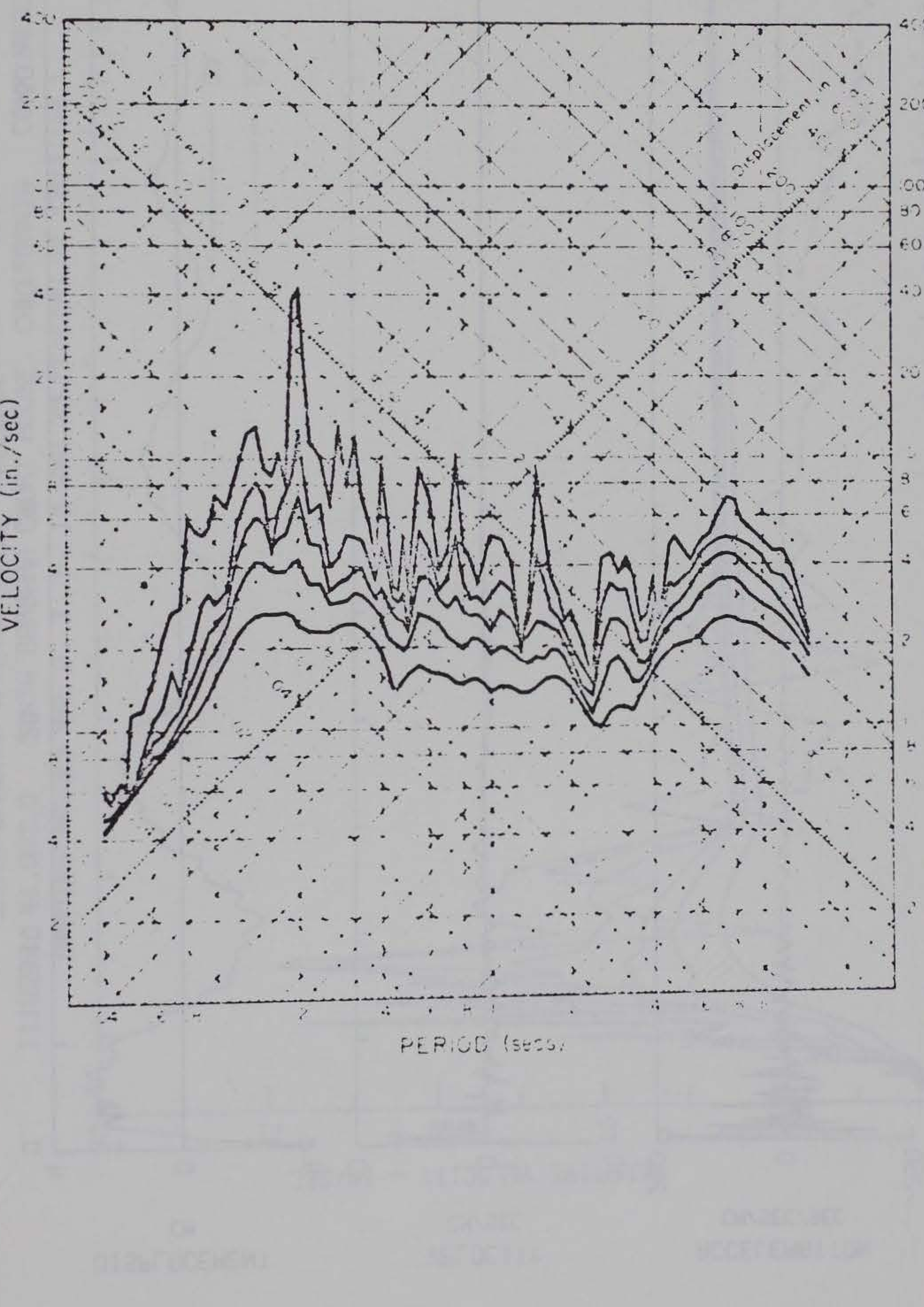

RELATIVE VELOCITY RESPONSE SPECTRUM
SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST
IIIP221 71.150.0 SANTA ANITA RESERVOIR, ARCADIA, CAL. COMP N87W
DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL
SV
FS
RELATIVE VELOCITY - IN/SEC
50
40
30
20
10
0
0
1
2
3
7
11
15
PERIOD - SECONDS

RESPONSE SPECTRUM

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIP221 71 .50 0 SANTA ANITA RESERVOIR, ARCADIA, CAL. COMP N87W

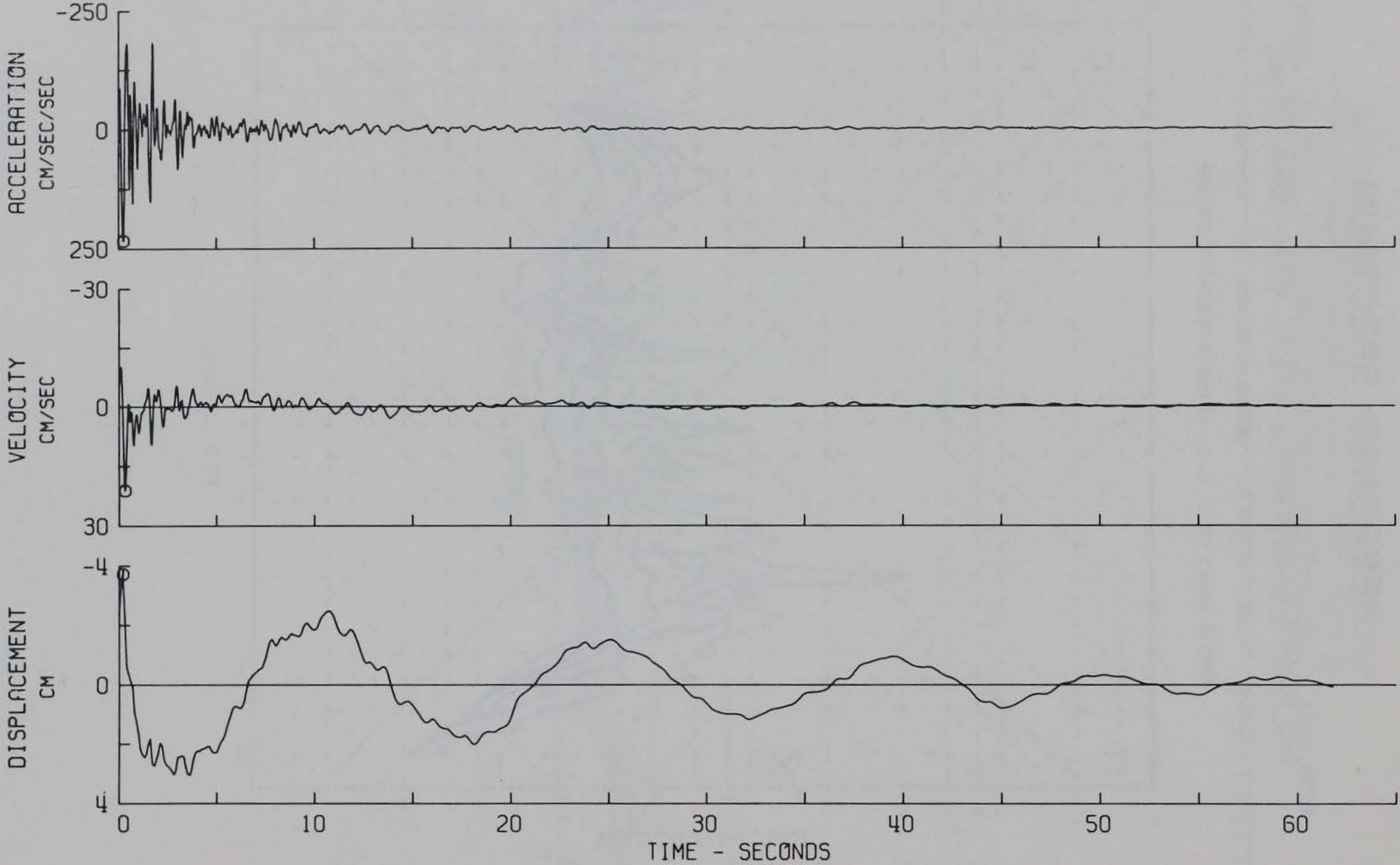
DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL



SANTA BARBARA EARTHQUAKE JUN 30, 1941 - 2351 PST

IIU299 41.002.0 SANTA BARBARA COURT HOUSE, CALIFORNIA COMP N45E

⊙ PEAK VALUES : ACCEL = 233.8 CM/SEC/SEC VELOCITY = 21.1 CM/SEC DISPL = -3.7 CM

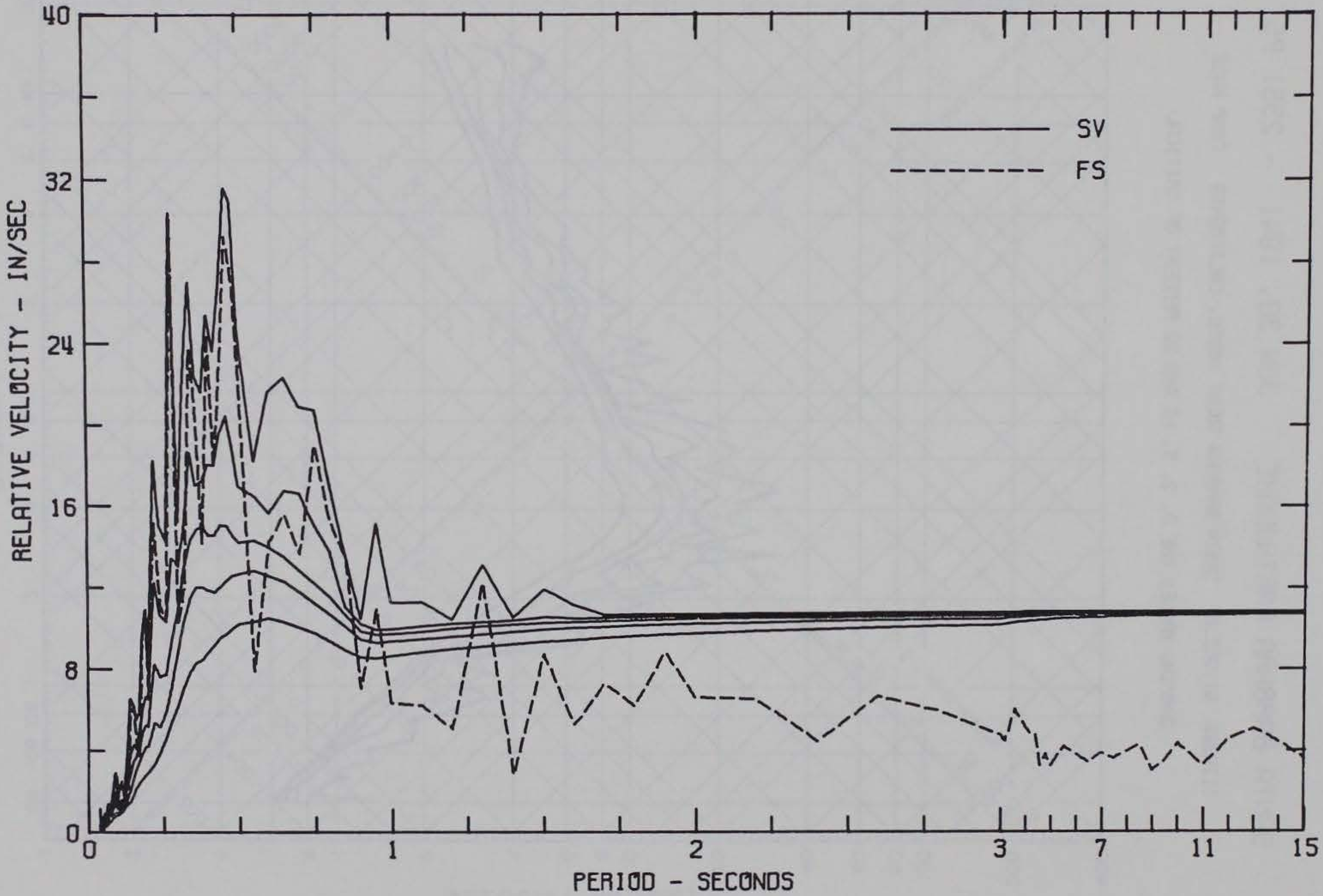


RELATIVE VELOCITY RESPONSE SPECTRUM

SANTA BARBARA EARTHQUAKE JUN 30, 1941 - 2351 PST

IIIU299 41.002.0 SANTA BARBARA COURT HOUSE, CALIFORNIA COMP N45E

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



RESPONSE SPECTRUM

SANTA BARBARA EARTHQUAKE JUN 30, 1941 - 2351 PST

IIIU299 41.002.0 SANTA BARBARA COURT HOUSE, CALIFORNIA COMP N45E

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