TEI-782

FREQUENCY OF EARTHQUAKES FOR SELECTED AREAS IN THE WESTERN UNITED STATES FOR THE PERIOD 1945-59

By W. S. Twenhofel, R. A. Black, and D. F. Balsinger

Trace Elements Investigations Report 782

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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DEPARTMENT OF THE INTERIOR
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June 7, 1961

AEC-191/1

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Assistant Manager for Test Operations
Albuquerque Operations Office
U.S. Atomic Energy Commission
P.O. Box 5400
Albuquerque, New Mexico

Dear Mr. Reeves:

Transmitted herewith are ten copies of TEI-782, "Frequency of earthquakes for selected areas in the Western United States for the period 1945-59," by W. S. Twenhofel, R. A. Black, and D. F. Balsinger, February 1961.

We have no publication plans for this report.

Sincerely yours,

Wenonah E. Bergquist
for
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Assistant Chief Geologist
Interagency Programs and
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UNITED STATES DEPARTMENT OF THE INTERIOR

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W. S. Twenhofel, R. A. Black, and D. F. Balsinger

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*Prepared on behalf of the U.S. Atomic Energy Commission.

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FREQUENCY OF EARTHQUAKES FOR SELECTED AREAS IN THE WESTERN UNITED STATES FOR THE PERIOD 1945-59

By W. S. Twenhofel, R. A. Black, and D. F. Balsinger

INTRODUCTION

A meeting of the Shoal Site Evaluation Committee for the Vela Uniform explosion series was held in Albuquerque, N. Mex., on January 24, 1961, to consider possible sites for the Shoal experiment. The code name Shoal refers to a proposed underground explosion (5 KT) in a currently active area of shallow-focus earthquakes. A report, "Possible sites for Project Shoal" (Black and Twenhofel, 1960), previously submitted to the U.S. Atomic Energy Commission by the U.S. Geological Survey evaluated areas in the continental United States as possible sites for the Shoal experiment. The states of Alaska and California were found to be the two most seismic areas in the continental United States, and of these California was considered most suitable from the viewpoint of the technical criteria established by the Air Force Technical Application Center (AFTAC) for the Shoal experiment.

Several areas in California fulfilled the technical and other requirements for the Shoal experiment and several potential sites were recommended for the further consideration of the Site Evaluation Comittee. Of the minor seismic areas in the United States, Nevada, Montana, Missouri, and Utah were briefly discussed as possible sites for the Shoal experiment in the event that California was unsuitable.

Since the above report was submitted, additional geologic information has been obtained from field examination of granitic rock outcrops in Nevada, which indicates the possibility of an excellent site for the Shoal experiment in the Sand Springs Range about 25 miles southeast of Fallon, Nev. Information concerning this possible site was given to the Site Evaluation Committee at the meeting of January 24. In light of this new development it was decided that the seismicity of other minor seismic areas in the United States should be compared in detail with the Fallon, Nev., area and with the three sites chosen in California. The Site Evaluation Committee authorized the U.S. Geological Survey to proceed with library research to establish a measure of the relative seismicity of possible sites in the minor seismic areas of the United States.

Accordingly, this report presents earthquake frequency data for the period 1945-59 for the states of California, Nevada, Washington, Montana, Wyoming, Utah, Arizona, and New Mexico. In addition it presents earthquake-frequency data for 100-mile square areas in California (White Wolf fault, Lost Valley, and Wonderland-of-Rocks), Nevada (Fallon), Washington (area 1), and Montana-Wyoming (areas 1, 2, and 3).

SOURCES OF INFORMATION

An attempt has been made to collect and tabulate earthquakes occurring in the period 1945-59, in the readily accessible and published seismological literature. The following sources of information were used.

1. United States earthquakes, U.S. Coast and Geodetic Survey, 1945-57, annual bulletin.

2. Preliminary determination of earthquakes, U.S. Coast and Geodetic Survey, 1958-61.

3. Seismological bulletins, U.S. Coast and Geodetic Survey, MSI 122-228, 1945-59.

4. Seismological laboratory bulletin, California Institute of Technology, Pasadena, 1945-59.

5. Bulletin of seismograph stations, University of California, v. 16-28, 1946-58.

6. Preliminary bulletins, Jesuit Seismological Association, St. Louis, Mo., 1950-57.

7. Cleveland seismological observatory bulletin, John Carroll University, Cleveland, Ohio, 1954-58.

8. Seismological bulletin, Lamont Geological Observatory, Columbia University, Palisades, N. Y., 1951-60.

9. University of Arkansas seismological bulletin, Fayettsville, Ark., v. 3-9, 1954-60.

10. Registration of earthquakes at Seattle, University of Washington seismograph station, Bulletins no. 6, 1952, no. 7, 1953, no. 9, 1955, no. 10, 1956.

11. Harvard University seismograph station bulletins, nos. 41, 42, 43, 44, 45, 1953-57.

12. Seismological bulletin, Seismological Service of Canada, Dominion Observatory, Department of Mines, Ottawa, 1954-60.

13. Seismological notes, bulletin, Seismological Society of America, v. 35-50, 1945-60.

Each earthquake for the states in question was listed according to location, date, and magnitude (or intensity if magnitude was not given). Because many earthquakes were duplicated in one or more publications, after the list for each state was compiled all duplications were eliminated.

In cases where several earthquakes occurred on the same day at the same location, it was arbitrarily decided to list only the largest earthquake.

After all duplications were removed the known earthquake epicenters were then plotted on maps of California (fig. 1), Nevada (fig. 2), Montana-Wyoming (fig. 3), Washington (fig. 4), Arizona (fig. 5), Utah (fig. 6), and Missouri (fig. 7).

MEASURES OF SEISMICITY

Two general schemes of measuring and comparing the seismicity of different areas are used in this report.

1. For each state and selected area a "Seismicity Index" is given on figures 8-17. The "Seismicity Index" applies to the period 1945-59. The first figure is the number of earthquakes of unknown magnitude, the second the number of earthquakes of Richter magnitude greater than 3.5 and less than 4.5, the third the number of earthquakes of Richter magnitude 4.5 to 6.0, and the fourth the number of earthquakes of Richter magnitude greater than 6.0.

Where earthquakes were listed in terms of intensity rather than magnitude, the intensities (Modified Mercalli scale) were converted to magnitudes (Richter scale), using the relationship given by Murphy and Ulrich (1948).

Such Seismicity Indices provide a measure of seismicity for regions of equal area, but should not be used directly to compare regions such as states of greatly dissimilar areas.

2. For each state and each selected area, histograms (figs. 8-17) were prepared that show number of earthquakes of various magnitudes in each year of the period 1945-59. Unlike the Seismicity Index (mentioned above), these histograms provide a means of showing the number of earthquakes on a yearly basis. Like the Seismicity Index, they provide a measure of seismicity for regions of equal area, but should not be used directly to compare regions of dissimilar areas.

Because both means of measuring seismicity used in this report are area-dependent, the selected areas, such as Lost Valley, Fallon, etc., arbitrarily were decided to include all earthquakes within a 100-mile square centered about the sites in question. The 100-mile square boundaries are shown on figures 1, 2, 3, and 4. Therefore, the Seismicity Index and the histograms for the selected areas may be compared directly. The Seismicity Index and histograms for the individual states, however, cannot be compared directly.

CALIFORNIA

California (figs. 1 and 8) is an extremely active seismic area. The Seismicity Index is 176-911-249-10. For the period 1945-59 there were 1,346 earthquakes of which 259 were of Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1952 when there were 194; the fewest earthquakes were in 1959 when there were 26.

All the geomorphic provinces comprising the state of California (table 1) were examined for seismicity and the presence of granitic rocks suitable for the Shoal experiment (Black and Twenhofel, 1960).

From the areas listed in table 1, 27 sites were selected for preliminary evaluation with regard to seismicity, geologic setting, topographic relief, population density, and the possibility of water contamination. From the 27 sites, 3 of the better ones were selected by the Site Selection Committee for further evaluation; the White Wolf fault area, Wonderland-of-Rocks in the Little San Bernardino Mountains, and Lost Valley in the area between the Elsinore-San Jacinto fault zones.

White Wolf fault area

Figure 14 shows the earthquake history for the period 1945-59 of an area 100 miles square centered about the White Wolf fault area, California (fig. 1). The Seismicity Index is 33-183-40-6. Two hundred and sixty-two earthquakes are recorded, of which 46 were of Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1952 when there were 104; the fewest earthquakes were in 1945 when there was only one.

The White Wolf fault histogram shows a low level of earthquake activity for the years 1945-51, followed in 1952 by extreme activity which has steadily and significantly decreased to a low of three earthquakes in 1959.

Table 1

1. Great Valley of California
2. Klamath Mountains
3. Modoc Plateau
4. Cascade Range
5. Coast Ranges
    a. Gabilan Range
    b. Bear Mountains - Junipero Serra Peak
    c. Creston - Pozo - La Ponza
    d. Alamo Mountain - Cobblestone Mountain
    e. Blue Ridge - Mount Pinos
    f. Palo Corono - Mount Carmel
    g. Cape Mendocino
6. Sierra Nevada
    a. White Wolf - Kern Canyon
7. Basin-Range
    a. Owens Valley
    b. Coso Range
8. Transverse Range
    a. Little San Bernardino
9. Peninsular Range
    a. Elsenore - San Jacinto fault zone
10. Colorado Desert
11. Mojave Desert
    a. Lane Mountains
    b. Chocolate Mountain

Lost Valley

Figure 15 shows the earthquake history for the period 1945-59 of an area 100 miles square centered about Lost Valley, Calif. (fig. 1). The Seismicity Index is 22-119-22-2. One hundred and sixty-five earthquakes are recorded, of which 24 were of Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1949 when there were 39; the fewest earthquakes were in 1948 when there was only one.

The Lost Valley histogram shows a generally consistent level of earthquake activity for the period 1945-59. For each of the last 11 years the number of earthquakes has been 5 or more per year. For the 15-year period only in 2 years has there been fewer than 5 earthquakes in a single year.

Wonderland-of-Rocks

Figure 15 shows the earthquake history for the period 1945-59 of an area 100 miles square centered about the Wonderland-of-Rocks site in Joshua Tree National Monument, California (fig. 1). The Seismicity Index is 33-104-21-1. One hundred and fifty-nine earthquakes are recorded of which 22 were of Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1949 when there were 47; the fewest earthquakes occurred in 1948 when there was only one.

The Wonderland-of-Rocks histogram shows a generally consistent level of earthquake activity for the period 1945-59. For 11 of the

last 15 years there were 6 or more earthquakes per year.

The similarity between the histograms of Lost Valley and Wonderland-of-Rocks is to be noted. This similarity is due to the fact that the 100-mile squares overlap about 40 percent, and thus, the earthquakes occurring in the overlap area are included on both histograms.

NEVADA

Figure 9 shows the earthquake history of Nevada for the period 1945-59. Earthquake epicenters and granitic rocks in western Nevada are shown on figure 2. The Seismicity Index is 128-279-67-5. Four hundred and seventy-nine earthquakes are recorded, of which 72 were of Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1955 when there were 97; the fewest earthquakes were in 1945 when there were 10.

Most of the earthquakes prior to 1954 were in the Boulder City area of southern Nevada and in western Nevada adjacent to California. A large proportion of the earthquakes prior to 1954 was of unknown magnitude the epicenters of which were not determined and may well have originated in nearby California. Since 1954 most of the Nevada earthquakes have originated from the Fallon area (compare figs. 9 and 13).

Fallon

Figure 13 shows the earthquake history for the period 1945-59 of an area 100 miles square centered about the Stillwater Range 20 miles east

of Fallon, Nev. (see fig. 2). The Seismicity Index is 13-142-40-5. Two hundred earthquakes are recorded, of which 45 were of Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1955 when there were 88; there were no earthquakes in the Fallon area in 1946, 1947, and 1951.

The Fallon histogram shows a very low level of earthquake activity for the years 1945-51, followed in 1954 and 1955 by extreme activity which has steadily and significantly decreased to a low of seven earthquakes in 1959.

WASHINGTON

Figure 11 shows the earthquake history of Washington for the period 1945-59. Most of the earthquake epicenters in Washington are near Puget Sound. Earthquake epicenters and granitic rocks in western Washington are shown on figure 4. The Seismicity Index is 50-51-23-3. One hundred and twenty-seven earthquakes are recorded, of which 26 were of Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1952 when there were 17; the fewest earthquakes were in 1947 and 1950 when there were 4 per year.

Area 1

Figure 16 shows the earthquake history for the period 1945-59 of an area 100 miles square centered about the southwest outcrop of the granitic rocks of the Coast Range batholith (see fig. 4). The Seismicity index is 16-9-20-0. Forty-five earthquakes are recorded,

of which 20 were of Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1954 when there were 6; there were no earthquakes in this area in 1951 and 1958.

MONTANA-WYOMING

Figure 10 shows the earthquake history of Montana for the period 1945-59. Earthquake epicenters and granitic rocks in western Montana are shown on figure 3. The Seismicity Index is 147-54-13-3. Two hundred and seventeen earthquakes are recorded, of which 16 were of Richter magnitude 4.5 or greater. The years 1945 and 1959 stand out as the years of most frequent earthquakes, 38 and 35, respectively. The fewest earthquakes occurred in 1958, when there was only one earthquake. Almost all the Montana earthquakes have been in western Montana; eastern Montana is essentially nonseismic.

Figure 10 shows the earthquake history of Wyoming for the period 1945-59. Earthquake epicenters and granitic rocks in northwestern Wyoming are shown on figure 3. The Seismicity Index is 17-37-3-1. Fifty-eight earthquakes are recorded, of which only 4 were of Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1954 and 1959 when there were 8 per year; all other years the frequency ranges from 1 to 6 per year. Almost all of the Wyoming earthquakes have been in the northwestern part of the state.

Selected areas in Montana-Wyoming

Figure 12 shows the earthquake history for the period 1945-59 of three selected areas each 100 miles square centered about granitic rocks in Montana-Wyoming (see fig. 3). The Seismicity Index for area 1 is 29-16-8-1, for area 2 is 19-9-12-0, and for area 3 is 98-37-8-0. In area 1, 54 earthquakes are recorded, of which 9 were of Richter magnitude 4.5 or greater. In area 2, 30 earthquakes are recorded, of which 12 were of Richter magnitude 4.5 or greater. In area 3, 143 earthquakes are recorded, of which 8 were of Richter magnitude 4.5 or greater. In all three areas the number of earthquakes is few except for the year 1945 in area 1 and the year 1959 in areas 2 and 3.

UTAH

Figure 11 shows the earthquake history of Utah for the period 1945-59. Earthquake epicenters are shown on figure 6. The Seismicity Index is 15-33-7-0. Fifty-five earthquakes are recorded, of which 7 are Richter magnitude 4.5 or greater. The greatest number of earthquakes occurred in 1950 when there were 11. Only 1 earthquake was recorded for each of the years 1946, 1948, and 1956.

NEW MEXICO

Figure 11 shows the earthquake history of New Mexico for the period 1945-59. The Seismicity Index is 3-8-1-0. No earthquakes

were recorded for the years 1945, 1946, 1948, 1950, 1953, 1957, 1958, and 1959. Only one earthquake epicenter has been recorded for New Mexico in the references consulted. As a consequence no map of epicentral locations has been prepared for this state.

ARIZONA

Figure 11 shows the earthquake history of Arizona for the period 1945-59. Earthquake epicenters are shown on figure 5. The Seismicity Index is 15-6-8-0. The greatest number of earthquakes occurred in 1957 when there were 6. No earthquakes were recorded in 1955.

SOUTHEAST MISSOURI AND ADJACENT STATES

The area comprised of southeastern Missouri, western Kentucky and Tennessee, northern Arkansas, and southern Illinois is a minor seismic area. The only sizable outcrops of granitic rocks are on the northeastern flank of the Ozark Uplift in southeastern Missouri. Earthquake epicenters and granitic rocks for this area are shown on figure 7. The histogram, figure 17, shows the earthquake history of this area for the period 1945-59. The Seismicity Index is 17-26-9-0. Fifty-two earthquakes are recorded, of which 9 were of Richter magnitude 4.5 or greater.

COMPARATIVE ANALYSIS

A comparison of the histograms for the various states shows that Arizona and New Mexico have had considerably less earthquake activity during the period 1945-59 than have the other states considered in this report. With no reason to assume an increase in seismic activity in these states in the near future, it is concluded that they can be removed from further consideration for the Shoal experiment.

The states of Utah and Wyoming, and the area comprised of southeastern Missouri and adjacent states have had comparable earthquake activity for the period investigated. Although seismic activity in these areas has been greater than in Arizona and New Mexico, the level of activity is considerably less than that of the other areas considered in this report.

The histograms for the states of Washington and Montana show considerably greater earthquake activity than any of the states mentioned in the preceeding paragraph. The histogram for Washington (fig. 11) shows moderate, continued activity for the period 1945-59. The areas of granitic rocks lie to the east of the area of greatest seismic activity as shown by the concentration of epicenters (fig. 4). A 100-mile square was chosen with its center on the western edge of the granitic rock outcrop, and figure 16 shows the earthquake histogram for this area. The overall seismicity of this area is low, but it may be of interest to note that there have been 14 earthquakes with magnitudes of 4.5 or above in this area during the last 8 years.

The histogram for Montana (fig. 10) shows high earthquake activity during 1945, followed by a more or less steady decrease in activity to 1959, when earthquake activity suddenly increased. Three 100-mile squares were chosen (fig. 3) with centers in areas of granitic rocks and situated to enclose areas of significant seismic activity. Histograms for these three areas are shown in figure 12. The histograms for areas 1 and 2 both show a low level of earthquake activity for the period 1945-58, and a sudden increase in seismic activity during 1959, largely a result of the Hebgen Lake earthquakes of August 17 and 18, 1959, and its aftershocks. The histogram for area 3 (fig. 12) shows a decided peak of earthquake activity during 1945 and a general decrease in activity to the very low level shown for 1957-59.

The histograms for the states of California (fig. 8) and Nevada (fig. 9) show high earthquake activity in these two states, with the activity in California greatly exceeding that in Nevada.

A histogram of earthquakes in a 100-mile square centered about the Stillwater Range 20 miles east of Fallon, Nev., is shown in figure 13. Comparison of figures 9 and 13 indicates that the greater part of the earthquake activity in Nevada since 1953 has occurred in the Fallon area. The Fallon area is characterized by little activity during the early part of the 15-year period, followed by several years of extreme activity in the early 1950's and a rapid and progressive decrease in activity for the past 4 to 6 years. This trend may indicate a continued decrease in activity for the future

to the low levels of earlier years, or it is equally possible that there will be another period of renewed activity.

The histogram for the White Wolf fault area (fig. 14) is somewhat similar to that of the Fallon area in that a pronounced peak (in 1952) occurs, followed by decreasing activity, but it differs in that it shows continuous earthquake activity throughout the 15-year period. The histograms for the Wonderland-of-Rocks area and the Lost Valley area (fig. 15) show a moderate level of earthquake activity that has continued for most of the 15-year period. In the Lost Valley area there have been only two years in which there have been less than five earthquakes and in the Wonderland-of-Rocks area there are only four years in which there have been less than five earthquakes.

CONCLUSIONS

For purposes of the Shoal experiment the best site is one in which there is a reasonable expectation of an earthquake occurring with a magnitude of 4.5 within a year. All seismologists agree that past activity is a most uncertain basis for predicting the future, but nevertheless past activity is the only criterion that is available and it is used in this report for the conclusions herein presented.

The area centered around northwest Wyoming and adjacent Montana (areas 1 and 2, fig. 3) has had a generally low level of seismic activity during the past 15 years, but the probability exists that aftershocks of the Hebgen Lake earthquake will continue in this area

in the immediate future. This area may be considered as a possible site for the Shoal experiment because of recent seismic activity and presence of granitic rocks, but past earthquake activity is not sufficiently high to justify a rank equal to that of the four areas discussed in the next paragraph.

The Wonderland-of-Rocks, Lost Valley, White Wolf fault area, and Fallon area all have had a high level of continued seismicity compared to all other areas considered in this report. The Wonderland-of-Rocks and Lost Valley areas are considered to have a greater probability of continued high-level earthquake activity than are the other two areas. The extremes of activity in the Fallon and White Wolf fault areas suggest a somewhat lower probability of continued frequent earthquakes.

REFERENCES CITED

Black, R. A., and Twenhofel, W. S., 1960, Possible sites for Project Shoal: U.S. Geol. Survey preliminary report.

Murphy, L. M., and Ulrich, F. P., 1948, United States earthquakes: U.S. Coast and Geodetic Survey, serial no. 746, p. 5.

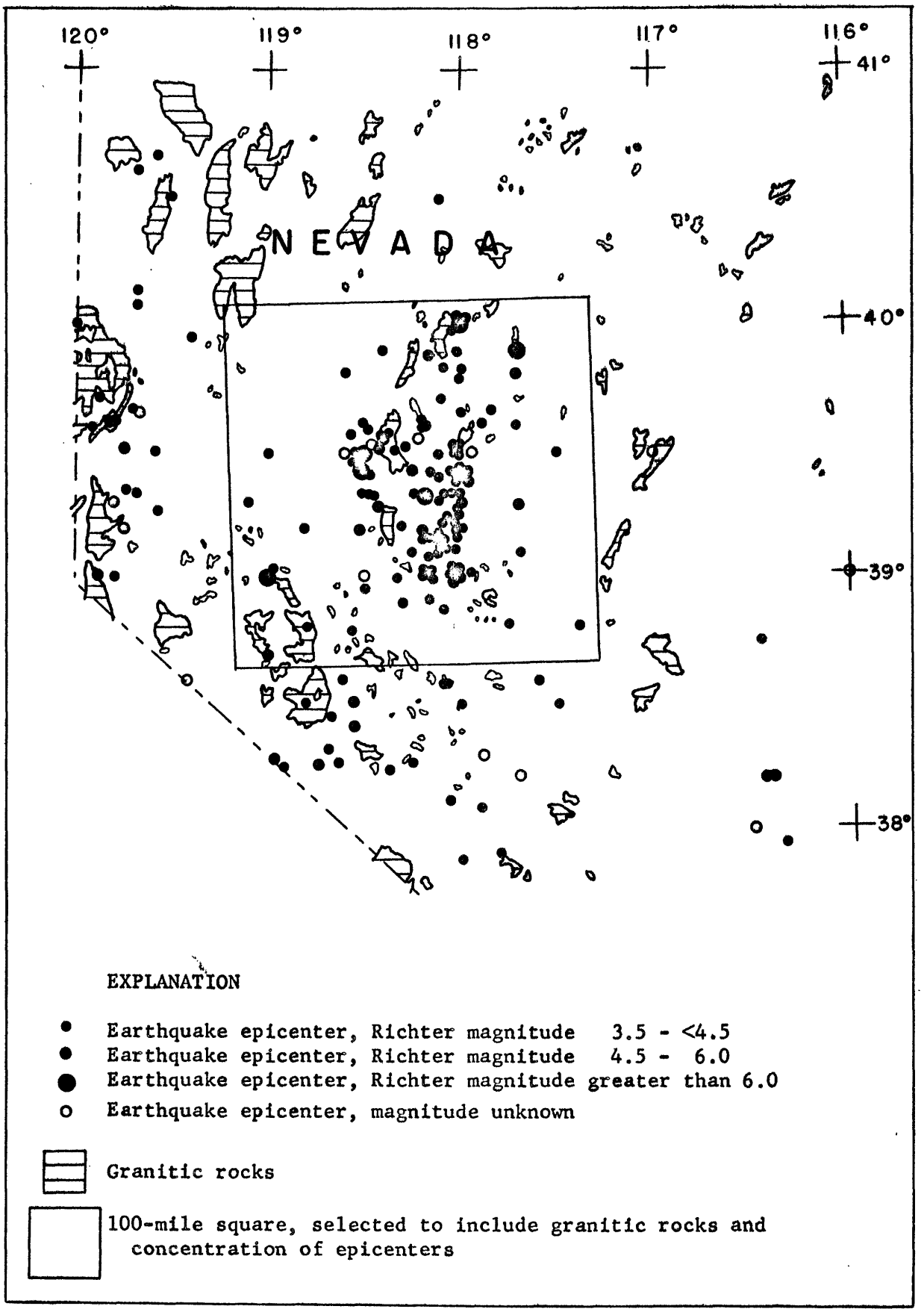

Figure 2.--Granitic rocks and earthquake epicenters, western Nevada

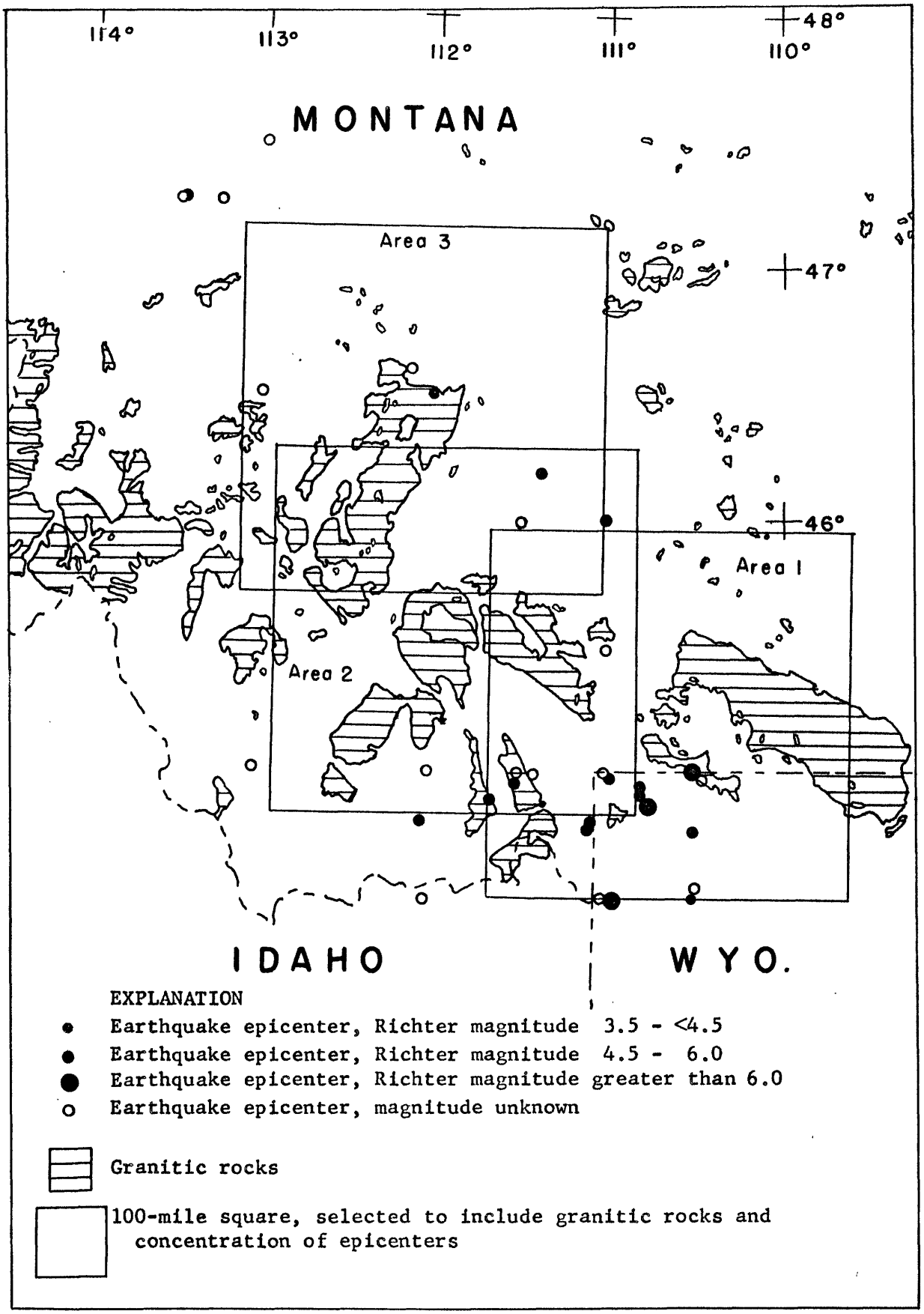

Figure 3.--Granitic rocks and earthquake epicenters, western Montana and northwestern Wyoming

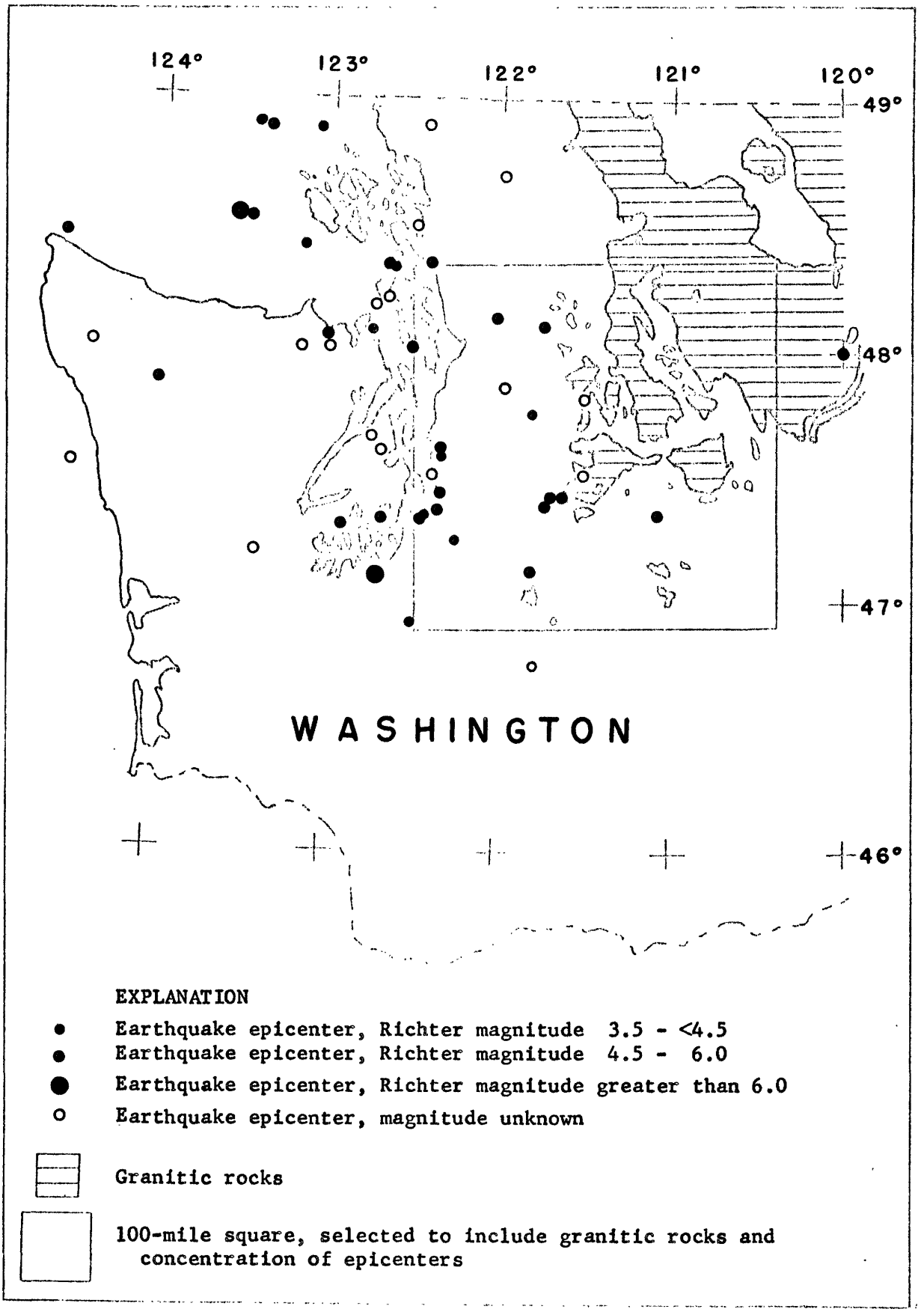

Figure 4.--Granitic rocks and earthquake epicenters, western Washington

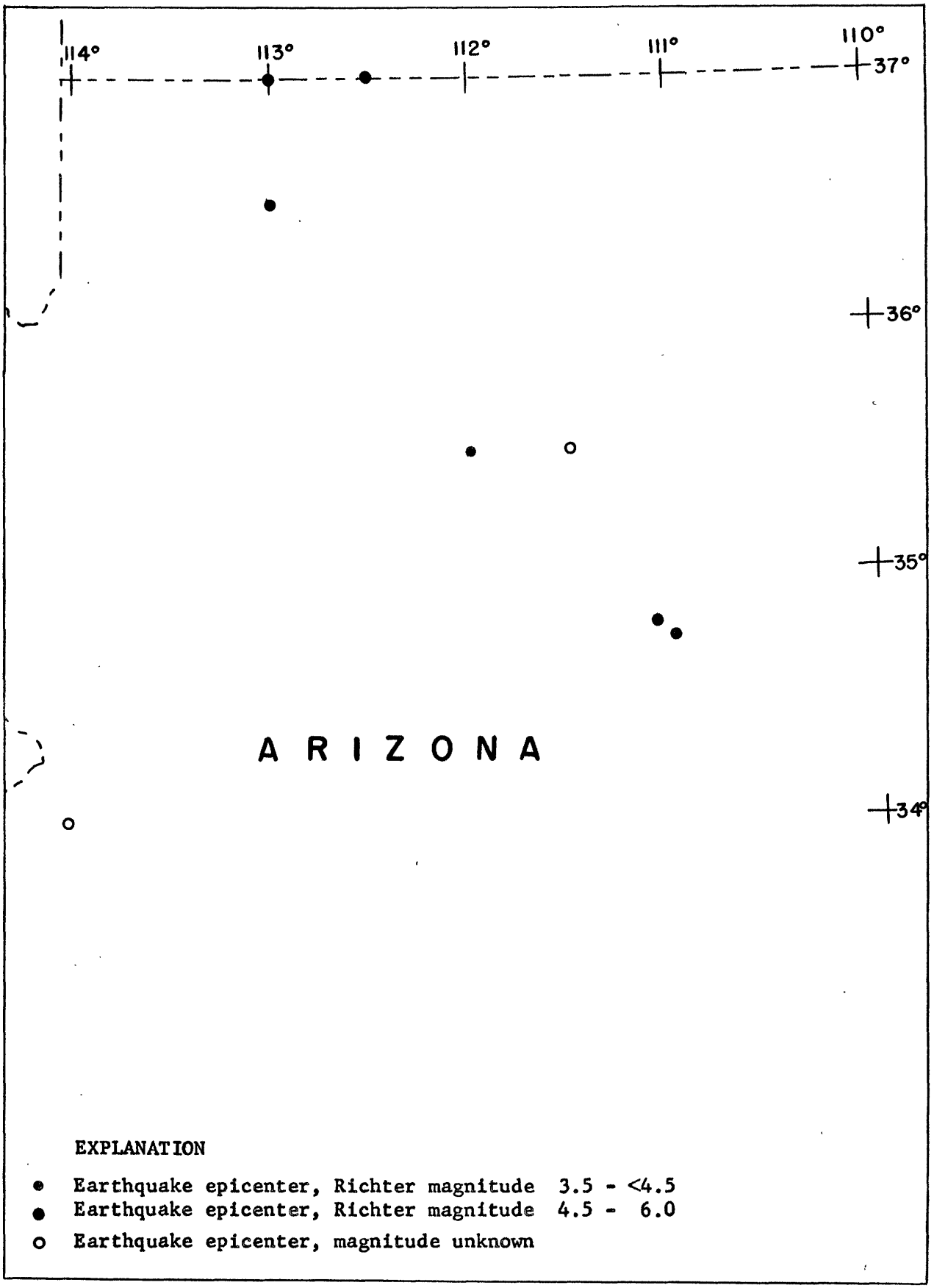

Figure 5.--Earthquake epicenters, Arizona

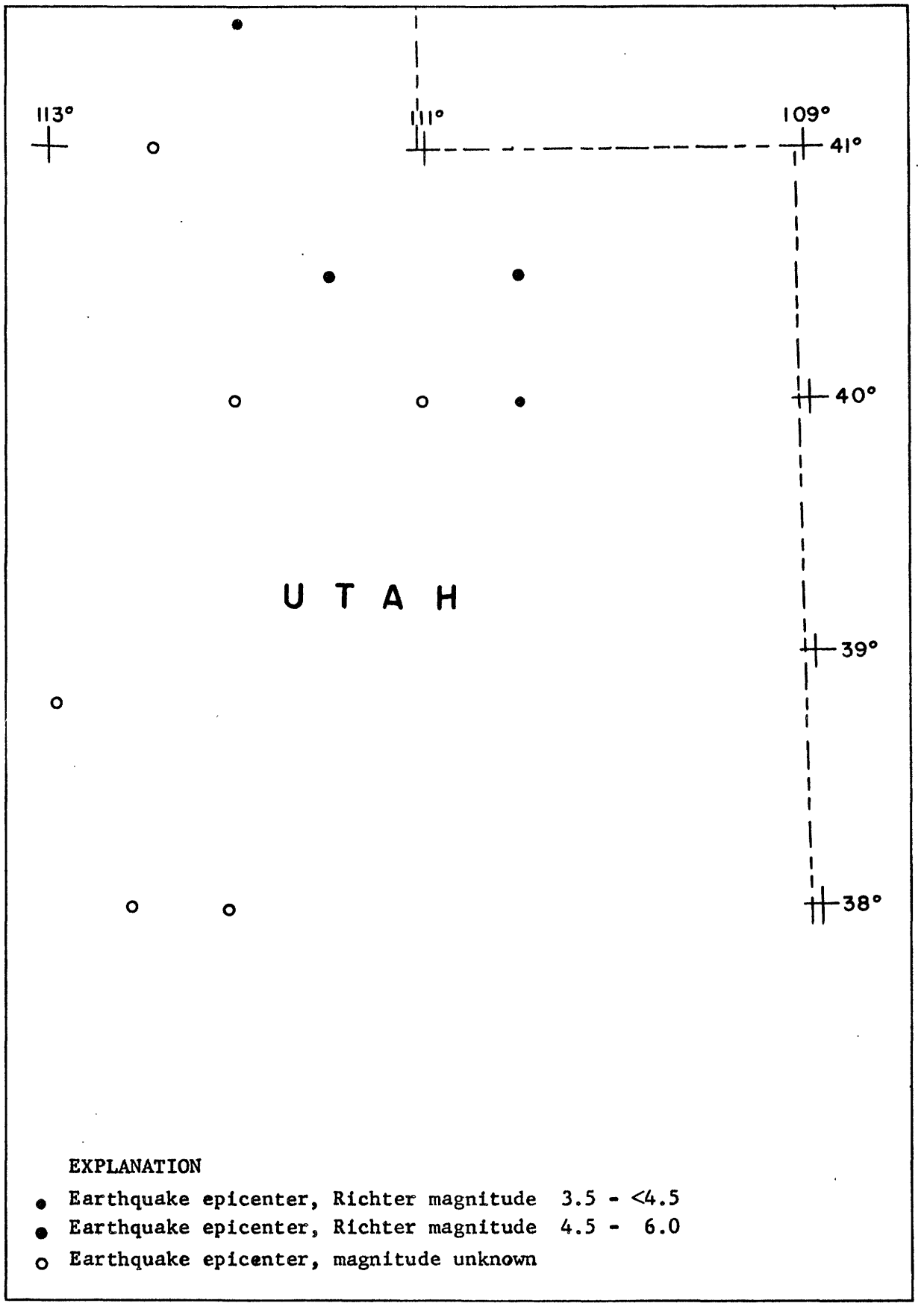

Figure 6.--Earthquake epicenters, Utah

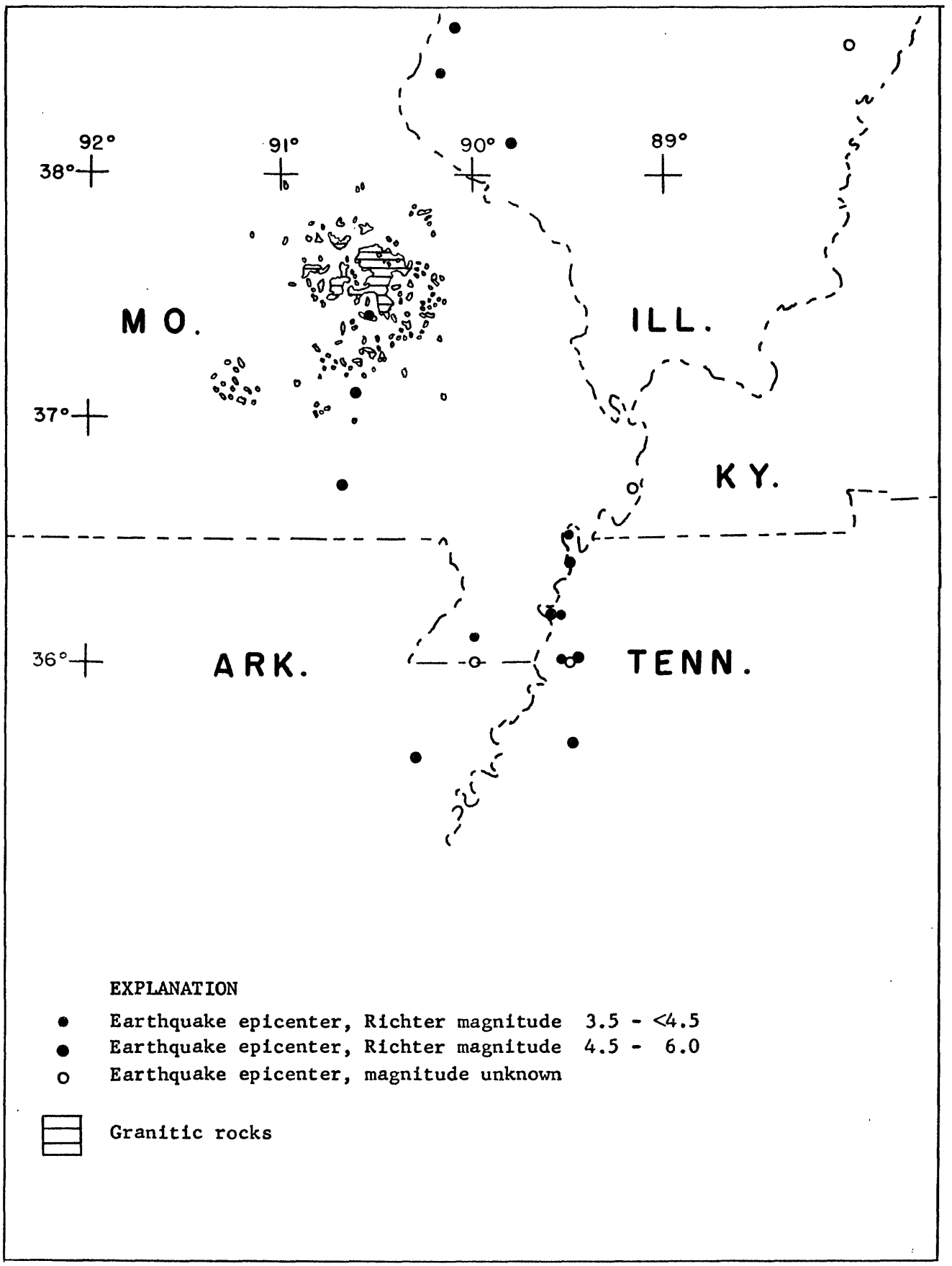

Figure 7.--Granitic rocks and earthquake epicenters in southeast Missouri and adjacent states

Explanation for histograms that follow, figures 8 - 17

Earthquakes of Richter magnitude greater than 6.0

Earthquakes of Richter magnitude 4.5 to 6.0

Earthquakes of Richter magnitude greater than 3.5 and less than 4.5

Earthquakes of unknown magnitude and intensity, most of which are presumed to be small

The seismicity index is for the entire period 1945-1959. The first figure is the number of earthquakes of unknown magnitude and intensity; the second figure is the number of earthquakes of Richter magnitude greater than 3.5 and less than 4.5; the third figure is the number of earthquakes of Richter magnitude 4.5--6.0; the fourth figure is the number of earthquakes of Richter magnitude greater than 6.0.

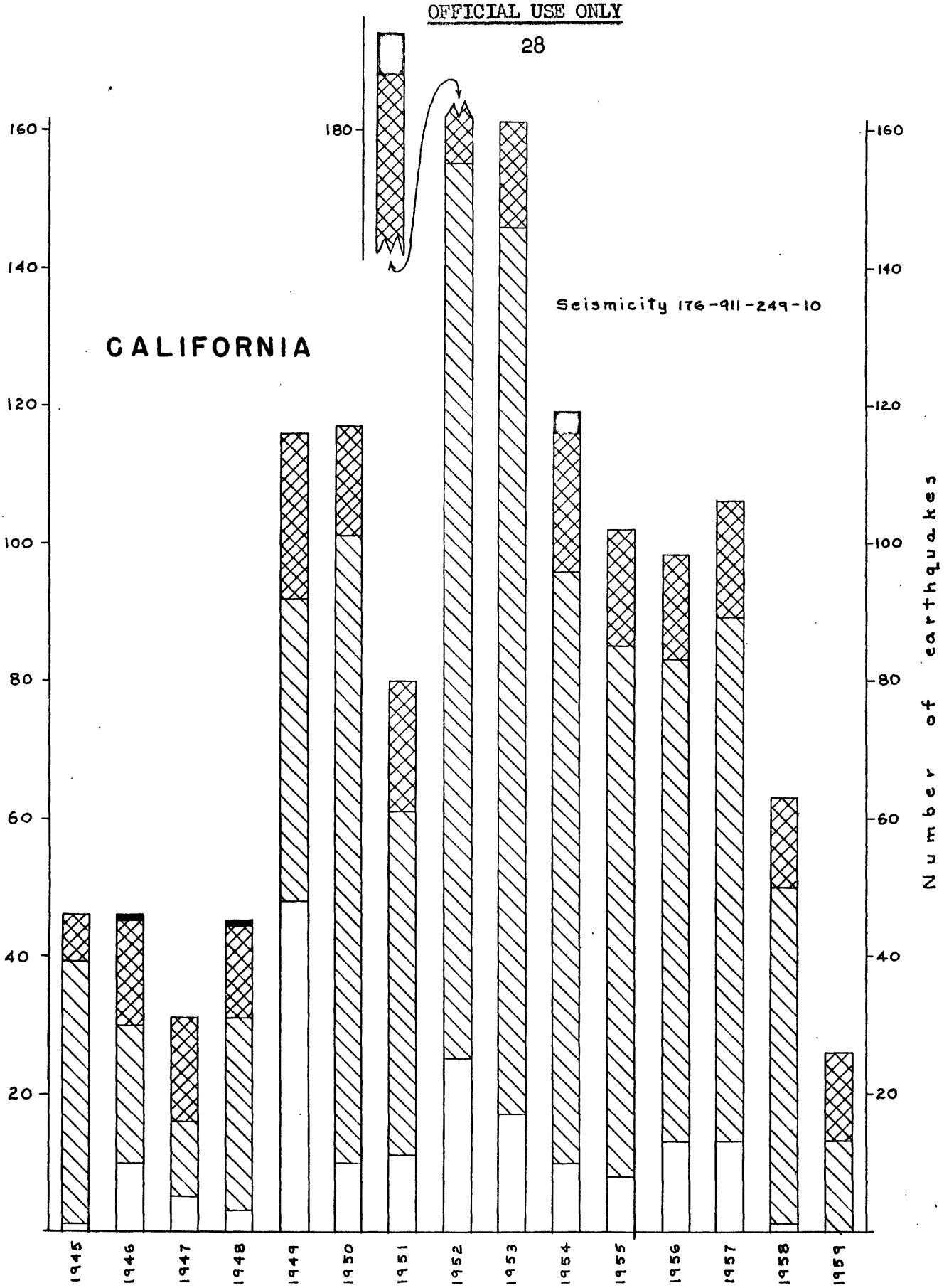

Figure 8. FREQUENCY OF EARTHQUAKES IN CALIFORNIA, 1945-1959

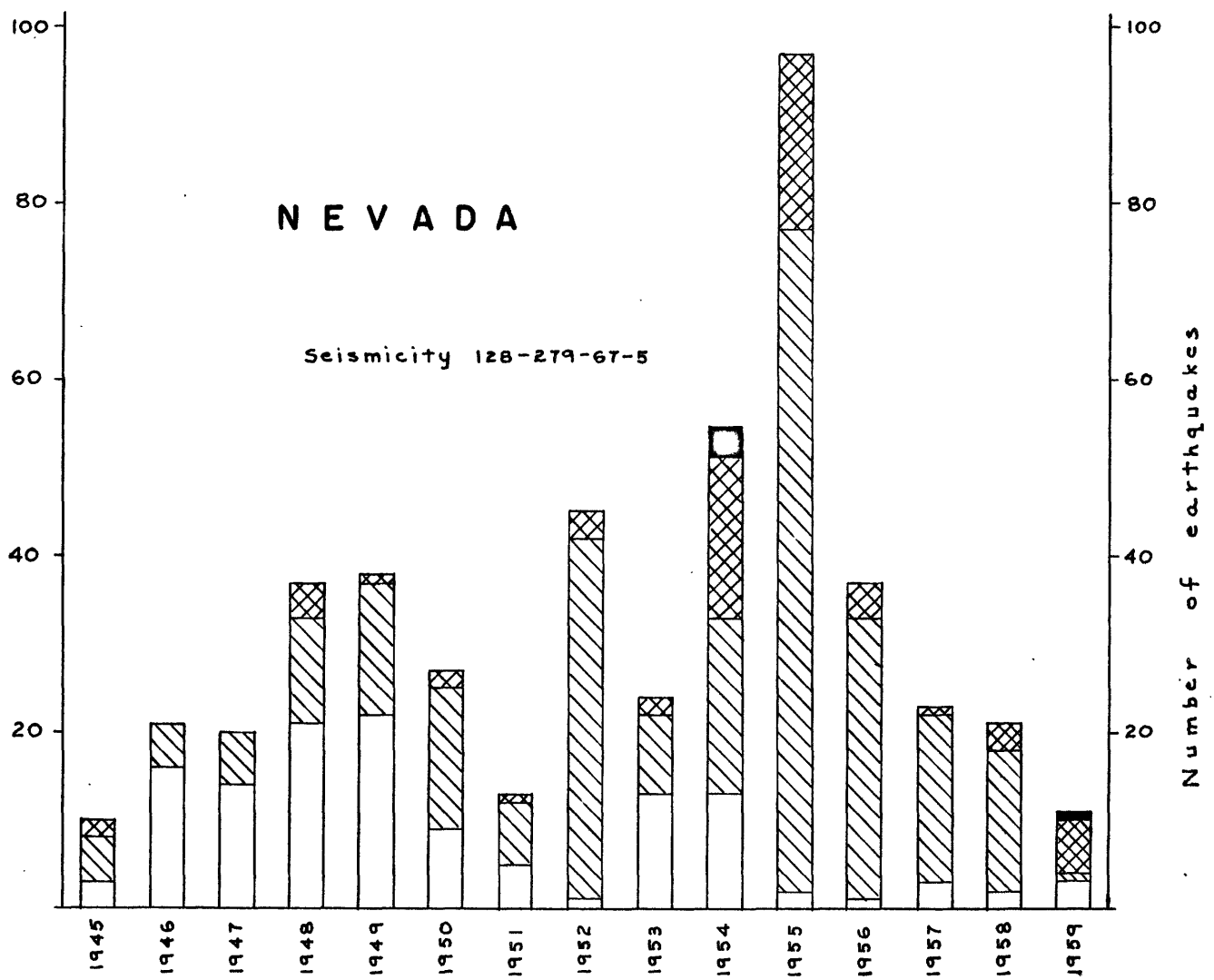

Figure 9. FREQUENCY OF EARTHQUAKES IN NEVADA, 1945-1959

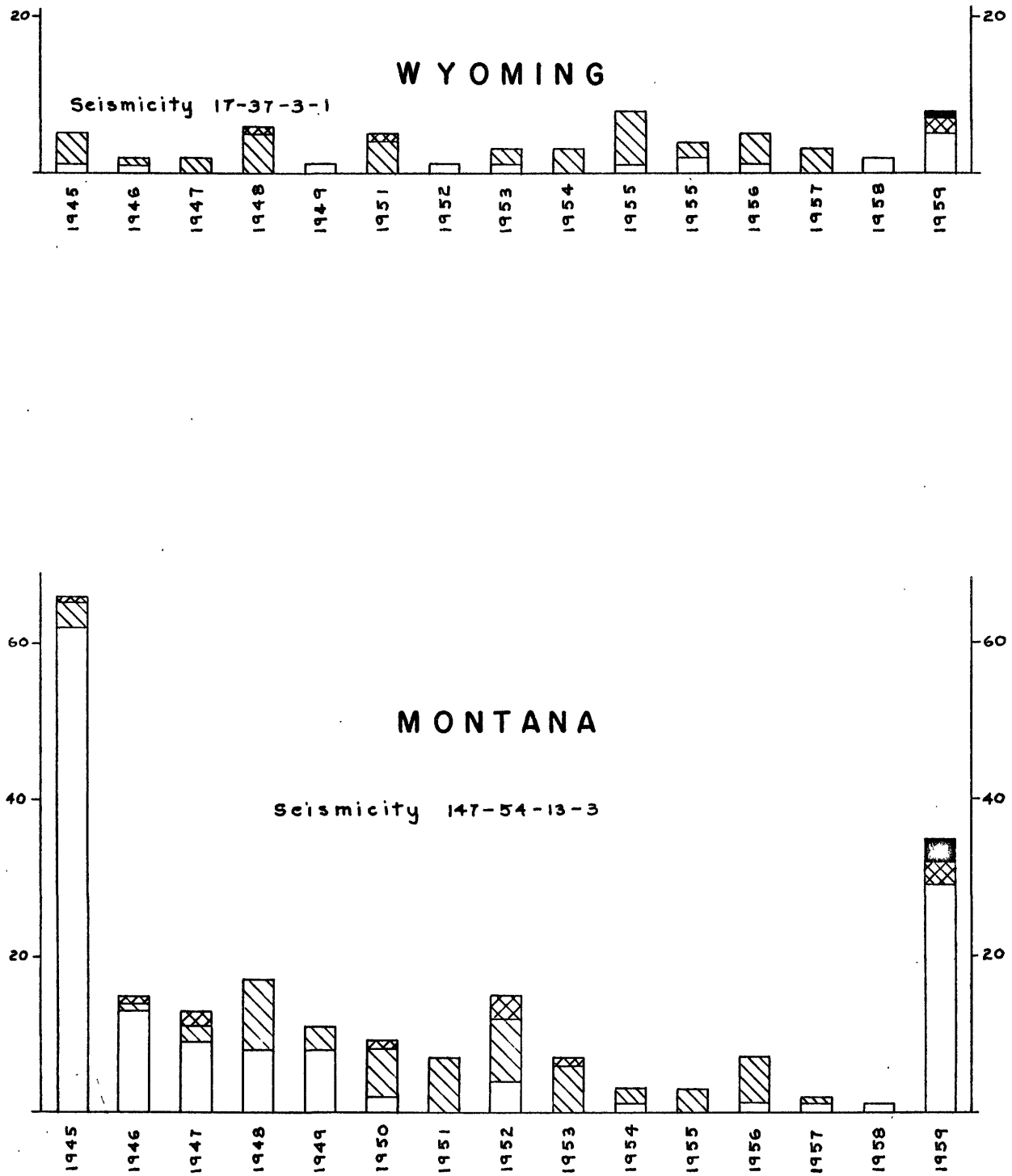

Figure 10. FREQUENCY OF EARTHQUAKES IN WYOMING AND MONTANA, 1945-1959

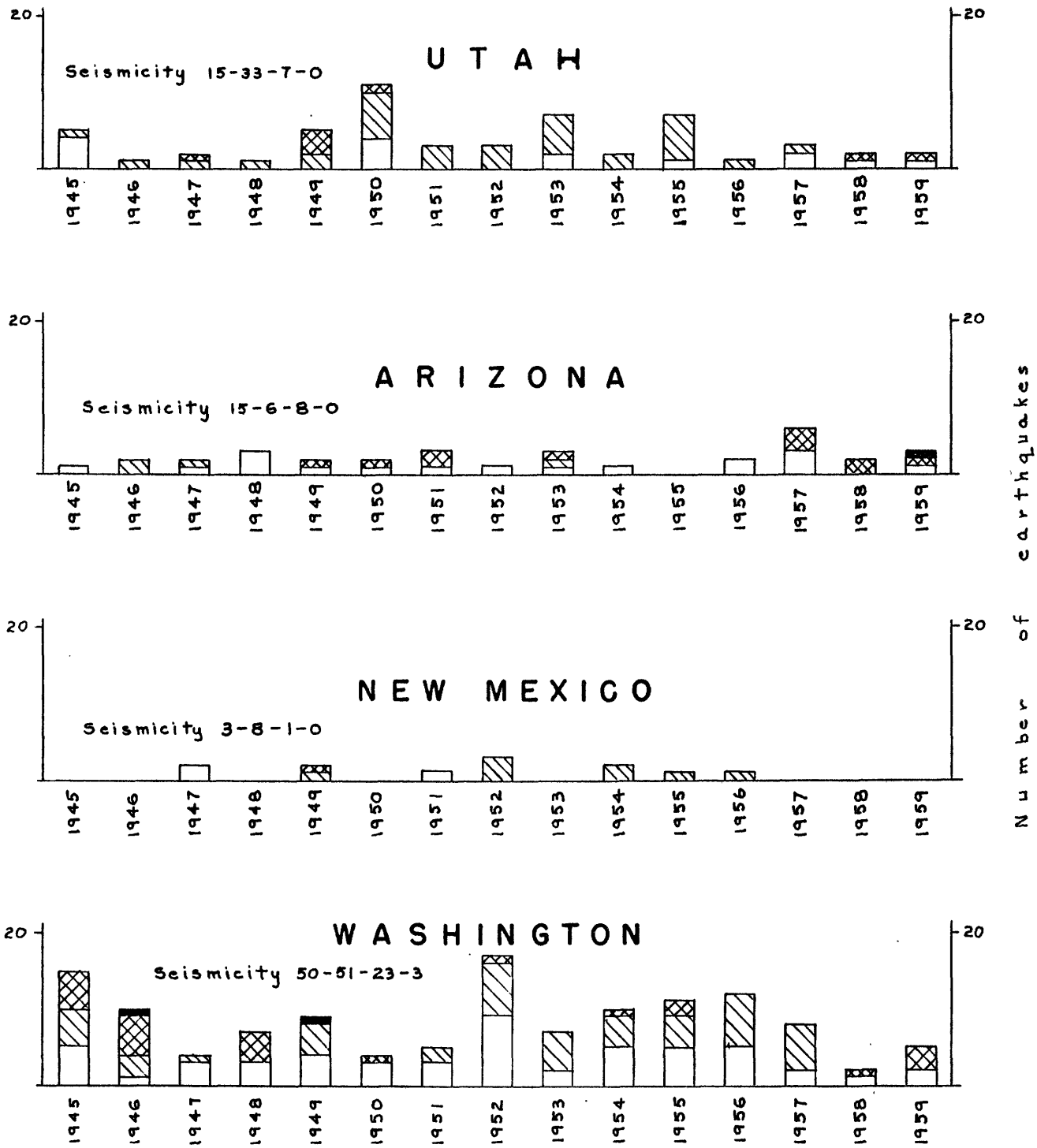

Figure 11. FREQUENCY OF EARTHQUAKES IN UTAH, ARIZONA, NEW MEXICO, and WASHINGTON, 1945-1959

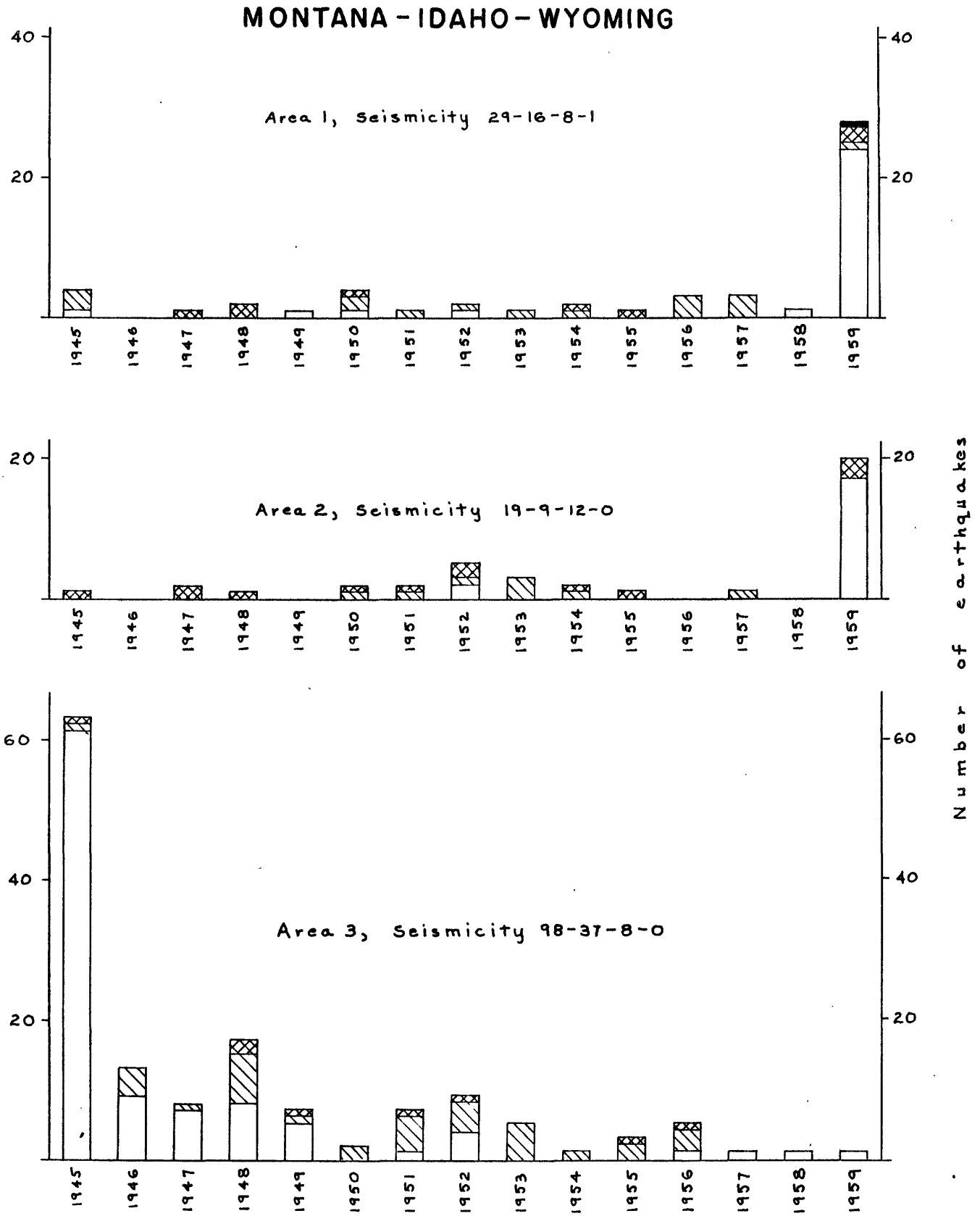

Figure 12. FREQUENCY OF EARTHQUAKES IN THREE AREAS IN MONTANA, IDAHO, and WYOMING, 1945-1959

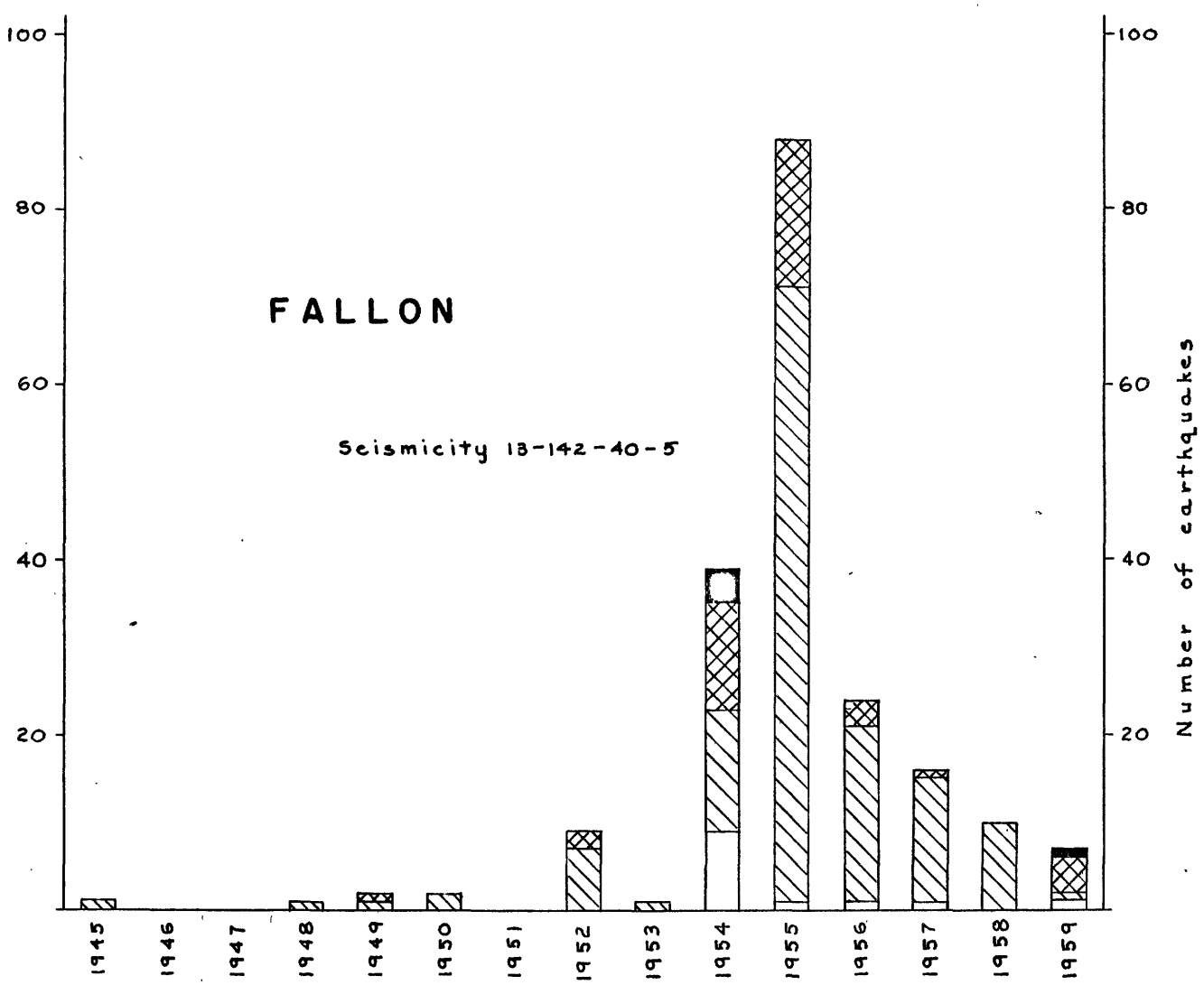

Figure 13. FREQUENCY OF EARTHQUAKES IN THE FALLON AREA, NEVADA, 1945-1959

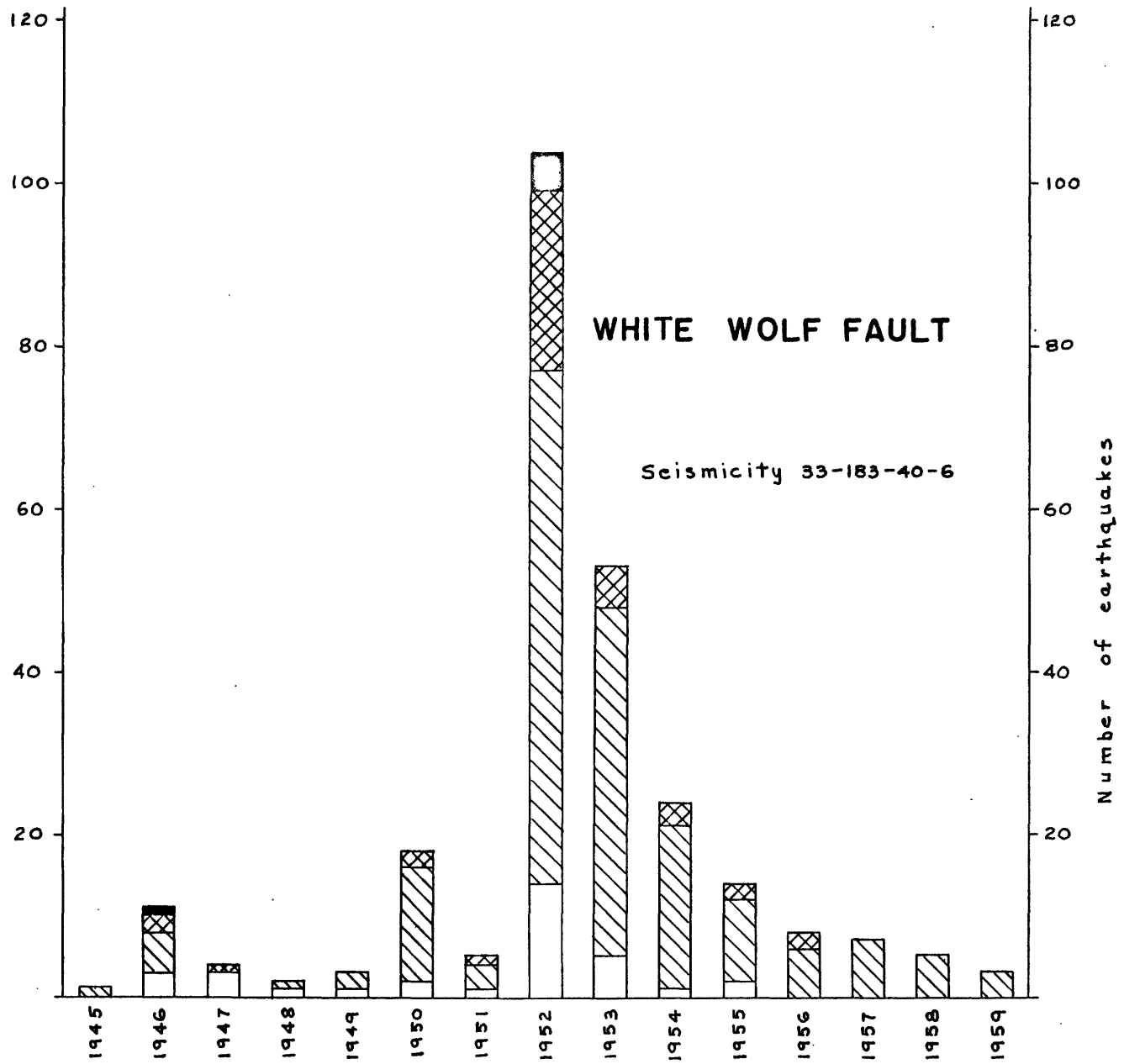

Figure 14. FREQUENCY OF EARTHQUAKES IN THE WHITE WOLF FAULT AREA, CALIFORNIA, 1945-1959

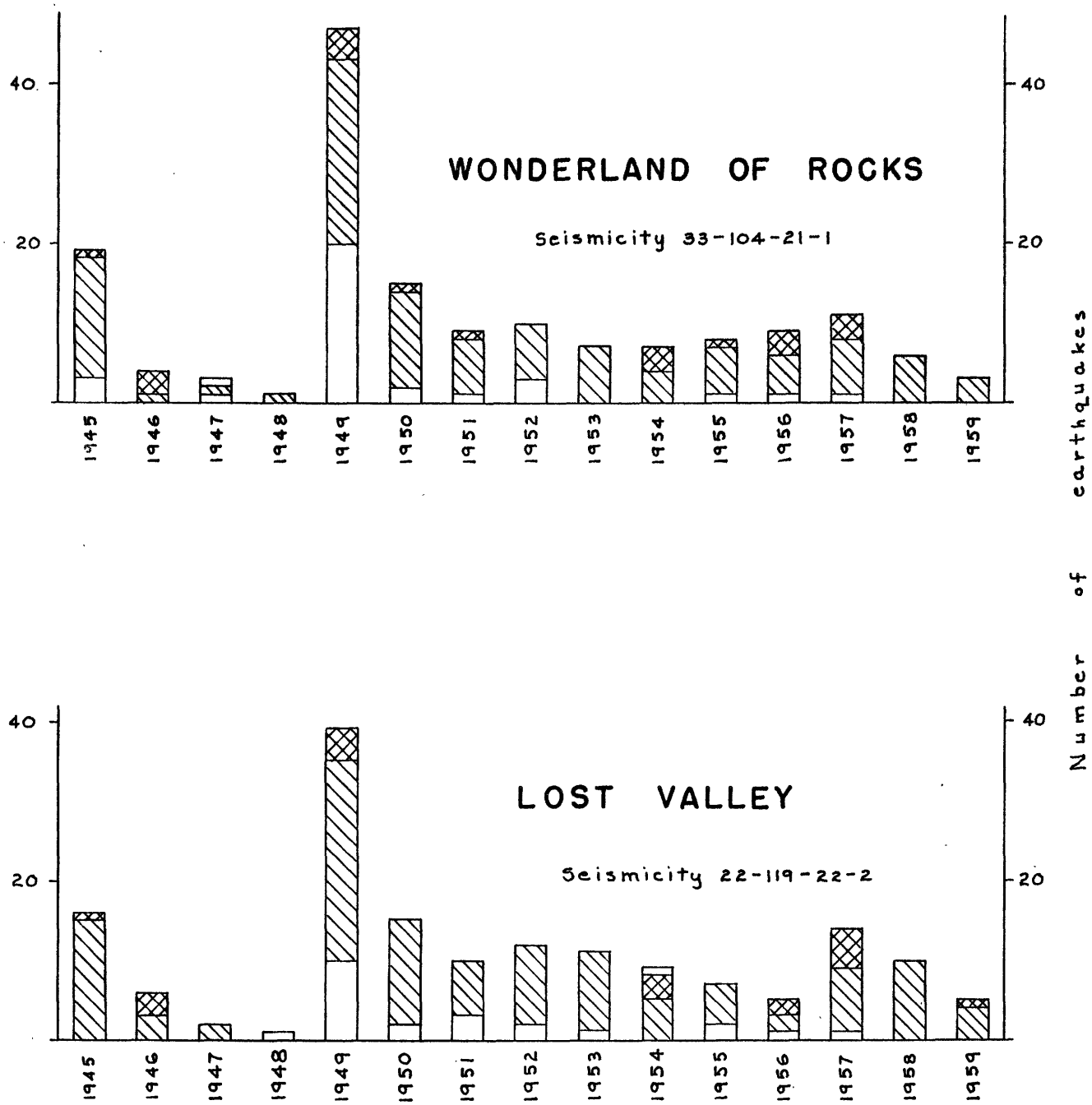

Figure 15. FREQUENCY OF EARTHQUAKES IN THE WONDERLAND-OF-ROCKS AREA AND THE LOST VALLEY AREA, CALIFORNIA, 1945-1959

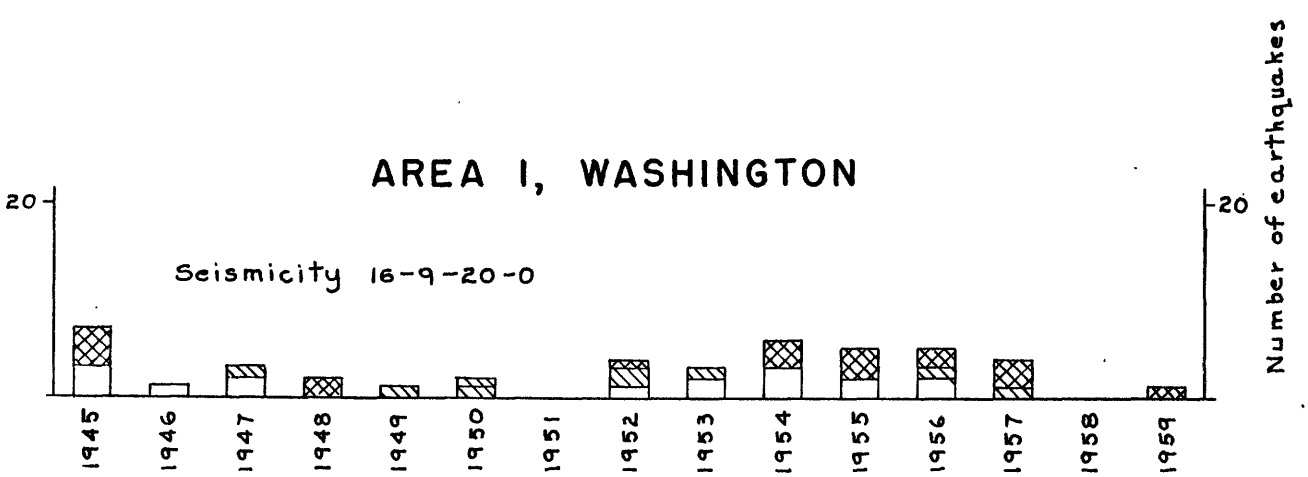

Figure 16. FREQUENCY OF EARTHQUAKES IN AN AREA IN WASHINGTON, 1945-1959

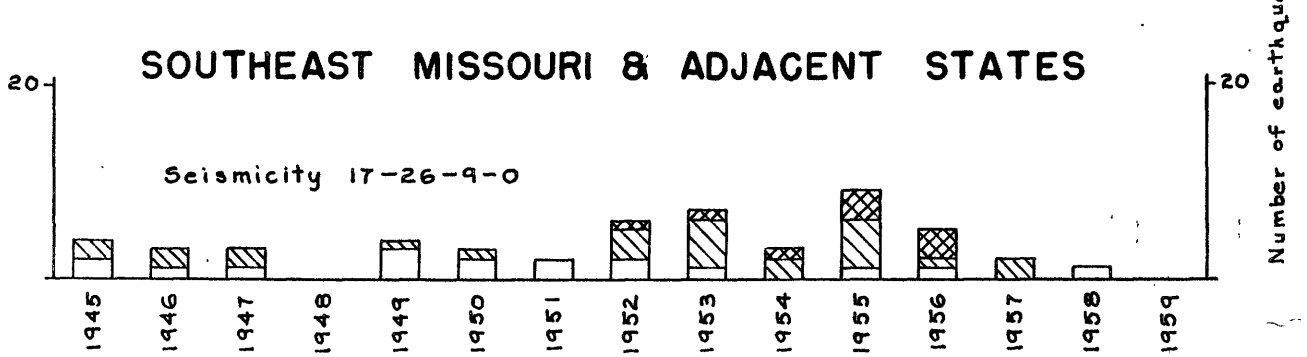

Figure 17. FREQUENCY OF EARTHQUAKES IN SOUTHEAST MISSOURI AND ADJACENT STATES, 1945-1959