

**Basic Seismological Characterization
for
Washakie County, Wyoming**

by

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BACKGROUND

Seismological characterizations of an area can range from an analysis of historic seismicity to a long-term probabilistic seismic hazard assessment. A complete characterization usually includes a summary of historic seismicity, an analysis of the Seismic Zone Map of the Uniform Building Code, deterministic analyses on active faults, “floating earthquake” analyses, and short- or long-term probabilistic seismic hazard analyses.

Presented below, for Washakie County, Wyoming, are an analysis of historic seismicity, an analysis of the Uniform Building Code, deterministic analyses of nearby active faults, an analysis of the maximum credible “floating earthquake”, and current short- and long-term probabilistic seismic hazard analyses.

Historic Seismicity in Washakie County

The enclosed map of “Earthquake Epicenters and Suspected Active Faults with Surficial Expression in Wyoming” (Case and others, 1997) shows the historic distribution of earthquakes in Wyoming. Four magnitude 2.5 and greater earthquakes have been recorded in Washakie County. These earthquakes are discussed below.

The first earthquake recorded in Washakie County occurred on December 12, 1970. This magnitude 4.9 event was centered approximately 8 miles southwest of Ten Sleep. No damage was reported.

On September 19, 1974, a magnitude 4.4, intensity V earthquake occurred approximately 6 miles north-northwest of Ten Sleep. Residents reported that shock waves were felt in the Ten Sleep Canyon area (Casper Star-Tribune, September 21, 1974).

A magnitude 3.5 earthquake was detected approximately 10 miles south of Ten Sleep on November 16, 1993. No damage was reported from the event.

Most recently, a magnitude 3.3 earthquake occurred in Washakie County on April 5, 2002. The earthquake's epicenter was located approximately 10 miles southwest of Worland. Although the Washakie County Emergency Management agency reported ground shaking, the earthquake did not cause any damage.

Regional Historic Seismicity

Several earthquakes have also occurred near Washakie County in surrounding counties. The first occurred on November 17, 1925, in the southeastern portion of Big Horn County. This intensity V event was located approximately 23 miles north of Ten Sleep. People in Ten Sleep, Sheridan, Fort McKenzie, and at Dome Lake Resort in the Big Horn Mountains reported feeling the earthquake tremors. The tremors shook cabins, pictures, and furniture. A "distinct roar" heard at Dome Lake was attributed to a possible earthquake-induced landslide (Casper Daily Tribune, November 18, 1925). No damage was reported.

On April 12, 1966, an earthquake of no specified magnitude or intensity was detected in Johnson County approximately 22 miles northeast of Ten Sleep. No one reported feeling this event (U.S.G.S. National Earthquake Information Center).

A magnitude 4.0 earthquake was reported in Hot Springs County on June 6, 1978. This event was centered approximately 29 miles south-southeast of Worland. No damage was reported.

Another earthquake occurred in Johnson County on August 30, 1992. This magnitude 3.6, intensity IV earthquake was centered near Mayoworth, approximately 23 miles east-southeast of Big Trails. It was felt in Barnum and Kaycee, but no damage was reported.

On November 9, 1999, the U.S.G.S. National Earthquake Information Center reported a 3.10 earthquake in northwest Natrona County. This event was centered approximately 21 miles south-southwest of Big Trails. No one reported feeling the earthquake.

Finally, a magnitude 3.0 earthquake was detected in northeastern Fremont County on November 7, 2000 (U.S.G.S. National Earthquake Information Center). The earthquake's epicenter was located approximately 29 miles southwest of Big Trails. Again, no one reported feeling this event.

Uniform Building Code

The Uniform Building Code (UBC) is a document prepared by the International Conference of Building Officials. Its stated intent is to "provide minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of all buildings and structures within this jurisdiction and certain equipment specifically regulated herein."

The UBC contains information and guidance on designing buildings and structures to withstand seismic events. With safety in mind, the UBC provides Seismic Zone Maps to help identify which design factors are critical to specific areas of the country. In addition, depending upon the type of building, there is also an “importance factor”. The “importance factor” can, in effect, raise the standards that are applied to a building.

The current UBC Seismic Zone Map (Figure 1) (1997) has five seismic zones, ranging from Zone 0 to Zone 4, as can be seen on the enclosed map. The seismic zones are in part defined by the probability of having a certain level of ground shaking (horizontal acceleration) in 50 years. The criteria used for defining boundaries on the Seismic Zone Map were established by the Seismology Committee of the Structural Engineers Association of California (Building Standards, September-October, 1986). The criteria they developed are as follows:

<u>Zone</u>	<u>Effective Peak Acceleration, % gravity (g)</u>
4	30% and greater
3	20% to less than 30%
2	10% to less than 20%
1	5% to less than 10%
0	less than 5%

The committee assumed that there was a 90% probability that the above values would not be exceeded in 50 years, or a 100% probability that the values would be exceeded in 475 to 500 years.

Washakie County is in Seismic Zone 1 of the UBC. Since effective peak accelerations (90% chance of non-exceedance in 50 years) can range from 5%g-10%g in this zone, and there has been some significant historic seismicity in the county, it may be reasonable to assume that an maximum peak acceleration of 10.0%g could be applied to the design of a non-critical facility located in the county if only the UBC were used. Such acceleration, however, is significantly less than would be suggested through newer building codes.

Recently, the UBC has been replaced by the International Building Code (IBC). The IBC is based upon probabilistic analyses, which are described in a following section. Washakie County still uses the UBC, however, as do most Wyoming counties as of October 2002.

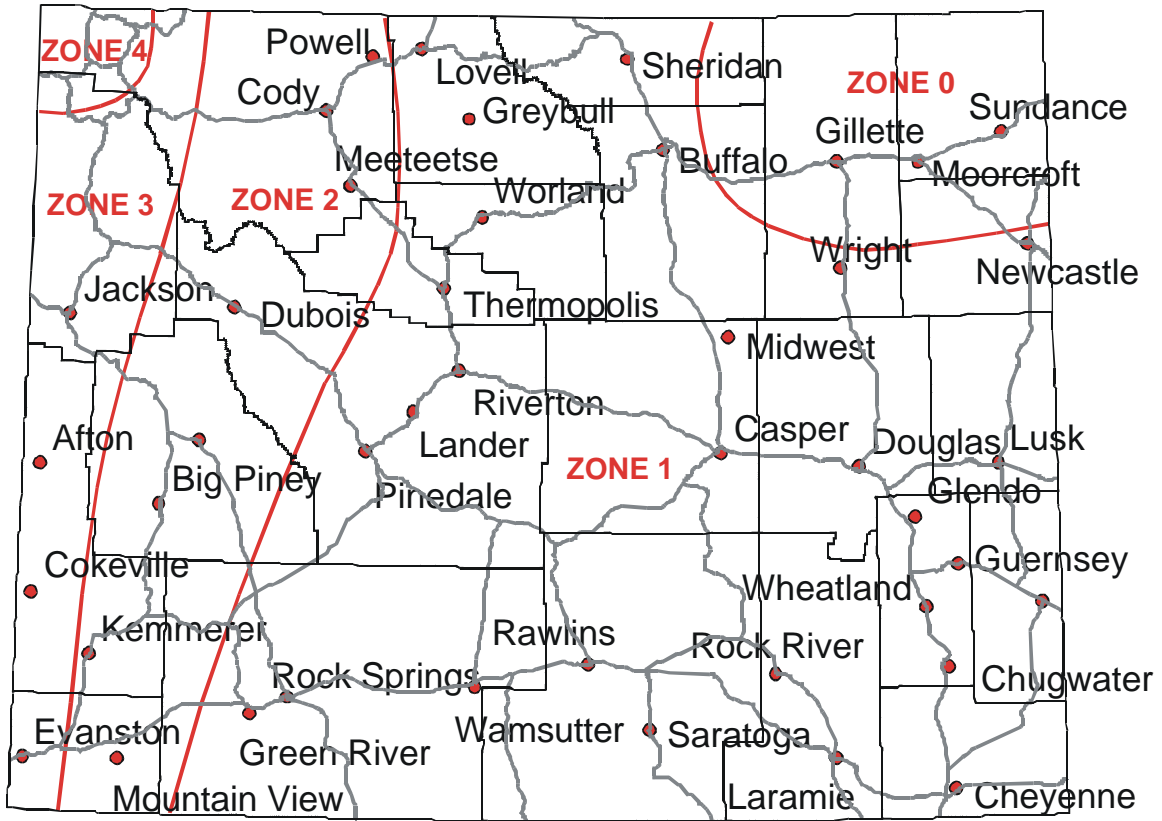


Figure 1. UBC Seismic Zone Map.

Deterministic Analysis Of Regional Active Faults With A Surficial Expression

An active fault system called the Cedar Ridge/Dry Fork fault system is present near the southern border of Washakie County in Natrona and Fremont Counties. The 35-mile long Cedar Ridge fault comprises the western portion of the fault system, and the 15-mile long Dry Fork fault makes up the eastern portion. The only Pleistocene-age movement on the fault system was found in northeastern Fremont County (T39N R92W NE ¼ Section 10). A short scarp on the Cedar Ridge fault, approximately 0.8 miles long, was identified at that location. Since the entire fault system is approximately 50 miles long, and only one small active segment was discovered, Geomatrix (1988a) stated that the “age of this scarp and the absence of evidence for late Quaternary faulting elsewhere along the Cedar Ridge/Dry Creek fault suggest that this fault is inactive.” As a result of this assessment, it is not possible to conduct a reliable deterministic analysis on the fault system; however general estimates can be made.

Although there is no compelling reason to believe that the Dry Fork fault system is active, if it did activate as an isolated system, it could potentially generate a magnitude 6.7 earthquake. This is based upon a postulated fault rupture length of 15 miles (Wong et al., 2001). A magnitude 6.7 earthquake on the fault system could generate peak horizontal accelerations of approximately 4.5%g at Big Trails, approximately 2.9%g at Tensleep, and approximately 2%g at Worland (Campbell, 1987). Those accelerations would be roughly equivalent to an intensity V earthquake at Big Trails and intensity IV earthquakes at Worland and Ten Sleep. Minor damage could occur at Big Trails. Again, there is no compelling reason to believe that the Dry Fork fault system is active.

There is also no compelling reason to believe that the Cedar Ridge fault system is active. Based upon its fault rupture length of 35 miles, however, if the fault did activate it could potentially generate a maximum magnitude 7.1 earthquake (Wong et al., 2001). A magnitude 7.1 event could generate peak horizontal accelerations of approximately 7.4%g at Big Trails, approximately 3.8 %g at Ten Sleep, and approximately 3.7%g at Worland (Campbell, 1987). Those accelerations would be roughly equivalent to an intensity V earthquake at Big Trails and intensity IV earthquakes at Ten Sleep and Worland. Minor damage could occur at Big Trails.

Floating or Random Earthquake Sources

Many federal regulations require an analysis of the earthquake potential in areas where active faults are not exposed, and where earthquakes are tied to buried faults with no surface expression. Regions with a uniform potential for the occurrence of such earthquakes are called tectonic provinces. Within a tectonic province, earthquakes associated with buried faults are assumed to occur randomly, and as a result can theoretically occur anywhere within that area of uniform earthquake potential. In reality, that random distribution may not be the case, as all earthquakes are associated with specific faults. If all buried faults have not been identified, however, the distribution has to be considered random. “Floating earthquakes” are earthquakes that are considered to occur randomly in a tectonic province.

It is difficult to accurately define tectonic provinces when there is a limited historic earthquake record. When there are no nearby seismic stations that can detect small-magnitude earthquakes, which occur more frequently than larger events, the problem is compounded. Under these conditions, it is common to delineate larger, rather than smaller, tectonic provinces.

The U.S. Geological Survey identified tectonic provinces in a report titled “Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States” (Algermissen and others, 1982). In that report, Washakie County was classified as being in a tectonic province with a “floating earthquake” maximum magnitude of 6.1. Geomatrix (1988b) suggested using a more extensive regional tectonic province, called the “Wyoming Foreland Structural Province”, which is approximately defined by the Idaho-Wyoming Thrust Belt on the west, 104° West longitude on the east, 40° North latitude on the south, and 45° North latitude on the north. Geomatrix (1988b) estimated that the largest “floating” earthquake in the “Wyoming Foreland Structural Province” would have a magnitude in the 6.0 – 6.5 range, with an average value of magnitude 6.25.

Federal or state regulations usually specify if a “floating earthquake” or tectonic province analysis is required for a facility. Usually, those regulations also specify at what distance a floating earthquake is to be placed from a facility. For example, for uranium mill tailings sites, the Nuclear Regulatory Commission requires that a floating earthquake be placed 15 kilometers from the site. That earthquake is then used to determine what horizontal accelerations may occur at the site. A magnitude 6.25 “floating” earthquake, placed 15 kilometers from any structure in Washakie County, would generate horizontal accelerations of approximately 15%g at the site. That acceleration would be adequate for designing a uranium mill tailings site, but may be too large for less critical sites, such as a landfill. Critical facilities, such as dams, usually require a more detailed probabilistic analysis of random earthquakes. Based upon probabilistic analyses of random earthquakes in an area distant from exposed active faults (Geomatrix, 1988b), however, placing a magnitude 6.25 earthquake at 15 kilometers from a site will provide a fairly conservative estimate of design ground accelerations.

Probabilistic Seismic Hazard Analyses

The U.S. Geological Survey (USGS) publishes probabilistic acceleration maps for 500-, 1000-, and 2,500-year time frames. The maps show what accelerations may be met or exceeded in those time frames by expressing the probability that the accelerations will be met or exceeded in a shorter time frame. For example, a 10% probability that acceleration may be met or exceeded in 50 years is roughly equivalent to a 100% probability of exceedance in 500 years.

The USGS has recently generated new probabilistic acceleration maps for Wyoming (Case, 2000). Copies of the 500-year (10% probability of exceedance in 50 years), 1000-year (5% probability of exceedance in 50 years), and 2,500-year (2% probability of exceedance in 50 years) maps are attached. Until recently, the 500-year map was often used for planning purposes for average structures, and was the basis of the most current Uniform Building Code. The new International Building Code, however, uses a 2,500-year map as the basis for building design. The maps reflect

current perceptions on seismicity in Wyoming. In many areas of Wyoming, ground accelerations shown on the USGS maps can be increased due to local soil conditions. For example, if fairly soft, saturated sediments are present at the surface, and seismic waves are passed through them, surface ground accelerations will usually be greater than would be experienced if only bedrock was present. In this case, the ground accelerations shown on the USGS maps would underestimate the local hazard, as they are based upon accelerations that would be expected if firm soil or rock were present at the surface. Intensity values can be found in Table 1.

Based upon the 500-year map (10% probability of exceedance in 50 years) (Figure 2), the estimated peak horizontal acceleration in Washakie County ranges from approximately 5%g in the north-central part of the county to over 6%g in the southeastern portion of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g). These accelerations are comparable to the accelerations to be expected in Seismic Zone 1 of the Uniform Building Code. Intensity V earthquakes can result in cracked plaster and broken dishes. Worland and Ten Sleep would be subjected to accelerations of approximately 5-6%g or intensity V.

Based upon the 1000-year map (5% probability of exceedance in 50 years) (Figure 3), the estimated peak horizontal acceleration in Washakie County ranges from 7.5%g in the northwestern corner of the county to over 10%g in the south-central and southeastern portions of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g) to intensity VI earthquakes (9.2%g – 18%g). Intensity V earthquakes can result in cracked plaster and broken dishes. Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Worland and Ten Sleep would be subjected to accelerations of approximately 8-9%g (intensity V) and 9-10%g (intensity VI), respectively.

Based upon the 2500-year map (2% probability of exceedance in 50 years) (Figure 4), the estimated peak horizontal acceleration in Washakie County ranges from approximately 12%g in the northwestern corner of the county to over 20%g in the east-central portion of the county. These accelerations are roughly comparable to intensity VI earthquakes (9.2%g – 18%g), and intensity VII earthquakes (18%g – 34%g). Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Intensity VII earthquakes can result in slight to moderate damage in well-built ordinary structures, and considerable damage in poorly built or badly designed structures, such as unreinforced masonry. Chimneys may be broken. Worland and Ten Sleep would be subjected to accelerations of approximately 16%g (intensity VI) and 18%g (intensity VII), respectively.

As the historic record is limited, it is nearly impossible to determine when a 2,500-year event last occurred in the county. Because of the uncertainty involved, and based upon the fact that the new International Building Code utilizes 2,500-year events for building design, it is suggested that the 2,500-year probabilistic maps be used for Washakie County analyses. This conservative approach is in the interest of public safety.

Table 1:

Modified Mercalli Intensity	Acceleration (%g) (PGA)	Perceived Shaking	Potential Damage
I	<0.17	Not felt	None
II	0.17 – 1.4	Weak	None
III	0.17 – 1.4	Weak	None
IV	1.4 – 3.9	Light	None
V	3.9 – 9.2	Moderate	Very Light
VI	9.2 – 18	Strong	Light
VII	18 – 34	Very Strong	Moderate
VIII	34 – 65	Severe	Moderate to Heavy
IX	65 – 124	Violent	Heavy
X	>124	Extreme	Very Heavy
XI	>124	Extreme	Very Heavy
XII	>124	Extreme	Very Heavy

Modified Mercalli Intensity and peak ground acceleration (PGA) (Wald, et al 1999).

Abridged Modified Mercalli Intensity Scale

Intensity value and description:

- 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 automobiles may rock slightly. Vibration like passing of truck. Duration estimated.
- IV** During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.
- V** Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; 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 and 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 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. Persons driving cars disturbed.
- IX** Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
- X** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.
- XI** Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
- XII** Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

**Peak Acceleration (%g)
with 10% Probability
of Exceedance in 50 Years
site: NEHRP B-C boundary**

U.S. Geological Survey
National Seismic Hazard Mapping Project

Albers Conic Equal-Area
Projection
Standard Parallels: 29.5

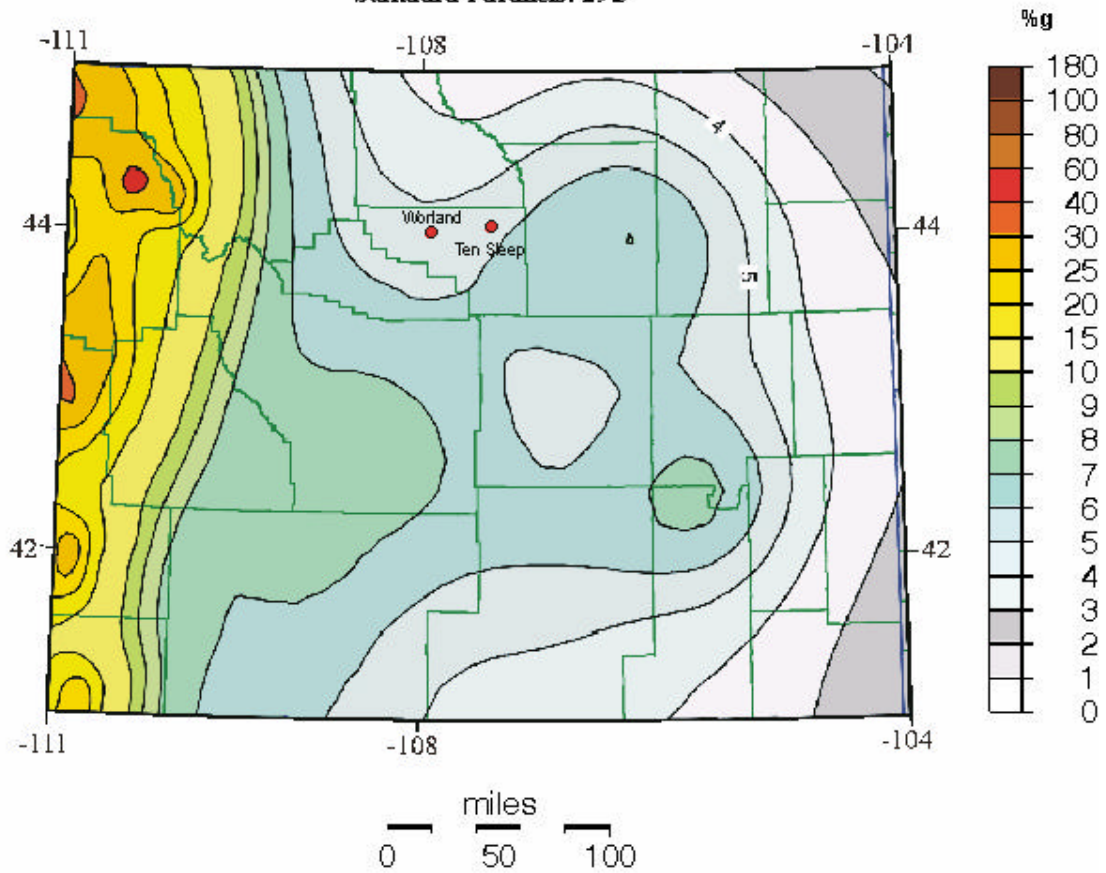


Figure 2. 500-year probabilistic acceleration map (10% probability of exceedance in 50 years).

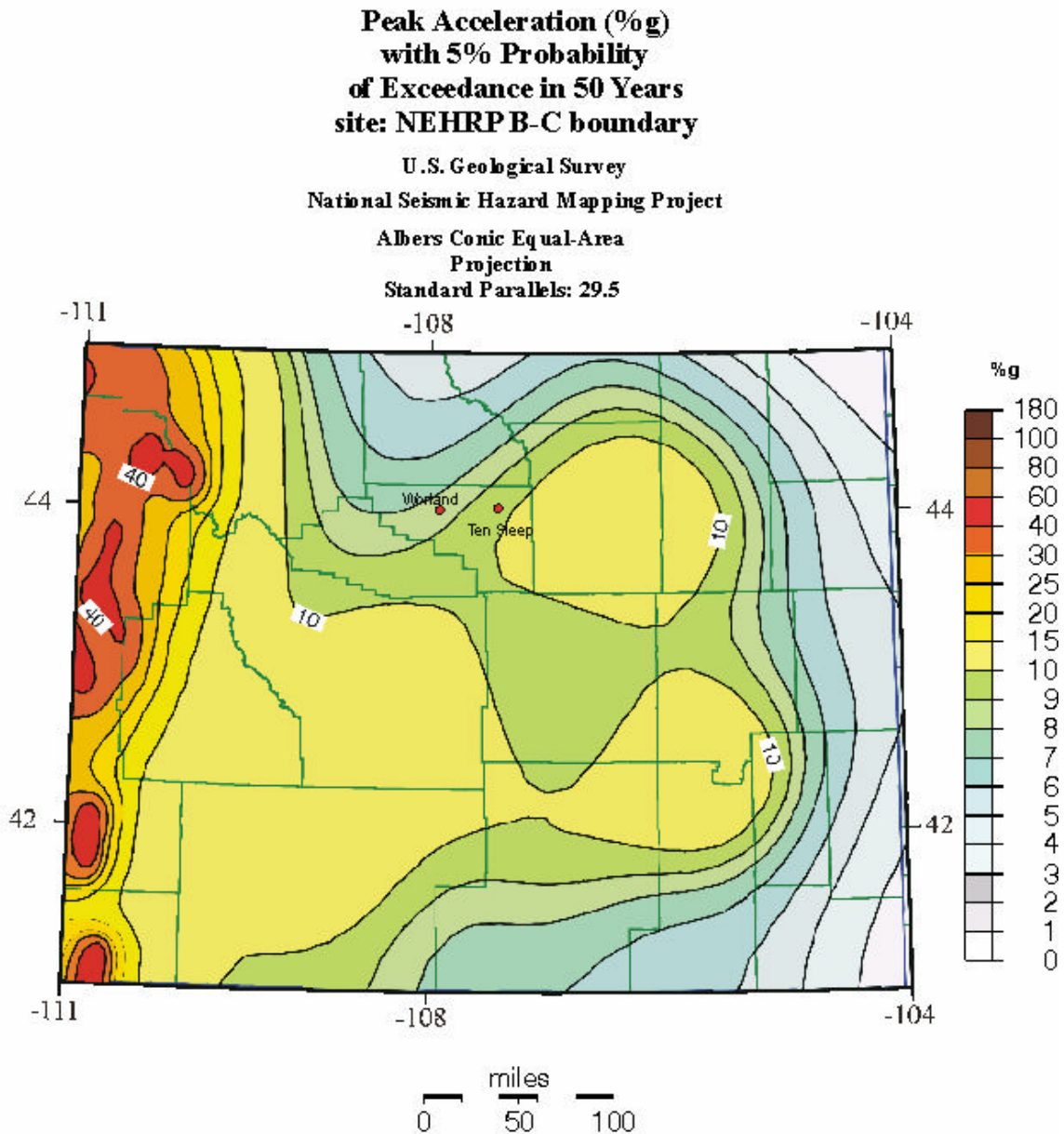


Figure 3. 1000-year probabilistic acceleration map (5% probability of exceedance in 50 years).

**Peak Acceleration (%g)
with 2% Probability
of Exceedance in 50 Years
site: NEHRP B-C boundary**

U.S. Geological Survey
National Seismic Hazard Mapping Project
Albers Conic Equal-Area
Projection
Standard Parallels: 29.5

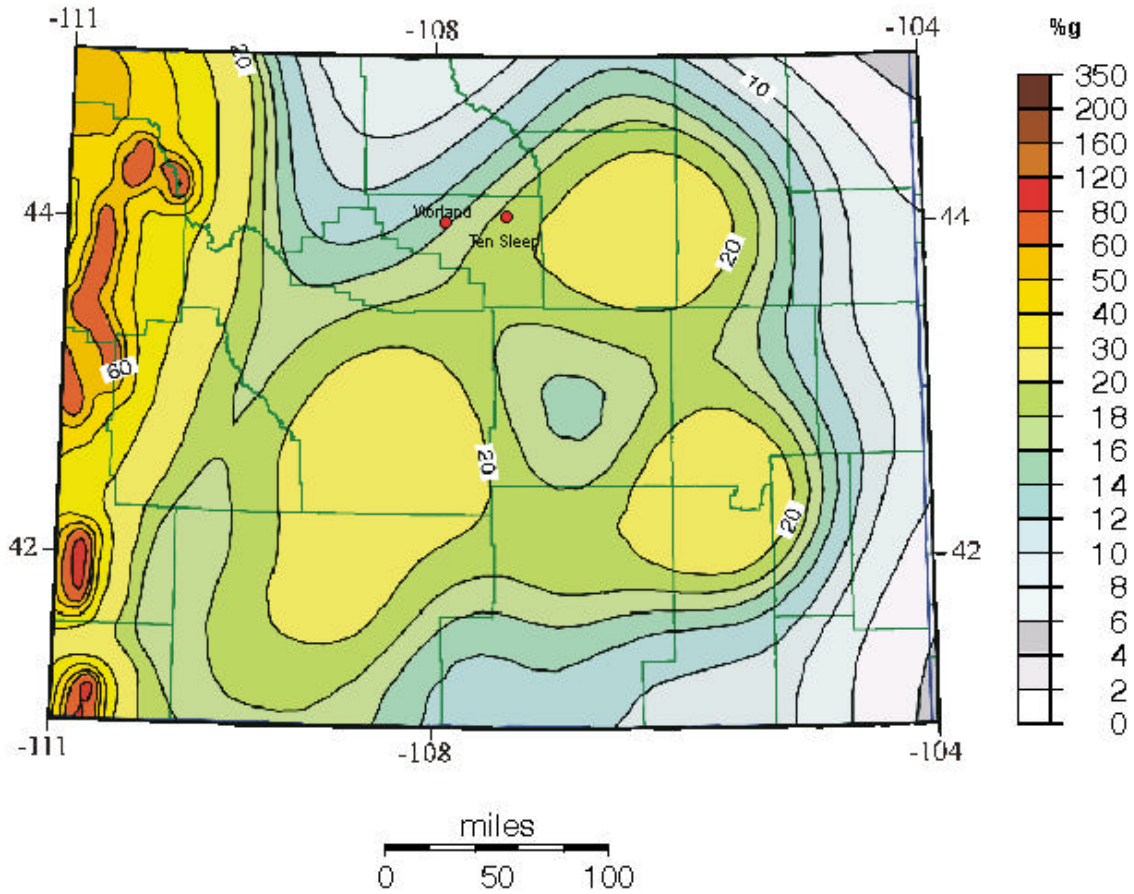


Figure 4. 2500-year probabilistic acceleration map (2% probability of exceedance in 50 years).

Summary

There have been four historic earthquakes with a magnitude greater than 2.5 recorded in Washakie County. Because of the limited historic record, it is possible to underestimate the seismic hazard in Washakie County if historic earthquakes are used as the sole basis for analysis. Earthquake and ground motion probability maps give a more reasonable estimate of damage potential in areas without exposed active faults at the surface, such as Washakie County.

Current earthquake probability maps that are used in the newest building codes suggest a scenario that would result in moderate damage to buildings and their contents, with damage increasing from the northwest to the east. More specifically, the probability-based worst-case scenario could result in the following damage at points throughout the county:

Intensity VII Earthquake Areas

Big Trails
Ten Sleep

In intensity VII earthquakes, damage is negligible in buildings of good design and construction, slight-to-moderate in well-built ordinary structures, considerable in poorly built or badly designed structures such as unreinforced masonry buildings. Some chimneys will be broken.

Intensity VI Earthquake Areas

Worland

In intensity VI earthquakes, some heavy furniture can be moved. There may be some instances of fallen plaster and damaged chimneys.

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