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EARTHQUAKE FLUCTUATIONS IN WELLS IN NEW JERSEY

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EARTHQUAKE FLUCTUATIONS
IN WELLS IN
NEW JERSEY

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State of New Jersey

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Department of Conservation
and Economic Development

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INTRODUCTION

New Jersey is fortunate to be situated in a region that is relatively stable, geologically. For this reason scientists believe, on the basis of the best scientific evidence available, that the chances of New Jersey experiencing a major earthquake are very small. The last major earthquake on the east coast occurred at Charleston, S. C., in 1886. Minor shocks have been felt in New Jersey, however, from time to time. Reports of dishes being rattled or even of plaster in buildings being cracked are not uncommon. These minor disturbances are generally restricted to relatively small areas.

The study of earthquakes, their causes and effects, and the ways in which the shocks are transmitted, is called "seismology." Seismologists, the scientists who specialize in the study of earthquake activity, are men trained in geology, engineering, and physics. They have learned that earthquakes are the result of the sudden release of stresses that have developed in the crust of the earth. Earthquakes are recorded by sensitive instruments called seismographs, which measure the duration and magnitude of the shock waves throughout the world. Through the interchange of seismologic information from widely scattered stations over the earth, the epicenters of earthquakes are located and their magnitudes computed. (An epicenter is the area on the earth's surface directly above the place of origin of an earthquake.)

Major seismograph stations near New Jersey are in New York City, Philadelphia, and Washington, D. C. The instruments at these stations are so sensitive that they are able to pick up shock waves from most of the earthquakes that occur daily throughout the world. The clearing house and point of distribution for this seismologic information in the United States is in Washington, D. C.

Since 1923, the New Jersey Division of Water Policy and Supply and its predecessors have cooperated with the U. S. Geological Survey in a study of the ground-water resources of the State. The investigations have been centered largely in areas of major ground-water use, and one phase of this work has been the observation and recording of water-level changes in wells. Fluctuations of water levels are important because they are related to the discharge and replenishment of water that occurs in the rocks. During these many years, measurements have been made in several thousand wells. A small proportion of these measurements have been made by recording instruments called water-stage recorders, which make a continuous graphic record of the water-level fluctuations in a well. About 100 of these recorders are currently in operation in New Jersey. *(See fig. 1.)*

Beginning several decades ago, scientists studying charts produced by the water-stage recorders occasionally noticed unusual fluctuations of water levels, most of which involved sudden changes that interrupted an otherwise steady condition. Such fluctuations did not appear to be related to the discharge and replenishment of the ground-water supply, so other causes were sought. Occasionally the engineer or geologist on the job found that a small animal, such as a frog or a mouse, had fallen into the well and created the disturbance. In other cases the fluctuation was found to be caused by wind, by tampering, or by quirks in the operation of the instrument. Many anomalies remained, however, that appeared to represent actual sudden changes in the water level in the well, unrelated to the well itself.

It is now known that the shock wave resulting from an earthquake, in being transmitted through the earth may disarrange, either temporarily or permanently, the structure of a water-bearing formation and cause fluctuations of water levels. This idea has been confirmed by correlating the time of occurrence of many of these fluctuations with the recorded time of an earthquake. Since 1950, about 200 sudden fluctuations of water levels in 38 wells in New Jersey definitely have been correlated with earthquakes. *(See fig. 2.)* Thus, the maintenance of water-stage recorders on wells, in the course of ground-water investigations, has provided a new means of studying earthquakes and many observation wells are, in effect, crude seismographic stations.

A careful study of the recorder charts indicates that there has been no permanent effect on the water levels in any well in New Jersey. This suggests that there also has been no permanent effect on the water-bearing formations.

DESCRIPTION OF OBSERVATION WELLS

Figure 2 shows the location of all wells whose hydographs have shown the results of earthquake shocks since 1950. *Table 1* shows the name of each well and its geographic location, the number of times fluctuations have been observed, the depth of the well, and the character and name of the water-bearing formation. These wells range in depth from 8 to 843 feet. Two are dug wells 8 and 17 feet deep. The others are drilled wells 24 to 843 feet deep. Some of the wells are more consistent in showing fluctuations than others. The greatest number of fluctuations observed has been in the Esterbrook Pen Co. well in Camden *(table 1, well 21)*. Besides well 21, three others show earthquake effects consistently. Wells 6, 7, and 13 have shown 10 or more quakes; well 9 has recorded 5 quakes; and all the others have shown less than 5. Most of the wells described in this report are in sands and gravels of the several Coastal Plain formations, eight are in the reddish sandstones of the so-called Triassic belt of rocks; four are in sand and gravel laid down during the Ice Age, and one is in ancient crystalline rock called the Wissahickon formation.

SEISMIC EFFECTS IN WELLS

Earthquakes have caused water-level fluctuations in New Jersey wells that range in amplitude from a trace to 2.66 feet. This largest fluctuation was noted in the Upsala College well in Union County on July 6, 1954 *(table 1, well 8)*. The quake causing this disturbance had

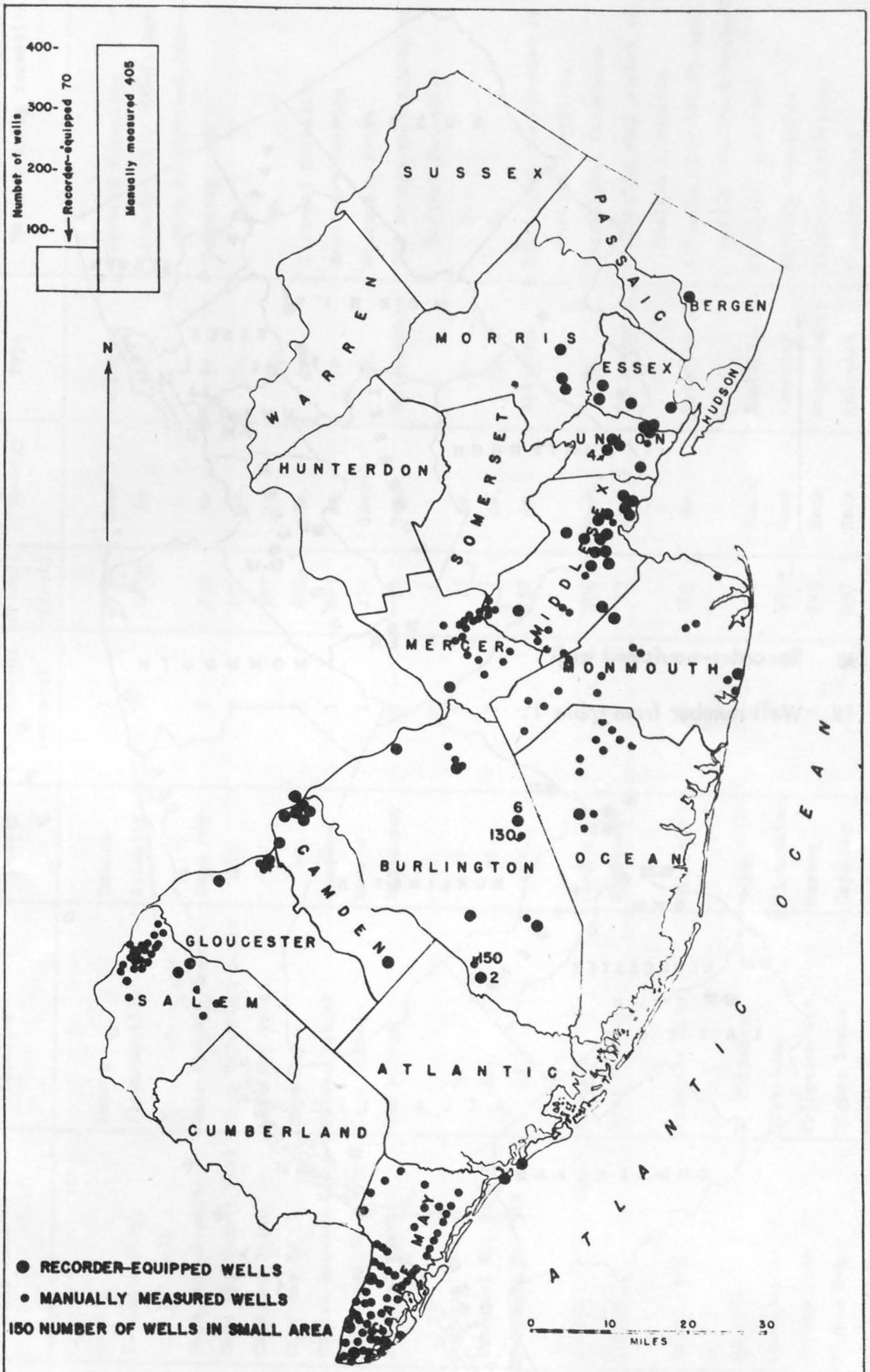

Figure 1.-- GROUND-WATER OBSERVATION WELLS IN NEW JERSEY

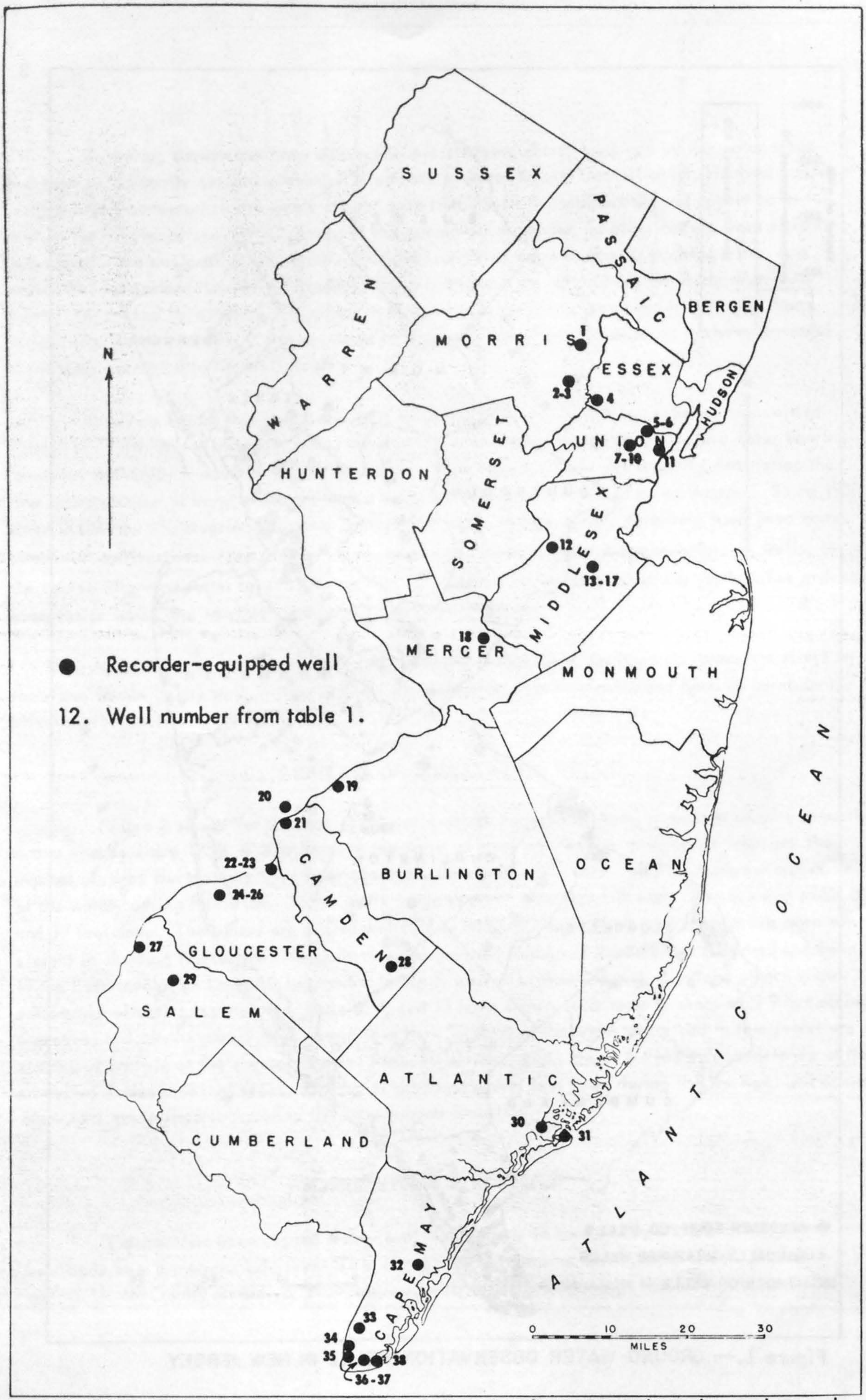

Figure 2.--Location of wells in which earthquake fluctuations have been observed.

Table 1.--Wells in which earthquake fluctuations have been recorded from 1950 through September 30, 1959

Map location No.	Well name	Location	County	Number of fluctuations reported	Depth of well (feet)	Aquifer: Lithology	Aquifer: Type	Aquifer: Water-bearing formation
28	Ancora	Ancora	Camden	1	450	Sand	Artesian	Kirkwood formation
30	Atlantic City 600' well	Pleasantville	Atlantic	1	680±	do.	do.	Atlantic City 800-ft sand unit of Kirkwood formation
33	Cape May Airport	Near Fishing Creek	Cape May	3	255	do.	do	Cohansey sand
32	Cape May County Park	Cape May Court House	do.	2	232	do.	do.	Do.
35	Cape May Point	Cape May Point	do.	1	277	do.	do.	Do.
36	Cape May No. 4	Cape May	do.	1	600	do.	do.	Kirkwood formation
20	Cities Service Oil	Pettys Island	Camden	1	143	do.	do.	Raritan formation
4	Commonwealth No. 30	Near Chatham	Morris	1	130	Gravel	do.	Wisconsin drift
13	Duhernal No. 1	Old Bridge	Middlesex	17	67	Sand	Water-table	Old Bridge sand member of Raritan formation
14	Duhernal No. 4	do.	do.	1	75	do.	do.	Do.
15	Duhernal No. 39 O B	do.	do.	3	?	do.	do.	Do.
16	Duhernal No. 52F	do.	do.	1	250	do.	Artesian	Farrington sand member of Raritan formation
21	Esterbrook Pen Co.	Camden	Camden	31	286	Rock	do.	Wissahickon formation
12	Fisher	Near Milltown	Middlesex	3	17	Sand	Water-table	Farrington sand member of Raritan formation
31	Galen Hall	Atlantic City	Atlantic	1	843	do.	Artesian	Atlantic City 800-ft sand unit of Kirkwood formation
11	Grassman	N. Elizabeth	Union	1	200	Shale	Semiartesian	Brunswick formation
24	Hercules No. 3	Gibbstown	Gloucester	1	100±	Sand	Artesian	Raritan formation
18	Heyden Chem. Co.	Princeton Jct.	Mercer	1	248	Rock	Water-table	Stockton formation
34	Higbee Beach	Higbee Beach	Cape May	1	252	Sand	Artesian	Cohansey sand
5	Hillside No. 1	Hillside	Union	3	400	Shale	do.	Brunswick formation
6	Hillside No. 4	do.	do.	23	400	do.	do.	Do.

Table 1.--Wells in which earthquake fluctuations have been recorded from 1950 through September 30, 1959--Continued

Map location No.	Well name	Location	County	Number of fluctuations reported	Depth of well (feet)	Aquifer		
						Lithology	Type	Water-bearing formation
2	Madison "D"	Madison	Morris	4	181	Sand and gravel	Artesian	Wisconsin drift
3	Madison No. 4	do.	do.	2	100	do.	do.	Do.
27	Penns Grove No. 24	Penns Grove	Salem	2	51	Sand	Water-table	Raritan and Magothy formations
25	Repauno No. 1	Gibbstown	Gloucester	2	127	do.	Artesian	Do.
26	Repauno No. 2	do.	do.	2	98	do.	do.	Do.
17	Runyon No. A-4	Near Old Bridge	Middlesex	1	24	do.	Water-table	Old Bridge sand member of Raritan formation
19	Riverton-Palmyra	Palmyra	Burlington	1	46	do.	Artesian	Raritan and Magothy formations
29	Seabrook No. 5	Woodstown	Salem	4	8	do.	Water-table	Kirkwood formation
22	Texas Co. No. 1	Westville	Gloucester	1	327	do.	Artesian	Raritan and Magothy formations
23	Texas Co. No. 2	do.	do.	2	300	do.	do.	Do.
7	Union Co. Park Well	Kenilworth	Union	10	290	Shale	do.	Brunswick formation
38	U. S. Coast Guard	Sewells Point	Cape May	1	325	Sand	do.	Cohansey sand
8	Upsala College	Kenilworth	Union	3	190	Shale	do.	Brunswick formation
37	West Cape May	West Cape May	Cape May	2	293	Sand	do.	Cohansey sand
1	Whippany	Near Whippany	Morris	1	170	Sand and gravel	do.	Wisconsin drift
9	White Labs. No. 2	Kenilworth	Union	5	250	Shale	do.	Brunswick formation
10	White Labs. No. 4	do.	do.	2	400	do.	do.	Do.

its epicenter at Fallon, Nevada, and was 6.6 in magnitude *(p. 10)*. A check of the amplitude of all fluctuations reported since 1950 shows that they generally range between 0.08 and 0.10 foot.

West Yellowstone Earthquake

On August 18, 1959, an earthquake which caused heavy damage and resulted in the death of a number of persons occurred near West Yellowstone, Montana. This quake was recorded at about 7:00 a.m. Greenwich Civil Time (usually written 7h 00m G.C.T.) in six wells in New Jersey. (Greenwich Civil Time is used throughout the world in reporting earthquakes; it is 5 hours later than Eastern Standard Time.) The initial shock caused the observed water levels to fluctuate 0.8 to 0.72 foot. Hillside Well 4 *(table 1, well 6)* showed the greatest fluctuation. Later that day there was a second shock, or aftershock, of less magnitude. This was recorded on the same chart at approximately 16h 00m G.C.T. *Figure 3* is a reproduction of a portion of the recorder chart from this well showing how these shocks cause water levels to fluctuate. A quake that occurred in the Solomon Islands the day before is shown also.

Other Earthquakes

Figure 4 shows other earthquke fluctuations in the same well. T' shock of November 29, 1957, originated in Southern Bolivia at 22h 19m G.C.T. and was recorded here at about 22h 30m G.C.T. The computed travel time for the shock wave to reach the well was less than 15 minutes, and this shock caused the water level in the well to fluctuate 0.05 foot. On January 19, 1958, two shocks were reported as originating near the coast of Ecuador; the main shock had a magnitude *(p. 10)* of 7 1/2, and the aftershock, which followed 36 minutes later, had a magnitude of 6 3/4. Both the main shock and the aftershock were recorded in Hillside Well 4 *(table 1, well 6)*. The main shock caused the water level to fluctuate 0.16 foot, and the aftershock 0.05 foot. The travel time for these two shock waves to reach New Jersey was less than 10 minutes each.

Earthquake shocks that cause seismic fluctuations in wells in New Jersey are generally 7.0 or greater in magnitude. Water-level disturbances have been caused by shocks of magnitudes less than 7.0 also, but in all such cases the epicenters of the shocks were relatively close to New Jersey.

Figure 5 is a map of the world showing the epicenters of earthquakes that caused observable water-level disturbances in wells in New Jersey during the period 1950-59, inclusive. In a few cases, more than one shock originated within the area of one dot.

Earth shocks origninating in the Atlantic Ocean, northeast and southeast of New Jersey, produced no discernible water-level disturbances in New Jersey. There have been several shocks with a magnitude of 6.0 or greater reported from this area, and the epicenters of several quakes were relatively close to the New Jersey coast, but a careful check of well records failed to show any disturbance. The reason for this apparent damping effect is not clearly understood.

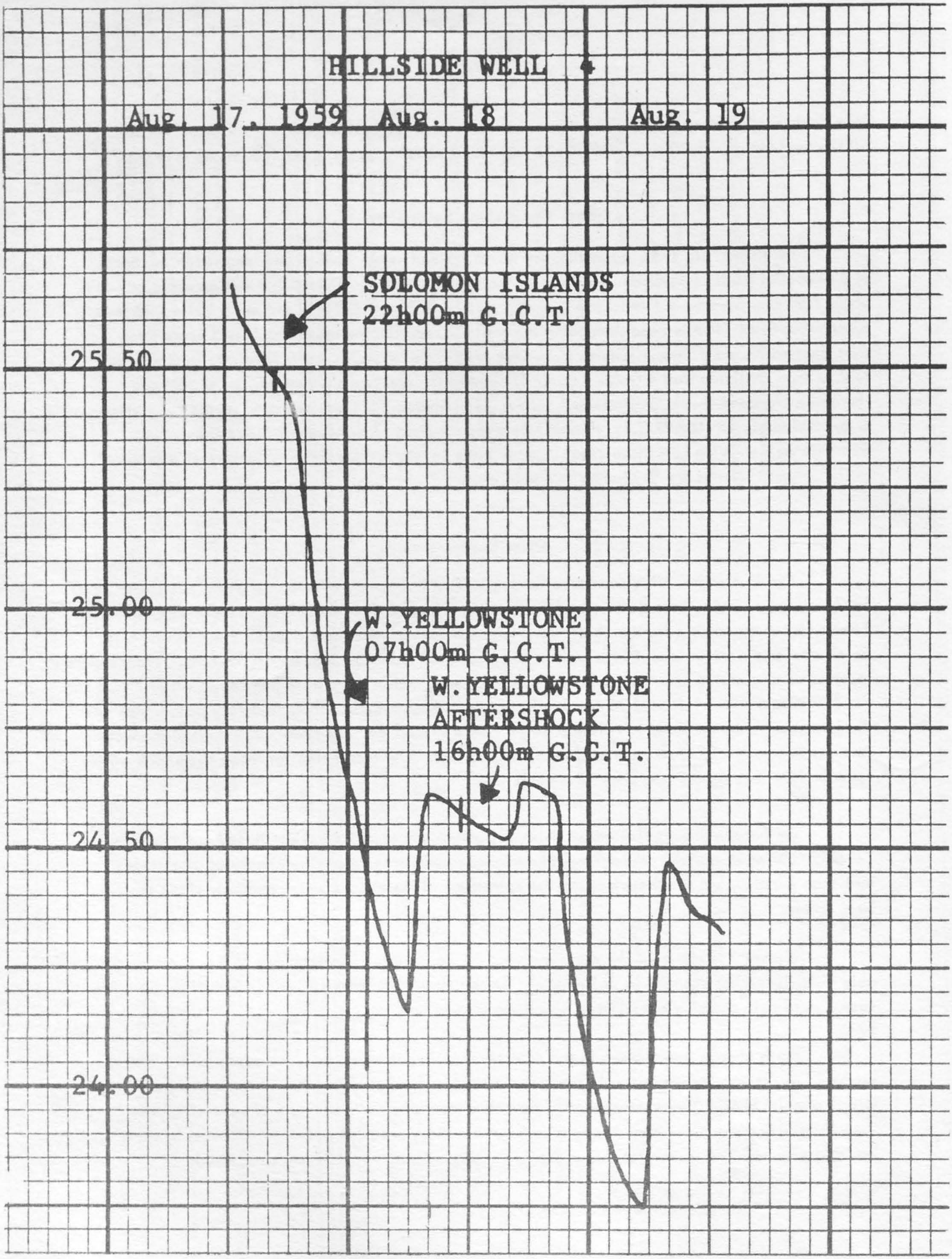

Figure 3. – Chart from Hillside Well 4 showing effects of West Yellowstone earthquake of August 18, 1959, and of Solomon Island earthquake of August 17, 1959.

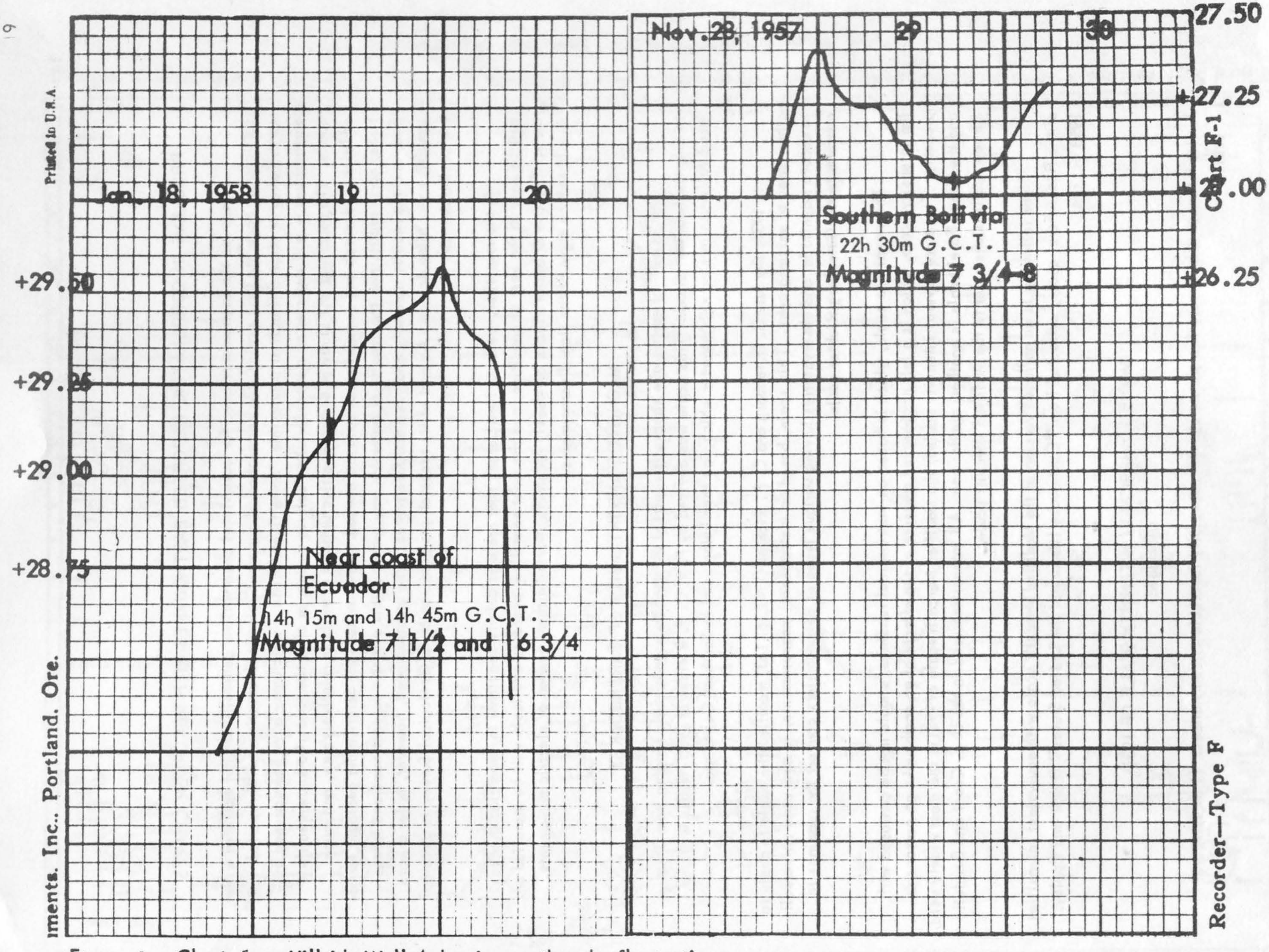

Figure 4.--Charts from Hillside Well 4 showing earthquake fluctuations.

PROBLEMS IN CORRELATING REPORTED EARTHQUAKES WITH RECORDER CHARTS

Because the instruments used for water-level observations generally are not operated with sufficiently accurate time scales, the correlation of apparent seismic fluctuations with reported earthquakes is often difficult or impossible. Some fluctuations – which may have been caused by earthquakes – will register on a recorder chart before, during, or after the time of a known earthquake. The reporting and study of earthquake fluctuations in wells is relatively new, and much additional research and correlation of data are needed. New methods for determining geologic formations, earth faults, and the density of materials may result if this program is continued and intensified, and the results carefully analyzed and interpreted. The greatest need, however, is for a more sensitive recording device. As part of its research program, the U. S. Geological Survey is developing such a device.

In the meantime, wells in New Jersey that are particularly sensitive in recording shocks will be kept in the best of condition, and the most sensitive recorders available will be installed on them. The use of better clocks on weekly recorders, having either jeweled or electric movements, should reduce some of the time discrepancies.

MAGNITUDE AND INTENSITY OF EARTHQUAKES

The "size" of earthquake shocks is reported as magnitude on a scale ranging from 0, up to 8.5, the heaviest shock. This scale was devised by Prof. C. F. Richter in 1935 for use with the Wood-Anderson torsion seismometer which was then being used in Southern California.

In 1936, the late B. Gutenberg and C. F. Richter (1942, p. 163) modified the scale to apply to other types of seismographs. This scale, based on instrumental measurements, is now used universally to denote magnitude, and observatories having various types of seismometers convert the readings to conform to the Gutenberg-Richter scale.

The magnitude scale, which is based on instrumental readings, should not be confused with the intensity scale, which is a felt or observed measure of the effects of an earthquake on persons or property. There are several intensity scales; the Modified Mercalli scale of 1931 is the most widely used, and the Rossi-Forel scale is another, similar one. All intensities used in the U. S. Coast and Geodetic Survey publications refer to the Modified Mercalli scale.

The following is an abridged version of the Modified Mercalli scale with equivalent intensities of the Rossi-Forel scale, extracted from "Earthquake History of the United States" (Heck and Eppley, 1958, p. 3, 4).

MODIFIED MERCALLI INTENSITY SCALE OF 1931
(Abridged)

1. Not felt except by a very few persons under especially favorable circumstances. (1 Rossi-Forel scale.)

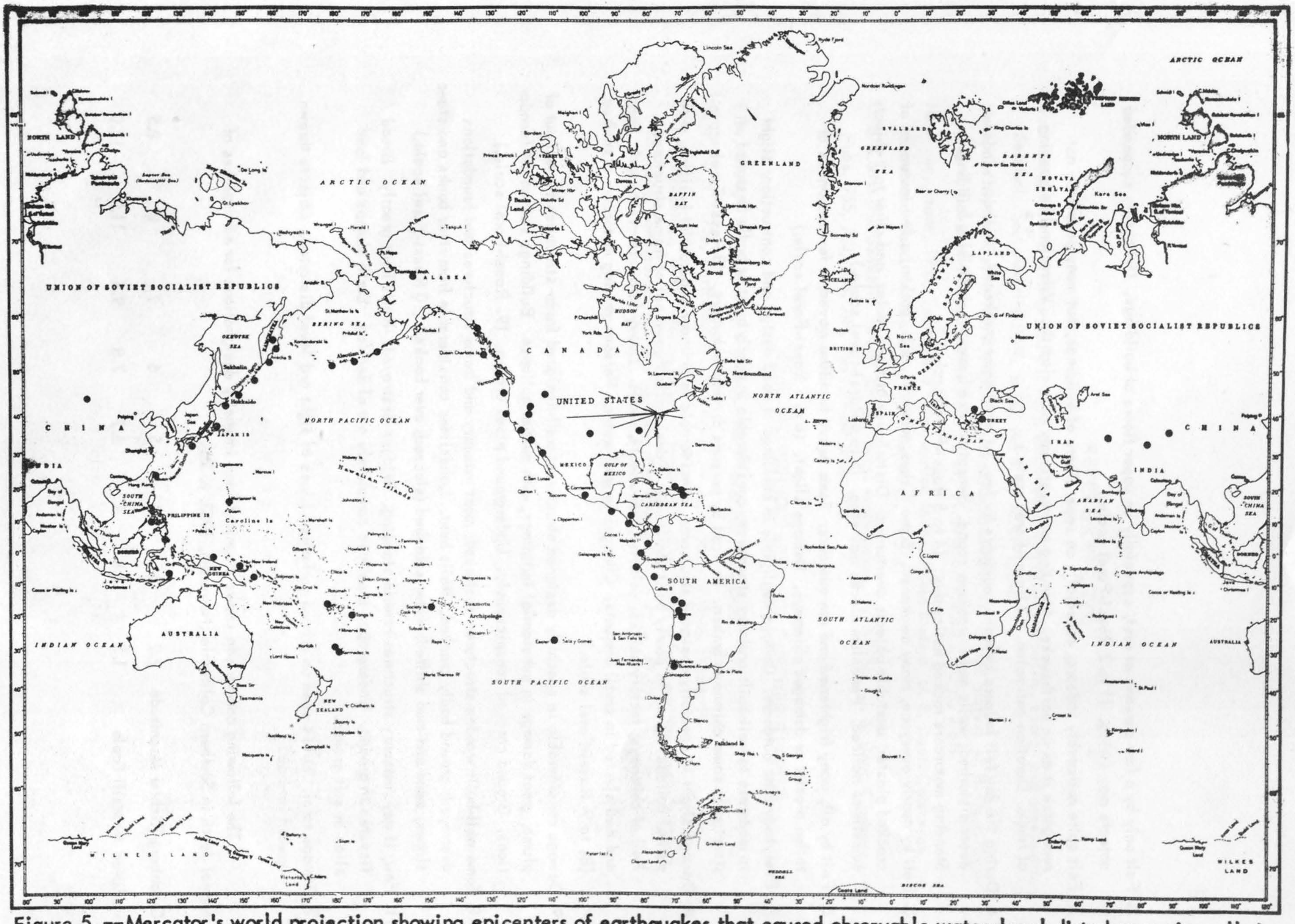

Figure 5.--Mercator's world projection showing epicenters of earthquakes that caused observable water-level disturbances in wells in New Jersey during 1950 through September 30, 1959.

2. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (1 to 2 Rossi-Forel scale.)

3. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (3 Rossi-Forel scale.)

4. 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. (4 to 5 Rossi-Forel scale.)

5. 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. (5 to 6 Rossi-Forel scale.)

6. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (6 to 7 Rossi-Forel scale.)

7. Everybody runs outdoors. Damage negligible in buildings of good design and contruction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (8 Rossi-Forel scale.)

8. Damage slight in specially designed structures, considerable in ordinary substantial building, 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. (8+ to 9- Rossi-Forel scale.)

9. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great damage in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (9+ Rossi-Forel scale.)

10. Some well-built wooden structures destroyed; most masonry and frame structures and foundations destroyed; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes; sand and mud shifted; water splashed (slopped) over banks. (10 Rossi-Forel scale.)

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

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

The following comparison shows magnitude and intensity designations for earthquakes of normal depth in Southern California (Newmann, 1953, p. 26).

Gutenberg-Richter Magnitude	2.2	3	4	5	6	7	8	8.5
Modified Mercalli Scale	1.5	2.8	4.5	6.2	7.8	9.5	11.2	12.0

REFERENCES CITED

Gutenberg, B., and Richter, C. F., 1942, Earthquake magnitude, intensity, energy and acceleration: Seismol. Soc. America Bull., v. 32, no. 3, p. 163-191, inc.

Heck, N. H., and Eppley, R. A., 1958, Earthquake history of the United States: U. S. Dept. Commerce, Coast and Geod. Survey Pub. 41, pt. 1 (revised 1956 ed.), 80 p., 2 pls.

Newmann, Frank, 1953, Earthquake investigation in the United States: U. S. Dept. Commerce, Coast and Geod. Survey Spec. Pub. 282, 40 p., 11 pls.

U. S. Coast and Geodetic Survey, United States earthquakes, 1950-1955: U. S. Dept. Commerce Pubs. 755, 762, 773, 785, 793 (issued annually).

SELECTED BIBLIOGRAPHY FOR FURTHER READING

Eiby, G. A., 1957, About earthquakes: New York, Harper & Bros.

Heck, N. H., 1936, Earthquakes: Princeton, N. J., Princeton Univ. Press.

Vorhis, Robert C., 1955, Interpretation of hydrologic data resulting from earthquakes: Stuttgart, Germany, Sanderdruck aus der Geologischen Rundshau, v. 43, p. 47-52.