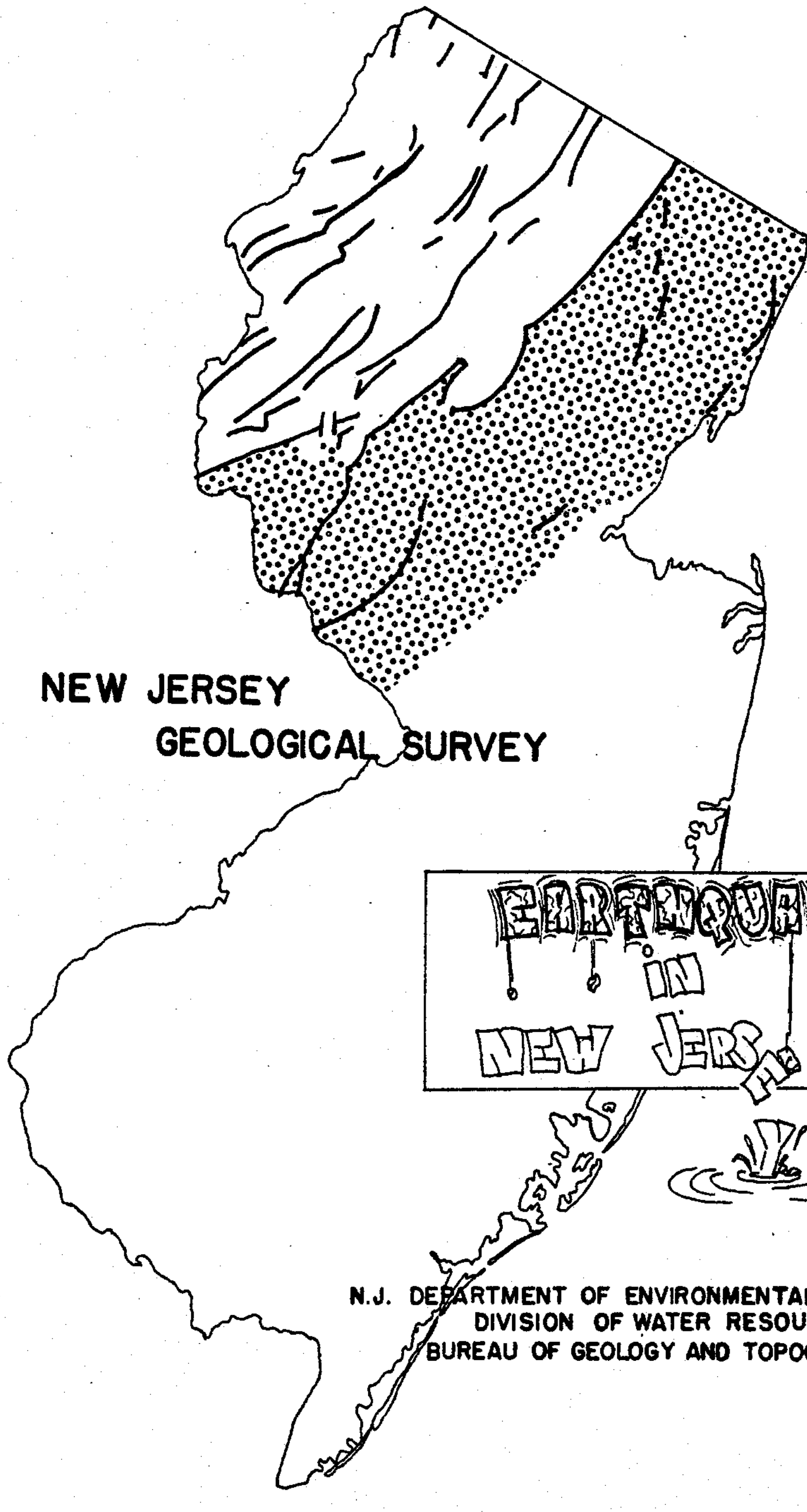

NEW JERSEY GEOLOGICAL SURVEY

EARTHQUAKES IN NEW JERSEY

REVISED

N.J. DEPARTMENT OF ENVIRONMENTAL PROTECTION
DIVISION OF WATER RESOURCES
BUREAU OF GEOLOGY AND TOPOGRAPHY

Cover: LOCATION OF INACTIVE FAULTS IN NEW JERSEY
Design by Frank Viscomi

Faults -

Triassic Lowlands -

The Border Fault System separates the Triassic Lowlands from the areas of older rocks to the north. The Triassic Lowlands probably contain more faults than shown, since faults are difficult to recognize in this area.

The younger sediments of the Coastal Plain cover the Triassic and older rocks which form the basement or bedrock of the southern part of the state. These thick sediments conceal any faults that may be present.

STATE OF NEW JERSEY

Department of Environmental Protection
Rocco D. Ricci, Commissioner
Glenn L. Paulson, Assistant Commissioner

Bureau of Geology and Topography
Kemble Widmer, State Geologist

EARTHQUAKES IN NEW JERSEY

by

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1973
Revised 1977

Bureau of Geology and Topography
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INTRODUCTION

New Jersey is not located in an earthquake-prone area. It has never, in the recorded history of the state, had a severe earthquake which caused great damage. The entire eastern seaboard, with the exception of the St. Lawrence River Valley, is rather stable. The St. Lawrence River Valley is moderately active.

In recorded history this region as a whole has experienced only about four earthquakes large enough to have caused extensive damage and destruction. Two of these were in the St. Lawrence River valley. All four were felt in New Jersey, but caused no major damage here. Minor tremors occur from time to time in this region as they do in all parts of the world.

Earthquake-like shocks occasionally occur from non-earthquake sources, such as the sonic boom of a jet plane breaking the sound barrier. Others come from quarry blasts or field artillery practice at military bases which can often be felt over ten miles away. Military bases have also been known to destroy old ammunition and thus produce small but sharp shocks. Other possible non-earthquake sources are mentioned in the description of the earthquakes.

We have tabulated all the major and minor earthquakes large enough to be felt in New Jersey, and a few (too weak to be felt) detected by very sensitive seismographs. A verbal description is given of most earthquakes listed. The older descriptions came from various sources, such as: old newspaper accounts, correspondences, etc., as well as some reports from trained observers. The more recent descriptions came from a larger percentage of trained observers, and also from recording instruments such as seismographs, in addition to the newspaper accounts and personal communications. The most recent listing (added after our first edition) contains more earthquakes per year than previous lists. This is due to our more carefully maintained update file - not a greater occurrence of earthquakes. A larger percentage of small magnitude shocks and some questionable events are included.

Before listing the earthquakes, we have included sections of interest. First is a brief general discussion of seismology. Following this is a listing of seismograph stations in and near New Jersey. Finally, an account of minor seismic activity related to the Triassic Border Fault and other areas in the state.

ACKNOWLEDGMENTS

The author wishes to thank Dr. Kemble Widmer, State Geologist of the State of New Jersey, who directed that this paper be written, supervised its production, read preliminary drafts, and gave advice and guidance.

This paper was written to replace and update "Earthquakes and Seismology," by Dr. Jack Oliver of Lamont-Doherty Geological Observatory. Dr. Mark L. Sbar, of Lamont-Doherty Geological Observatory, reviewed the preliminary draft; his contributions include additions to both the list of seismograph stations and the list of earthquakes, as well as suggestions to improve the text. Mrs. Agatha Weston, Publications Office, Lamont-Doherty Geological Observatory, graciously gathered and supplied several publications from which data was extracted for this paper.

Mr. Waverly Person of the National Earthquake Information Center supplied additional data and recommendations. Mr. Charles Ellis (Mahwah Environmental Commission, Mahwah, N.J.) who has been actively interested in local earthquake activity for many years has supplied us with several newspaper accounts, data from local police stations, and several reports (from local residents) which he has accumulated in his files. We also wish to thank Mr. Joseph Miller, New Jersey Bureau of Geology & Topography, for the data he has supplied and for the suggestions he has given.

Mr. Philip J. Del Vecchio, former director of the Paterson Museum, reviewed the preliminary draft of this paper. Mr. Del Vecchio operates a private seismograph station in Paterson (see list of Seismograph Stations). His valuable suggestions and corrections have been incorporated into the final text.

Our thanks also go to Ms. Mary Golisano of Lamont-Doherty Observatory for helping update the list of seismograph stations for the revised edition.

ELEMENTARY SEISMOLOGY FOR THE LAYMAN

An earthquake is a shaking of the ground caused by a breaking of rock within the crust of the earth. This breakage may be at the surface or up to several hundred miles beneath the surface. The point of breakage is called the focus or hypocenter. The point directly above this on the surface is called the epicenter. A fracture along which motion has taken place is called a fault.

Each earthquake sends out seismic waves in all directions, some penetraiting within the earth. These waves may be detected and recorded by seismographs at distant locations, even on other continents. Some seismographs have amplifiers that multiply the sensitivity of the instrument several thousand times.

A seismic wave is composed of several component waves. Seismologists classify these components into surface waves and body waves. The principal surface wave is the "L" wave, which travels on the surface like a wave on water. Its period is longer and its amplitude is greater than the other components. It is responsible for most of the damage caused by earthquakes.

The basic body waves are the "P" and "S" waves, which penetrate the interior of the earth. These two waves travel at different velocities. The difference in their arrival times, recorded at a seismograph station, can be used to determine the distance to the epicenter. Seismographs at three different locations are usually needed to fix the exact location of a quake when local reports are absent.

Body waves travel in all directions from the focus - upward, downward, and in all intermediate directions. A seismograph first receives the body waves that travel directly from the focus to the instrument. It may also receive an "echo" of this wave by route of a shallower path, bouncing off the surface of the crust one or more times. Still other paths are created by refraction of the waves within the various zones of the mantle and core of the earth. By studying the extra signals on seismic records seismologists have been able to decipher the extra paths involved. Thus, very detailed information has been learned about the interior and crust of the earth.

Magnitude and Intensity

The size and severity of an earthquake is generally reported on either of two scientific scales, the Richter or the Modified Mercalli.

The Richter scale of magnitude measures the amplitude of the seismic waves. It is determined by the amount of motion of the pen of the seisomography, with correction made for the sensitivity of the seismography and the distance to the focus. Each Richter scale unit corresponds to a ten-fold increase in the amplitude of the seismic wave; i.e., ten times the pen displacement of the seismograph (two units, 100 fold; three, 1,000, etc.). This tenfold increase in amplitude represents a 31-fold increase in the energy released by the earthquake. The scale has negative values for the very small quakes. The largest earthquakes ever recorded are about 8.8 or 8.9 Richter. The smallest detectable by a person without a seismograph is about +2 Richter.

The Mercalli scale of intensity measures the effects caused by a quake to structures and to the ground surface. It depends upon reports from persons at the scene or from observations by seismologists sent to the area. Its values are given in Roman numerals to differentiate them from Richter values. The scale is given below.

A rule of thumb relationship between the two scales which holds for most shallow focus earthquakes is given by the formula:

Richter Magnitude - 1.3 + 0.6 x Maximum Mercalli Intensity

Intensities and, therefore, damage potential tend to be greater in areas covered by thick deposits of unconsolidated sediments. Such areas include glacial moraines and thick glacial till, river valley deposits, bog, swamp and meadow areas, and deposits of volcanic ash.

Much of the damage associated with California tremors occurs on hillsides, where mud and gravel quickly succumb to landslides. The greatest damage in the San Francisco quake of 1906 was on the "Barbary Coast" which was built on fill over harbor muck. This type of deposit tends to vibrate like jello with a greater amplitude than bedrock areas. The effects of the Anchorage, Alaska, earthquake of 1964 were most severe on marine clay deposits, which turned fluid and flowed like liquid, and also on gravel areas, which shifted and settled.

In New Jersey, the Riverton tremor of December 10, 1968, had a magnitude of 2.9. Applying the formula previously described, the intensity should have been less than III. Actually, it was V. This apparent high intensity in the Riverton area is because it is underlain by unconsolidated sand, mud and gravel.

<u>Modified Mercalli Intensity Scale of 1931 (Abridged)</u>

Values in parentheses are equivalent intensities in the Rossi-Forel Scale, still used in some countries.

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

II Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended object may swing. (I to II)

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

IV During the day, felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V)

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

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

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 motorcars. (VIII-)

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. Persons driving motorcars disturbed. (VIII+ to IX)

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. (IX+)

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

XI Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines 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 air.

Prediction and Control of Earthquakes

Although the subject of study for many years, scientific prediction of earthquakes has finally become more than wishful thinking. Russian scientists recently (1969) discovered that a decrease in the ratio of the "P" to "S" wave velocities of micro-earthquakes precedes a larger earthquake. It was thought to be a peculiarity of the Siberian region. A similar relationship was later found to be true elsewhere. To use this relationship micro-earthquakes must (and quite often do) precede the larger shock.

Lamont-Doherty Geological Observatory has been studying a series of shocks in the Blue Mountain Lake region of the Adirondack Mountains of New York State. On August 1, 1973, it was predicted that an earthquake of magnitude 2.5 would occur "in a couple of days." Two days later it came, registering 2.5 on the Richter scale.

The vast area of China has been plagued with major earthquakes throughout its 3,000 year recorded history. More than 820,000 died in the Shensi earthquake of January 23, 1556. In the mid-sixties, during its Cultural Revolution, the Peoples Republic of China embarked on an all-out program to develop methods of predicting earthquakes. In early 1975 a major earthquake at Haicheng (February 4th) was accurately predicted. Although 80 percent of the homes were destroyed, very few lives were lost. Three additional major earthquakes of about magnitude 7 (Richter) were also successfully predicted in 1976, and a timely imminent warning issued. On July 28th of that year, however, a major quake struck and virtually destroyed the industrial city of T'angshan without any "imminent prediction" being issued. An unofficial Chinese source indicates 655,000 lives were lost, second only in lives lost to the Shensi quake of 1556.

China's approach is multi-faceted, including every method suggested in any part of the world. These include measurements of Radon gas in well water, rock strain, and observation of strange behavior of animals (which is often noted before earthquakes). See "Earthquake Research in China" (Bibliography) for more details.

Much more work must be done, and is being done, before reliable earthquake prediction becomes a complete reality.

Control of earthquakes is also entering its infancy. It was discovered, by accident, that deep well disposal of liquids triggered earthquakes in a previously inactive fault. This suggests a method of turning earthquakes on and off by pumping water in or out of a fault zone. By thus slowly relieving stresses built up in major faults, it is hoped that major earthquakes could be prevented.

Effect of Earthquakes on Wells

Well water often becomes muddy during an earthquake. The shock wave stresses the rock, squeezing and stretching the water-bearing zones in the rock. This stirs up the mud in the bottom of wells.

This is not unexpected near an earthquake, but what is not widely known is that distant earthquakes also affect wells. Many New Jersey wells became muddy from the shock wave from the Good Friday earthquake at Anchorage, Alaska (1964). Automatic recording equipment at nine observation wells in New Jersey recorded a fluctuation in the ground water level up to two feet at the time of arrival of the shock wave.

LIST OF SEISMOGRAPH STATIONS IN AND NEAR NEW JERSEY

Station Name	Code	County	State	Comment
Stations Operated by Lamont-Doherty Geological Observatory - These stations send their data immediately via telemetry hookups to Lamont-Doherty Observatory				
Greenpond	GPD	Morris	N.J.	
Long Valley	LVNJ	Morris	N.J.	
Ogdensburg	OGD	Sussex	N.J.	In N.J. Zinc mine, 1780 feet deep
Pahaquarry	PQN	Warren	N.J.	
Princeton (Township)	PRIN	Mercer	N.J.	
Tabernacle	TANJ	Burlington	N.J.	
Manhattan	MAN	New York	N.Y.	Museum of Natural History
Palisades	PAL	Rockland	N.Y.	Lamont-Doherty Geol.Obs.
Tablerock	TBR	Rockland	N.Y.	
Ward Pond Ridge	WPR	Westchester	N.Y.	
Stations Operated by the Geological Survey of Delaware				
Blackbird State Forest	BBD	New Castle	Del.	
Newark	NED	New Castle	Del.	
Redden Fire Station	GTD	Sussex	Del.	
Stations Operated by the University of Pennsylvania				
Abington	PHI	Montgomery	Pa.	(near Philadelphia)
Millersville	MLV	Lancaster	Pa.	
Individually Operated Stations				
Paterson	PNJ	Passaic	N.J.	
City College	CNY	New York	N.Y.	City University of N.Y.
Fordham	FOR	New York	N.Y.	Fordham University
Glen Cove	GCY	Nassau	N.Y.	

NOTE: The Franklin Institute in Philadelphia no longer operates a seismograph.

MINOR TREMORS IN BERGEN COUNTY NEAR THE RAMAPO SECTION OF THE TRIASSIC BORDER FAULT

The "Border Fault" is probably the longest system of faults in New Jersey. It is the western border of the Triassic Basin and extends from Stony Point, New York, to Reading, Pennsylvania and beyond. The Ramapo section of this fault in Bergen County lies just west (1/4 to 1/2 mile) of U.S. Route 202.

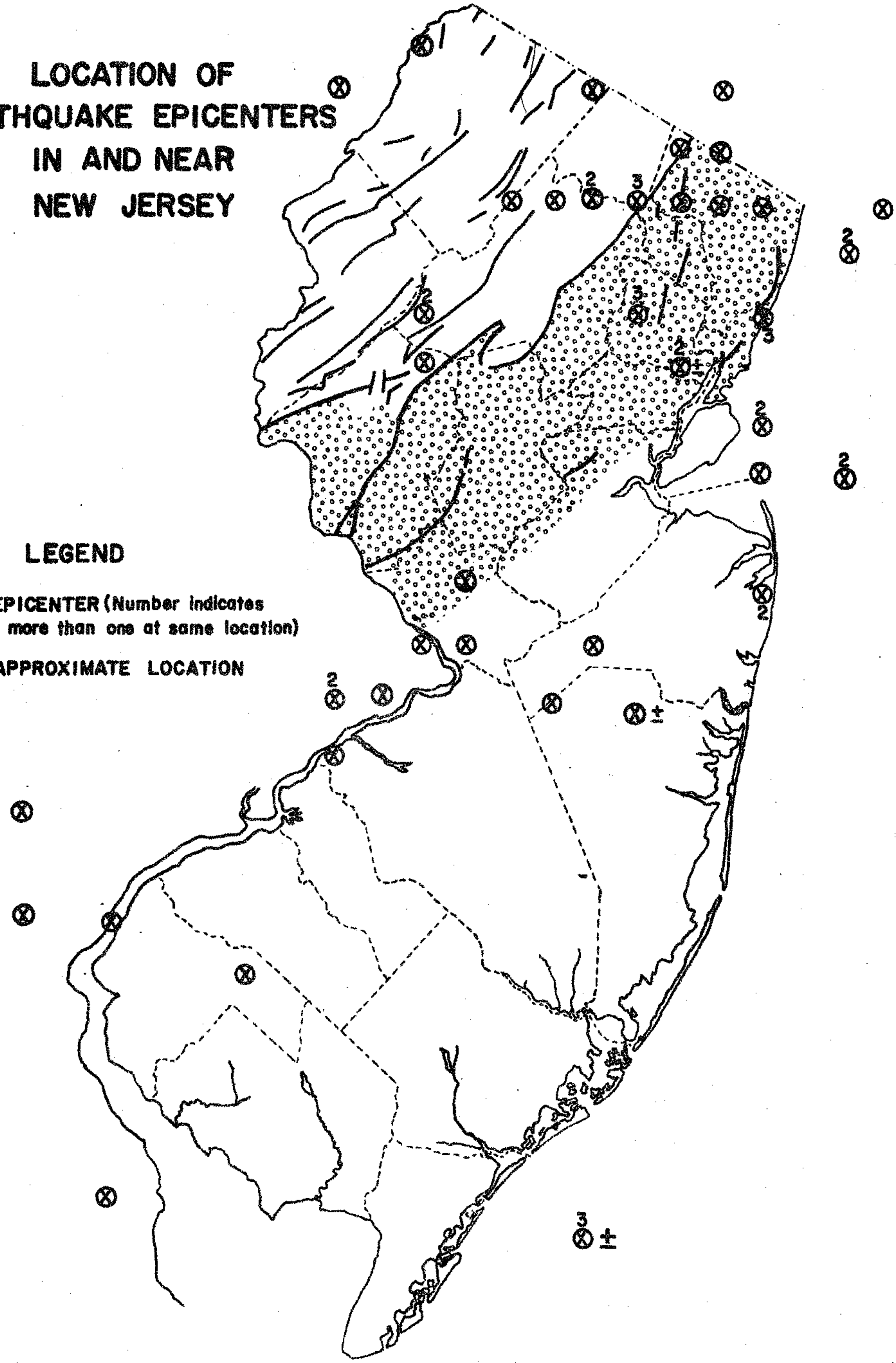
This fault, formed at least 200 million years ago, has not been active during the recent geological past. The area immediately to the east of it has, however, been the site of several very minor tremors. This activity probably constitutes only minor readjustments in the earth's crust, comparable to the cracking that develops in an old building as it settles.

In addition to the quakes listed below for the Fall of 1943, December 29, 1972, and February 5, 1973, and February 5, 1973, several others of equal magnitude have been reported in Bergen County and Rockland County, N.Y. Water mains serving Immaculate Conception Seminary in Mahwah Township have broken in numerous places between 1964 and 1970. The seminary grounds are very close to the fault and are traversed by branches from it. Many quite minor quakes have been detected by Lamont-Doherty Geological Observatory's seismographs. Lamont-Doherty Observatory seismologists have suggested that building codes provide for construction able to withstand a shock of Richter magnitude of +5. It must be pointed out that the art of earthquake hazard estimation is not as advanced as we would like it to be. Much work still needs to be done before we arrive at a more complete understanding of earthquake occurrence in the eastern United States.

OTHER MINOR QUAKES IN NEW JERSEY

"Mini" quakes are reported from time to time from all parts of the state. A series of mini quakes in the Lake Hopatcong area is noted in the listing below.

LOCATION OF EARTHQUAKE EPICENTERS IN AND NEAR NEW JERSEY



LISTING OF EARTHQUAKES FELT OR OCCURRING IN NEW JERSEY

The following list of twenty-four earthquakes and the data pertaining to them was extracted mainly from Report No. 41-1.

YEAR	DATE	LOCAL TIME	LOCATION	N. LAT.	W. LONG.	AREA SQ.MI.	MERCALLI INTENSITY
1737	Dec. 18	23:00	Near New York City	40.8	74.0	-	VII
1755	Nov. 18	4:11	East of Cape Ann, Mass.	42.5	70.0	300,000	VIII
1811	Dec. 16	2:00	New Madrid, Missouri	36.6	89.6	2,000,000	XII
1812	Jan. 23	-	New Madrid, Missouri	36.6	89.6	2,000,000	XII
1812	Feb. 7	-	New Madrid, Missouri	36.6	89.6	2,000,000	XII
1860	Oct. 17	6:00	Canada, felt to south	47.5	70.0	700,000	VIII, IX
1871	Oct. 9	9:40	Wilmington, Delaware	39.7	75.5	-	VII
1872	July 11	5:25	New York, felt in New Jersey	40.9	73.8	100	V
1874	Dec. 10	22:25	Westchester, New York	40.9	73.8	5,000	VI
1877	Sept. 10	9:59	Near Burlington, New Jersey	40.1	74.9	300	IV, V
1879	March 25	19:30	Delaware River	39.2	75.5	600	IV, V
1884	Aug. 10	14:07	Near New York City, N.Y.	40.6	74.0	70,000	VII
1886	Aug. 31	21:51	Charleston, So. Carolina	32.9	80.0	2,000,000	X
1895	Sept. 1	6:09	Near High Bridge, New Jersey	40.7	74.8	35,000	VI
1910	Apr. 23	-	New Jersey Coast	-	-	2,000	III, IV
1921	Jan. 26	18:40	Near Riverton, New Jersey	40	75	150	V
1925	Feb. 28	21:19	Canada, felt to south	47.6	70.5	2,000,000	VIII
1927	June 1	7:20	New Jersey Coast	40.3	74.0	3,000	VII
1933	Jan. 24	21:00	Near Trenton, New Jersey	40.2	74.7	600	V
1938	Aug. 22	22:36	Central New Jersey	40.1	74.5	5,000	V
1939	Nov. 14	21:54	Salem County, New Jersey	39.6	75.2	6,000	V
1951	Sept. 3	20:26	New York, felt in New Jersey	41.2	74.1	5,500	V (+4.4R)
1957	March 23	14:03	West-central New Jersey	40.8	74.8	-	VI
1961	Dec. 27	12:06	Pennsylvania-New Jersey Border	40.2	74.8	150	V

The following list of twenty-four earthquakes and their data were taken from "Earthquakes of Eastern Canada and Adjacent Areas"

YEAR	DATE	LOCAL TIME	LOCATION	N. LAT.	W. LONG.	AREA SQ.MI.	MERCALLI INTENSITY
1663	Feb. 5	17:30	St. Lawrence River	47.6	70.1	750,000	X
1727	Nov. 10	22:40	Near Newbury, Mass.	42.8	70.8	75,000	IX
1783	Nov. 29	22:50	West of New York City	41.0	74.5	-	VI
1804	May 18	-	Felt at New York City*	-	-	-	III
1841	Jan. 25	a.m.	Felt at New York City*	-	-	-	III
1847	Sept. 2	-	Felt from Newport, R.I. to Philadelphia, Pa. *	40.2	72.0	-	V
1847	Sept.29	-	Near New York City. Felt from R.I. to Phila.,Pa.*	40.5	74.0	-	V
1848	Sept. 9	22:00	Near New York City. Felt from R.I. to Phila.,Pa.*	-	-	-	V
1861	Mar. 5	12:00	Newark, N.J. (two shocks)*	-	-	-	III
1870	Oct. 20	11:30	Quebec, Canada	47.4	70.5	1,000,000	IX
1893	Mar. 9	12:30	New York City	40.6	74.0	-	V
1935	Nov. 1	1:04	Canada	46.8	79.1	1,000,000	VII(+6.25R)
1937	Sept.30	17:08	Verona, New Jersey*	40.8	74.3	-	III
1938	May 16	14:25	Felt in Verona, N.J.*	40.8	74.3	-	II, III
1938	July 29	2:44	New York City, Westchester Cty. and Palisades,N.Y.*	41.0	73.7	-	-
1938	Aug. 27	17:36	Felt in Trenton, N.J.*	40.2	74.4	-	III
1938	Dec. 6	14:38	Felt at Verona, N.J.*	40.8	74.3	-	III
1938	Sept.12	20:22	Felt in Union City, N.J.*	40.8	74.0	-	III
1940	Dec. 20	2:27	New Hampshire	43.8	71.3	150,000	VII(+5.8R)
1943	July 24	00:18	Off New Jersey Coast*	40.0	72.7	-	II
1944	Sept. 4	23:39	Massena, N.Y.	44.9	74.8	175,000	VIII(+5.9R)
1947	Apr. 1	8:25	Pompton Lakes, N.J.*	41.0	74.3	-	III
1953	Aug. 16	23:22	Bergen Co., New Jersey*	40.3	74.0	-	IV
1954	Mar. 31	16:25	Monmouth Co. Shoreline*	40.3	74.0	-	IV

*No additional information available for these shocks.

The following fifteen earthquakes and their data were compiled from sources, such as newspaper clippings, publications, and personal communications.

YEAR	DATE	LOCAL TIME	LOCATION	N. LAT.	W. LONG.	AREA SQ.MI.	MERCALLI INTENSITY
1943	Fall	evening	Mahwah, N.J. & Suffern, N.Y.	41.1	74.2	5+	V
1962	Mar. 6	-	N.J., 6 mi. from Ogdensburg	-	-	-	+0.3R
1962	Aug. 11	-	N.J., 12 mi. from Ogdensburg	-	-	-	+0.0R
1962	Oct. 13	-	Near Pompton Plains, N.J.	-	-	-	+1.0R
1962	Dec. 20	-	Near Pompton Plains, N.J.	-	-	-	+2.0R
1963	Jun. 24	-	N.J., 17 mi. from Ogdensburg	-	-	-	+0.5R
1968	Dec. 10	4:13	Near Riverton, N.J.	40.1	75.0	-	V(+2.9R)
1969	Aug. 14	-	Lake Hopatcong, N.J.	41.0	74.6	0	+1R
1969	Sept. 14	-	" " "	41.0	74.6	-	+1R
1969	Oct. 6	-	" " "	41.0	74.6	13	IV(+1.25R)
1969	Oct. 10	-	" " "	41.0	74.6	-	+1R
1969	Nov. 3	-	" " "	41.0	74.6	-	+1R
1972	Dec. 29	1:34	Wyckoff, N.J.	41.0	74.2	10	III
1973	Feb. 5	-	Hohokus, N.J.	41.0	74.1	5	I, II
1973	Feb. 28	3:21	Mahwah, N.J. to Baltimore Md.	40.1	75.0	3,000	VI(+3.8R)

Update to first edition. Various sources, including Bulletins 1, 2 and 3, Northeastern Seismic Network.

YEAR	DATE	LOCAL TIME	LOCATION	N. LAT.	W. LONG.	AREA SQ.MI.	MERCALLI INTENSITY
1974	Apr. 28	10:19	Wilmington, Del.	39.7	75.7	5	IV(+2-1/2R)
1974	May 17	10:08	Near Dingman's Ferry, Pa.*	41.2	75.0	-	(+1/2 R)
1974	June 9	16:45	Atlantic City to Wildwood, N.J.	-	-	100	IV, V
1974	June 17	14:30	Atlantic City to Ocean City, N.J.	-	-	50	IV
1974	June 27	11:33	Near Dingman's Ferry, Pa.*	41.3	74.8	-	(+1/2R)
1974	Sept.22	9:00	Atlantic & Ocean Counties N.J.	-	-	-	-
1974	Sept.23	-	" " "	-	-	-	-
1974	Sept.25	-	" " "	-	-	-	-
1975	Jan. 19	1:30	Mahwah, N.J.	41.1	74.1	-	-
1975	Feb. 9	-	West of Bricktown, N.J.	-	-	-	-
1975	Oct. 12	3:30	Princeton, N.J.	40.3	74.7	-	-
1975	Nov. 6	Noon	Atlantic City, N.J.	-	-	-	-
1975	Nov. 9	22:02	Greenwood Lake, N.J.*	41.2	74.4	-	-
1976	Mar.11	16:07	Riverdale, N.J.	41.0	74.4	-	IV (+2.5R)
1976	Mar. 12	5:29	Riverdale, N.J.	41.0	74.4	-	(+1-1/2-2R)
1976	Apr. 13	10:39	Ridgefield, N.J.	40.8	74.0	30	(2.5R)
1976	May 11	2:55	Off Sandy Hook, N.J.*	40.5	73.8	-	-
1976	May 11	8:18	" " " " *	40.5	73.8	-	-
1976	June 26	14:45	75 mi. off N.J.Coast*	39.8	72.5	-	-
1976	Dec. 5)	8:00	Morris County, N.J.	40.8	74.8	2	III
1976	Dec. 5)	11:32	" " "	40.8	74.8	2	III
1976	Dec. 6)	23.52	" " "	40.8	74.8	2	III
1977	Feb. 10	14:14	Wilmington, Del.	39.8	75.7	3	V (+2R)

*Small magnitude, picked up only by seismographs; no additional data.

Detailed Information on Earthquakes Listed

1663, February 5

In the St. Lawrence River between the mouth of Riviere LaMelbale on the north and the mouth of Riviere Ouelle on the south. Felt over the entire eastern part of North America--750,000 square miles. Accompanied by vast landslides along the St. Maurice, Batiscan and St. Lawrence Rivers. Sulte has shown from contemporary accounts that one of these slides practically levelled a very great waterfall at Les Gres on the St. Maurice River. Other damage was confined to cracked chimneys and the like. No loss of life was reported.

> "On the shores of Massachusette Bay houses were shaken so that pewter was jarred from the shelves and the tops of several stone chimneys were broken."

1727, November 9

In the mouth of the Merrimac River, near Newbury, Mass. Felt from Maine to Delaware. This extent (75,000 square miles) suggests that it could have been felt in southern Quebec; however no Canadian record of the shock has been found. In a history of Newbury, Stephen Jacques wrote the following eye witness account:

> "On the twenty-ninth day of October," (November 9 Gregorian Calendar,) "between ten and eleven, it being sabath day night, there was a terabel earthquake. The like was never known in this land. It came with a dreadful roreing, as if it was thunder, and then a pounce like grate guns two or three times close one after another. It shook down bricks from ye tops of abundance of chimnies, some allmost all the heads.... All that was about ye houses trembled, beds shook, some cellar walls fell partly down. Benjamins Plumer's stone without his dore fell into his cellar. Stone wals fell in a hundred plasis. Most peopel gat up in a moment. It came very often all ye night aftar, and it was heard two or three times some days and nights, and on the sabath day night on ye twenty-fourth of December following, between ten and eleven, it was very loud, as any time except ye first, and twice that night aftar but not so loud. The first night it broke out in more than ten places in ye town in ye clay low land, blowing up ye sand, sum more, sum less. In one place near Spring Island it blew out, as was judged twenty loads, and when it was cast on coals in ye night, it burnt like brimstone."

This earthquake was followed by many aftershocks.

1737, December 18

Chimneys were thrown down at New York City. Also felt at Boston, Philadelphia, and New Castle, Delaware.

1755, November 18

The earthquake came with a roaring sound like distant thunder, seemingly from the northwest. The shock resembled a long rolling sea and it was necessary to hold something to prevent being thrown to the ground. Tops of trees swayed through a large angle. Houses were shaken, windows rattled, and beams cracked. This lasted 2 minutes. The shock was felt from Chesapeake Bay to Annapolis River, Nova Scotia. It was felt on Lake George, and a ship at sea 200 miles east of Cape Ann was thought to have grounded though the water depth was considerable. At Boston, Mass., walls and chimneys were thrown down; waves were reported seen on the surface of the earth like the swelling of the sea. Gable ends of brick buildings were thrown down. Vanes on buildings were broken off. Stone fences were generally knocked down. A very strong cistern was broken by the agitation of the liquid within it. At Pembroke and Scituate, Mass., small chasms were broken open in the earth through which fine sand reached the surface. In the harbors and along the coast large numbers of fish were killed and many vessels felt shocks as if they were striking bottom. The tsunami which accompanied this earthquake withdrew the water from St. Martins Harbor in the West Indies, leaving vessels aground.

On November 22 at 20:27, there was a quite severe aftershock and others occurred on December 19, 22:00.

1783, November 29

West of New York City. Felt from New Hampshire to Pennsylvania. A foreshock at 9:00 PM and an aftershock at 2:00 PM November 30 were felt at both New York City and Philadelphia but nowhere else.

1811, December 16
1812, January 23 and February 7

Three quakes of maximum intensity, XII (IV to V in New Jersey). Numerous others of smaller intensity. Topographic changes over an area of 30,000 to 50,000 square miles. The total area shaken was at least two million square miles - distinctly felt over about one million square miles.

Damage - Very small for such great earthquakes because of sparse population.

Description - A little over 02:00 on December 16, the inhabitants of the New Madrid region suddenly were awakened by the groaning, creaking, and cracking of the timbers of their houses and cabins, the sounds of furniture being thrown down, and the crashing of falling chimneys. In fear and trembling, they hurriedly groped their way from their houses to escape the falling debris. The repeated shocks during the night kept them from returning to their weakened and tottering dwellings until morning.

Daylight brought little improvement to their situation, for early in the morning another shock, preceded by a low rumbling and fully as severe as the first, was experienced. The ground rose and fell as earth waves, like the long, low swell of the sea, passed across the surface, bending the trees until their branches interlocked and opening the soil in deep cracks. Landslides swept down the steeper bluffs and hillsides; considerable areas were uplifted; and still larger areas sank and became covered with water emerging from below through fissures or craterlets, or accumulating from the obstruction of the surface drainage. On the Mississippi, great waves were created which overwhelmed many boats and washed others high upon the shore, the returning current breaking off thousands of trees and carrying them into the river. High banks caved and were precipitated into the river; sandbars and points of islands gave way; and whole islands disappeared.

During December 16 and 17, shocks continued at short intervals but with diminishing intensities. They occurred at longer intervals until January 23 when there was another shock, similar in intensity and destruction to the first. This was followed by 2 weeks of quiescence, but on February 7, there were several alarming and destructive shocks, the last one equaling or surpassing any previous disturbance. For several days the earth was in constant tremor. There is a definite record kept at Louisville, Ky., that the aftershocks lasted throughout at least 2 years.

The record of earlier earthquakes goes back only to 1776, when a shock of moderate intensity occurred. There were similar shocks in the nineties and in the first decade of the following century. These caused the Indians to predict a great earthquake, the prediction being based on the Indian tradition of an earthquake at an earlier time. The geological evidence confirms this, but the date cannot be fixed.

In spite of the great intensity of the earthquakes, the loss of life was insignificant. At New Madrid, only one life was lost through falling buildings. Of course, the log cabin, which was the most common type of building at that time, was peculiarly suited to withstand earthquake damage. Chimneys were knocked down, and all the houses were thrown down or badly damaged at New Madrid. The destruction from various causes extended over the entire site of the town, which was consequently abandoned.

Chimneys were knocked down in Cincinnati, Ohio, St. Louis, Mo., and in many places in Tennessee, Kentucky, and Missouri.

Several persons were drowned when thrown into the river by caving banks, and a number of boatmen were lost when their boats sank. Also, many canoes were seen drifting, their occupants probably having drowned.

The most seriously affected area was characterized by raised and sunken lands, fissures, sinks, sand blows, and large landslides. This area was 30,000 to 50,000 square miles in extent, from a point west of Cairo, Ill., to the latitude of Memphis, Tenn., and from Crowleys Ridge to Chickasaw Bluffs, Tenn., a distance of 50 miles.

The shock of December 16 was felt distinctly in Washington, D.C., and the people were frightened badly. As might be expected, the western parts of the South Atlantic States were shaken more severely than the eastern parts. The shocks were moderate in the North Atlantic States, being felt at Boston and Baltimore.

During the New Madrid series, there seem to have been periods of darkness, probably caused by rising clouds of dust. There is little doubt that sulphur gas, due to buried vegetation, escaped from many of the crevices.

According to contemporary accounts, waves with visible depressions between the swells rolled across the earth and finally broke open leaving parallel fissures. These were reported to be from 600 to 700 feet long; one had a length of 5 miles.

Another type of fissure consisted of a long, narrow block that dropped and left a trench with vertical sides. In some places, the fissures were very close together, around 10 to 15 feet apart. Those near rivers were parallel to their courses. Others were usually northeast-southwest. Simple fissures ran up to 300 feet in length; others were considerably greater. The block fissures averaged 300 to 500 feet, with others much longer. The depths were from 10 to 20 feet - the depth to quicksand below.

There is some evidence of vertical faults, one of which is believed to have caused quite marked falls in the river, that lasted until the slope had been leveled off. Landslides occurred wherever the river banks were steep and where there were steep bluffs. In places, sections of forests were carried down or overthrown by the slides; many were split. In other areas, the vibration alone threw down trees.

Several sections were raised 15 to 20 feet above the level of the highest floods. One of these areas, known as Tiptonville Dome, is 15 miles long by 5 to 8 miles wide. There is another area about 10 miles in diameter with an uplift of 10 to 15 feet.

Large areas dropped by amounts reaching 15 feet in some cases, though 5 to 8 feet was more common. In eastern Arkansas, Lake St. Francis, so formed, is 40 miles long by a half mile wide. Over the sunken country, trees were killed by water overflowing the lower parts of the trunks. The cumulative effects of the earthquake destroyed forests over an area of 150,000 acres. The most typical sunken land of the area is Reelfoot Lake in Tennessee. This lake is 8 to 10 miles in length and 2 to 3 miles in width. The submergence ranged from 5 to perhaps 20 feet, although greater depths were reported.

To this day the region still experiences minor to moderate quakes from time to time.

<u>1860, October 17</u>

Center apparently near Riviere Ouelle, Canada, which was violently shaken, walls being damaged and chimneys thrown down. The shock was felt along the Atlantic coast of New England as far south as Newark, N.J.

1870, October 20
Centered near Baie-St.Paul, Que., where the greatest damage occurred. Felt throughout eastern Canada and in the United States westward to Iowa and southward to Virginia.

"Quebec:--...Buildings shook and bells rang; several chimneys were knocked down in Desfosses Street, and two persons nearly killed.

"A hasty note to let you know the disasters that were suddenly caused, here and in the vicinity, by the strangest earthquake in the memory of man. Approximately half an hour before noon a thunderbolt - this is the only word I can use for what happened - an enormous detonation threw everyone in a state of shock and the earth started not to shake but to boil in a manner to cause dizziness not only to the people in houses but also to the ones in the open air. All the dwellings seemed to be on a volcano and the earth, forming fissures in five or six places, was throwing up columns of water to six, eight and perhaps fifteen feet in the air carrying with it a quantity of sand which spread on the ground. Almost every chimney was thrown down and I believe there were not more than six left in the whole village. Walls of houses were thrown down; here and there stoves, furniture and other objects were overturned carrying with them utensils, china, etc. ... The church suffered very much; a part of the portico fell down and part of the ceiling and the remaining walls are so cracked that it is doubtful if they can be repaired... Some people arrived from various concessions so that we have reports from about twelve miles around and nowhere has a house remained intact. Everywhere the shock was as violent as here ..." quoting from a letter by Father Plamondon of Baie-St-Paul.

1871, October 9
At Wilmington, Del., chimneys toppled and windows broke. Damage also reported at Newport, New Castle, and Oxford. Rumbling and explosive sounds heard. Also felt in Middletown, Del., Haddonfield and Salem, N.J., and Chester and Philadelphia, Pa.

1872, July 11
The shock was felt over a nearly circular area, 10 miles in diameter with New Rochelle, N.Y., at the center. At Port Washington, L.I., long pendulum clocks stopped. A rumbling noise, then sounds like bursts of thunder, accompanied the shock. Felt in New Jersey.

1874, December 10
Shock felt in Westchester and Rockland Counties, N.Y., and Bergen County, N.J. Felt from Peekskill, N.Y., to Norwalk, Conn. Felt most strongly at Tarrytown and Nyack, N.Y., but no damage done. The shock lasting 5 to 6 seconds was accompanied by a noise like a long rumble ending in an explosion.

1877, September 10

Delaware Valley; felt from Trenton to Philadelphia over an area 20 miles wide with center near Burlington, N.J.

1879, March 25

Delaware River below Philadelphia, Pa. Felt from Chester, Pa., to Salem, N.J., over a distance of 30 miles. Felt most strongly on east side of river.

1884, August 10

This strong shock affected an area extending from Portsmouth, N.H., to Burlington, Vt., southwest to Binghamton, N.Y., Williamsport, Pa., southeast to Baltimore, Md., and east to Atlantic City, N.J. Greatest damage occurred at Jamaica and Amityville, N.Y., where large cracks appeared in walls. Thirty towns from Hartford, Conn., to West Chester, Pa., reported fallen bricks and cracked plaster.

1886, August 31

Charleston, S.C. The earthquake started with a barely perceptible tremor, then a sound like a heavy body rolling along; the sound became a roar. There was no break in the increasingly heavy jar. Everyone feared instant death. Finally the earth became quiet, the roar stopped, and the various human sounds, such as cries of pain and fear, wailing, and excited shouts, became audible.

The first shock was at 21:51 and the second 8 minutes later. People immediately began to gather in the large public square in Charleston to escape injury from falling buildings. The period until morning was filled with great anxiety, especially as there were exaggerated rumors of the number killed. Further shocks occurred at about 02 and 04. The utter stillness after each shock, combined with the lack of apparent cause, was appalling. A severe shock occurred at 08:30 which aroused great apprehension, as it was now seen that many of the buildings were either ruined or in dangerous condition. It was also known that about 60 people had been killed in the night and many injured, and it was feared that there were more casualties to come. Further shocks occurred at 13:00, 17:00, and about 20:00. By this time practically all people were in the streets.

In the vicnity of Charleston special effects were noted. In one place sulphur gas was very evident. There was a wave of some height on the Cooper River. In some places the motion was so great that people were overcome with nausea.

The great masonry structures were found to be severely damaged, though in some cases new portions were destroyed while the old remained intact. Buildings of three or more stories had diagonal cracks in the walls at the middle stories and vertical cracks near the top. Well-built wooden houses with parts carefully pinned together form a complete and elastic whole which tends to return to its original shape as soon as the disturbance has passed. However, some of the best houses were loosened at the joints so that they were shaken by passing vehicles and they were somewhat out of plumb. Curiously, a family living in a one-story wooden building slept through the earthquake without knowing that it had occurred. Chimineys of at least 14,000 houses were destroyed in Charleston.

Part of the damage was due to aftershocks, and on the whole it was considerable. Fortunately there was no wind, and the fires which started were extinguished without difficulty.

The first shock lasted 35 to 40 seconds and was apparently first vertical and then horizontal. The wave motion was very complex. Pictures were found with faces to the walls. In the cemeteries there was no prevailing direction for the fall of monuments, indicating that the shocks came from many directions, as might be expected so near the origin. Earth waves similar to ground swell were seen and estimated to be 2 feet high. This may have been the case in certain places, but in general, it seems likely they were not more than 4 or 5 inches in height. Such waves explain much of the destruction. Buildings showed both horizontal and vertical displacements. There were 10 severe and numerous moderate to light aftershocks up to September 30, and probably countless others recordable only by instruments. The series of heavy aftershocks undoubtedly helped to weaken the buildings previously damaged.

Through the epicentral area and in some regions outside of it, the ground was greatly fissured and in some cases water extruded. The cracks were rarely more than an inch wide, but near the streams the movement of the banks toward the stream left wider cracks. Where large quantities of water came up there was a round hole of considerable size with a greater basin at the ground surface. These were of all sizes from very small up to 20 feet in diameter. Much sand was brought up, usually from known beds of quicksand. In some cases the water rose in high jets carrying sand and mud.

The bending of rails and lateral displacement of the tracks were very evident in the epicentral region though not at Charleston. At a number of places the effect on culverts and other structures demonstrated that there was a strong vertical force in action at the time of the earthquake.

The estimated depth of focus, or depth below the surface at which the earthquake actually occurred, was 12 miles.

The area of severe effect was large, and the tremors were actually felt over an area with a radius of about 800 mi. so that 2,000,000 sq. mi. were affected, including undersea areas. Within an area of 100 miles in diameter, the destruction would have been severe except for the character of the country; settlements were few and far between and the prevailing type of building primitive, the log cabin being well designed to resist destruction by earthquakes. Throughout this region it was hard for people to remain on their feet.

The belt from 50 to 100 miles in radius was strongly shaken. This included two cities, Savannah and Columbia, each about 90 miles away. At the former, 300 chimneys were damaged and those poorly constructed were shaken down. Columbia felt the shocks still more strongly. Buildings swayed, plaster fell, and the undulatory movement of the ground made walking difficult.

The effect did not vary exactly with distance from epicenter, as geological conditions were an important factor. At Augusta, just over 100 miles from the epicenter, 100 chimneys fell and a dam fissured and broke. The shocks were as severe at Raleigh, 215 miles away, as at Wilmington, 152 miles away. The shock was felt at Boston, Milwaukee, Cuba, and as far east as Bermuda, 1,000 miles away. It was felt sharply at New York. There appears to have been a shadow zone where it was lightly felt, as compared with other places of similar distance in the Appalachian region of West Virginia, Maryland, and Pennsylvania.

Intensity felt in New Jersey was about III or IV.

1893, March 9

Centered in New York City. Animals at the Zoo were disturbed and billiard playing affected.

1895, September 1

Generally felt, extreme points, Virginia to Maine; centered in Hunterdon County, N.J., near High Bridge. In various places in this county buildings rocked; articles fell from shelves. Two shocks were felt at New Brunswick. Intensity V at Atlantic Highlands. Felt in all parts of the city of Newark. Fairly sharp at Camden and Burlington. At Philadelphia, windows were broken and crockery overturned. The shock seems to have been felt over a considerable distance northeast-southwest but rather narrow at right angles to this line. Not reported in Pennsylvania west of Easton.

1910, April 23

Atlantic City to Cape May, N.J., and Snow Hill, Md. While these shocks do not appear to have exceeded intensity IV, they were so widespread that they are included. At 21:30 there was a similar shock near Catonsville, Md.

1921, January 26

Moorestown and Riverton, N.J., shaken with intensity V. Rumbling noise.

1925, February 28

While the earthquake was felt widely in the northeastern U.S., and especially in Michigan, there was no record of damage or of direct loss of life though there were several deaths from shock. It was more instrumental in securing attention to the earthquake problem than any since 1906.

The earthquake was remarkable for moderate intensity over a great area and for great variations in intensity at the same distance from the epicenter in various directions. It probably affected a larger number of people than any previous shock in the United States since it was felt with an intensity IV or more in New York and Boston.

While a very large area was shaken, the area of important damage was comparatively small, confined to a narrow belt on either side of the St. Lawrence River. It was not easy to determine the epicenter since the epicentral region had few inhabitants and the instrumental records were somewhat conflicting.

The effects at Quebec are instructive as they were confined to places where the depth of soil was considerable. The upper part of the wall of the Canadian Pacific Railway station was damaged. At a large hotel not far away on rock, it was scarcely known that an earthquake occurred. This indicates the care that must be taken in judging the position of the epicenter from effects on buildings. Terrain, character of buildings, and geological formations are all determining factors in these effects.

In the vicinity of the epicenter there were few towns, and few buildings of considerable size except for occasional churches. At Pointe-au-Pic two old buildings with thick stone walls were badly damaged. At St. Urbain a church was badly damaged but otherwise only a few chimneys were thrown down, these being on buildings which were new, strong, and on a rock foundation. At Riviere Ouelle a 53 year old church in good repair, but built on alluvial soil, had the bells in its tower dislodged and the organ pipes twisted. Several houses were damaged here but only 20 miles away, buildings on rocky ground were unharmed.

Vertical motion could be expected near the epicenter but there were few opportunities for direct observation. At Riviere Ouelle a stone weighing 200 pounds was thrown clear of its foundation though there were dowel pins 2 feet apart and extending 2 inches above the foundation. A chimney collapsed through vertical thrust from below.

The ground was deeply frozen. Cracks appeared on the south shore in the form of grids. There was a crack near Riviere Ouelle 4 inches wide and more than 2 feet deep after it had been partly filled. No cracks in rocks were reported. In places of deep alluvium the frozen part seemed to have slid on the unfrozen part, leaving cracks through which water and wet sand reached the surface.

The only way to determine whether change of elevation occurred was by lines of precise levels. A former line in the general region was rerun with definite indication in some places of changes of about 3 inches. Because of the lack of railways no previous lines had been run in the epicentral region.

One hundred aftershocks were noted in a week at Chicoutimi, and shocks continued for several months. The strongest were felt on

April 10 at Murray Bay and April 25 at Chicoutimi. A preliminary shock occurred on September 30, 1924.

Intensity experienced in New Jersey was about IV or less.

1927, June 1
Three shocks were felt along the New Jersey coast from Sandy Hook to Toms River. Highest intensities were observed at Asbury Park to Long Branch, where several chimneys fell, plaster cracked, and articles were thrown from shelves.

1933, January 24
A sharply felt shock near Trenton, N.J. Pictures thrown from wall and people reported thrown out of bed at Lakehurst.

1935, November 1
About 4 miles north and a little to the east of Timiskaming Station, Que. The shock was felt over an area of more than 500,000 square miles. The limit of perceptibility to the north is not defined because of lack of human habitation. It extends, however, from Fort William, Ont., in the west to the Bay of Fundy in the east and southward into Kentucky and Virginia. The shock was felt at scattered points outside this area.

Hodgson made an extensive study of the epicentral region for a month after the shock. He reports that the greatest damage occurred in Timiskaming, Que. Here, about 80 percent of the chimneys were damaged even though they were nearly all lined with tile and capped with cement. The tops of the chimneys "mushroomed" and had to be rebuilt but did not actually fall at the time of the shock. Some cracks developed in solid brick walls though much brick-veneer construction escaped damage. Forty miles from the epicenter, at Mattawa and North Bay, many chimneys were thrown down.

Cracks appeared in the gravel and sand at the edges of islands and borders of lakes. One beside Lake Timiskaming was more than 200 feet long and a stick could be thrust into it to a depth of 3 feet. The deep and clear water of T-Lake, close to the epicenter, was muddied to the colour of "cafe au lait" by the shock. Other lakes in the area were not affected. Displacement of heavy bodies was common in and near Timiskaming.

This shock furnished a well-documented instance of triggering of a landslide by an earthquake. At Parent, Que., 190 miles from the epicenter, more than 100 feet of the Canadian National Railways right of way slid into a small lake. That the slide was imminent and the earthquake acted as a trigger was deduced from the fact that delicately balanced rocks in rock cuts near the slide were not disturbed.

As is usual when shocks are of the size of this one, many aftershocks were felt in the epicentral area. They were very frequent during the rest of November 1 and continued for some months after the main shock.

1938, August 22
In western corner of Monmouth County. Slight damage at Gloucester City and Hightstown, N.J.; and Ardmore, Pa. Felt through central New Jersey, southeast Pa., and northern Delaware. Four smaller shocks occurred on the 23rd and one on the 27th.

1939, November 14
Salem County, N.J. About 6,000 square miles affected. Little or no damage.

1940, December 20
Centered near Ossipee Lake, N.H. This shock was followed by a dozen aftershocks large enough to be located from instrumental data. The first was of equal magnitude. Three others had magnitude 3 to 4. The remaining eight to which magnitudes have not been assigned but which were presumably smaller, occurred at the following times: December 24, - 13:00, 14:32, 18:12; January 2 - 3:42; January 4 - 11:10; January 18 - 23:25; January 23 - 0:14; February 12 - 22:23. One observer in the vicinity of the epicenter, reported that 129 aftershocks had occurred by the end of January. The two largest shocks reached intensity VII at Tamworth and Wonalancet, both in New Hampshire. They were felt from Pennsylvania and New Jersey eastward through Maine and in southern Canada.

1943, Fall
This account was given recently from memory by a resident, long after the event, in response to publicity of quakes in local newspapers:

> Doors and dishes rattled, hanging lamps swung, furniture shifted. Earth shook perceptibly underfoot after group ran outside in night clothes.

This shock also felt in Suffern, N.Y., about 2-1/2 miles to the north.

1944, September 5
About 3 miles north of Massena, N.Y., close to the International Boundary. The origin time and co-ordinates, together with their respective uncertainties, are those calculated by Milne who used data from 23 seismograph stations.

The area over which this earthquake was perceptible extends from James Bay south to Virginia and from New Brunswick west to Lake Michigan. However, the area in which the shock was felt with an intensity as great as V or VI is relatively small. The area of greatest intensity extends farther lengthwise along the St. Lawrence River than perpendicular to it. The region where the intensities were of the order of VI extends from Montreal to the

Thousand Islands but at Ottawa, which is 20 miles closer to the epicenter than either, the intensity was only V. The same pattern is evident south of the river. The maximum intensity of VIII occurred in the vicinity of Cornwell, Ont., and Massena, N.Y. The total damage was estimated at $2,000,000.

Prior to the earthquake neither seismograph records nor reports from residents gave any indication of increasing seismic activity in the area. Three small events recorded only at Ottawa during the year may or may not have originated near Massena.

The main shock was followed by many aftershocks.

1951, September 3

Many people were alarmed and buildings creaked at Greenwood Lake and Tomkins Cove, N.Y. Felt from Windsor, Conn., southwest to Pompton Lakes and Dover, N.J., and from north shore of Long Island Sound to Walden and Middletown, N.Y.

1957, March 23

West-central New Jersey. Slight damage in the Lebanon-Hamdon-Long Valley areas, consisting of cracked chimneys, broken windows and dishes, cracked walls and plaster, and broken well curb. Many people were frightened.

1961, December 27

Pennsylvania-New Jersey border. At Bristol and in northeastern part and suburbs of Philadelphia, buildings cracked and dishes rattled. Police and newspaper offices were swamped with calls from alarmed citizens. Felt by many of Levittown and Langhorne, Pa., and Bordentown and Trenton, New Jersey.

1962-1963, March 6, 1962 to June 24, 1963

Five minor earthquakes in northern New Jersey, as well as several other minor quakes from more distant locations were detected by Lamont-Doherty Geological Observatory seismographs in a special study by Bryan Isacks and Jack Oliver.

The principal instrument was an extremely sensitive (magnification of 8 million) seismograph located in a deep mine at Ogdensburg, N.J. This instrument could detect quarry blasts in New England and was, therefore, used only at night when such blasts and other noises were rare.

Two other less sensitive seismographs (one at Ogdensburg and one at Sterling Forest, N.Y.) were also used in this study.

No local reports from the areas affected were given in the report; therefore, Mercalli intensities cannot be given.

The shocks of March 6, August 11 and June 24 were detected only by the one instrument. Therefore, only the distance to the epicenter and not the exact location could be determined (see section on elementary seismology above).

<u>1968, December 10</u>

Epicenter near Delaware River, 15 miles southwest of Newbold Island. Felt in small area of northeastern Pennsylvania; southern New Jersey and Delaware, but caused no damage.

<u>1969, August 14 to November 3</u>

Five shocks felt in the Lake Hopatcong area. Reports were received by Lamont-Doherty Geological Observatory seismologists in response to questionnaires published in local newspapers.

The quake of October 6 was the most widely felt. One of the 81 positive responses to the questionnaire for this quake reported cracking in plaster walls; all others reported less severe effects.

The other four quakes were milder and less widely felt. Intensity data are not available for these four.

According to residents of the region, no shocks have been felt in the 30 years preceding this sequence.

A total of 42 earthquakes was recorded by the seismograph at Ogdensburg, N.J., from August 13 to November 9, 1969.

<u>1972, December 29</u>

Waldwick, Wyckoff and parts of Midland Park, N.J., experienced a very local shock. Waldwick police headquarters was forcefully shaken and a rumble (like a sonic boom) was heard. The Waldwick police received 57 telephone calls about the shock.

Although about III on the Mercalli scale, Lamont-Doherty Observatory's seismographs in Rockland County (10 and 17 miles away) reported no major tremors. (This shock is probably assosociated with the Ramapo Fault, see text.)

Note: Mr. Del Vecchio reports that his high gain seismograph in Paterson (only 6 or 7 miles away) showed ".... not the slightest trace of activity...." for this presumed quake or for the one of February 5, 1973. Noting that his equipment was definitely operating properly, he suggested that these events might have been man-made, perhaps sonic booms.

<u>1973, February 5</u>

Very local tremors at 8:55 P.M., 10:00 P.M., and 11:15 P.M. Five calls to Hohokus police reporting shocks. Possibly an aftershock from tremor of December 29.
(See Note above.)

<u>1973, February 28</u>

Mahwah, N.J., to Baltimore, Md. Richter magnitude 3.8, lasting six seconds. The fault motion was "dip slip" (vertical) on a nearly vertical plane striking N 28 E with the southeast side moving down relative to the northwest. Focal depth from 3 to 5 miles. Intensity felt in New Jersey reached IV (Mercalli).

Trenton area police departments received over 50 telephone calls from residents reporting shaking dishes, rattling, and tables and chairs jiggling. One homeowner in Lawrence Township reported that her well water became muddy.

Two residents from Ringwood and one from Mahwah, N.J., reported vibrating furniture and pictures on walls disturbed. This earthquake was more severely felt in Philadelphia where residents reported being dumped out of bed.

1974, April 28

At least fifty (50) phone calls to police and radio stations and fifty-six (56) detailed "felt reports" to the Delaware Geological Survey. Reported as a loud explosive sound with a sharp vibration. Felt about two to three seconds. Doors, windows and small objects rattled, pictures shifted.

1974, June 9 and June 17

Windows rattled, buildings shook, explosive type noise. Windows broken in Wildwood on June 9th. Five or six individual tremors felt in Northfield on the 9th. Seven shocks reported on the 17th.

The cause of these shocks is unknown. They were not picked up by seismographs of Lamont Observatory. Speculations ranging from sonic booms to meteorite showers have been offered, but largely discounted. Offshore oil explorations using explosive charges is strongly suspected but not confirmed.

1974, September 22, 23 and 25

Widely reported to police, not confirmed by seismographs. Fort Dix was conducting artillery practice on the 22nd and the 25th but not the 23rd.

Shocks of unknown origin similar to these and those of June 9th and 17th have been reported off the coast of North Carolina. These have been dubbed the name "Seneca Guns." These were picked up by a number of seismographs. The time delays between the reception of the shocks at successive seismograph stations indicates that their velocity equals the velocity of sound in air, not rock. The Seneca Guns are therefore not earthquakes. Perhaps the South Jersey coast shocks are the same.

1975, January 19

Shook houses in Mahwah. The water level in a swamp dropped four to six inches, returning to normal in a week. At least one well in Mahwah turned brown.

1975, February 9

Rumbling, explosion-like west of Bricktown toward Fort Dix.

1975, October 12

Shook windows for a few seconds. Shook bed of person not yet asleep, others not awakened.

<u>1975, November 6</u>
Numerous reports to radio station. Not picked up by seismographs.

<u>1976, March 11</u>
Numerous calls to police stations at Kinnelon, Riverdale and Bloomingdale with a "flurry of inquiries." Lamont Observatory installed two portable seismographs the next day to monitor possible aftershocks.

<u>1976, March 12</u>
Although only slightly smaller in magnitude than the previous day's shock no reports were received by the police. This may be due to the early hour of the morning.

<u>1976, April 13</u>
Like explosion or sonic boom. Like truck hitting side of building. Felt in at least a dozen Bergen and Hudson County communities. Knocked dishes off table, pictures off wall and vase off TV set. Rattled windows. Felt over a much larger area than the shock of March 11th even though about the same magnitude.

<u>1976, December 5 and 6</u>
Three very sharp shocks felt in a very limited area. Rumbling or explosion-like shocks heard indoors. Water main ruptured, presumably weakened by the first shock. Picked up by several seismographs of Lamont Observatory. Magnitude in doubt but rather small. Smaller shocks have been felt from time to time in this area. Two smaller shocks were felt January 6 and March 8, 1977.

Due to the limited area and magnitude, a shallow focus is indicated. The source may simply be mine collapse within one of the many abandoned iron mines in the area.

<u>1977, February 10</u>
Small earthquake centered near Wilmington, Delaware. "Most observers felt a small, sharp jolt accompanied by an explosive noise."

About thirty similar shocks have been recorded in the Wilmington area since 1971, including the most widely felt one of February 28, 1973.

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