

SEISMIC INTENSITIES IN IDAHO

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Seismic Intensities in Idaho

By
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and
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ABSTRACT

Idaho ranks fifth in the nation in seismic danger. Of the two largest earthquakes in the contiguous United States since 1952, one occurred in Idaho and the other within a few miles of the state's border. This report evaluates the seismic shaking hazard in the state.

Probabilistic seismic intensity maps were produced to evaluate the shaking hazard. Because two factors—bedrock acceleration and site condition—locally affect intensity, maps were produced for both stable and unstable sites. We were able to find significant differences within a given region. In the Boise area, for example, structures on bedrock will experience intensity V at the same time that structures on unstable soils will shake at intensity IX. Based on the twelve-point scale for seismic intensity, a level VII is a critical one in Idaho for determining the structural safety of buildings. At this intensity and above, damage can be considerable and fatalities may occur in

poorly built or badly designed structures. Intensity VII shaking occurs somewhere in the Idaho region at least once every 3 to 4 years.

The probabilistic intensity maps for stable sites were derived directly from state and federal maps of maximum probable acceleration in bedrock for 50-year exposure times. Accelerations were converted to seismic intensities using an empirical formula.

The intensity map for unstable sites was derived from the actual historical record of seismic intensities in Idaho for the past century. Extreme value statistics were used to derive 50-year seismic intensities in the same manner that hydrologists predict 50-year floods.

Less than 1 percent of the area of Idaho is subject to intensity VIII or higher shaking, if structures are on stable foundation material. Hence, careful site selection alone can greatly reduce the hazard of very strong seismic shaking to well-built buildings.

On the other hand, 26 percent of the area of the state is subject to intensity VII or higher shaking even if the buildings are on stable sites. The historical record shows that at least an additional 38 percent of the state is subject

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to shaking at intensity VII or higher if site conditions are unsafe. Hence, over much of the state, older poorly built structures are at considerable risk from seismic shaking.

INTRODUCTION

How critical and widespread is the seismic threat in Idaho? Based on the Uniform Building Code seismic zones (Figure 1), only California, Nevada, Utah, and Alaska have a greater overall seismic hazard than Idaho. Of the two largest earthquakes in the contiguous United States since 1952, one occurred in Idaho and the other within a few miles of the state's border. The one in Idaho was the 1983 Borah Peak event at magnitude 7.3 (M7.3); the other was the 1959 M7.5 Hebgen Lake earthquake in Montana. Despite the sparse population near the epicenters, both of these tremors caused fatalities and millions of dollars in damage.

In all parts of Idaho, the historical record of seismicity reveals at least a moderate threat from earthquakes. In the central and southeastern parts of the state, seismic activity has rivaled that of the more prominently discussed earthquake country of California. Although admittedly infinitesimal in terms of geological time, the historical record shows that Idaho has undergone several major earthquakes during the last 100 years (Figure 2), besides those at Borah Peak and Hebgen Lake. The record also warns us that the

locations of today's urban settings are vulnerable to the severe ground shaking and consequent destruction such catastrophic geologic events can bring. We have all been made acutely aware of the devastation wrought by earthquakes. We witnessed over global television the recent disasters in Mexico City, China, Armenia, and northern California. The citizens of Idaho cannot ignore this confirmed threat to life and property posed by earthquakes for the greater part of the state.

One way to cope with the danger of living in "earthquake country" is to know in what areas of the state and under what conditions earthquake shaking may imperil the buildings in which people live, learn, and work. To determine the extent of this hazard, we have examined all the information currently available on earthquake shaking in Idaho. The result is a set of seismic hazard maps which show that, over much of the state, older poorly built structures are at considerable risk from seismic shaking. These maps will continue to be valuable in numerous ways with planning new structures and remodeling older buildings to meet the earthquake safety codes being insisted upon by an ever more aware public.

The seismic hazard maps show the seismic intensities that can be expected over the next 50 years for any area of the state. Seismic intensity is based on the observed effects of shaking. For this report we used the 12-point Modified Mercalli Scale (see Figure 3). The scale ranges from level I, shaking not felt by humans, to level XII, the nearly total

Uniform Building Code Seismic Zone Map of the United States

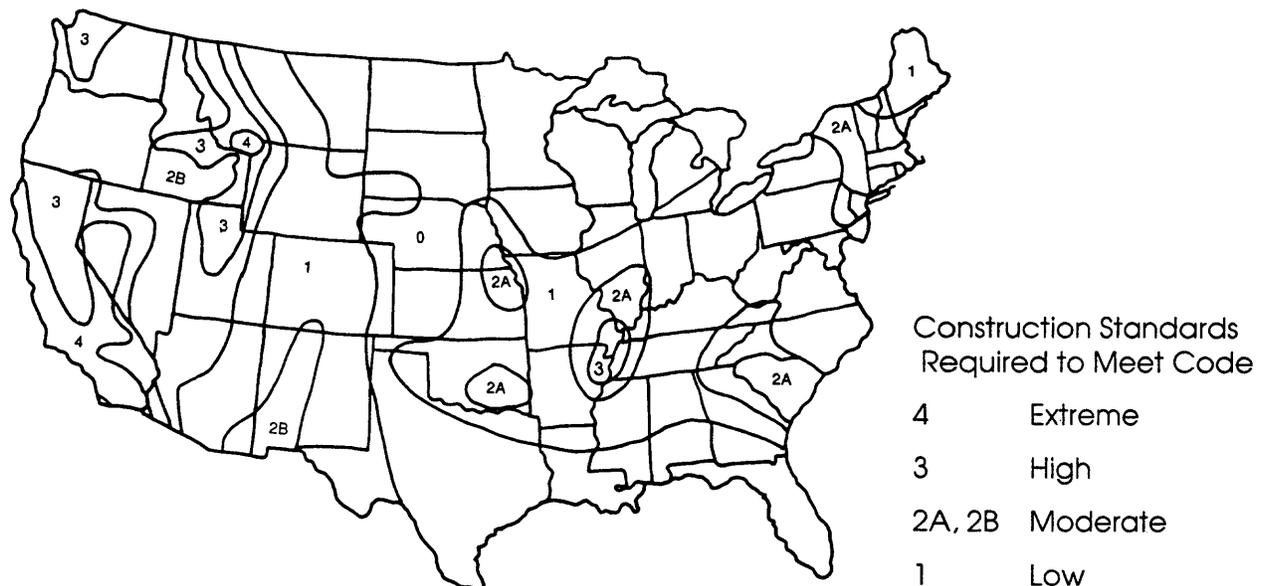


Figure 1. The 1988 Uniform Building Code map.

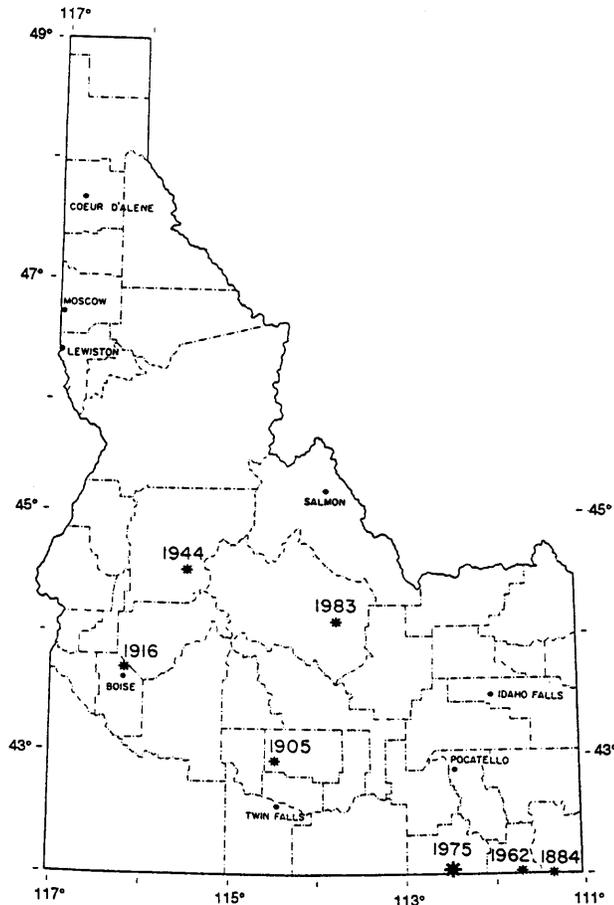


Figure 2. Major recorded earthquakes in Idaho since 1884.

destruction of man-made structures. We chose an intensity scale rather than an acceleration scale, also common in seismological studies, so that the descriptions of earthquake effects could be more readily understood by equating them to the amount of damage incurred. We did, however, use acceleration studies to calculate seismic intensities in different areas of the state. Only two reports are available on maximum probable bedrock acceleration in Idaho. One (Figure I-1) is Algermissen and others (1982) published by the U.S. Geological Survey; the other is Greensfelder (1978) prepared for the Idaho Transportation Department. The most recent acceleration maps (Figures I-2 and I-3), based on Greensfelder's work (1978), are those published by the Idaho Transportation Department (Smith, 1991).

The acceleration maps from these two studies were used to develop the minimum shaking intensities likely to occur in the state. These maps yield only lower limit values because they are based on bedrock shaking. The actual shaking that a structure endures is strongly affected by the geological characteristics of the site. The density, thickness, grain size, elastic properties, and water content of the overburden material control how a site responds to passing seismic waves. An unstable site intensifies the effects of

bedrock accelerations. Water-saturated alluvial soils, for example, may quiver like "jello" during an earthquake and greatly increase the shaking motion. Sandy layers in the overburden may liquefy during earthquake shaking and cause building foundations to shift. If local site conditions were well known across the state, then reasonable estimates of seismic intensities at building sites could be calculated. The data required to determine probable intensities would be the bedrock acceleration maps and the geotechnical parameters of the site. These site parameters include the thickness, density, elastic modulus, grain size, and damping factors for the overburden material. Such information is generally not available for the state as a whole. Hence, we were able to use the existing federal and state bedrock acceleration maps to establish only the lower limit of shaking.

Our estimate of the upper limit of shaking in Idaho is based strictly on the historical record of ground shaking during the past century. The historical record of ground shaking is based, for older events, on newspaper reports and, for more recent events, on questionnaires collected by the U.S. Coast and Geodetic Survey and the U.S. Geological Survey. Essentially the 50-year maximum shaking intensity is determined from the history of shaking in the same manner that hydrologists determine the 50-year flood cycle from annual stream flow records. The resultant map shows higher values of shaking than the bedrock acceleration map because it is only the worst shaking in an area that tends to be reported in the newspapers and on the questionnaires.

We analyzed the maps of probable seismic intensities for both stable and unstable sites, with emphasis on the critical intensity level VII. At this intensity, damage is considerable in poorly built or badly designed structures. We found that in 26 percent of the area of the state, these structures have a 10-percent chance of considerable damage from earthquake shaking in any 50-year period, even if they are built on stable sites. Sixty-four percent of the state suffers from a similar hazard for structures built on unstable sites. Conversely, if buildings were well designed and placed only on stable sites, less than one percent of the area of Idaho would be subject to severe seismic hazard. Hence, careful site selection and adherence to enlightened building codes can greatly reduce the seismic risk to new construction in Idaho.

EXISTING DATA ON SEISMIC SHAKING IN IDAHO

Seismic-shaking data for Idaho consist of catalogs of occurrences and isoseismal maps. The catalogs show the dates, origin times, geographic locations, focal depths, magnitudes, and maximum intensities of earthquakes.

The Modified Mercalli Scale

- I *Not felt except by a very few under especially favorable circumstances.*
- II *Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.*
- III *Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing truck. Duration estimated.*
- 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 motor cars rocked noticeably.*
- V *Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.*
- VI *Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.*
- VII *Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.*
- VIII *Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars.*
- IX *Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.*
- X *Some well-built, wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Train rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed over banks.*
- 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. Train rails bent greatly.*
- XII *Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.*

Figure 3. *The Modified Mercalli Intensity Scale of 1931 (abridged). Note that at intensity VII and above, poorly built structures are considerably damaged.*

Isoseismal maps show the geographic distributions of seismic intensities associated with very large earthquakes.

EARTHQUAKE CATALOGS

The most useful earthquake catalog for Idaho is that of Stover and others (1986). This listing and map gives a fairly complete and well-edited compilation of the seismic events that have occurred in Idaho up to and including 1983. Unfortunately, this listing does not include events close to Idaho but outside its borders. Such events are important for hazard analysis. A listing that includes these peripheral events is given in Breckenridge and others (1984). A map showing the epicentral locations of the larger events in the Idaho region is shown in Figure 2. A comprehensive data base for all earthquakes in the United States is maintained by the National Geophysical Data Center (Rinehart and others, 1985).

The accuracy of historic epicentral locations in Idaho is generally no better than about 10-20 miles for instrumentally detected events. For events before 1932, the location of epicenters is based entirely on damage reports. Given the rural setting of Idaho, such locations can be 30-60 miles in error. Estimations of individual epicenter locations in Idaho are given by Stover and others (1986).

Before 1962, many earthquakes in the Idaho region were undetected owing to low population density and few seismograph stations. Even today, the detection of earthquakes of magnitude less than 5 is strongly influenced by the distribution of functional seismograph stations. Hence, the historic record of Idaho earthquakes contains temporal and spatial gaps. This fact must be given careful consideration in the development of a hazard assessment for the state.

ISOSEISMAL MAPS

Isoseismal maps show the geographic distribution of seismic intensity after large earthquakes. The data for these maps are obtained by interviewing people in the affected areas, by observing any structural damage, and by studying newspaper accounts of shaking. Miller and Jones (1988) have reviewed the available intensity maps for the Idaho region. Isoseismal maps exist for thirteen events in the Idaho region. They are reproduced in Appendix II of this report because of their importance to seismic hazard assessment in the state.

Isoseismal maps record the maximum shaking that was observed in a given locality. Because this maximum shaking occurs where the site conditions most amplify the shaking, the intensities indicated on isoseismal maps represent the severest shaking that can be expected in a given area. Hence, we use data from the isoseismal maps to establish a more reasonable upper limit of probable seis-

mic intensities at given locations than can be obtained from bedrock acceleration maps.

An important use of isoseismal maps is in determining how ground shaking falls off with distance from the epicenter in different regions. The spatial attenuation of intensities in California, for example, is much higher than it is in the eastern United States (Gupta and Nuttli, 1976). Studies on the spatial attenuation of intensities in the Idaho region have been made by Uhrich (1986) and Dodge and others (1988). Generally, intensities in Idaho attenuate over shorter distances than in the east but over longer distances than in California.

METHOD

To estimate the seismic intensities in the state, the basic data we used were the bedrock acceleration maps (Appendix I), which are appropriate for stable sites, and the isoseismal maps (Appendix II), which represent information from unstable sites.

To estimate how buildings on stable sites will shake, we used the probabilistic estimates of bedrock acceleration by Algermissen and others (1982) and Greensfelder (1978). An empirical relationship between acceleration A in cm/sec^2 ($0.03 \text{ ft}/\text{sec}^2$) and seismic intensity is

$$I = 4 \log A - 1 \quad (1)$$

This formula is from Murphy and O'Brien (1977).

First, we sampled the two maps by dividing the state into 309 small grid areas about 17 miles (27 km) square. The average value of probable bedrock acceleration was estimated for each grid square. Where the federal and state maps disagreed, the larger of the two estimates was used. We did this to err toward more strict building standards in regions where the seismic hazard is controversial. Finally, the above equation was used to convert the bedrock accelerations to seismic intensities.

As an example, we will consider the Boise area. Both the federal and state maps of bedrock acceleration (Appendix I) show the Boise area as having a 10-percent chance of exceeding an acceleration of $4 \text{ cm}/\text{sec}^2$ in any 50-year period. Using equation (1), this translates to a 10-percent chance of intensity V or greater in any 50-year period. However, the historical record shows that intensity V or greater shaking has occurred in Boise at least six times in the last 100 years. This discrepancy dramatically points out the importance of considering the effect of unstable site conditions in seismic hazard assessments.

To estimate the seismic intensities for unstable sites, we have evaluated seismic shaking in the same manner that civil engineers would estimate the 50-year flood using the methods of extreme value statistics (Gumbel,

1958). This approach has previously been applied to seismic intensity data by Glass and others (1978), Carr (1983), Krieski (1984), and Miller and Jones (1988). We assume that at any location in the state, seismic shaking is exponentially distributed in intensity but randomly distributed in time.

The following steps are required to produce a seismic hazard map based on extreme value statistical analysis of the historical record of shaking.

1. Divide the state into small grid areas, establish an appropriate data-collection period, and determine an attenuation model for Idaho.
2. Use the existing data and the results of step 1 to reconstruct the historical record of ground shaking for each grid area.
3. Establish the distribution of historic intensities for each grid area.
4. Calculate the intensity that is likely to be equalled or exceeded over any 50-year interval for each grid area. Below, we describe each step in detail.

GRID AREAS

For hazard analysis, we divided the state into 309 small areas. Each area is nearly square, with sides about 17 miles (27 km) long. This subdivision is about as small as reasonably possible considering that epicentral locations in Idaho over historical time are accurate to only 10 to 20 miles (Greensfelder, 1978; Stover and others, 1986). For each grid area, we will calculate the highest intensity that is likely to occur in the area assuming unstable site conditions. Thus, we are not forecasting that all structures within the grid area will be so affected. The actual shaking that a particular structure within the grid square will experience is determined by the local site conditions—the thickness, density, grain-size, elastic properties, and water content of overburden—and, for local earthquakes, by the actual distance to the causative fault.

DATA-COLLECTION PERIOD

Extreme value statistics are most commonly done on data collected annually. For example, stream flow tends to go through one cycle per year. Stream flow is controlled by seasonal weather patterns which generally repeat on an annual basis. Hence, looking for the maximum flow over a 1-year period makes sense. Earthquakes in the Idaho region do not repeat annually, but they do show a cyclical pattern.

Figure 4 is a chart showing the maximum annual intensity of shaking during the past 100 years at Boise. This particular data set is based on an attenuation model by Uhrich (1986). These data form a time sequence which—like all time sequences—is very amenable to standard statistical techniques.

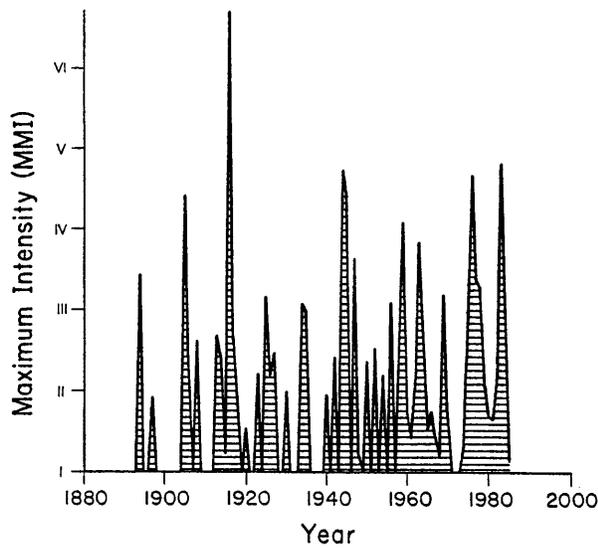


Figure 4. The history of maximum annual seismic intensities in Boise, Idaho. The record is incomplete. For some years, there is no reliable data, as noted by gaps in graph. See Figure 3 for intensity scale.

For example, Figure 5 shows the autocorrelation function of the historical intensity chart at Boise. The discrete autocovariance A of a sample function $g(k)$ of length N is defined by

$$A(j) = \sum_{k=0}^{N-1} g(j+k) g(k) \quad (2)$$

where j is the time lag. This function involves shifting the time sequence past itself with a cross-multiplication and sum at each lag. The result is a set of correlation coefficients as a function of time lag. When the data are in agreement at particular lags, high positive correlation will occur. The autocovariance function of the Boise data shows the recurrence of earthquake shaking intensities at 10, 20, 30, and 40 years. This pattern suggests a 10-year cyclicity in earthquake shaking at Boise. Because the shaking at Boise is due to events from throughout the Idaho region, this cyclicity can probably be extended to the entire state.

Another statistical function that can be used to analyze a time sequence is the variogram defined as

$$V(j) = \frac{1}{N} \sum_{k=0}^{N-1} [g(j+k) - g(k)]^2 \quad (3)$$

Variograms show the expected variance between observations separated by a given time lag. If the observations are not correlated, the variance will approach a constant level—the sill level—indicative of random earthquake activity. In Figure 6, the variogram for the Boise intensity data, a sill occurs with a variance of about 3. However, for shorter lags, the variance is below the sill. The time re-

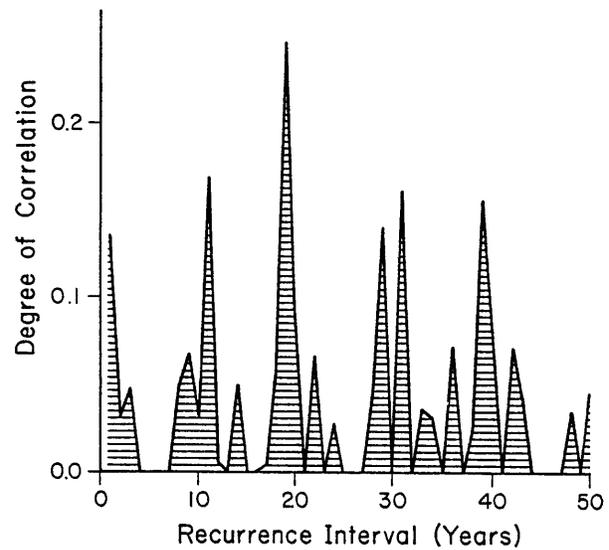


Figure 5. Autocovariogram of maximum annual seismic intensities at Boise, Idaho. Only positive correlations are shown. The strong peaks at 10, 20, 30, and 40 years indicate a 10-year cyclicity in shaking. See Figure 3 for intensity scale.

quired for the variance to rise to the sill level is 4 years in the Boise example. This result suggests some causal relationship between shaking events at Boise in the short term. For example, a year of very high maximum intensity will result in higher than average annual intensities for the following 4 years. This suggests that aftershock sequences last 4 years in the Idaho region.

In summary, a statistical analysis of the maximum annual shaking data at Boise shows that shaking occurs within a 10-year cycle and that maximum annual shaking values are independent only if at least 4 years separate the observations. Because extreme value statistical analysis demands that events be distributed randomly in time, the effect of the 4-year aftershock duration and the 10-year cyclicity must be removed from the shaking data. We accomplish this by analyzing the maximum intensity once for each cycle (i.e., once per decade). This is analogous to a hydrologist determining the maximum flood stage once per each cycle (i.e., annually). Because the cycle length (10 years) exceeds the aftershock duration (4 years), the nonrandom effects of the aftershocks are also eliminated from the data set.

Because of the 10-year cyclicity apparent in the shaking due to earthquakes in the Idaho region, we have chosen to use decades rather than single years as the fundamental data collection period in the extreme value hazard analysis for the state. By doing this, theoretical problems associated with the nonrandom shaking of aftershocks are avoided. In addition, the pre-instrumental part of the earthquake catalog of the region is more likely to show the maximum

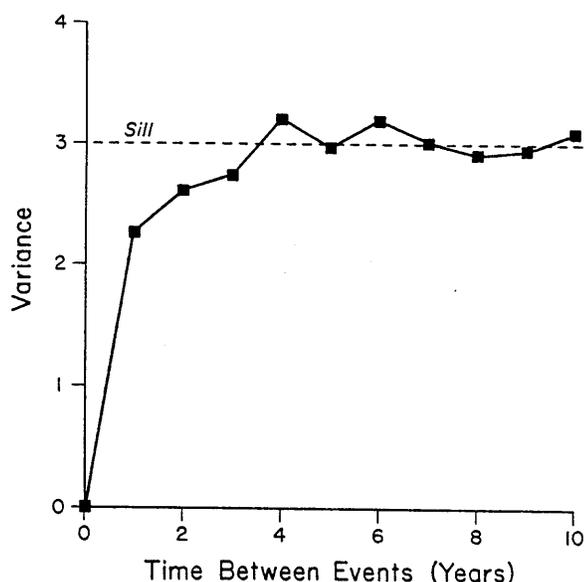


Figure 6. Variogram of maximum annual seismic intensities at Boise, Idaho. The sill level represents a random relationship between seismic shaking events. For time lags less than 4 years, there is a causal relationship between events, probably a result of aftershocks.

intensity of a 10-year shaking event than the maximum amplitude of annual events. Hence, errors associated with the temporal and spatial gaps of the historical record are minimized.

AN ATTENUATION MODEL FOR IDAHO

To estimate the seismic intensity at various locations in the state for large historical events for which isoseismic maps are not available, we set up an attenuation model for the state. This mathematical model predicts the intensity, $I(R)$, at any distance, R , from the epicenter given the maximum intensity, I_0 , of the event. For many events in the earthquake catalog, a direct observation of I_0 is given. If not, then empirical relationships between I_0 and various magnitude scales can be used to estimate I_0 .

The attenuation model we use is given by

$$I(R) = I_0 + 3.8 - C R - 2.7 \log R \quad (4)$$

where the 3.8 factor was determined by regression analysis for the Idaho region by Dodge and others (1988) and the 2.7 factor is from Gupta and Nuttli (1976). The attenuation constant C for the Idaho region is discussed below. Solving equation (4) for C ,

$$C = \frac{I_0 + 3.8 - I(R) - 2.7 \log R}{R} \quad (5)$$

The felt area, A , for most large historical earthquakes in the Idaho region is known. If we presume that the felt area includes the outermost limit of intensity IV shaking and

that the felt area is circular, then the mean radius for intensity IV shaking can be calculated for each event.

Using this approximation, a value of C can be found for each major historical earthquake in the Idaho region. The average value of C for the Idaho region is 0.004. Figure 7 shows I_0 versus mean radius of felt area for the events tabulated. The attenuation model is also shown with $C=0.004$. The model appears to be a step function because intensities are always integer values. The overall fit seems reasonable considering the subjective nature of I_0 observations and the sparse population of the the region.

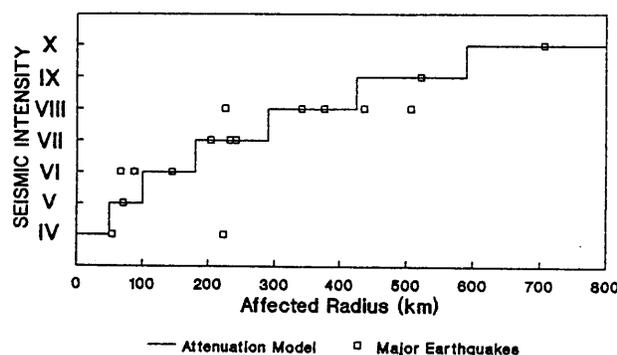


Figure 7. Relationship between maximum intensity and radius affected for large shocks in the Idaho region. The step function is the attenuation model used in the present study. See Figure 3 for intensity scale.

In summary, the attenuation model used in this study for those historical earthquakes for which actual isoseismic data does not exist is

$$I(R) = I_0 + 3.8 - 0.004 R - 2.7 \log R \quad (6)$$

where R is the distance from the epicenter to the nearest location in the grid area.

A major difficulty in working with intensities is that the degree of "shaking" is a continuous physical variable but the Mercalli Scale is not. A given seismic intensity actually represents a range of possible shaking. On the other hand, no two shaking events are exactly alike. In this study, we presume that observed shaking falls in the midrange of the given intensity. If two or more shaking events are rated at the same intensity, we presume that they are different but that their average shaking falls in the midrange of their rated intensity. All projections are based on midrange intensities as well.

HISTORICAL RECORD OF GROUND SHAKING

For each grid area, the history of ground shaking was compiled for each decade from the 1880s through the 1980s. For those events in the decade for which actual isoseismic maps were available, the observed intensity in the grid area was read directly from the map. For the remaining earthquakes during the decade, the intensity in

the grid area was estimated by the magnitude of the event and the attenuation model discussed above. Finally, only the largest intensity of the decade at each grid area was retained for extreme value analysis.

Figures 8 to 18 show the maximum observed intensities in Idaho for each decade from the 1880s through the 1980s. These eleven maps form the basic data from which all the statistical inferences in this report are derived. The significant earthquake event or events of each decade are described briefly below.

The 1880s

The big event of the 1880s (Figure 8) was an intensity VII earthquake centered in the extreme southeastern corner of the state near Paris on November 10, 1884. Considerable damage to houses occurred in Paris and chimneys fell in Richmond, Utah. The quake shook a train on the Utah and Northern Railway north of Ogden, Utah. Several other northern Utah events in 1880s may have shook southeastern Idaho, but the 1884 event certainly produced the largest shaking of the decade in this part of the state. A mine explosion near Mount Idaho on August 19, 1881, was incorrectly reported in the press as a volcanic eruption.

The 1890s

The 1890s (Figure 9) featured three separate shaking events at Boise on December 24, 1894. The largest reached intensity V. Three strong earthquakes in the neighboring states of Oregon, Montana, and Utah also shook Idaho during the decade with intensities as high as V in some areas.

The 1900s

An intensity VII earthquake occurred in the middle of the Snake River Plain on November 11, 1905. It was centered at Shoshone where the intensity was VII. The walls of the courthouse and schools cracked. Plaster fell from ceilings in nearly all buildings. The quake was felt from Salt Lake City, Utah, to Baker, Oregon. Parts of eastern Idaho were also shaken by a 1906 intensity V event in Idaho and a 1908 intensity VI event in southwestern Montana (Figure 10).

The 1910s

The 1910s (Figure 11) formed an active decade for earthquake shaking in Idaho. On May 13, 1914, an intensity VII event occurred on the Idaho-Utah border southwest of Montpelier. On October 14, 1913, an intensity VI event near the Oregon border broke windows and dishes in Idaho and Adams counties. On October 3, 1915, a M7.75 earthquake centered in Dixie Valley, Nevada,

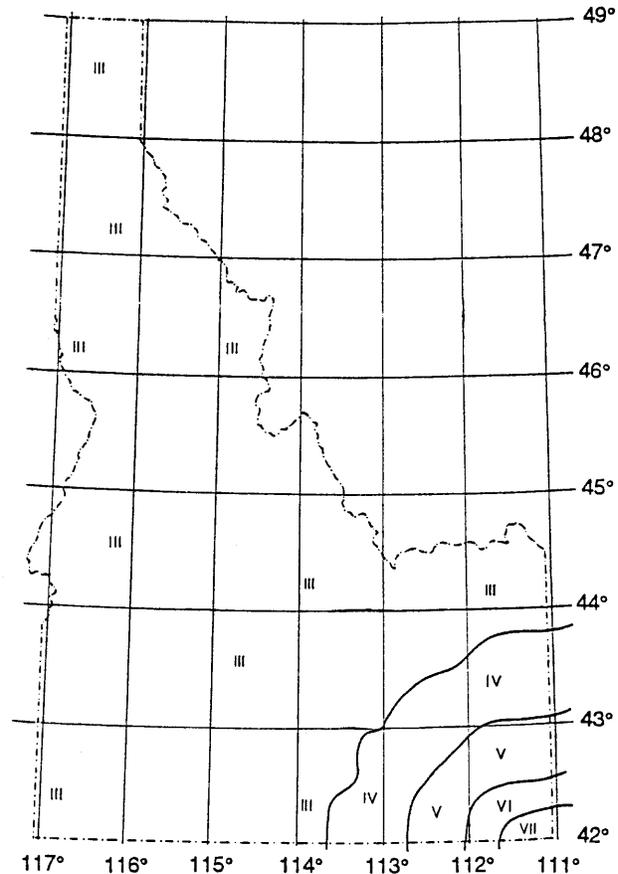


Figure 8. Maximum seismic intensities in Idaho during the 1880s. See Figure 3 for intensity scale.

shook much of Idaho with intensities as high as VII in the southwestern corner of the state. On May 13, 1916, Boise was shook by an intensity VII event. Some chimneys fell. The event was felt from eastern Oregon to western Montana. Investigators have speculated that the true epicenter of this event is 60 to 180 miles north of Boise (Greensfelder, 1978). If this is true, it will not alter the fact that Boise shook at intensity VII. However, it will result in higher estimated isoseismals north of Boise. Even northern Idaho did not escape the great shaking of the 1910s. In 1918, shocks near Sandpoint, Idaho, and Colville, Washington, caused intensities as high as V in the panhandle.

The 1920s

A M6.75 earthquake on June 28, 1925, in western Montana caused the maximum shaking observed during the 1920s (Figure 12) over most of Idaho. A July 10, 1925, intensity VI event occurred on the Idaho-Wyoming border east of Montpelier. On April 9, 1927, an intensity V event occurred in the Connor Creek fault area on the Idaho-Oregon border. A November 28, 1926, event shook Wallace with an intensity V.

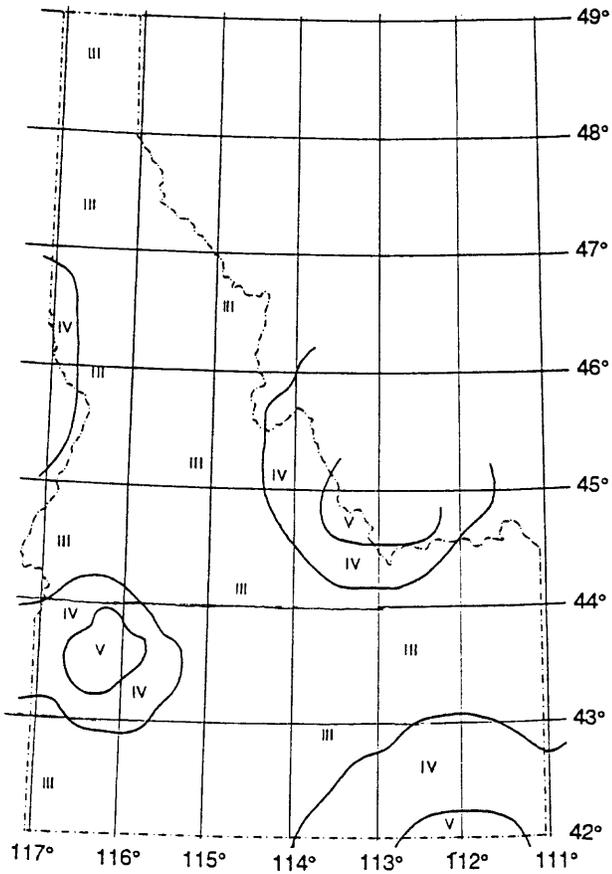


Figure 9. Maximum seismic intensities in Idaho during the 1890s. See Figure 3 for intensity scale.

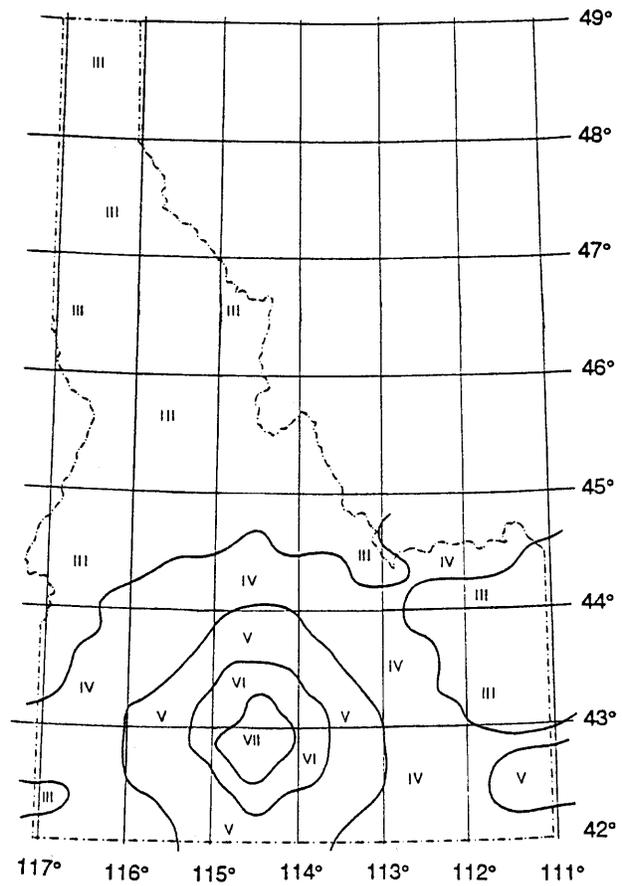


Figure 10. Maximum seismic intensities in Idaho during the 1900s. See Figure 3 for intensity scale.

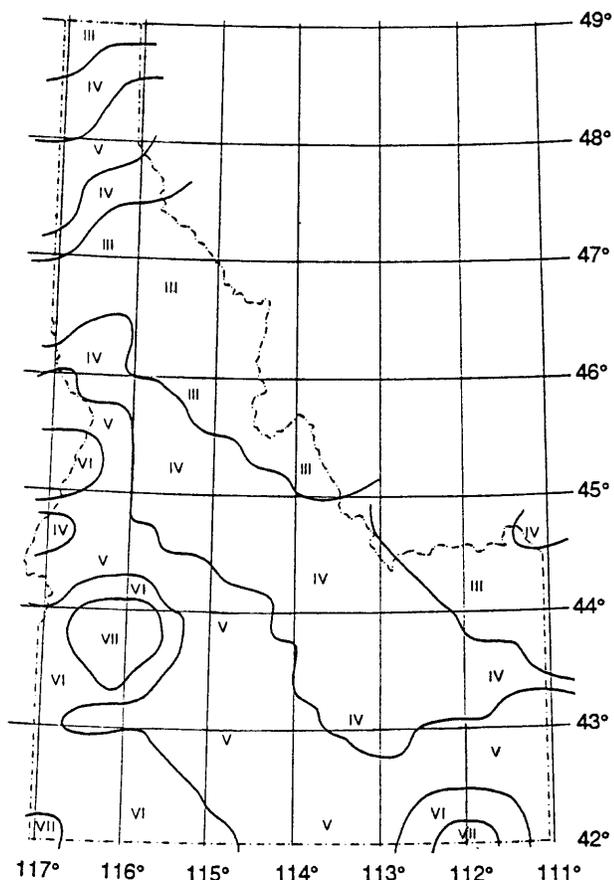


Figure 11. Maximum seismic intensities in Idaho during the 1910s. See Figure 3 for intensity scale.

The 1930s

The maximum shaking in Idaho during the 1930s (Figure 13) was mostly caused by three events: the 1934 M6.6 Hansel Valley earthquake in northern Utah; the October 18, 1935, M6.5 Helena, Montana, earthquake; and the July 15, 1936, M6.4 Walla Walla, Washington, earthquake. Actual isoseismal maps of all three events are shown in Appendix II. A December 18, 1937, intensity V event shook Cascade. A June 12, 1930, event shook the Wyoming border area northeast of Montpelier with an intensity VI.

The 1940s

The 1940s (Figure 14) witnessed much ground shaking in Idaho. Two M6 events occurred in the Idaho batholith northwest of Boise in 1944 and 1945. Isoseismal maps of these events are given in Appendix II. Observers of these events reported spectacular ground effects. The first event caused rocks to jump at least a foot in the air. Boulders rolled down the hills. A canyon wall on the Rapid River collapsed. People could not stand during the event. The second event was felt most strongly at Idaho City and Weiser where slight damage,

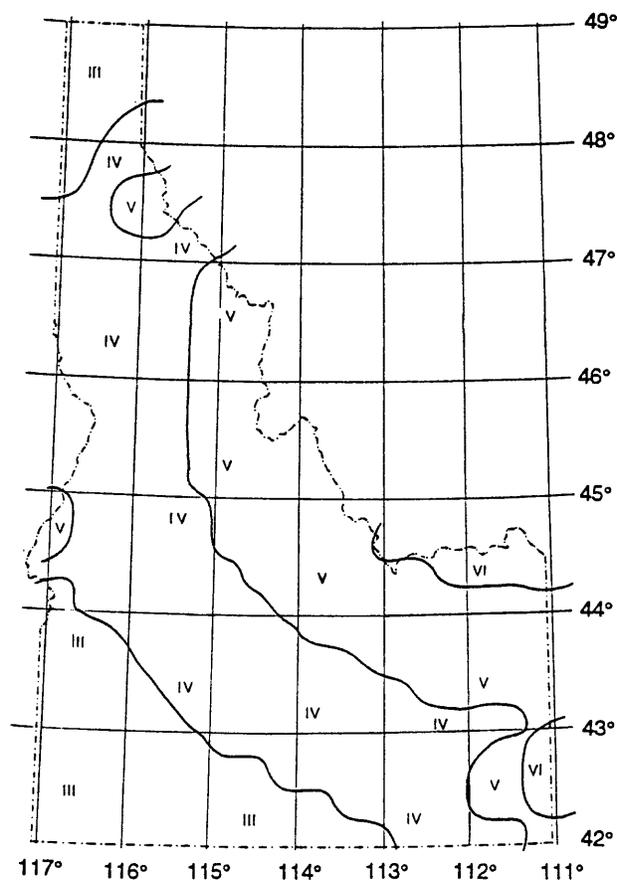


Figure 12. Maximum seismic intensities in Idaho during the 1920s. See Figure 3 for intensity scale.

cracked plaster, and broken dishes occurred. The M6.25 Lima, Montana, earthquake of November 23, 1947, also caused severe shaking in Idaho. An isoseismal map of this event is given in Appendix II. On November 1, 1942, an intensity VI event shook Sandpoint. This event, which was felt in three states, caused some cracks in plaster and halted railroad operations in northern Idaho due to rock debris on the tracks. An April 13, 1944, event at Lewiston caused intensity V shaking. A December 17, 1947, event on the Idaho-Wyoming border east of Idaho Falls caused intensity VI shaking.

The 1950s

The maximum earthquake shaking in Idaho during the 1950s (Figure 15) was caused by the 1959 M7.5 Hebgen Lake, Montana, earthquake. The epicenter of this huge event was only a few miles north of the Idaho border. No earthquake in the conterminous United States has since exceeded this event in energy release. The isoseismal map of this event is shown in Appendix II. The earthquake triggered a landslide that killed 29 people. Property damage was in the millions of dollars. Hebgen Lake Dam was severely damaged.

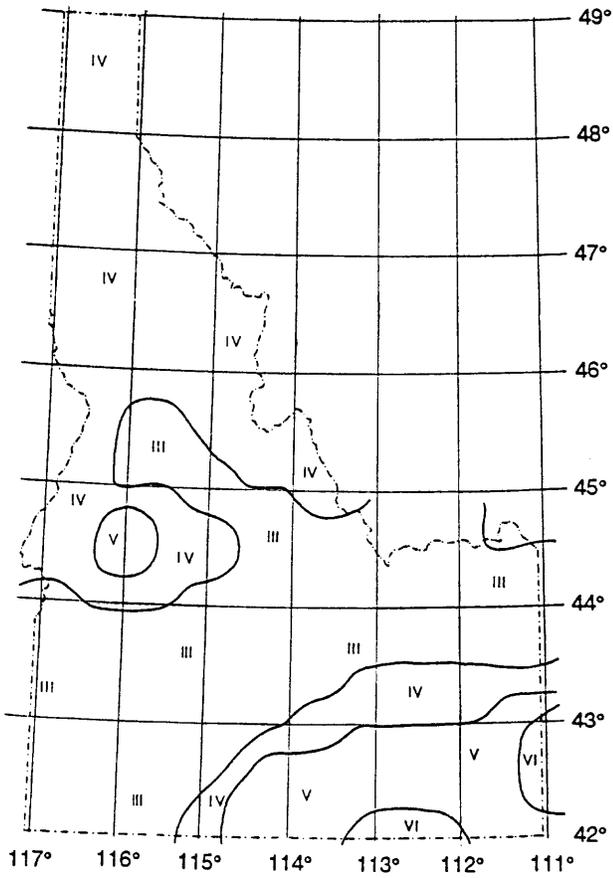


Figure 13. Maximum seismic intensities in Idaho during the 1930s. See Figure 3 for intensity scale.

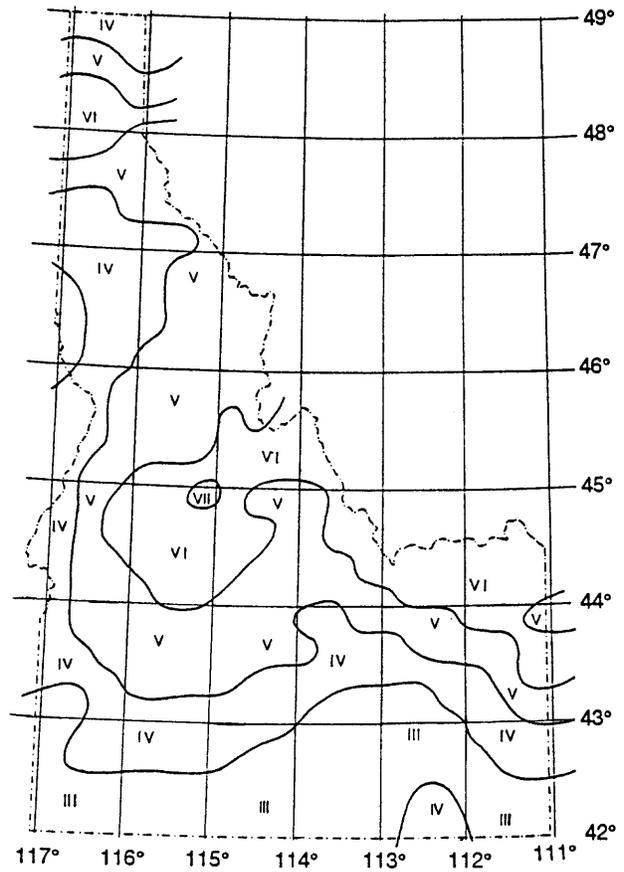


Figure 14. Maximum seismic intensities in Idaho during the 1940s. See Figure 3 for intensity scale.

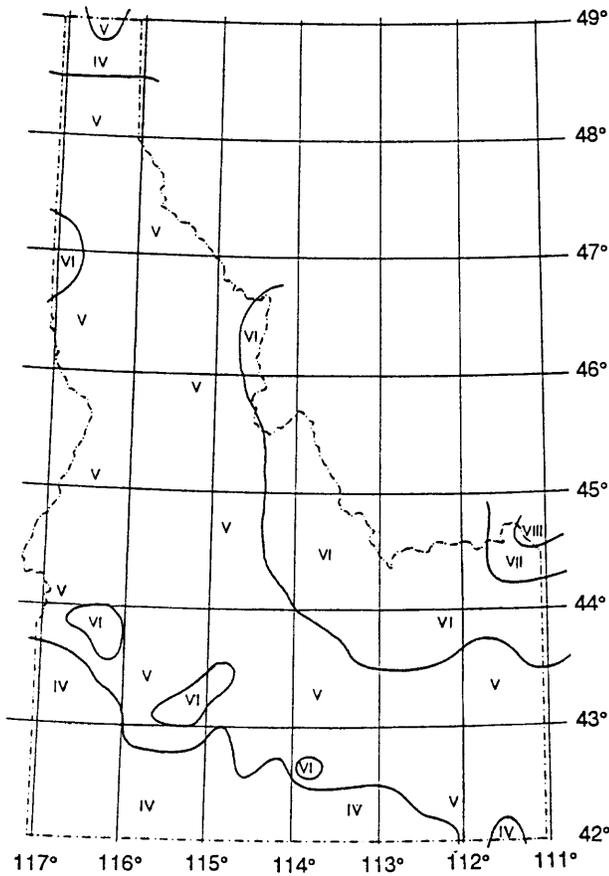


Figure 15. Maximum seismic intensities in Idaho during the 1950s. See Figure 3 for intensity scale.

The 1960s

Some shaking in Idaho during the 1960s (Figure 16) was caused by aftershocks of the 1959 Hebgen Lake event. However, a swarm of events with intensities as high as VI in the Ketchum-Stanley-Clayton area was the most interesting occurrence. On January 27, 1963, plaster and windows were cracked at Clayton. On Sept 11, 1963, plaster fell in buildings at Redfish Lake. On April 26, 1969, cement floors were cracked in Ketchum and Warm Springs. An intensity VI event on August 7, 1960, near Soda Springs cracked plaster and concrete foundations. A M5.7 event on August 30, 1962, in the Cache Valley on the Idaho-Utah border heavily damaged old brick buildings and homes.

The 1970s

Five earthquakes accounted for ground shaking in Idaho during the 1970s (Figure 17). An M6.1 event in southwestern Montana on June 30, 1975, caused intensity VI and V shaking in the Yellowstone region of Idaho. An M6.1 event centered in the Pocatello Valley at Malad City on March 28, 1975, caused intensities as high as VIII in southeastern Idaho. The estimate of damage in the epicentral area was about

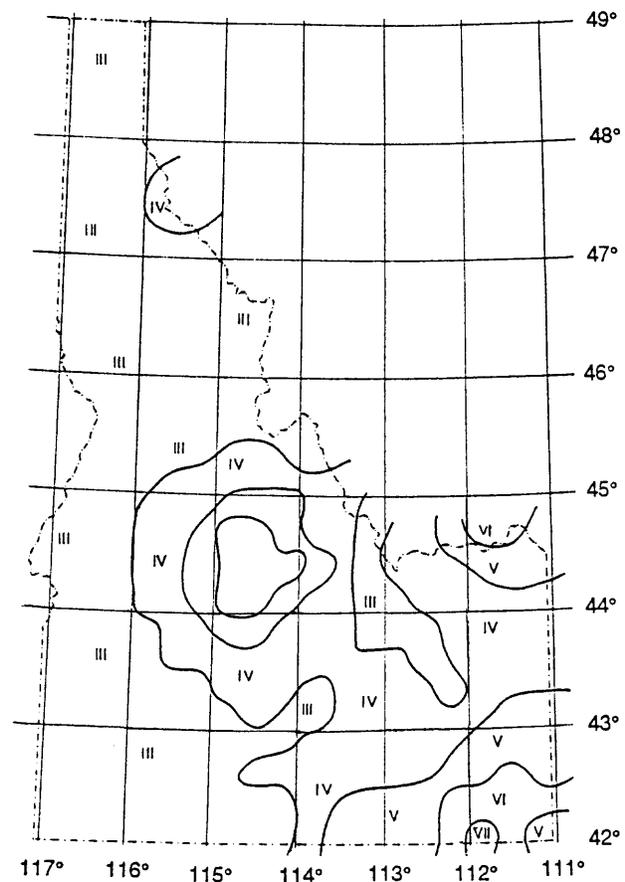


Figure 16. Maximum seismic intensities in Idaho during the 1960s. See Figure 3 for intensity scale.

\$1 million. Some 520 homes were damaged. Several were shifted off their foundations in the Ridgedale area. On November 27, 1977, an M4.5 earthquake occurred near Cascade. Drywall and foundations were cracked. Ceiling beams were separated. Well water and springs became muddied. On April 23, 1978, an intensity V event at Ovano, Montana, caused some intensity IV shaking in northwestern Idaho. On October 29, 1978, an M4 event near Ellis caused intensity V shaking. Isoseismal maps for the last four events mentioned are given in Appendix II.

The 1980s

The M7.3 Borah Peak earthquake of October 28, 1983, was the major event in Idaho during the 1980s (Figure 18). The isoseismal map of this event is shown in Appendix II. Its maximum intensity is now rated as IX (Stover and others, 1986). Earlier reports had given it a VIII or even a VII. Two children were killed in Challis. The total damage was \$12.5 million. Eleven buildings and 39 businesses sustained major damage. Over 200 homes had minor damage. The earthquake caused 21 miles of surface faulting. It also caused water fountains near Chilly Buttes and Mackay Reservoir. It diverted the flow of water from springs, flooded a mine, and caused many rock falls and

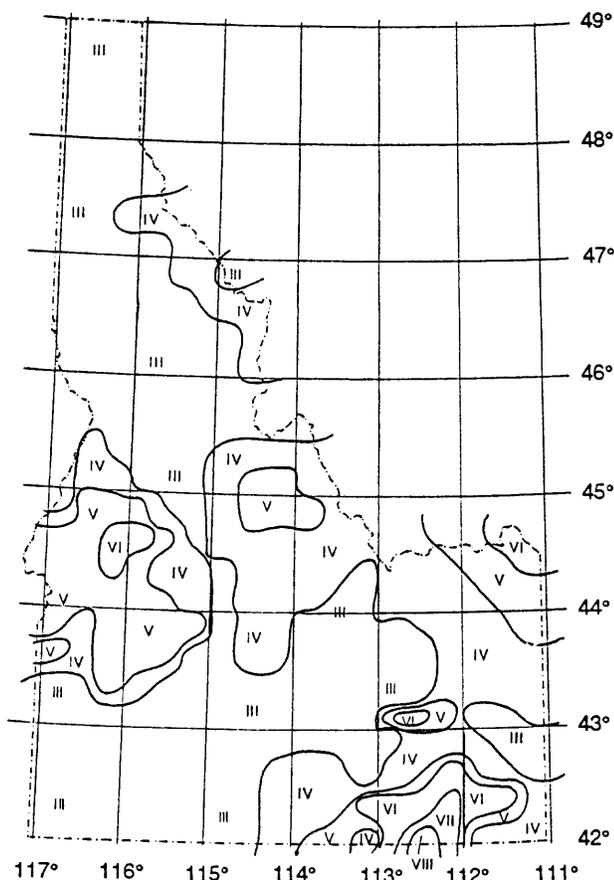


Figure 17. Maximum seismic intensities in Idaho during the 1970s. See Figure 3 for intensity scale.

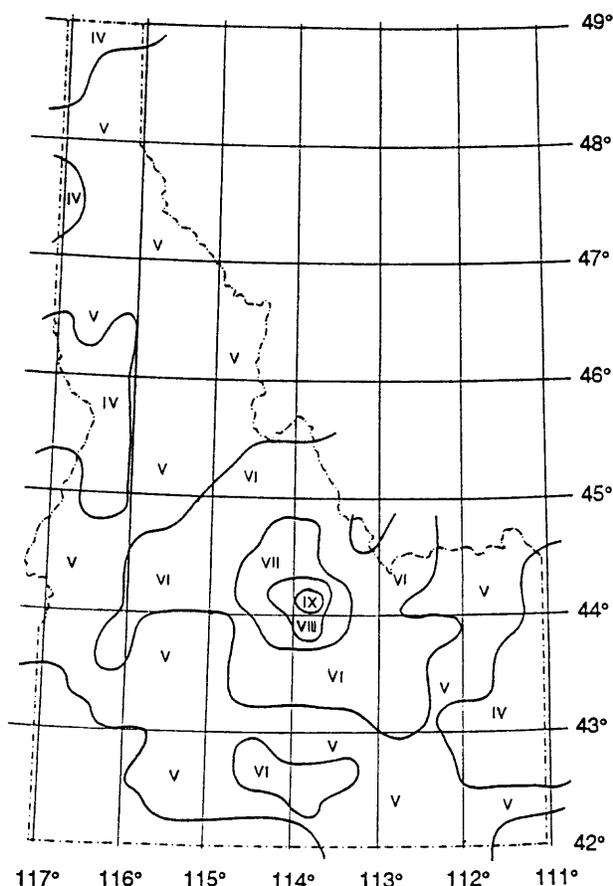


Figure 18. Maximum seismic intensities in Idaho during the 1980s. See Figure 3 for intensity scale.

landslides. Only the sparse population and lack of development between Mackay and Challis prevented this earthquake from being a major disaster. Had it occurred near Boise, hundreds would have been killed and property damage would have been in the several hundred millions of dollars. Had it occurred in a much more populated area such as Southern California, thousands would have died, and property damage would have been in the billions of dollars.

**DISTRIBUTION OF INTENSITIES:
BOISE EXAMPLE**

To illustrate the process of hazard evaluation for unstable sites, we will show the method for the Boise area in some detail. This process was repeated for all 309 grid areas in the state. Over the past century in Boise, the largest intensity experienced per decade has been a VII once, VI twice, V thrice, IV once, and III four times. These extreme values of intensity can be analyzed using methods developed by Gumbel (1958). Figure 19 shows the major shaking event of each decade at Boise plotted on Gumbel's (1958) Type I probability scale. The best-fit straight line through these events defines the parameters of a Gumbel Type I distribution. Though this line appears straight on

the probability scale, it actually represents an exponential distribution in intensity.

Figure 20 shows the probability per decade of shaking exceeding a given intensity at Boise based on the Gumbel Type I distribution found above. The bars indicate the actual probabilities observed over the last century. For example, intensity IV or greater shaking occurred in 7 of the 11 decades since 1880. Thus, the probability per decade of shaking equalling or exceeding IV is 7/11 or 63 percent. The exponentially curved line on Figure 20 represents the best fit Gumbel Type I distribution to the Boise data. This curve can be used to project the probability of shaking at Boise in any decade. For example, the chance of intensity VIII in any decade is about 5 percent (or one decade in twenty).

Return time is the average interval between shaking events that equal or exceed a given intensity. For example, during the past eleven decades, shaking at Boise has exceeded intensity IV seven times. So the average return time for intensity IV or greater shaking is 11/7 decades or about every 16 years. Figure 21 shows observed and projected return times at Boise. If the last century is representative, then Boise can expect intensity VIII shak-

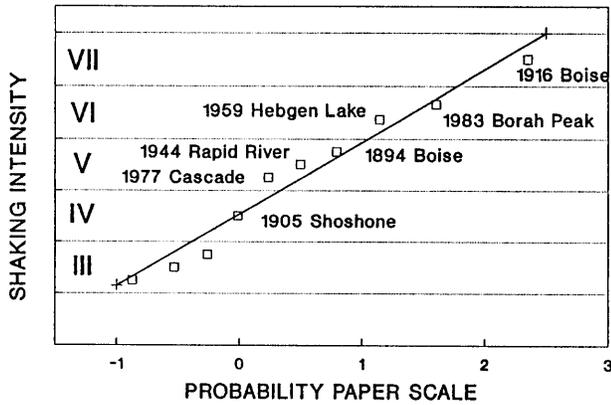


Figure 19. Probability paper plot of maximum shaking per decade at Boise, Idaho. On this type of plot, a Gumbel Type I double exponential distribution would appear as a straight line. The major seismic shaking events at Boise are identified on the plot as well. See Figure 3 for intensity scale.

ing every 190 years, intensity IX shaking every 395 years, and intensity X every 800 years.

50-YEAR PROBABILITY OF SHAKING: BOISE EXAMPLE

Using the historical distribution of extreme values of intensity in each grid area, we can find the probability of shaking at a given intensity or greater over any exposure time. A 50-year exposure time has become the standard for engineering purposes. For example, Figure 22 shows the 50-year probabilities of shaking at Boise. We note that

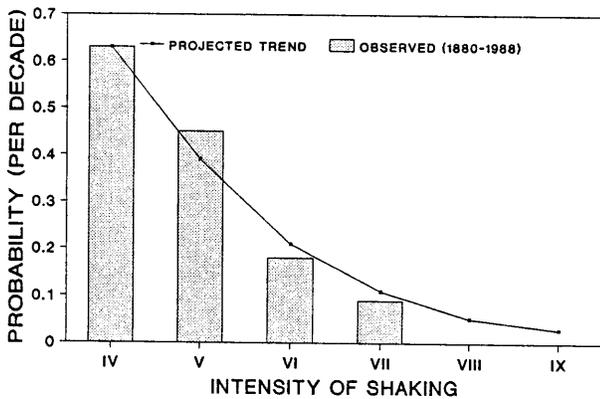


Figure 20. The probability per decade of the intensity shown being equaled or exceeded at Boise, Idaho. The bars represent actual observations over historical time. The line is the best-fit Type I Gumbel distribution. See Figure 3 for intensity scale.

there is better than a 50-percent chance of midrange intensity VI shaking or greater in any 50-year period at Boise and a 33-percent chance of intensity VII, an 18-percent chance of intensity VIII, and a 10-percent chance of intensity IX.

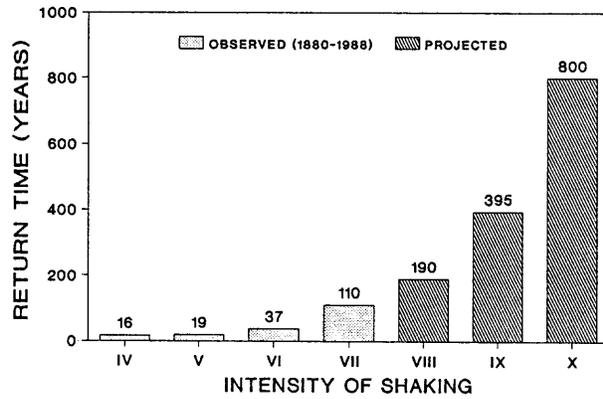


Figure 21. The return time at Boise, Idaho, for shaking equal to or greater than the seismic intensity shown. See Figure 3 for intensity scale.

It must be repeated at this point that these probabilities are for the maximum shaking on unstable sites somewhere in the 300-square-mile Boise area. Every site in Boise will not shake at these levels. As described in a previous section, buildings on stable sites in Boise have a 10-percent chance of experiencing only intensity V in any 50-year period. The difference between this intensity and the intensity IX estimate for unstable sites is immense. A poorly built structure on a stable site in Boise is far more likely to survive a large earthquake than a well-built structure on an unstable site. Thorough geotechnical site analysis should clearly be the rule for all new construction in this city.

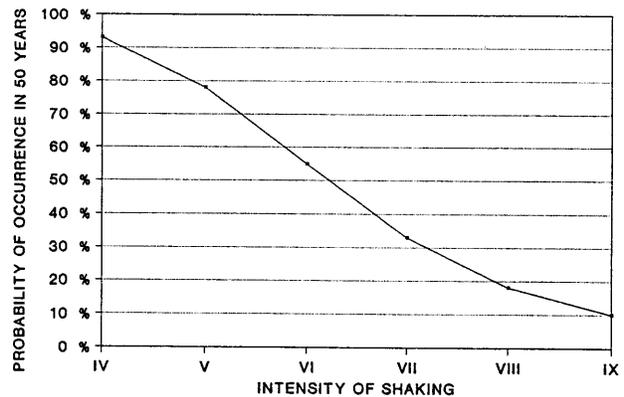


Figure 22. Probability of shaking greater than or equal to the seismic intensity shown for an exposure time of 50 years at Boise, Idaho. For example, the chance of shaking greater or equal to intensity IX is 10 percent; or, there is a 90-percent chance that the shaking at Boise over a 50-year period will be less than midrange intensity IX. See Figure 3 for intensity scale.

STATE SEISMIC HAZARD MAPS

The process above has been repeated for each grid area in the state. The resulting hazard maps are displayed in Figures 23 and 24. Both show intensities that have a

90-percent chance of not being exceeded in any 50-year period. Figure 23 is for structures on stable sites; it was derived directly from state and federal probabilistic bedrock acceleration maps. Figure 24 is for structures on unstable sites in the area; it was derived from extreme value analysis of the actual shaking history at each grid area. The intensities shown in Figure 23 should be viewed as those that are very likely to occur for buildings in the state. The intensities shown in Figure 24 represent what could happen to buildings on unstable sites.

Shaking at intensity VI or less generally does not pose a serious safety hazard. Although plaster may fall and chimneys collapse, the chance of physical injury to occupants is small.

On the other hand, intensities of VIII and higher are sure to produce serious structural damage even in the best built buildings, possibly inducing many to collapse and to cause serious injuries and even fatalities to inhabitants. At these intense levels of shaking, little can be done to improve or modify building design to prevent such disastrous consequences. However, Figure 23 shows that less than 1 percent of the area of the state is subject to intensity VIII shaking, if structures are built on bedrock or equivalently firm sites.

At intensity VII, considerable damage will occur in poorly built or badly designed structures. Two children were killed by collapsing unreinforced masonry in the intensity VII shaking at Challis in 1983. Buildings at Challis, Mackay, and Gooding were condemned as a result of this level of shaking. Intensity VII shaking occurs somewhere in the Idaho region at least once every 3 to 4 years.

Figure 23 shows that at the 90-percent confidence level, bedrock shaking alone can result in intensity VII in about 26 percent of the state. Regardless of their site conditions, poorly built structures in these areas are at an extreme risk from earthquake shaking.

Figure 24 shows that at the 90-percent confidence level, an additional 38 percent of the state can experience intensity VII or higher shaking if site conditions are unstable. The stability of a site can be determined by site-specific geotechnical investigation. This would generally require drilling to bedrock, collecting samples for laboratory analysis, and analyzing the dynamic response of the site.

A compilation of the results of this study is summarized in Figure 25. The map divides the state into three geographical areas on the basis of relative seismic-shaking hazard. A comparison of this map with Idaho on the 1988 Uniform Building Code (UBC) seismic zone map (Figure 1) shows agreement. The most hazardous areas delineated in our study generally correspond with UBC zones 3 and 4. The less hazardous areas generally correspond to UBC zone 2B. Because of the uncertainties associated with

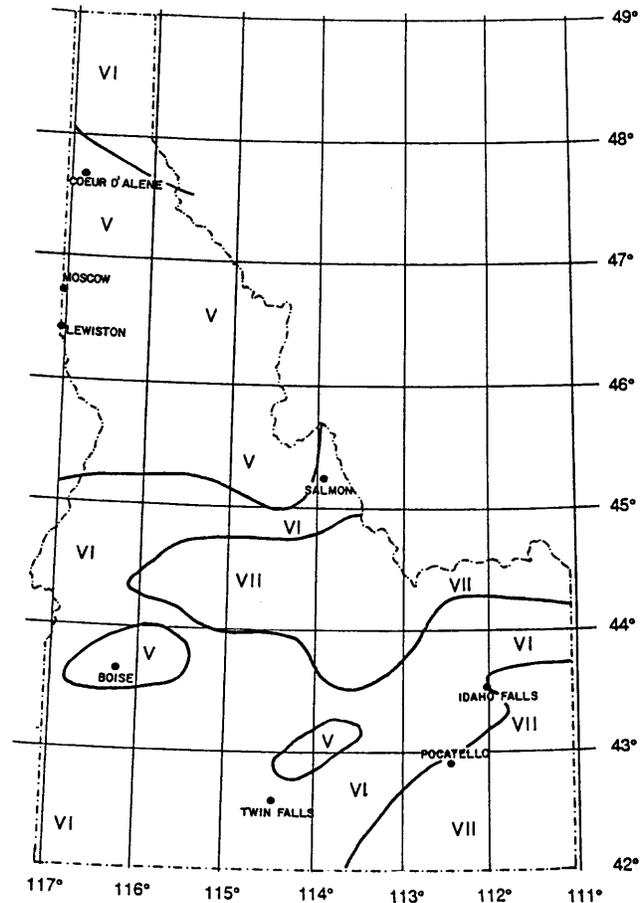


Figure 23. Map of seismic intensities on bedrock in Idaho with a 90-percent probability of not being exceeded in 50 years. See Figure 3 for intensity scale.

seismic hazard maps, the boundaries between different areas on such maps should always be interpreted as gradational. We therefore see no inconsistencies between the UBC seismic zone map and the results of our study, and we strongly endorse the use of UBC standards for all construction in the state.

SUMMARY

The maps produced in this report are all based on a 90-percent chance of intensities not being exceeded in 50 years. Hence, they will be wrong 10 percent of the time. This chance aspect of the maps shows up for many places in the state. For example, in the Pocatello-Idaho Falls area, the historical record of shaking (Figure 24) is far below the predicted level of bedrock shaking (Figure 23). Our interpretation is that this region has not, because of "chance" only, experienced large shaking during historical time. Quite the opposite, however, is the experience for the Boise and Shoshone areas, which seemingly have had far more than their share of shaking during historical time.

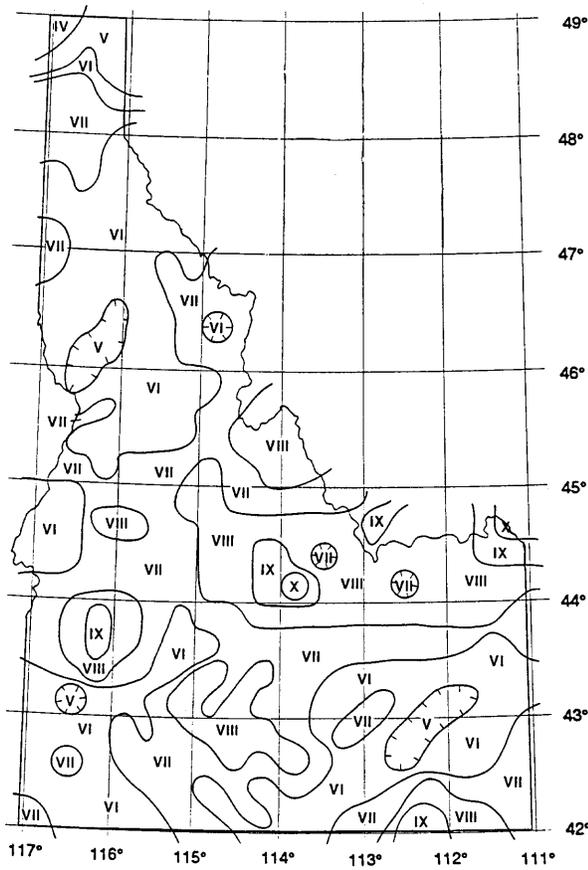


Figure 24. Map of seismic intensities on the ground surface in Idaho with a 90-percent probability of not being exceeded in 50 years. See Figure 3 for intensity scale.

Though we interpret this high level of ground shaking as due to unstable site conditions, chance may be important here as well.

Another possibility is that the bedrock acceleration maps of Algermissen and others (1982) or Greensfelder (1976) are wrong. To increase the factor of safety in this study, we assigned the larger estimate of the two maps in areas of disagreement. In the Idaho Falls-Pocatello area, for example, Greensfelder (1978) shows much lower probable bedrock acceleration than Algermissen (1982). Perhaps, Greensfelder is right. Certainly, his analysis fits the historical record of shaking better than the federal study. On the other hand, both the federal and state hazard maps grossly underestimate the hazard. According to the historical record, Boise has shook more than most locations in Idaho during the past century, yet both bedrock acceleration maps show the Boise area as very low in probable bedrock acceleration.

A fundamental problem for probabilistic bedrock acceleration estimates in Idaho may be a lack of data to successfully divide the state into discrete seismic source zones, a vital step in the construction of probabilistic bedrock accel-

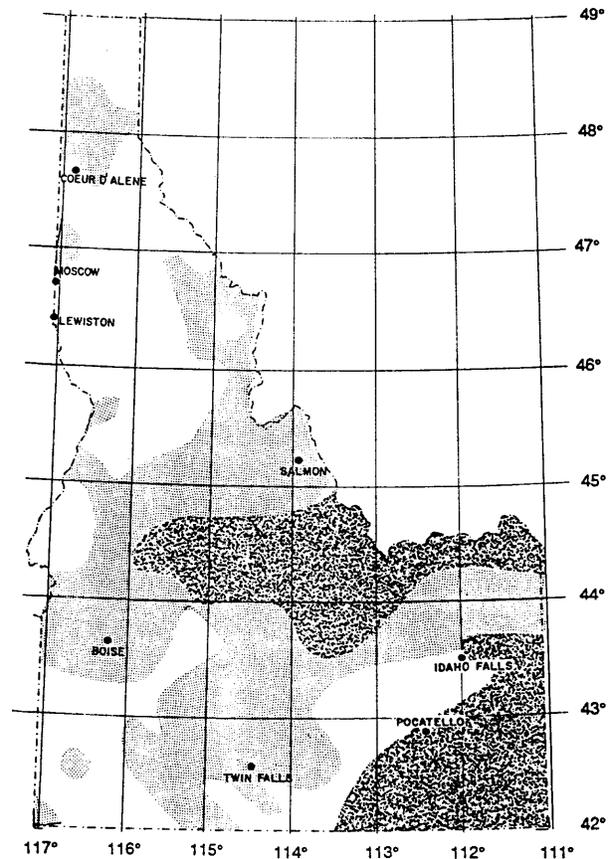


Figure 25. Map of Idaho showing areas of relative seismic shaking hazard. The darkest areas have the greatest hazard, and the lightest areas have the least.

eration maps. Greensfelder (1978, p. 24) recognized the problem, and we quote the following from his report:

Experience has shown that earthquake statistics representative of long-term seismicity can only be obtained from a time-area sample of sufficient size. This may be of the order of at least 10 million km²-years. Because the effective record of seismographically recorded earthquakes in the western United States is only about 40 years long, we infer that the minimum valid sample area is about 250,000 km² within the same tectonic province. This is roughly the area of the entire State of Idaho; therefore, observed differences in seismicity between sub-areas of Idaho might not be statistically significant.

If this is the case, then we should not try to divide the state into zones of different hazards. Perhaps the most sane approach to the shaking hazard in Idaho is to move toward upgrading all older buildings in the state to the point where they can withstand intensity VII shaking without danger to the occupants.

ACKNOWLEDGMENTS

This study is an outgrowth of a project that began with support from the Idaho Bureau of Disaster Services under the National Earthquake Hazard Reduction Program of the Federal Emergency Management Agency (FEMA).

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APPENDIX I: EXISTING PROBABILISTIC ESTIMATES OF MAXIMUM ACCELERATION ON BEDROCK IN IDAHO

Two probabilistic estimates of maximum acceleration on bedrock exist for Idaho. One (Figure I-1) is Algermissen and others (1982) published by the U.S. Geological Survey; the other is Greensfelder (1978) prepared for the Idaho Transportation Department. The most recent acceleration maps (Figures I-2 and I-3), based on Greensfelder's work (1978), are those published by the Idaho Transportation Department (Smith, 1991). Both the federal (Figure I-1) and the state (Figures I-2 and I-3) bedrock acceleration maps are based on the same historical seismic record and the same fault information. Both estimates were generated following the method of Cornell (1968). Yet the maps differ mainly because the investigators chose different earthquake source zones.

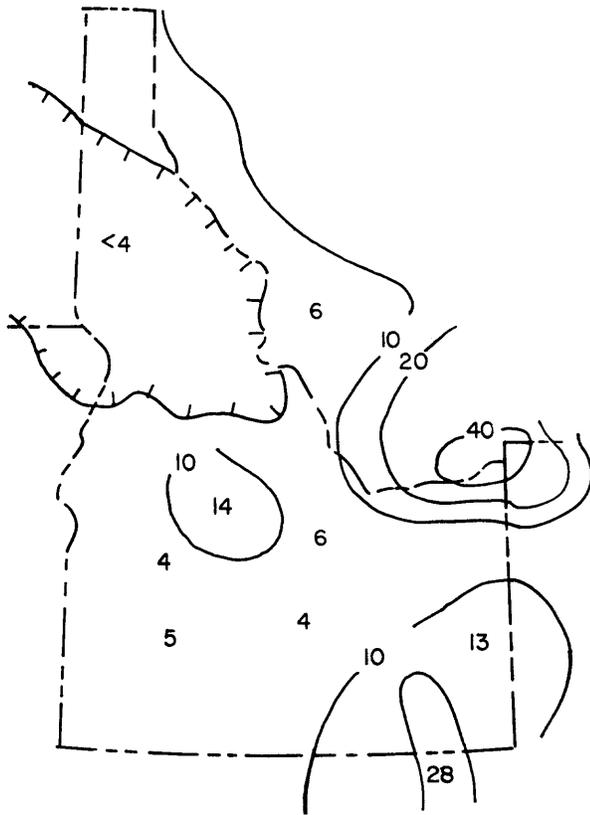


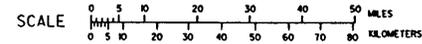
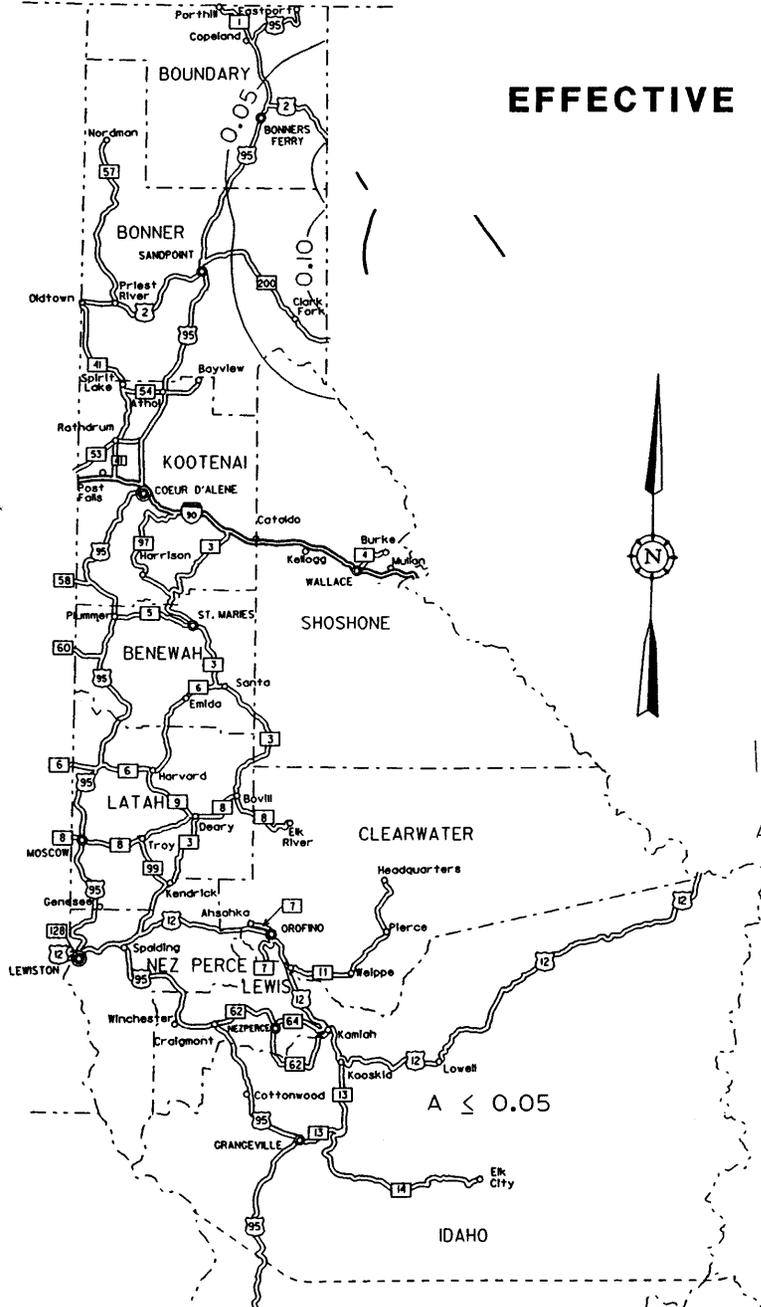
Figure I-1. Map of horizontal acceleration (expressed as a percent of gravity) in rock with a 90-percent probability of not being exceeded in 50 years. After Algermissen and others (1982).

A source zone is a region thought to be characterized by a particular distribution of earthquake occurrences. According to Algermissen and others (1982), the two general requirements for a seismic source zone are that it have seismicity and that it be a reasonable seismotectonic or seismogenic structure or zone. Unfortunately, this definition of a seismic source zone has problems. The first

requirement, that of seismicity, fails to recognize zones that are quite capable of large earthquakes, but which have been quiescent during historic time. The Borah Peak earthquake, for example, was not preceded by historic seismicity. The second requirement is subjective and leads to different interpretations by investigators. Because both studies used essentially the same information, the differences in them reflect the authors' subjective interpretations of seismic source zones. These differences are critical to the hazard maps eventually obtained from these source zone interpretations.

Sprenke and others (1988) noted that the overall correlation coefficient between the federal bedrock acceleration map and the state map is only 0.2 on a scale that ranges from 0 (no agreement) to 1.0 (perfect agreement). Thus, serious discrepancies exist between the two maps. In this report, for any given area in the state, the higher of the two estimates was used to produce the most conservative hazard map, that is, a hazard map that would lead to higher factors of safety in any building design decisions based on the maps.

INTERIM MAP EFFECTIVE PEAK FIRM GROUND ACCELERATION IN IDAHO

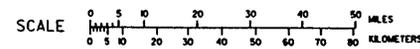
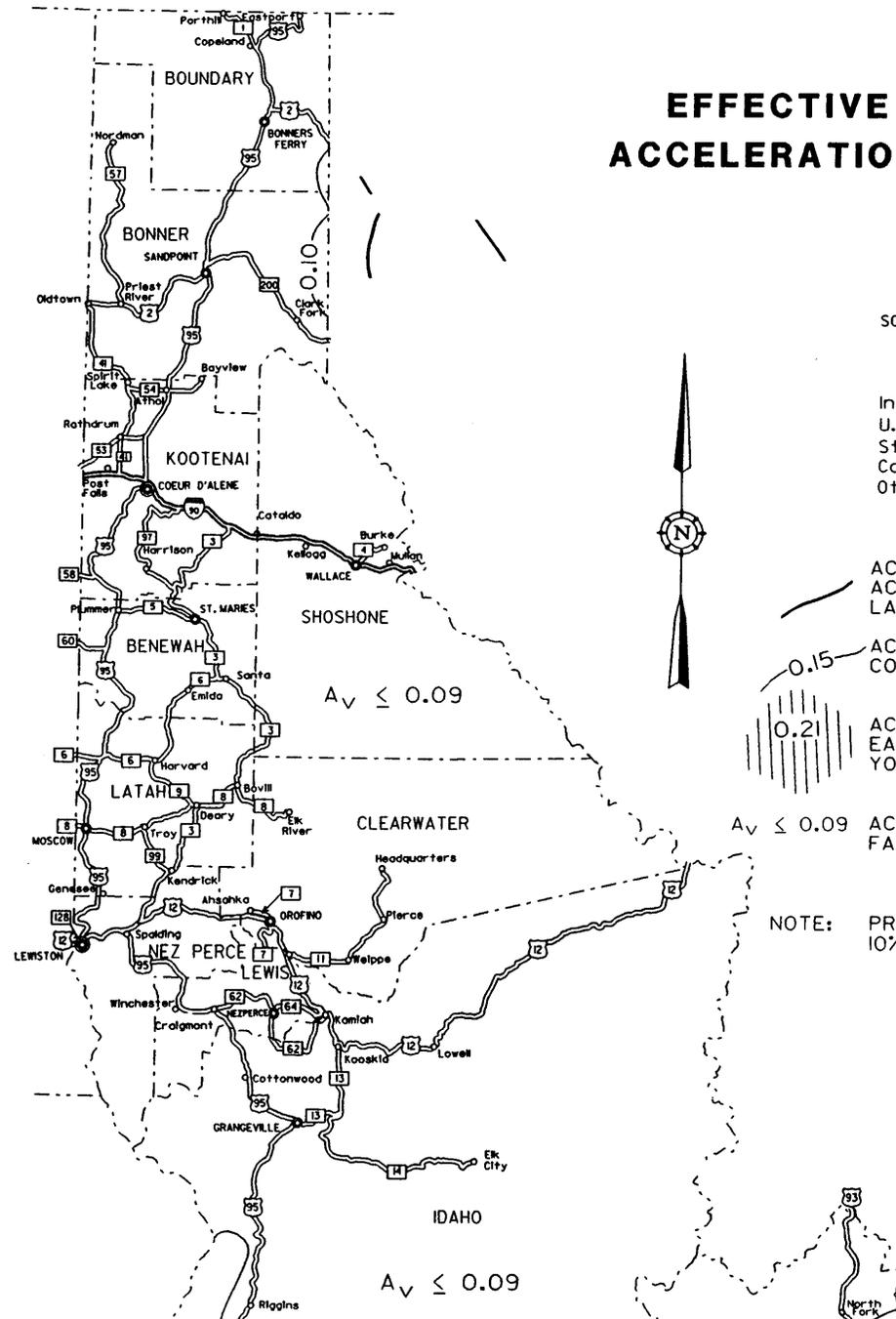


- Interstate numbered highway.....
- U.S. numbered highway.....
- State numbered highway.....
- County seats.....
- Other cities.....

- ACTIVE FAULT (WISCONSIN OR YOUNGER) OR PROBABLY ACTIVE FAULT (MAJOR DISPLACEMENT OF PROBABLE LATE QUATERNARY AGE)
- 0.15 EFFECTIVE PEAK FIRM GROUND ACCELERATION (DECIMAL FRACTION OF GRAVITY, g) POSITION CONTROLLED BY MAPPED FAULTS
- 0.21 ACCELERATION, g, FOR RANDOMLY LOCATED EARTHQUAKES LACKING FAULT CONTROL IN REGION OF YOUNG FAULTING
- $A \leq 0.05$ PEAK FIRM GROUND ACCELERATION, g, FOR EARTHQUAKES OCCURRING RANDOMLY OUTSIDE AREAS OF MAPPED FAULTS

NOTE: PROBABILITY OF EXCEEDING MAPPED ACCELERATIONS: 10% IN 50 YEARS

INTERIM MAP EFFECTIVE PEAK VELOCITY-RELATED ACCELERATION COEFFICIENT, A_V , IN IDAHO



- Interstate numbered highway.....
- U.S. numbered highway.....
- State numbered highway.....
- County seats.....
- Other cities.....



- ACTIVE FAULT (WISCONSIN OR YOUNGER) OR PROBABLY ACTIVE FAULT (MAJOR DISPLACEMENT OF PROBABLE LATE QUATERNARY AGE)
- ACCELERATION COEFFICIENT (DIMENSIONLESS) POSITION CONTROLLED BY MAPPED FAULTS
- ACCELERATION COEFFICIENT FOR RANDOMLY LOCATED EARTHQUAKES LACKING FAULT CONTROL IN REGION OF YOUNG FAULTING
- $A_V \leq 0.09$ ACCELERATION COEFFICIENT FOR AREAS OUTSIDE FAULT CONTROL

NOTE: PROBABILITY OF EXCEEDING MAPPED VALUES OF A_V : 10% IN 50 YEARS

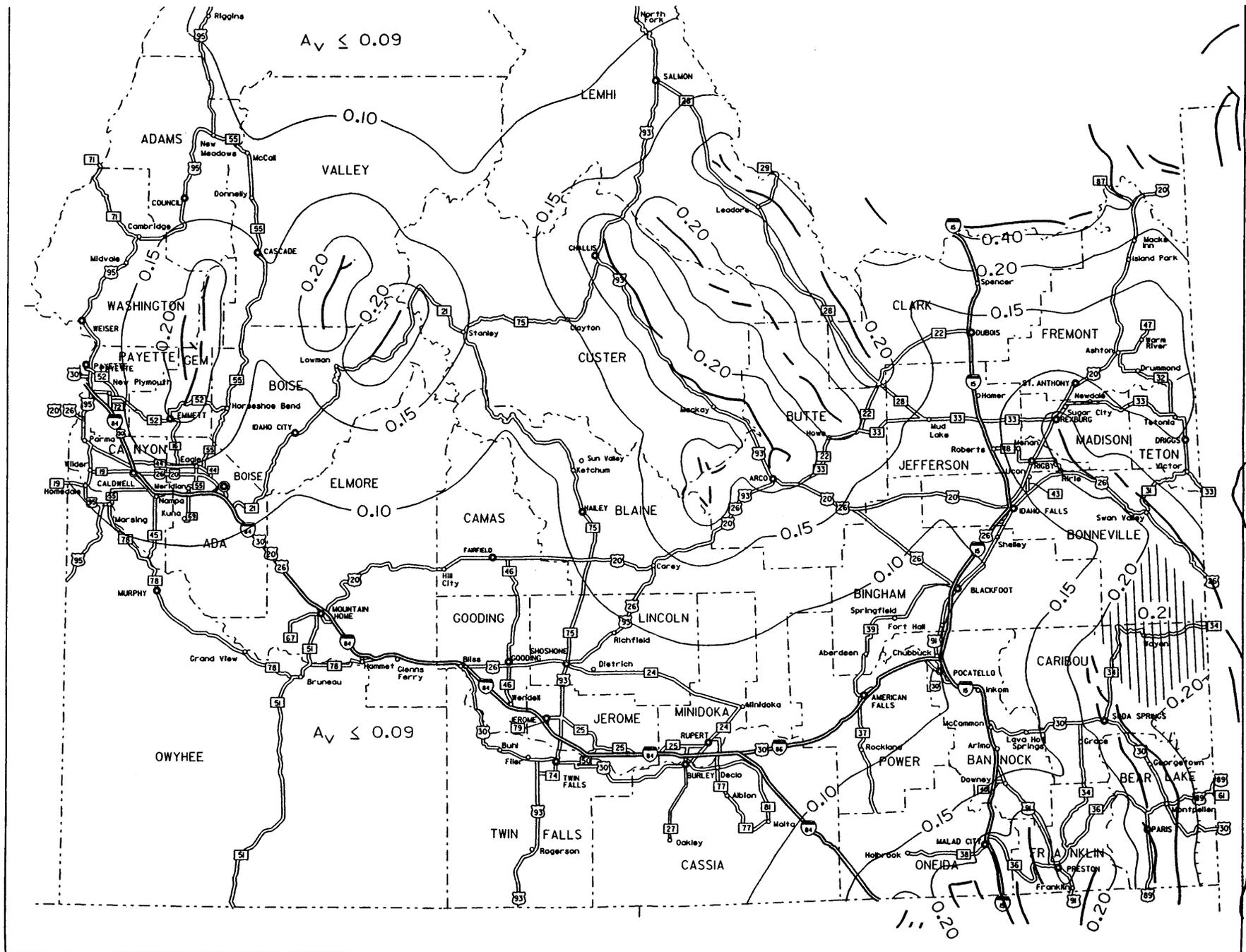


Figure I-3. Effective peak velocity-related acceleration in Idaho (Smith, 1991).

APPENDIX II: ISOSEISMAL MAPS FOR LARGE HISTORIC EARTHQUAKES IN THE IDAHO REGION

The figures in this appendix were provided by the U.S. Geological Survey, National Earthquake Information Center (NEIC), from various documents. The readability of these illustrations is only as good as the printed original, which for some is marginal. Although individual intensity

values may be illegible, the isoseismal lines on the maps show clearly, for the purposes of this report, the intensity contours of the historic earthquakes in the Idaho region. We include them here for the reader's reference, because they are not collectively available elsewhere.

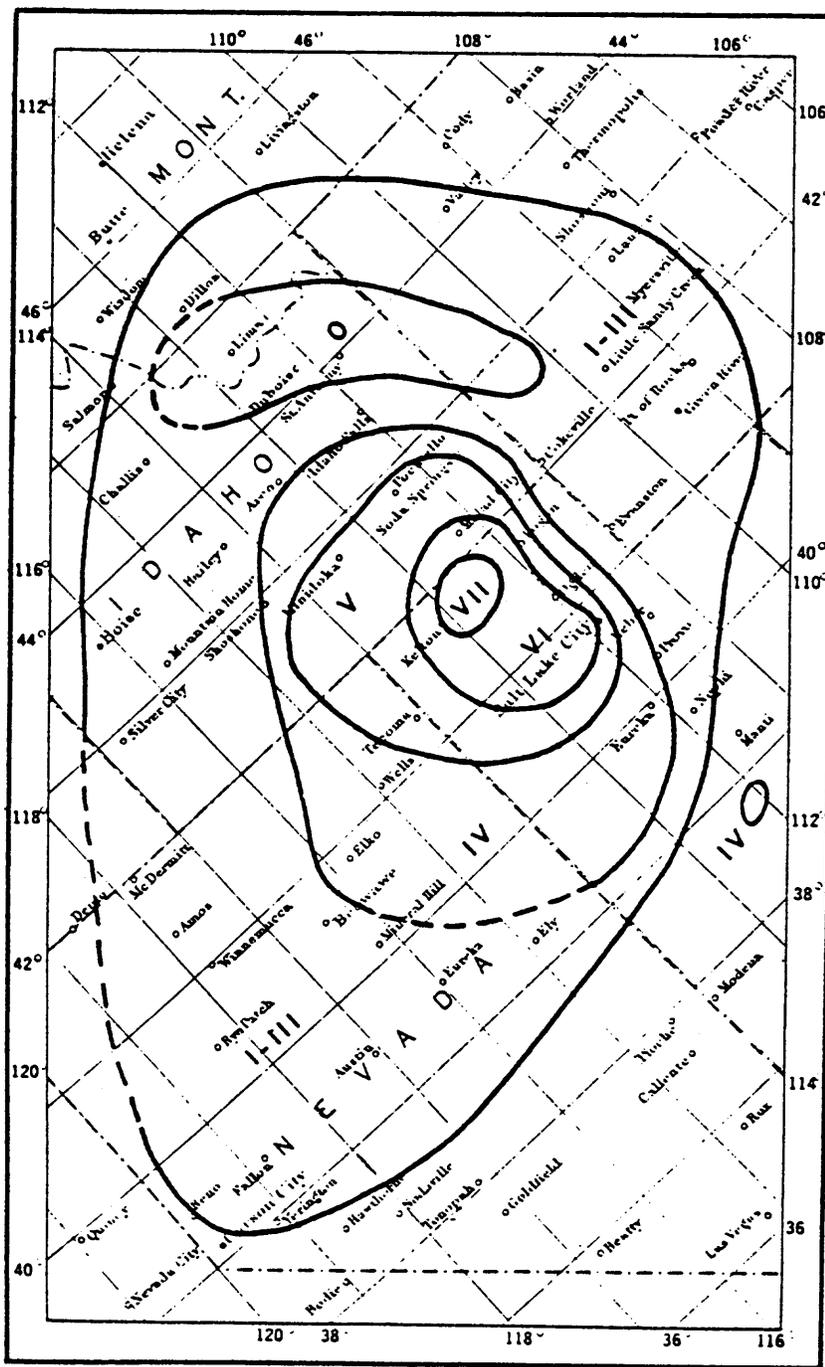


Figure II-1. Area affected by the Kosmo, Utah, earthquake of March 12, 1934.

SEISMIC HISTORY OF HELENA AREA

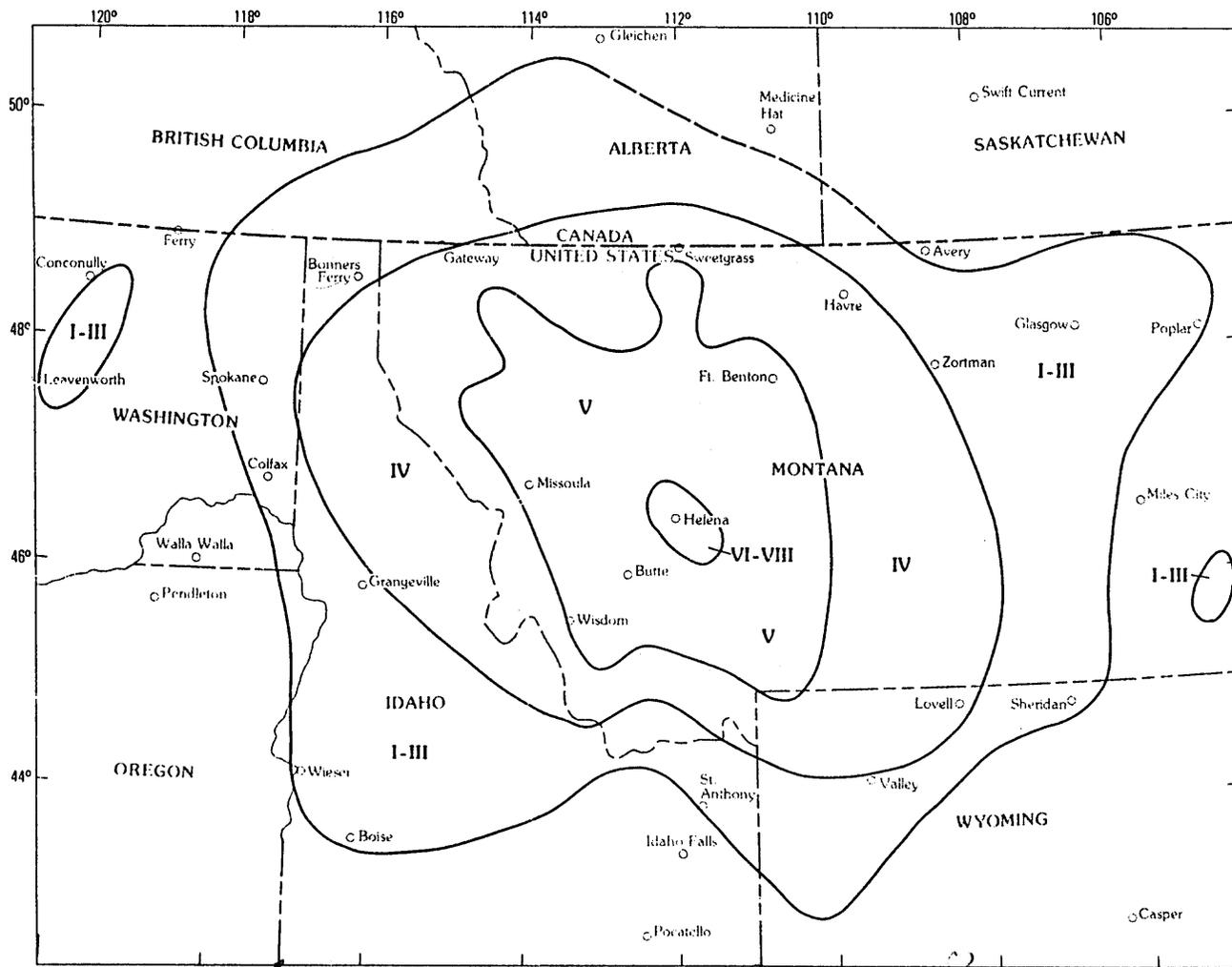


Figure II-2. Area affected by the Helena, Montana, earthquake of October 18, 1935.



Figure II-3. Area affected by the Freewater, Oregon, earthquake of July 15, 1936.

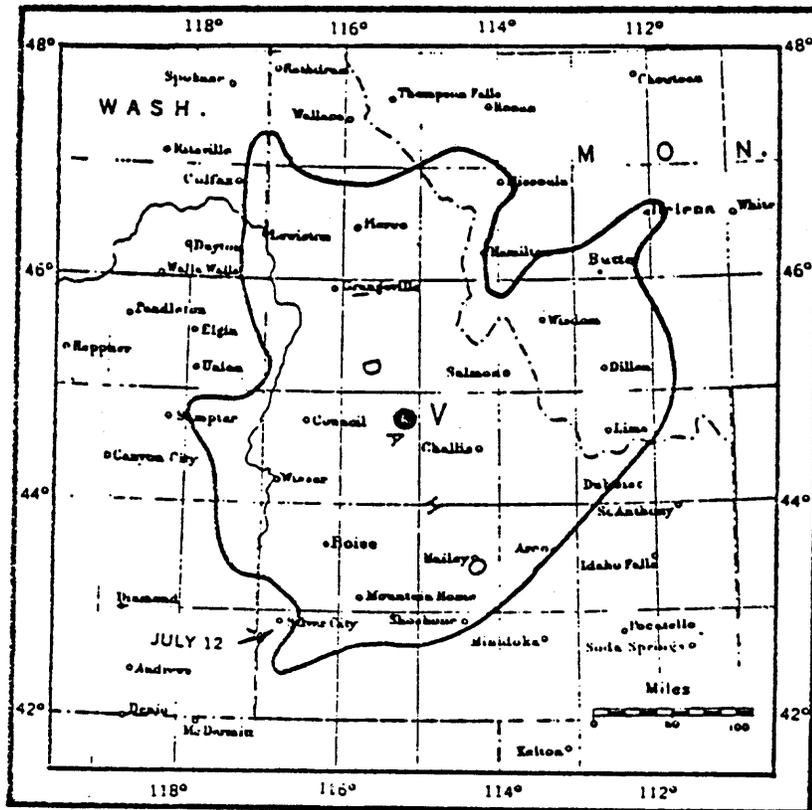


Figure II-4. Area affected by the Seafoam, Idaho, earthquake of July 12, 1944.

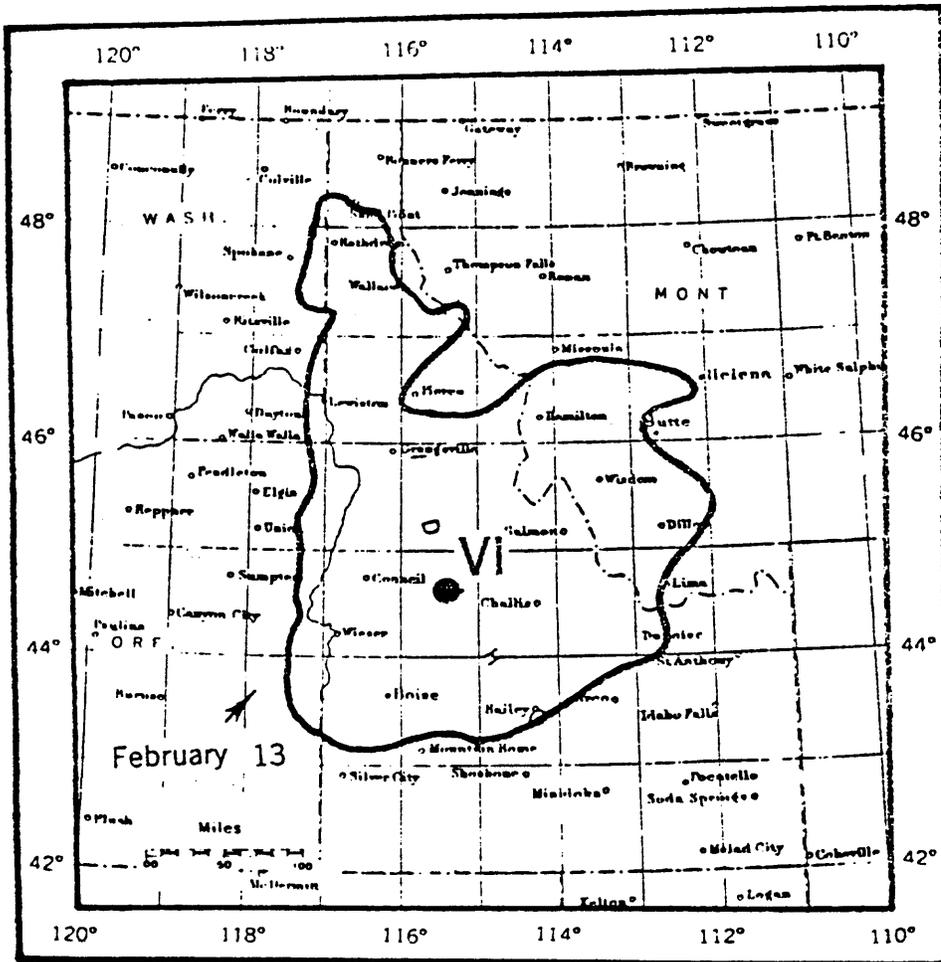


Figure II-5. Area affected Clayton, Idaho, earthquake of February 13, 1945.

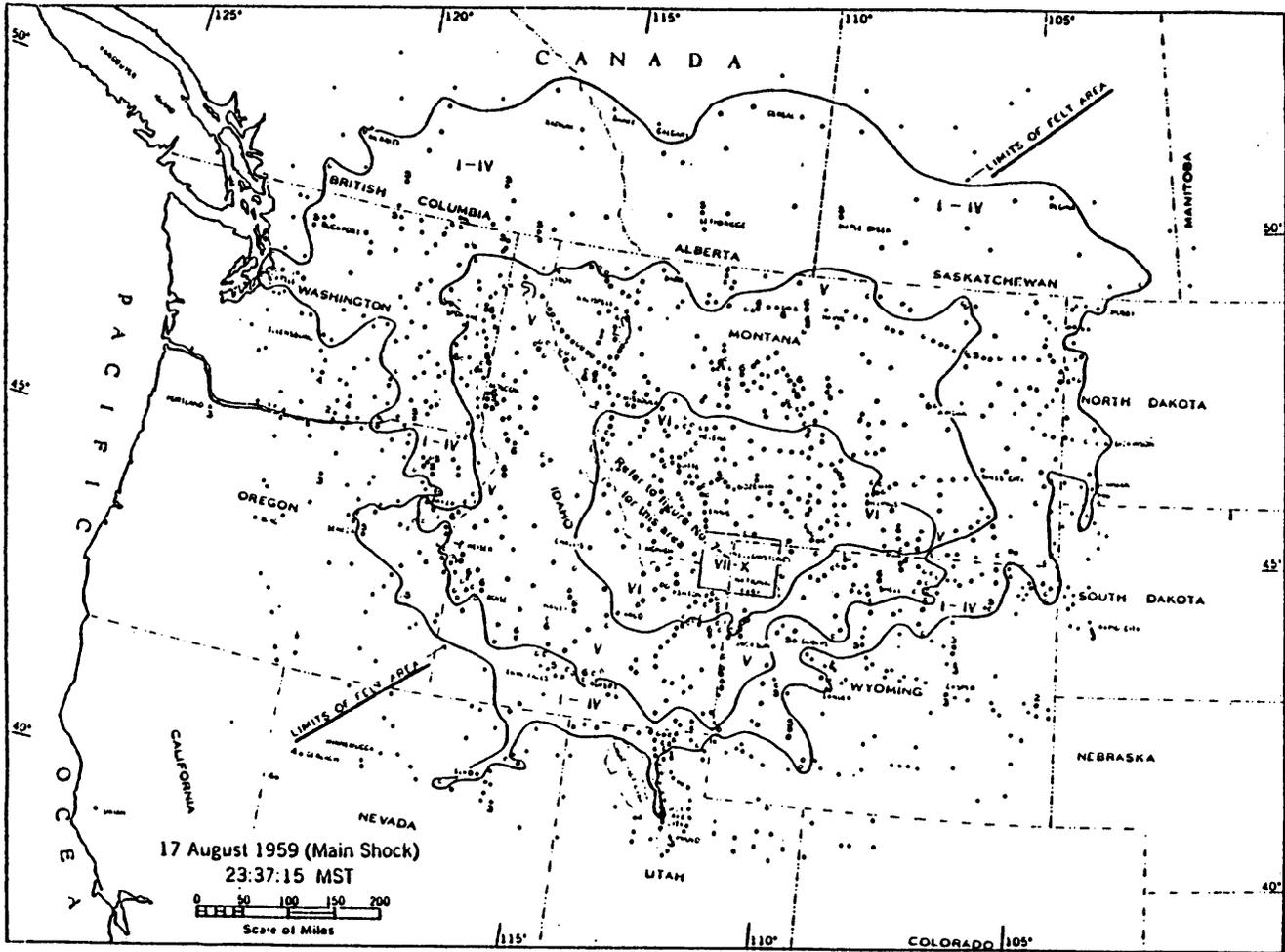


Figure II-7. Area affected by the Hebgen Lake, Montana, earthquake of August 17, 1959.

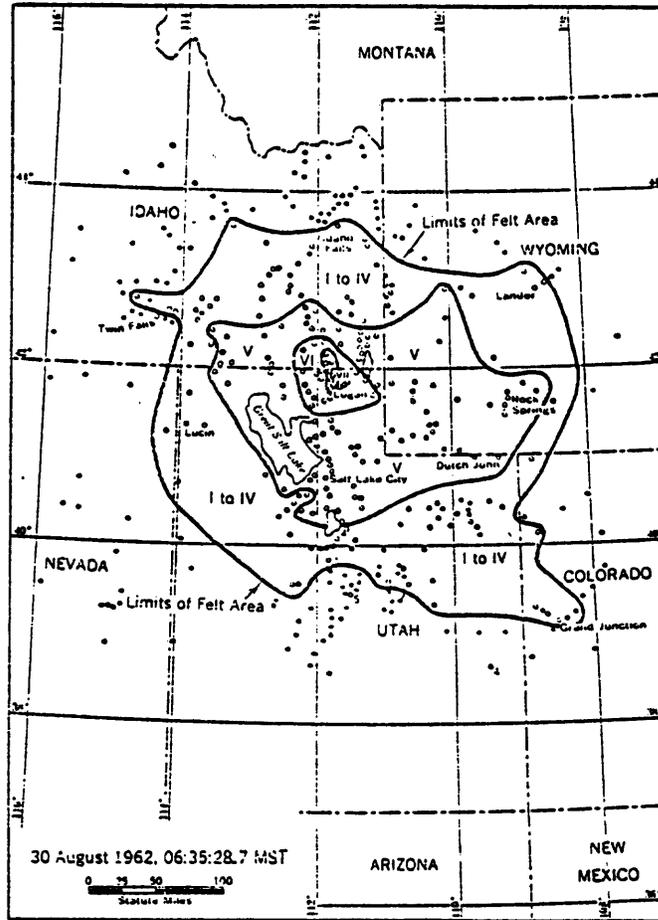


Figure II-8. Area affected by the Logan, Utah, earthquake of August 30, 1962.

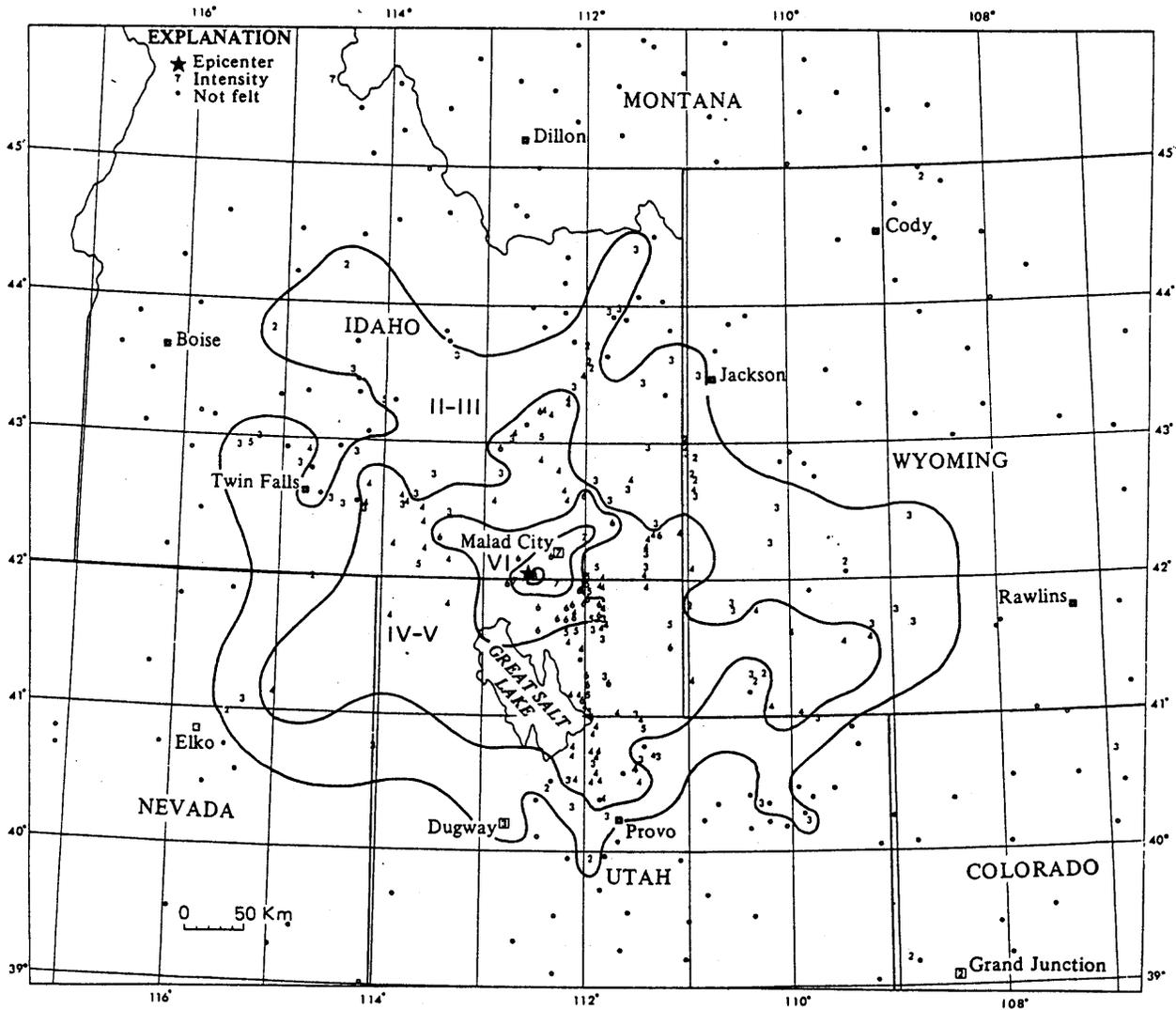


Figure II-9. Area affected by the Malad City, Idaho, earthquake of March 28, 1975.

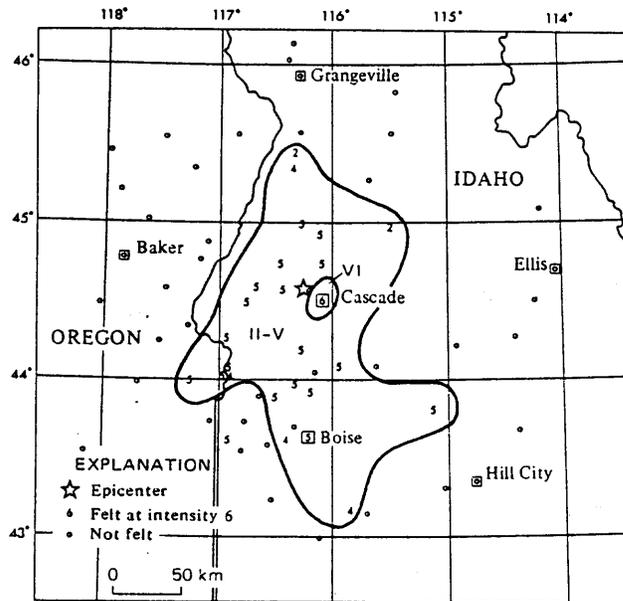


Figure II-10. Area affected by the Cascade, Idaho, earthquake of November 27, 1977.

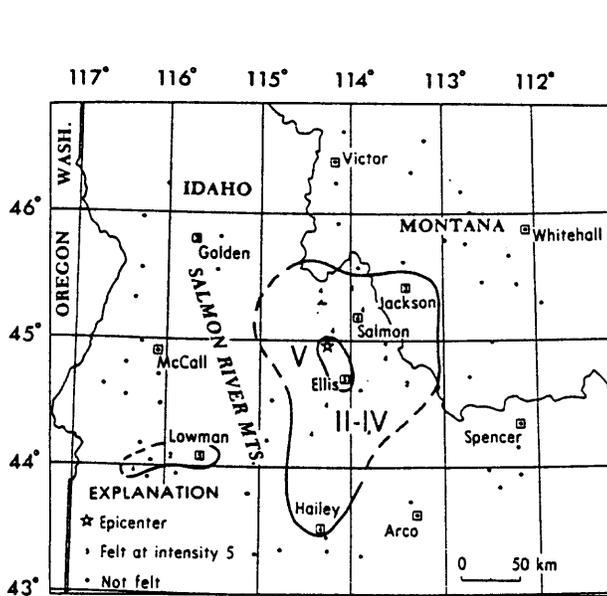


Figure II-11. Area affected by the Ellis, Idaho, earthquake of October 29, 1978.

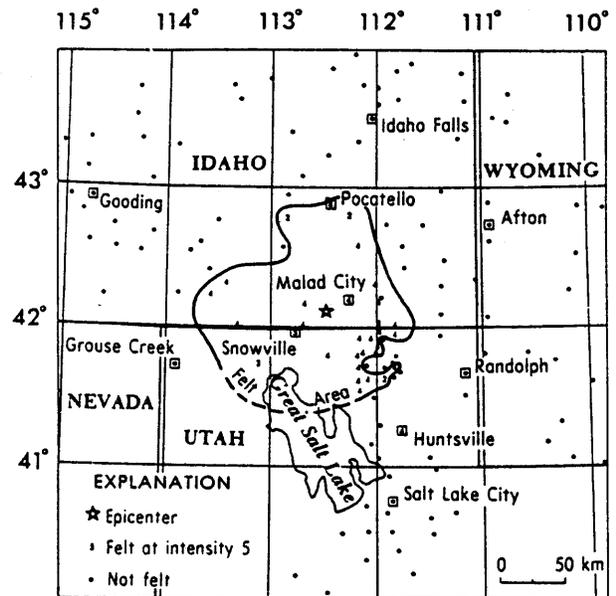


Figure II-12. Area affected by the Snowville, Utah, earthquake of November 30, 1978.

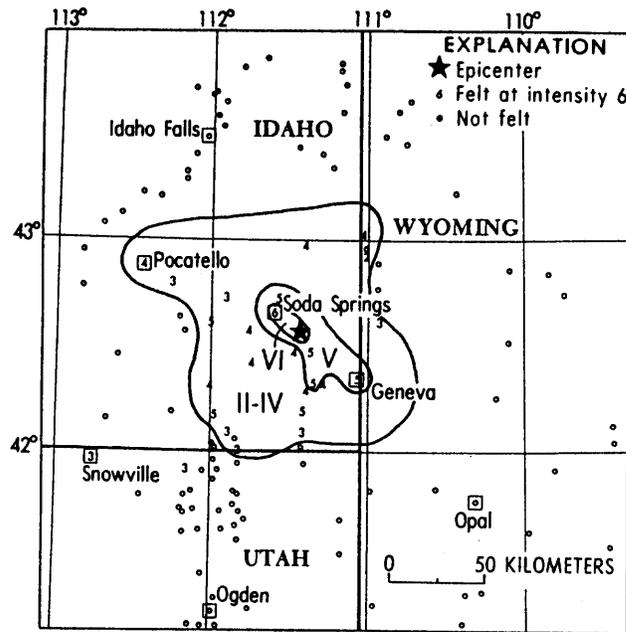


Figure II-13 Area affected by the Soda Springs, Idaho, earthquake of October 14, 1982.

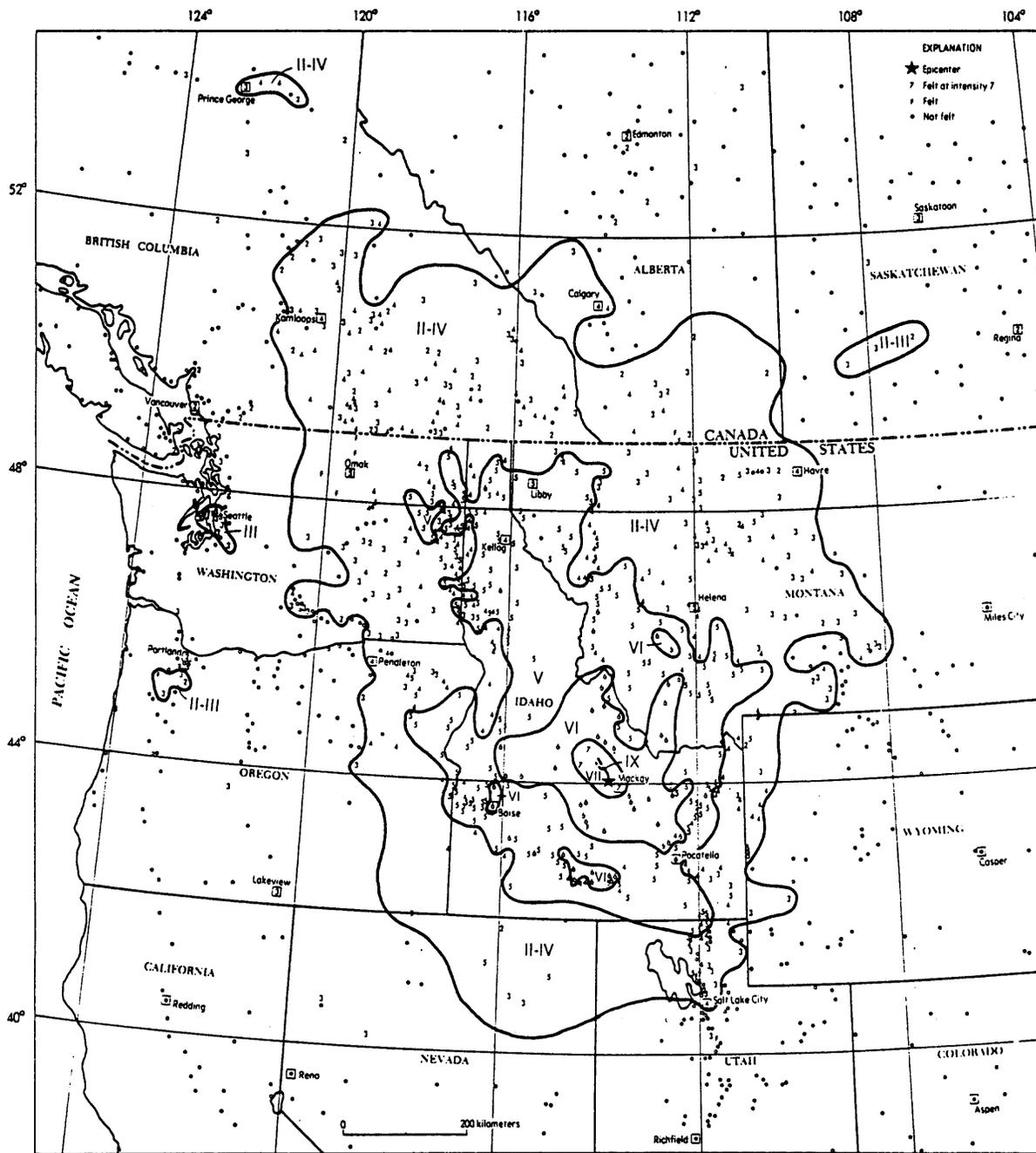


Figure II-14. Area affected by the Borah Peak, Idaho, earthquake of October 28, 1983.

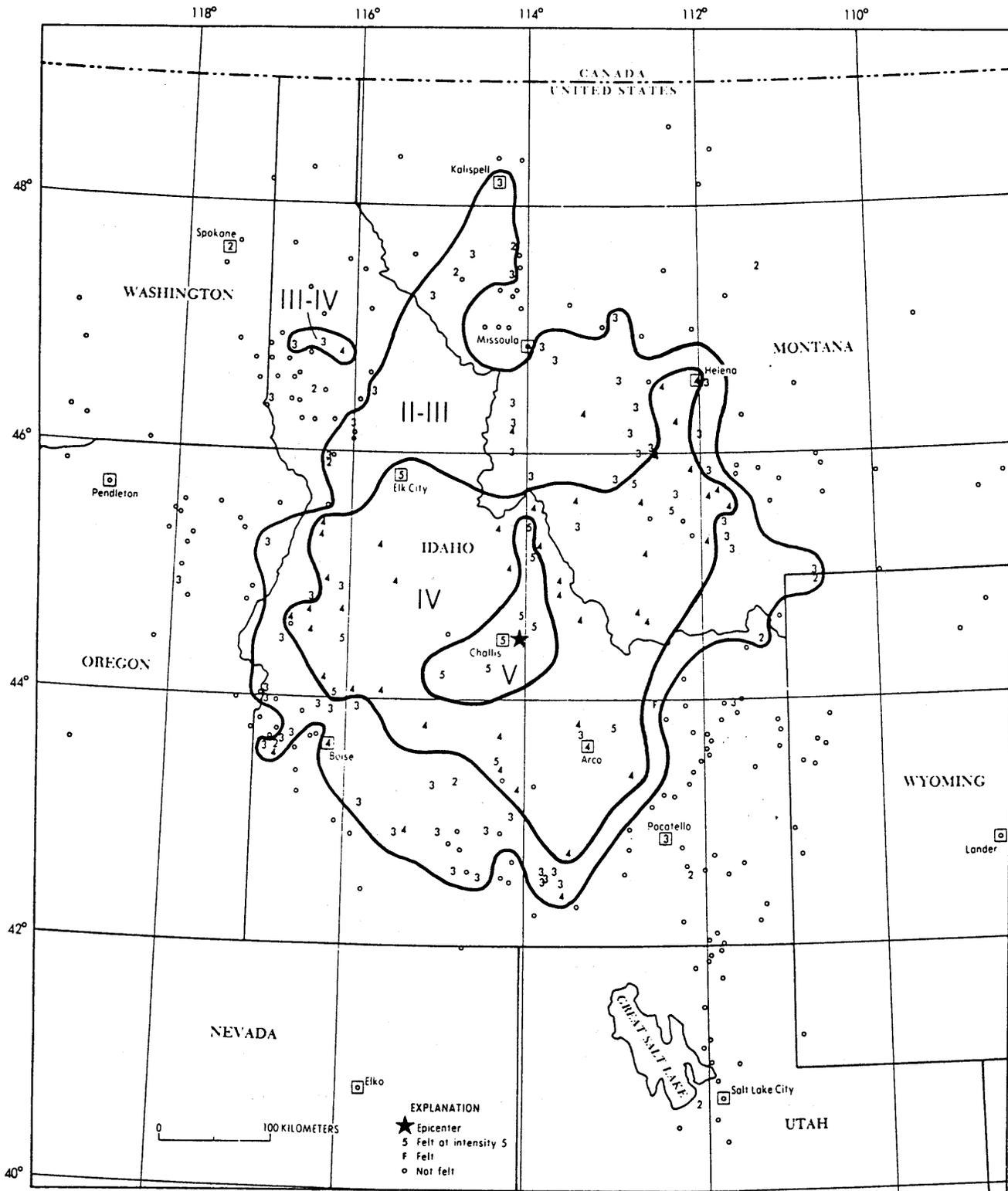


Figure II-15 Area affected by the Challis, Idaho, earthquake of August 22, 1984.

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