Basic Seismological Characterization
for
Hot Springs 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 Hot Springs 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

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. Eight magnitude 3.0 and greater earthquake have been recorded in Hot Springs County. These earthquakes are discussed below.

The first earthquake that was reported in Hot Springs County occurred on February 13, 1928, approximately 10 miles south of Thermopolis. The intensity IV earthquake was felt as three shocks in Thermopolis, and was "felt sharply" in Worland, Owl Creek, Gebo, Crosby, and Kirby. It was also strongly felt at a mine in the Copper Mountain mining district near Bonneville. Reports indicate that two men entered their mine when aftershocks were occurring and found that many of the mine props were so loose that they could be moved by hand (Heck and Bodle, 1930).

On June 19, 1928, another intensity IV earthquake was reported in the area, with the epicenter located approximately 6 miles northwest of Thermopolis (Heck and Bodle, 1930). A single shock from this event was felt in Thermopolis, with sounds slightly preceding the earthquake.

Two earthquakes occurred in Hot Springs County in the 1940s. On October 11, 1944, an intensity IV earthquake was reported approximately 3 miles south of Thermopolis. Several landslides occurred as a result of the earthquake, and rocks fell onto the highway in Wind River Canyon. At Hot Springs State Park, there was a “caving of earth on the south rim of the large hot spring in the park” (Casper Tribune-Herald, October 13, 1944). Yet another intensity IV earthquake occurred in the same area on January 26, 1946. This event, which was felt for approximately ten seconds, rattled windows and dishes and clouded the water in Hot Springs State Park for a few days (Laramie Republican-Boomerang, January 29, 1946).

On January 23, 1950, an intensity V earthquake was felt near Hamilton Dome, approximately 22 miles northwest of Thermopolis. Houses shook and dishes rattled in the Hamilton Done area, and the earthquake was felt in Thermopolis (Murphy and Ulrich, 1952). Another intensity V earthquake occurred approximately 3 miles south of Thermopolis on January 31, 1954 (Casper Tribune-Herald, February 2, 1954). No damage was reported from this event.

One of the largest earthquakes recorded in the Thermopolis area occurred on December 8, 1972. The magnitude 4.1, intensity V earthquake was centered approximately eight miles west of Thermopolis. It caused two cracks in the ceiling of a new addition to a Thermopolis rest home (Laramie Daily Boomerang, December 9, 1972), and the floor in a local lumberyard sank a few inches (Casper Star-Tribune, December 9, 1972). The earthquake was felt in Kinnear, Pavillion, and the Riverton area, and was reportedly felt as far away as Craig, Colorado.

Most recently, on June 6, 1978, a magnitude 4.0 earthquake was recorded approximately 20 miles east of Thermopolis (Reagor, Stover, and Algermissen, 1985). No damage was associated with that earthquake.

Regional Historic Seismicity

Several earthquakes have also occurred near Hot Springs County. Two earthquakes were recorded in northern Fremont County on April 26, 1967. A magnitude 4.7 event and a magnitude 4.2 event occurred approximately 32 miles southwest and approximately 38 miles west-southwest of Thermopolis, respectively (Reagor, Stover, and Algermissen, 1985). No damage was associated with either earthquake.

On August 7, 1991, a magnitude 3.5 earthquake was recorded in northern Fremont County, approximately 35 miles southwest of Thermopolis. This non-damaging earthquake was felt in Thermopolis.

A magnitude 3.0 earthquake occurred on November 8, 2000, in northeastern Fremont County. This event was centered approximately 29.5 miles southeast of Thermopolis. No one reported feeling this earthquake (U.S.G.S. National Earthquake Information Center).

The most recent earthquake to occur in the region occurred on April 5, 2002, in western Washakie County. The earthquake's epicenter was located approximately 11 miles northeast of Kirby. Although the Washakie County Emergency Management agency reported ground shaking, the earthquake did not cause any damage.

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:

Zone	Effective Peak Acceleration, % gravity (g)
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.

Hot Springs County is in Seismic Zones 1 and 2 of the UBC. Since effective peak accelerations (90% chance of non-exceedance in 50 years) can range from 5%g-20%g in these zones, and there has been some significant historic seismicity in the county, it may be reasonable to assume that an average peak acceleration of 10%g could be applied to the design of a non-critical facility located in the county if only the UBC were used. Such an acceleration, however, is less than would be suggested through newer building codes.

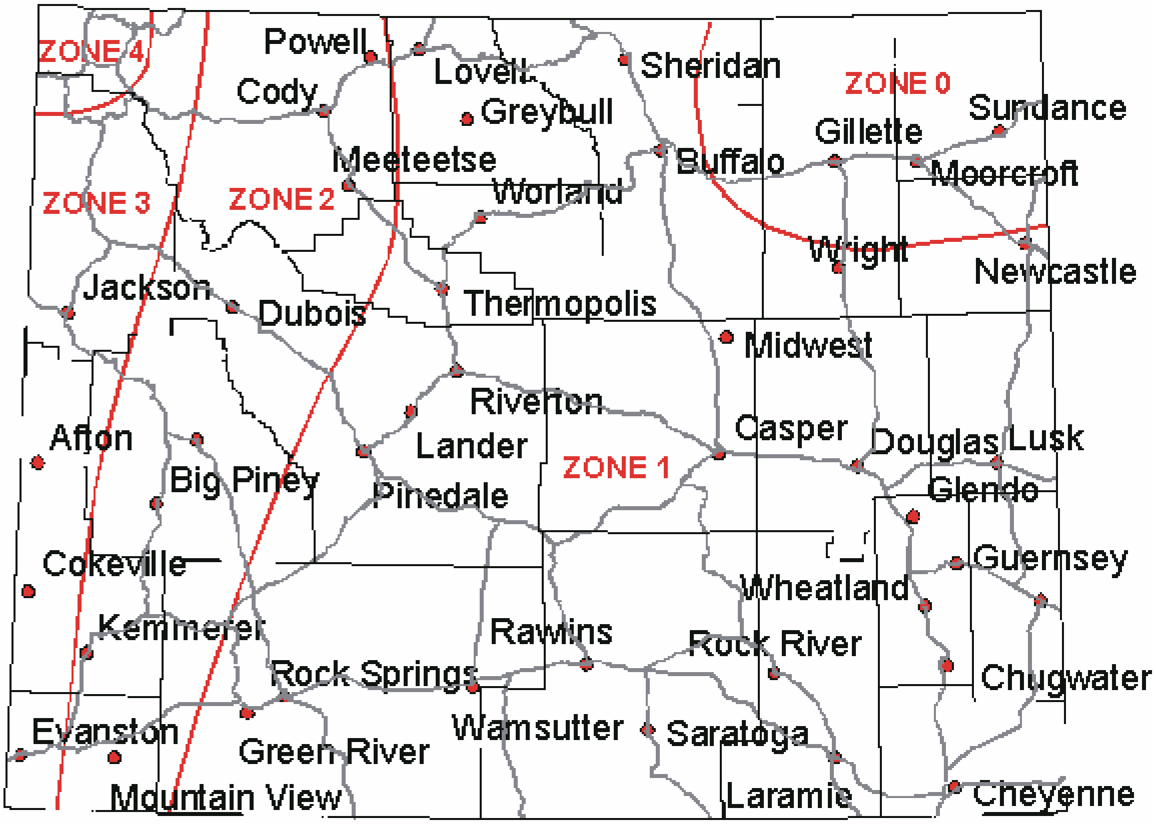


Figure 1. UBC Seismic Zone Map.

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. Hot Springs County still uses the UBC, however, as do most Wyoming counties as of November 2002.

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 southeastern border of Hot Springs 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 2.8%g at Thermopolis, approximately 2.3%g at Kirby, and approximately 1.5%g at Hamilton Dome (Campbell, 1987). Those accelerations would be roughly equivalent to an intensity IV earthquake. Earthquakes of this intensity usually cause no damage. 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 6.2%g at Thermopolis, approximately 5 %g at Kirby, and approximately 2.9%g at Hamilton Dome (Campbell, 1987). Those accelerations would be roughly equivalent to intensity V earthquakes at Thermopolis and Kirby and an intensity IV earthquake at Hamilton Dome. Minor damage could occur at Thermopolis and Kirby.

The Stagner Creek fault system is an east-west trending system located near Boysen Reservoir on the south flank of the Owl Creek uplift. Geomatrix (1988a) determined that the maximum length of the fault is 24 miles (38 km), with Quaternary-age displacement found along a 17 mile (27 km) segment of the fault between Mexican Pass and Tough Creek. The maxiumum credible earthquake was determined to be a magnitude 6.75 event with a recurrence interval of between 8,000 to 20,000 years (Geomatrix, 1988a). A magnitude 6.75 earthquake originating on the Stagner Creek fault system could generate peak horizontal accelerations of approximately 10%g at Thermopolis, approximately 6%g at Hamilton Dome, and approximately 5.7%g at Kirby.

These accelerations would be roughly equivalent to an intensity VI earthquake at Thermopolis and intensity V earthquakes at Hamilton Dome and Kirby. An intensity VI earthquake could cause minor damage at Thermopolis and intensity V earthquakes could cause very minor damage at Hamilton Dome and Kirby.

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, Hot Springs 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 Hot Springs 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 accelerations 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 Hot Springs County ranges from approximately 5%g in the northeastern portion of the county to nearly 8%g in the western portion of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g). Intensity V earthquakes can result in cracked plaster and broken dishes. Thermopolis would be subjected to an acceleration of approximately 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 Hot Springs County ranges from 7%g in the northern part of the county to greater than 10%g in the far western corner of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g) and 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. Thermopolis would be subjected to an acceleration of approximately 9-10%g or intensity V-VI.

Based upon the 2500-year map (2% probability of exceedance in 50 years) (Figure 4), the estimated peak horizontal acceleration in Hot Springs County ranges from approximately 12%g in the northern part of the county to over 18%g in the southeastern corner of the county. These accelerations are roughly comparable to intensity VI earthquakes (9.2%g – 18%g) to 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. Thermopolis would be subjected to an acceleration of approximately 17%g or intensity VI. Depending on local soil conditions, parts of Thermopolis may be subjected to intensity VII shaking.

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 Hot Springs 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.

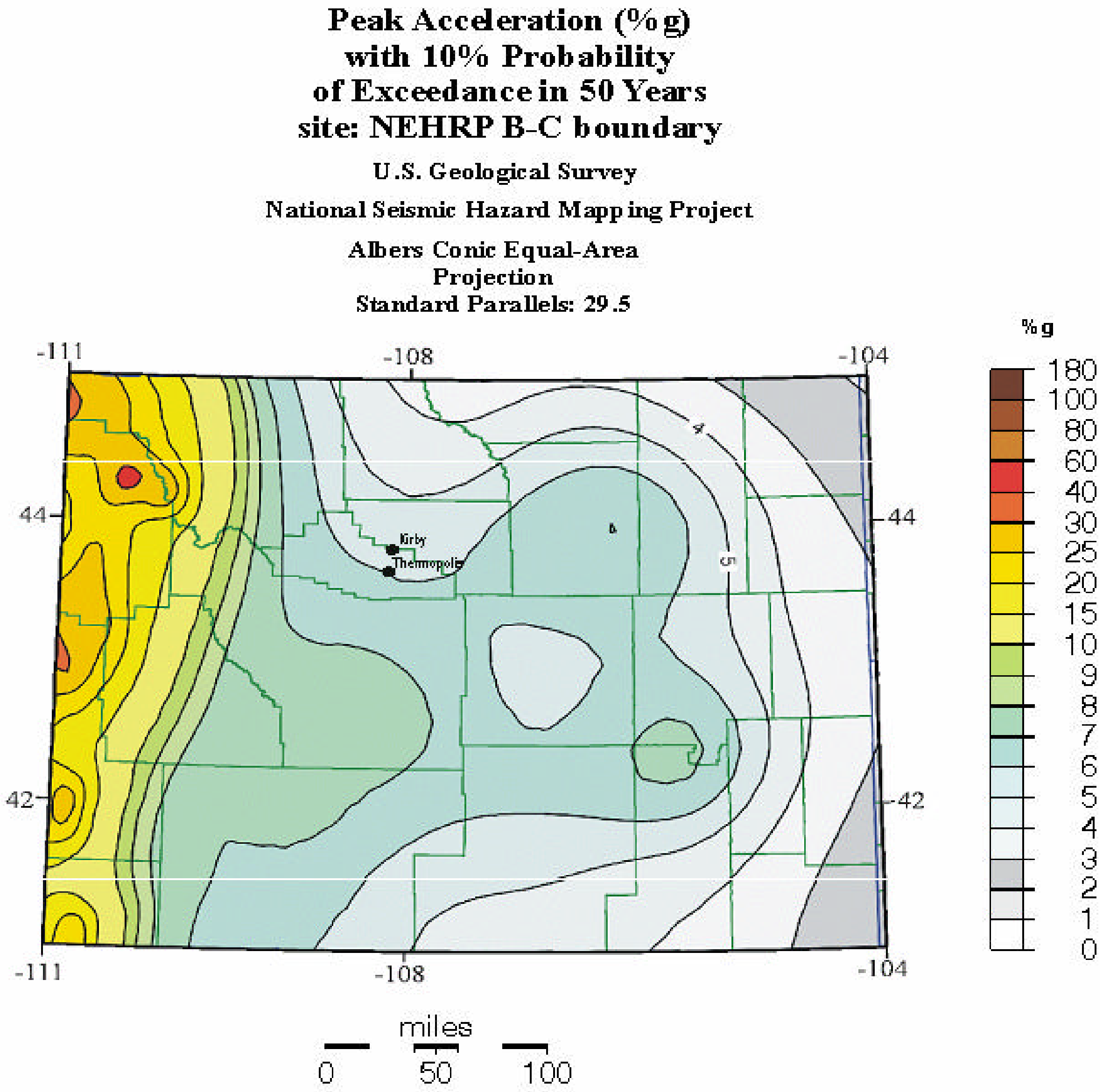
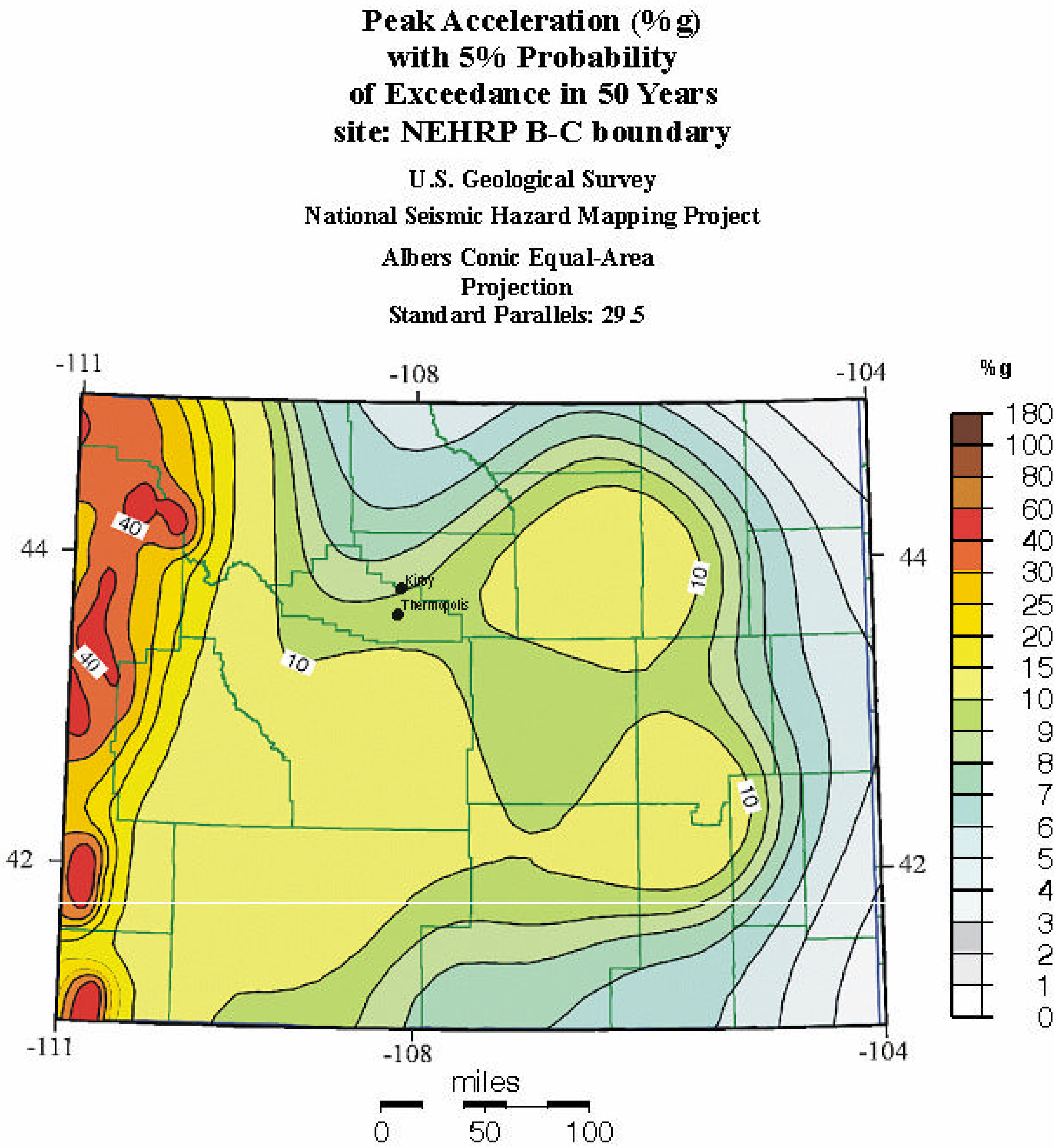


Figure 2. 500-year probabilistic acceleration map (10% probability of exceedance in 50 years).



Peak Acceleration (%g)
with 5% 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 3. 1000-year probabilistic acceleration map (5% probability of exceedance in 50 years).

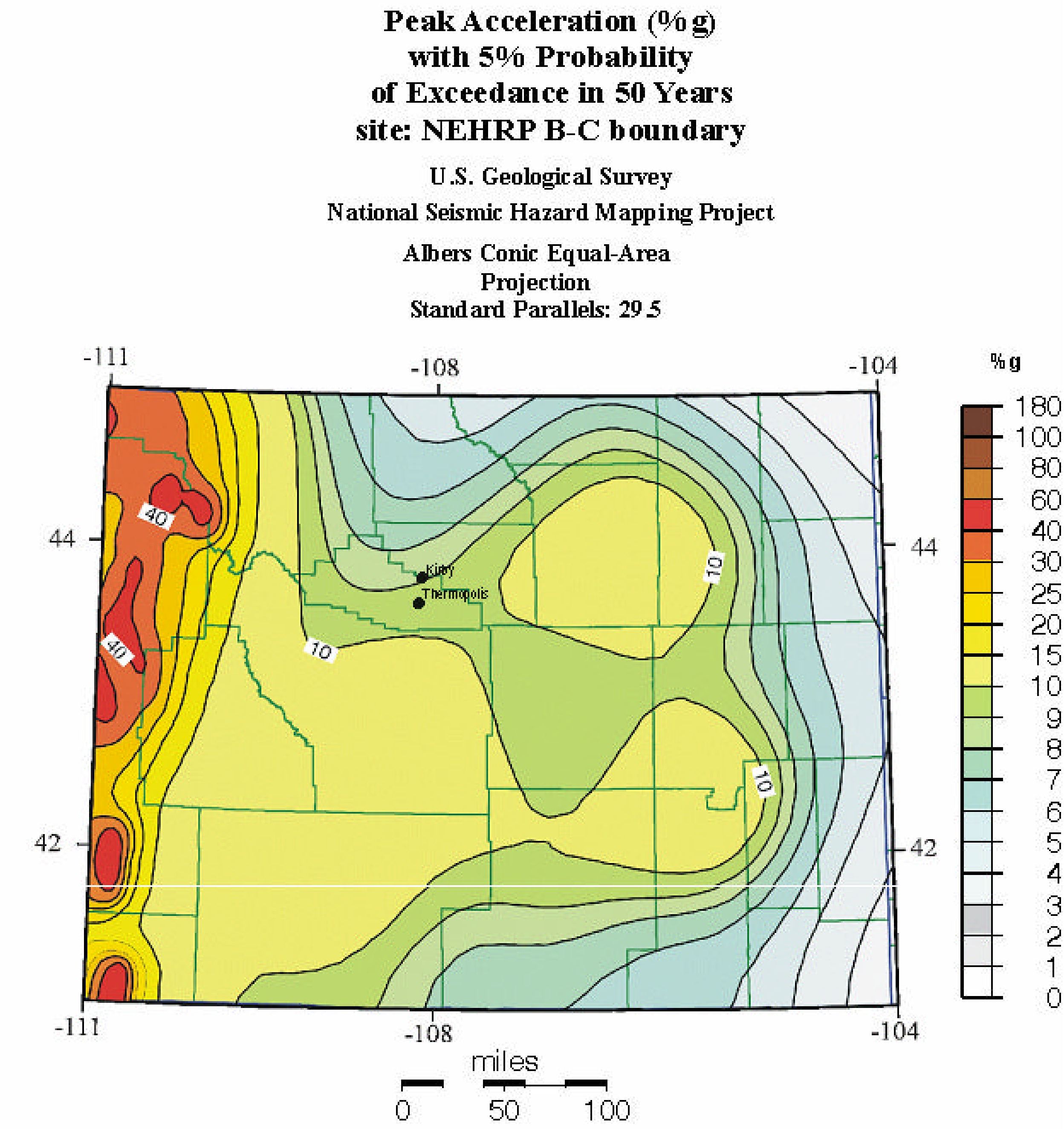


Figure 4. 2500-year probabilistic acceleration map (2% probability of exceedance in 50 years).

Summary

There have been thirteen historic earthquakes with a magnitude greater than 3.0 recorded in or near Hot Springs County. Because of the limited historic record, it is possible to underestimate the seismic hazard in Hot Springs County if historic earthquakes are used as the sole basis for analysis. Earthquake and ground motion probability maps and specific fault analyses give a more reasonable estimate of damage potential in Hot Springs County.

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

Intensity VII Earthquake Areas

East Thermopolis (locally may be subjected to Intensity VII)
Thermopolis (locally may be subjected to Intensity VII)

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

East Thermopolis (locally may be subjected to Intensity VII)
Gebo
Grass Creek
Hamilton Dome
Kirby
Lucerne
Thermopolis (locally may be subjected to Intensity VII)

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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