WYOMING STATE GEOLOGICAL SURVEY
Gary B. Glass, State Geologist

EARTHQUAKES AND ACTIVE FAULTS IN WYOMING

by

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PRELIMINARY HAZARDS REPORT
97-2

This report has not been reviewed for conformity with the editorial standards of the Wyoming State Geological Survey.

Laramie, Wyoming
1997

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ABSTRACT

Although the historic record of earthquakes in Wyoming is rather short, earthquakes have been felt in all counties with the first reported event dating from the 1870's in Yellowstone National Park. These more significant earthquakes all had maximum intensities greater than V. In 1959, a magnitude 7.5 (M_S), intensity X earthquake near Hebgen Lake, Montana, was felt over large portions of Wyoming. In 1975, an intensity VI event was recorded in central Yellowstone National Park. In 1932, the Jackson Hole area was subjected to an intensity VI event, preceded by an intensity VI event in the Star Valley area in western Wyoming. In 1984, an intensity VI event was reported in the Lander area. One of the largest earthquakes reported in central and eastern Wyoming was at Casper. In 1897, an intensity VII event caused significant damage. Most recently, in 1984, an intensity VI event in northern Albany County was felt over large portions of eastern Wyoming and surrounding states.

A number of active faults with a surficial expression have been identified in Wyoming. The western quarter of the State, from Yellowstone National Park in the north through Uinta County in the south, has a number of faults that are apparently capable of generating magnitude 7.5, intensity IX to X earthquakes. Predicted recurrence intervals for maximum credible earthquakes have been met or surpassed for most of the fault systems capable of generating magnitude 7.5 events in the western quarter of the State. In central Wyoming (Fremont, Hot Springs, and Natrona Counties), faults capable of generating magnitude 6.75 events have been investigated. In the rest of Wyoming, maximum credible earthquakes of magnitude 6.1 have been predicted. U.S. Geological Survey researchers have estimated that in the western quarter of the State, a maximum

of one intensity V earthquake may occur every 1.5 years. In the eastern three quarters of the State, a maximum of one intensity V earthquake may occur every 2.2 years. Larger events will occur less frequently.

SEISMIC HISTORY AND FUTURE EARTHQUAKE POTENTIAL OF WYOMING

INTRODUCTION

In historic times, earthquakes have occurred or have been felt in every county in Wyoming. Nearly all of the earthquakes have been due to movements on faults, either exposed at the surface or deeply buried. Many other geologic hazards, such as liquefaction, landslides, and mine subsidence, have also been associated with earthquake activities in the State. The potential does exist for large, damaging earthquakes to occur in the future, with the greatest threat in the western quarter of the State.

EARTHQUAKE MEASUREMENTS

There are two basic methods of monitoring and measuring various parameters of earthquakes. One method uses seismographs to measure or determine various aspects of seismic waves, including their source area, wave form, and the amount of energy they release. Magnitude is this instrumentally determined measure of the size of the earthquake and the total energy released. The other method of measuring an earthquake is derived from a compilation of personal observations of the effects that an earthquake has on the Earth's surface or on specific types of structures at a given locality. This measure is called the intensity.

MAGNITUDE

Magnitude is probably the most commonly cited earthquake measurement. There are four magnitude scales in use today. Three of these scales rely upon measuring the amplitude of various portions of seismic waves recorded on a seismograph. Due to limitations and inaccuracies of those basic methods, a fourth scale was formulated that relies on fault rupture length and the strength of materials.

Richter Scale

The most famous magnitude scale was developed by Charles Richter in 1935 (Richter, 1958). It was designed for use where recording stations are within 600 kilometers (370 miles) of an epicenter and hypocenters are fairly shallow. The original Richter magnitude scale represents local magnitude (M_L).

Richter's method utilizes a series of identical Wood-Anderson torsional seismometers to record seismic waves. Specific wave forms are not delineated with this procedure although most of the waves that are measured have periods (1/frequency) from 0.1 to 2 seconds. In developing his scale, Richter compared the common logarithms (base 10) of the maximum recorded amplitudes of seismic waves generated by earthquakes of various sizes to those generated by a standard earthquake. The standard earthquake is defined as one that would produce a recorded deflection of 0.001 millimeter on a torsion seismograph that is located at a distance of 100 kilometers (62 miles) from an earthquake source.

In order to have a reference point on the magnitude scale, a standard earthquake was assigned a magnitude of 0. Other points on the scale are defined by the formula $M_L = \text{Log } A - \text{Log } A_o$ (Figure 1A). As M_L represents a number that is a common logarithm (base 10), an earthquake with an M_L of 2 generates a seismic wave that has a maximum recorded amplitude that is 10 times larger than an earthquake with an M_L of 1, and 100 times larger than one with an M_L of 0. That is not to say that 10 or 100 times more energy was released. Although the complex relationship between magnitude and earthquake energy is not exact, it has been estimated that with a magnitude increase of one step the associated seismic energy increases about 32 times.

It is confusing to many people that an earthquake can have a negative magnitude. Earthquakes that generate a seismic wave with a maximum recorded amplitude of ground motion greater than that of a standard earthquake have a magnitude greater than 0 while those with a lesser amplitude would have a negative magnitude. The positive and negative values are for comparison purposes only. As with other magnitude scales, the M_L system is open ended, in that it has no theoretical minimum or maximum limits (no measured earthquake has exceeded a magnitude of 8.9).

Surface and Body Wave Scales

Due to the limitations of the M_L system, Richter and Beno Gutenburg developed scales to measure the magnitudes of earthquakes at distant locations and at depths of up to 700 kilometers (435 miles). The scales are based upon the recorded amplitude of both surface waves and body waves. Gutenburg realized that for earthquakes at great distances from a recording station, seismic surface waves with a period of 20 seconds are often dominant.

A. **Local magnitude** (Richter scale) (Stover, 1985)

M_L = Log A - Log A_o.

A = Recorded trace amplitude.

A_o = Amplitude of standard earthquake.

Seismometer within 600 kilometers of epicenter.

Focus depth less than 70 kilometers.

B. **Surface wave magnitude** (Stover, 1985; Spence, 1977)

M_S= Log(A/T)+1.66 Log D+3.3.

A = Maximum vertical surface-wave trace amplitude in microns.

T = Period in seconds ($18 \leq T \leq 22$).

D = Distance from epicenter to recording station in geocentric.

Earthquake must be in a distance range of 20° to 160° (geocentric degrees).

Focus depth less than 50 kilometers.

Valid to M_S = 8.6.

C. **Body wave magnitude** (Stover, 1985)

M_B = Log (A/T) + Q (D,h).

A = Ground motion amplitude in micros, taken from P-wave group (not necessarily the maximum).

T = period in seconds ($0.1 \leq T \leq 3.0$).

Q = Function of distance between hypocenter and station (D) and depth (h) where $D \geq 5°$ (geocentric).

Valid to M_B = 6.8 (Spence, 1977).

D. **Seismic moment magnitude** (Kanamori, 1980; Spence, 1977)

M_W = (log M_o/1.5) - 10.7.

M_o= µS <d> = seismic moment.

S = Area of fault.

<d> = Average displacement.

µ = Shear strength of faulted rock.

Seismic moment information is incorporated into an extention of existing magnitude scale.

Valid for all earthquakes;especially useful for those with magnitudes greater than 7.0.

Figure 1. Methods of calculating earthquake magnitude.

His surface wave magnitude scale (M_L) was based upon comparing the recorded amplitude of surface waves with periods between 18 and 22 seconds. The formula used is M_S= Log(A/T)+1.66 Log D+3.3 (Figure 1B) . Restrictions on the formula other than those already mentioned are that the earthquake must be in the distance range of 20° to 160° (geocentric), and that depth corrections have to be made for hypocenter depths greater than 50 kilometers (30 miles) (Stover, 1985).

Gutenburg utilized seismic body waves (P and S) to define another magnitude scale. The formula used by the U.S. Geological Survey is M_B = Log (A/T) + Q (D,h) (Figure 1C).

Upon examining the various scales, it becomes obvious that more than one magnitude can be assigned to a single earthquake, depending on the nearness of the hypocenter to recording stations, the depth of the hypocenter, and the period of the seismic waves.

Seismic Moment

There are certain inconsistencies in the theoretical basis of portions of the magnitude-scale approach when defining large earthquakes. When faults have a very long rupture, seismic waves from the closer end of a fault can reach a seismogram before those from the farther end (Boore, 1977). In addition, when long faults move, seismic waves that are generated can have very low frequencies and extremely large wave lengths. Both the M_S and M_B scales have limitations on the frequencies or periods that can be utilized. As a result, many of the wave forms generated along long faults or large earthquakes cannot be used with the M_B and M_S scales. The measured magnitude, using those scales, may represent only a portion of the energy released by the rupture. The size of the earthquake may be much larger than the magnitude calculation infers. As a result, seismologists are turning to seismic moment in order to more accurately represent the size of large earthquakes.

The method used to calculate the seismic moment ensures that the energy emitted from the entire fault is measured. The formula used to define seismic moment is $M_O=\mu S<d>$, where S is the area of the fault, $<d>$ is the average displacement on the fault, and μ is the shear strength of the faulted rock (Spence, 1977). An extension of the M_L, M_S, and M_B magnitude scales has been developed by incorporating seismic moment. The seismic moment magnitude (M_W) scale is defined by the formula $M_W=(\text{Log } M_O/1.5)-10.7$ (Figure 1D) (Kanamori, 1978). The 1964 Alaskan earthquake had an M_S of 8.3. This has been advanced to an M_W of 9.2 after incorporating seismic moment calculations.

INTENSITY

Intensity is a qualitative measure of the degree of shaking an earthquake imparts on people, structures, and the ground. A series of intensity scales have been developed that group earthquake effects into various scale values. The most widely used scale was introduced in Italy by G. Mercalli (1902) and modified by H.O. Wood and Frank Neumann (1931) in California. The scale that resulted is called the modified Mercalli scale of 1931. A shortened version of the scale was printed in the September-October, 1974 issue of the *Earthquake Information Bulletin* (v. 6, No. 5, Table 1).

For a single earthquake, intensities can vary depending upon the distance from the epicenter. While an intensity of I might be reported at the edge of the felt zone, the intensity at the epicenter would be much higher. Isoseismal maps that are generated from reported intensities can provide valuable information on earthquakes and their effects.

Table 1. Modified Mercalli intensity scale of 1931 (abridged)

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 vehicles may rock slightly. Vibration like passing of truck. Duration estimated.
IV.	Felt indoors by many during the day, outdoors by few. At night, some persons are awakened. Dishes, windows and doors are disturbed; walls make cracking sound. Sensation like heavy truck striking building; standing vehicles are rocked noticeably.
V.	Felt by nearly everyone; many awakened. Some dishes, windows, etc. broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI.	Felt by all; many persons are 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 damage in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving vehicles.
VIII.	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings, with partial collapse; extensive damage in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water levels(?). Disturbs persons driving vehicles.
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; extensive damage 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 along 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 pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII.	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects are thrown upward into the air.

HISTORIC EARTHQUAKES

There are earthquake epicenters located within the boundaries of nearly all of the counties in Wyoming. In the counties where there have not been recorded epicenters, tremors have been felt from earthquakes in adjacent counties. The highest incidence of historic earthquakes has been in western Wyoming. Yellowstone National Park has the highest historic density, followed by the Overthrust Belt and Jackson Hole. A summary of damaging earthquakes in thirteen areas of the State is presented below. In areas with a high historic earthquake density, only the most significant events are discussed. All earthquakes discussed below are shown on Plate 1. All reported intensities are the maximum for each earthquake.

Yellowstone National Park

Yellowstone National Park (YNP) has long been the center of intense seismic activity in Wyoming. F.V. Hayden (1872) reported that "on the night of the 20th of July (1871), we experienced several severe shocks of an earthquake, and these were felt by two other parties, fifteen or twenty-five miles distant, on different sides of the lake." This event was assigned an intensity V by Fischer (1960). On July 31, 1926, an intensity IV quake that rattled or moved dishes was reported at the Lake Ranger Station (Fischer, 1960). From August 24 through December 22, 1930, there were a series of earthquakes in YNP. An intensity V event was reported on August 25, 1930. This earthquake threw dishes from shelves, and obviously disturbed the water in Lewis Lake (Fisher, 1960). On January 14, 1936, southwest of YNP, there was an intensity VI event that cracked plaster and chimneys at the Lake Hotel. Free-swinging doors would not close (Fischer, 1960).

The most notable recent activity in YNP was the Hebgen Lake earthquake on August 17-18, 1959. Although the epicenter was located just outside Wyoming, its disastrous effects were felt well into the State. The quake had a M_S of 7.5 with a maximum intensity of X. A major landslide was initiated, which dammed the Madison River. So much material was displaced so quickly that it generated a great blast of air that blew people about like leaves (Witkind, 1964). Twenty-eight people were killed by that earthquake and its effects. New fault scarps were noted near Hebgen Lake, and many geysers were adversely affected in YNP. There were 156 aftershocks recorded during the first 21 hours after the main shock,including some magnitude 6.0 and 6.5 events within the Park. Minor earthquake activity continues in the Hebgen Lake area.

A M_L 6.4, intensity VII earthquake occurred in the central portion of YNP on June 30, 1975. Landslides closed twelve miles of road between Norris Junction and Madison Junction for almost a day. Three- to four-foot deep cracks that were fifteen to twenty feet long were found in the Virginia Cascades area. Other roads in the Park were closed for brief periods of time due to earthquake-induced landslides (*Jackson Hole News*, July 3, 1975). Since 1975, a number of earthquake swarms have been detected in the Park, along with almost daily, small magnitude earthquakes. In 1985, over 1,100 events with magnitudes greater than 1.0 were recorded (Smith and others, 1986).

<u>Jackson Hole Area</u>

Jackson Hole has a significant seismic risk due to its proximity to the Teton fault. In the last one hundred years, however, there have been very few earthquakes that have caused significant damage. One of the earliest recorded events with associated damage was on March 24, 1923. An intensity V earthquake was felt as far south as the Green River Basin. Rocks weighing tons were dislodged in the Tetons and around the now abandoned town of Grovont. Avalanches were also initiated by the event (*Jackson Hole Courier*, March 29, 1923).

On January 26, 1932, an intensity VI earthquake knocked plaster loose in a few homes, cracked foundations, and caused general alarm among people in the area. Because the event occurred at night, several individuals were thrown from their beds. A few people ran from their homes without waiting to grab any clothing, but none stayed outside very long in January (*Jackson Hole Courier*, January 28, 1932). On February 23, 1948, there was an intensity VI event in the area that cracked and twisted logwork in a few local buildings (*Jackson Hole Courier*, February 26, 1948). Numerous earthquakes have been reported in the Jackson area from the 1950's through the 1980's, but little damage has been observed.

On June 23, 1925, the lower Gros Ventre landslide north of Jackson activated, damming the Gros Ventre River. Seismic activity on June 21, 1925, was reported by the *Jackson Hole Courier* (June 25, 1925). The activity was described as being "quite severe". Voight (1978) described a report of seismic activity on June 22, 1925, the night before the Gros Ventre River was dammed by the landslide.

The seismic events, the fact that the bedrock had a 20° dip towards the river, the earlier heavy precipitation in the area, and the erosion of the toe of an older landslide mass all contributed to the destabilization of the landslide mass. Later, in 1927, the landslide dam partially failed, resulting in the loss of life at Kelly, Wyoming.

Wyoming Overthrust Belt

There have been numerous earthquakes in the Overthrust Belt, with the highest density in the northern third of the area. One of the earliest recorded events occurred in the Star Valley area (Lincoln County) near Bedford. On March 31, 1915, an intensity IV event shook buildings (Humphreys, 1915). No other damage was reported. On December 1, 1925, an intensity III event was reported near Evanston. That event was felt by few although some doors did swing (Neumann, 1927).

On June 12, 1930, the most damaging earthquake to occur in the Overthrust Belt caused noticeable damage at Grover in the Star Valley. The intensity VI event was felt by nearly everyone in Grover. One brick building was cracked, a concrete swimming pool was cracked, plaster was cracked, and clocks on many walls stopped (Neumann and Bodle, 1932). An intensity IV event was felt at La Barge on June 23, 1945. No significant damage was reported although many buildings creaked.

More recently, a M_L 4.2, intensity V earthquake was recorded on February 8, 1983, near the Palisades Reservoir in Idaho. The reservoir is near Alpine, Wyoming. The U.S. Forest Service reported that the event may have initiated snow avalanches in some areas (*Casper Star-Tribune*, February 9, 1983). In 1985, there were a series of events that occurred near the Snake River Canyon in northern Lincoln County. On August 21, 1985, a M_B 4.8 event may have caused a motorist to drive off the highway in the Snake River Canyon (*Casper Star-Tribune*, August 22, 1985). That event was felt in Jackson. A M_B 4.3 event was reported on August 22, 1985, and a M_L 4.3 earthquake was recorded on August 30, 1985, in the same general vicinity. No damage was reported for either of those events. A M_L 4.6, intensity V event was reported in the same area on September 7, 1985. As a result of that earthquake, a rockslide temporarily closed a portion of U.S. Highway 89 in the Snake River Canyon (*Casper Star-Tribune*, September 8, 1985).

Rock Springs Area

A few earthquakes have been reported in the Rock Springs area, some of which may have been the result of mine collapse. In July, 1910, the Union Pacific No. 1 mine in Rock Springs partially collapsed (*Cheyenne State Leader*, July 26, 1910). The mine had to be abandoned. Scores of houses were also shaken when the mine collapsed. At the time, some people thought that rapid mine subsidence caused an earthquake-like effect. In fact, the *Cheyenne State Leader* called it an "imitation earthquake". It has not been determined if shock waves that were generated by the collapse of the mine created the earthquake or if an earthquake actually caused the mine to collapse. In either case, the event had an estimated intensity of V.

On July 28, 1930, an intensity IV earthquake occurred near Rock Springs (*Casper Daily Tribune*, July 28, 1930). A portion of a mine at Reliance caved in during the disturbance. The tremor was felt at Rock Springs, but there was no appreciable damage. Again, many residents believed the shaking was again due to settling of the old No. 1 mine.

On September 24, 1948, there was another intensity IV earthquake centered near Rock Springs that caused no damage. The *Casper Tribune-Herald* (September 27, 1948) attributed the tremor to mine subsidence.

Lander-Atlantic City Area

One of the first reported earthquakes in the Lander-Atlantic City area occurred near Atlantic City on December 12, 1923. The intensity V event was felt by many in the area although no reports of damages could be found (Humphreys, 1924).

In 1934, an intensity V quake was centered northwest of Lander. For a radius of 10 miles around Lander, residents reported that dishes were thrown from cupboards and pictures fell from walls. Residents ran into the streets and expressed considerable concern. Cracks were found in buildings in two business blocks, and the brick chimney of the Fremont County Courthouse was moved two inches away from the building. The shock was felt at Rock Springs and Green River (*Casper Tribune-Herald*, November 25, 1934).

On August 17, 1950, there was an intensity IV event reported near Lander. Loose objects rattled, buildings creaked, and a few people reported other objects that were altered or moved by the earthquake (Murphy and others, 1952). On January 12, 1954, there was an intensity II event and on December 13, 1955, there was an intensity IV event near Lander with no damage reported. A M_B 4.3, intensity V event occurred southwest of Lander on February 25, 1963. No damage was reported (*Casper Star-Tribune*, February 26, 1963).

On November 3, 1984, a M_B 5.0, intensity VI event was recorded northwest of Atlantic City. The earthquake, which was felt in Dubois and Casper, was one of the strongest recorded in the southwestern quarter of the State. A number of residents in Lander and Atlantic City reported cracked walls, foundations, and windows (Casper Star-Tribune, November 4, 1984). Concern over the event was widespread in the region.

Sand Draw/Gas Hills Area

The Sand Draw/Gas Hills area between Riverton and Jeffrey City has had a few recorded earthquakes since the early 1970's although little damage has resulted. On April 22, 1973, a M_B 4.8, intensity V event was reported. Dishes were rattled and pictures on walls were disturbed in Jeffrey City (*Casper Star-Tribune*, April 24, 1973). On March 25, 1975, there was a M_B 4.8, intensity III event in the area. A mobile home 35 miles southeast of Riverton was moved an inch off its foundation as a result of the earthquake (*Laramie Daily Boomerang,* March 26, 1975). In 1985, a M_L 4.3, intensity IV event was recorded near Sand Draw. No damage was reported.

Thermopolis Area

Historically, the Thermopolis area has experienced a number of earthquakes with a few causing minor damage. The earliest reported event was on February 13, 1928. No damage was reported with that intensity IV earthquake. On October 11, 1944, however, an intensity IV event did result in some damage. Rocks fell onto the highway through the 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).

On January 27, 1946, there was an intensity IV event and on February 1, 1954, there was an intensity V event in the Thermopolis area. Neither caused any damage. The largest event recorded near Thermopolis occurred on December 8, 1972. The M_B 4.1, intensity V event cracked the ceiling in a new addition to a rest home in Thermopolis (*Laramie Daily Boomerang*, December 9, 1972).

Bighorn Mountains Area

The Bighorn Mountains area includes towns on the lower flanks of the mountains, such as Sheridan, Buffalo, and Tensleep. The earliest record of seismic activity is in the Buffalo area. On October 25, 1922, an intensity II event was reported which was felt in Buffalo and Sheridan. No damage was reported (*Sheridan Post*, October 26, 1922). On November 17, 1925, an intensity V earthquake with an epicenter near Tensleep, was felt from Tensleep to Sheridan. A ranch ten miles west of Sheridan reported that windows rattled and that pictures on walls moved. Near Dome Lake, approximately 20 miles southwest of Sheridan, there was a report of a cabin shaking "like an aspen leaf in the wind" (*Sheridan Post-Enterprise*, November 19, 1925). Another event was reported on November 18, 1925, although no damage was recorded (*Sheridan Post-Enterprise*, November 19, 1925).

On September 6, 1943, an intensity IV event was felt in the Sheridan area although the epicenter was located near Buffalo. Beds and chairs were reported "to sway" in the Sheridan area (*The Casper Tribune-Herald*, September 7, 1943). On April 26, 1953, an intensity IV event was reported in the Sheridan area. Some beds were rocked, dishes were rattled, and some electric wires swayed (Murphy and Cloud, 1955). No damage was reported in a September 19, 1974, M_B 4.4, intensity V event recorded near Tensleep (*Casper Star-Tribune*, September 21, 1974) or a March 24, 1977, intensity IV event reported near Big Horn.

Powder River Basin/Hartville Uplift Area

Very little damage has been attributed to earthquakes in the Powder River Basin area. The earliest reported event in the area occurred on May 1, 1926, near Osage. The intensity IV event was felt by several, and there were reports of dishes shifting and objects moving (Neumann, 1928). On February 25, 1942, an intensity V, event with an epicenter south of Lusk, did not cause any damage (*Casper Tribune-Herald*, February 27, 1942).

On October 3, 1954, an intensity IV earthquake was reported near Guernsey. Although the event was felt from Douglas to Wheatland, no damage was reported. Train traffic between Douglas and Wheatland was halted until it was determined that the tracks were not damaged (*Laramie Republican-Boomerang*, October 4, 1954). On March 28, 1964, there was an intensity V event with an epicenter southeast of Lusk, near the Nebraska state line. That earthquake was primarily felt in western Nebraska with no significant damage reported (*Casper Star-Tribune*, March 29, 1964). On August 22, 1964, there was a M_B 4.5, intensity V earthquake recorded with an epicenter northwest of Lusk. Much of the town was attending a concert in the town's new high school building and they thought that the furnace blew up when the tremor occurred (*Wyoming Star-Tribune*, August 23, 1964). No significant damage was reported.

In the 1970's and 1980's all other events of significance in the Powder River Basin occurred in the vicinity of Gillette and Kaycee. On September 3, 1976, a M_B 4.8, intensity IV event was reported in Kaycee although the epicenter was located between Kaycee and Gillette. No significant damage was reported. On May 29, 1984, a M_B 5.0, intensity V earthquake with an epicenter approximately 20 miles west of Gillette, was felt in Gillette, Sheridan, Casper, Sundance, and Thermopolis (*Casper Star-Tribune*, May 30, 1984). Approximately three months later, on September 8, 1984, a M_B 5.1, intensity V event was located in the same general area. Although the two magnitude V events were among the largest in the Powder River Basin in the last 100 years, little damage was reported.

Casper Area

Two of the earliest recorded earthquakes in Wyoming occurred near Casper (Mokler, 1923). The first was on June 25, 1894, and it had an estimated maximum intensity of V. In residences on Casper Mountain, dishes rattled to the floor and people were thrown from their beds. Water in the Platte River changed from fairly clear to reddish and became thick with mud due to the banks caving in during the earthquake (Mokler, 1923). On November 14, 1897, an even larger event was felt in the area. The intensity VII earthquake, the largest recorded in central and eastern Wyoming, caused considerable damage to a few buildings. As a result of the earthquake, a portion of the Grand Central Hotel was cracked from the first to the third story. The crack was from two to four inches wide. Some of the ceilings in the hotel were also severely cracked. Guests in the hotel ran into the streets without bothering to dress. In another part of Casper, a person that was sitting in a chair was thrown to the floor (Mokler, 1923)

On October 25, 1922, an intensity IV earthquake was reported in the Casper area. The event was felt in Casper, at Salt Creek 50 miles north of Casper, and at Bucknum which is 22 miles west of Casper. Glass was cracked in the windows of a ranch near Bucknum (Mokler, 1923). Dishes were rattled and hanging pictures were disturbed near Salt Creek. No significant damage was reported at Casper (*Casper Daily Tribune*, October 26, 1922). On December 11, 1942, an intensity IV earthquake was recorded north of Casper. Although no damage was reported, the event was felt in Casper, Salt Creek, and Glenrock (*The Casper Tribune-Herald*, December 12, 1942). On August 27, 1948, another intensity IV earthquake was reported in the Casper area. No damage was reported (*The Casper Tribune-Herald*, August 27, 1948).

On January 24, 1954, an intensity IV event near Alcova did not result in any reported damage. One area resident reported that he thought that an intruder in the attic of his house had fallen down (*The Casper Tribune-Herald*, January 24, 1954). On August 19, 1959, an intensity IV earthquake was felt in the Casper area. No significant damage was reported.

Northern Laramie Range Area

There have been a series of earthquakes recorded in the Douglas, Esterbrook, and northern Albany County areas. On April 14, 1947, an intensity V event was felt near La Prele Creek southwest of Douglas. The earthquake was felt by all in a ranch house and by a few outdoors. Windows were rattled, chairs were moved, and buildings shook (Murphy, 1950). On August 22, 1952, an intensity IV earthquake was reported near Esterbrook. While it was felt by several people in the area, it was also reportedly felt 40 miles to the southwest (Murphy and Cloud, 1954). In October, 1952 another small event was reported in the area, with no damage occurring (Murphy and Cloud, 1954).

In the 1980's there were a series of earthquakes in northern Albany County that caused general concern in southeast and central Wyoming. On February 13, 1983, a M_L 4.0, intensity IV event was recorded. The event was felt in Laramie, Casper, Wheatland, and Medicine Bow (*Laramie Daily*

Boomerang, February 15, 1983; *The Wyoming Eagle*, February 14, 1983). No damage was reported. On October 18, 1984, a M_B 5.5, intensity VI earthquake caused considerable concern in Wyoming. The earthquake, with an epicenter located approximately 21 miles south of Esterbrook, was felt in Wyoming, South Dakota, Nebraska, Colorado, Utah, Montana, and Kansas. Stover (1985) reports that cracks were found in the exterior brick walls of the Douglas City Hall and the public school in Medicine Bow. Chimneys were cracked at Casper, Douglas, Guernsey, Lusk, and Rock River, and broken underground pipes were reported from Casper and Shirley Basin. Foundations and exterior walls were cracked at Casper, Guernsey, Hanna, Lusk, McFadden, Rock River, and Shirley Basin. There were a number of aftershocks to the main event with none causing any significant damage. The earthquake was one of the largest felt in eastern Wyoming, surpassed only by the 1897 event near Casper.

<u>Laramie Basin and Vicinity</u>

A number of earthquakes have occurred in the Laramie Basin although none have caused significant damage. The earliest reported event was on January 1, 1898, and it occurred in the Laramie area. The intensity IV event shook buildings, and rattled dishes, windows, and loose objects. A number of people were awakened by the earthquake (*The Daily Boomerang*, January 14, 1898). On September 20, 1931, an intensity IV earthquake was felt in the Laramie area. Windows and dishes rattled, and a few residents ran from their homes (*The Laramie Republican-Boomerang*, September 21, 1931). Another intensity IV event was reported on November 10, 1935. This earthquake, which rattled dishes in Laramie, was also felt in Rock River and Rawlins (*The Laramie Republican-Boomerang*, November 11, 1935).

On January 20, 1954, an intensity V event was reported, with an epicenter thought to be located approximately 12 miles north-northeast of Laramie. Furnishings shifted and windows were rattled at Albany. Small objects were shifted at Jelm, and there were reports of dishes being shaken off tables in Laramie (Murphy and Cloud, 1956). The earthquake was also felt in Centennial, Tie Siding, and Ryan Park. A few days later, on January 23, 1954, an intensity IV event was reported at Jelm. A strong but brief shock was felt, but no damage was reported (Murphy and Cloud, 1956).

On May 22, 1955, an intensity IV earthquake near Jelm and Woods Landing caused considerable concern. Reflecting the fears of the time, one person thought that an atomic bomb had dropped on Denver. A group of fisherman camping near Woods Landing reported that they were rolled around in their tent. Dishes and windows were rattled in many cabins in the Woods Landing area (*The Laramie Republican and Boomerang*, May 23, 1955). On August 6, 1958, an intensity IV earthquake was felt in the same area. Windows were rattled and dishes shook in Foxpark. The earthquake was also felt in Laramie, where no damage occurred (*The Laramie Daily Boomerang*, August 7, 1958). On December 25, 1959, an intensity V earthquake, with an epicenter near Foxpark, was felt in Foxpark and Laramie. Concrete block buildings were cracked slightly at Foxpark (Coffman and others, 1982).

Rawlins/Baggs Area

A few earthquakes have been reported in the Rawlins to Baggs area although none have caused damage. The earliest recorded earthquake occurred on March 10, 1917. The intensity IV event caused some people to run out of their houses (Humphreys, 1917). On January 27, 1976, a M_B 2.3, Intensity V earthquake, with an epicenter north of Rawlins, did not cause any significant damage. A lamp fell from a table, and pictures fell from a wall (Coffman and others, 1982). On March 3, 1977, a M_B 4.2, Intensity V earthquake was recorded 30 miles south of Rawlins. The earthquake was felt in southern Carbon County, and there were reports of rattled doors and dishes (*The Laramie Daily Boomerang*, March 6, 1977). A plant fell from a window sill in Slater, Colorado (Coffman and others, 1982).

FUTURE EARTHQUAKE POTENTIAL

Wyoming has the potential to have damaging earthquakes in the future. A number of active faults with a surficial expression have been identified in the State with many being capable of generating magnitude 6.5 to 7.5 earthquakes. Based upon the *National Earthquake Hazard Reduction Program Recommended Provisions for the Development of Seismic Regulations for New Buildings* (Building Seismic Safety Council, 1988), the U.S. Geological Survey and the Federal Emergency Management Agency (Personal communications, 1990) have classified Wyoming as a very high seismic-hazard state. Alaska, California, Idaho, Montana, and Nevada are also classified as very high seismic-hazard states.

ACTIVE FAULTS WITH KNOWN AND SUSPECTED QUATERNARY OFFSET

In this report, the Quaternary Period is considered to extend from 2,000,000 years before present to the present. The Pleistocene epoch is considered to extend from 2,000,000 years to 10,000 years before present, and the Holocene is considered to extend from 10,000 years before present to the present. The late Quaternary refers to the late Pleistocene to early Holocene.

Wyoming has a number of known and suspected active faults that have been identified (Figure 2; Plate 1). The faults shown on Plate 1 are compiled from Witkind (1975), Gilbert and others (1983), Gibbons and Dickey (1983), Geomatrix (1988a), Geomatrix (1988b), Love (1961, 1973, 1974a, 1974b, 1975), Love and Taylor (1962), Ruppel (1972), U.S. Geological Survey (1972), Love and Keefer (1975), Rubey (1973), and Love and Christiansen (1985). Witkind (1975) compiled all available information on faults in Wyoming that have been recurrently active during the last 20 million years, with an emphasis on faults that have been active during the Quarternary. Gibbons and Dickey (1983) mapped, and in a few cases, dated Quaternary age faults in portions of Lincoln and Uinta Counties in southwestern Wyoming. Researchers from Geomatrix (1988a, b) analyzed aerial photography and conducted field investigations in the Granite Mountain area as well as along the southern flank of the Owl Creek uplift. Love (1961) mapped and described active faults in north-central, northeast, and south-central Yellowstone National Park. Love (1974b) and Love and Keefer (1975) mapped active faults in southern Yellowstone National Park. Ruppel (1972) mapped and described active faults in the northwestern portion of Yellowstone National Park. The U.S. Geological Survey (1972) prepared a geologic map for Yellowstone National Park. Faults that broke Quaternary age deposits on that map were included on Plate 1, Figure 2, and Figure 3. Love (1961, 1973, 1974a, 1975), Gilbert and others (1983), and Love and Taylor (1962) mapped active faults in the Jackson Hole area. Rubey mapped an active fault near the Greys River in Lincoln County.

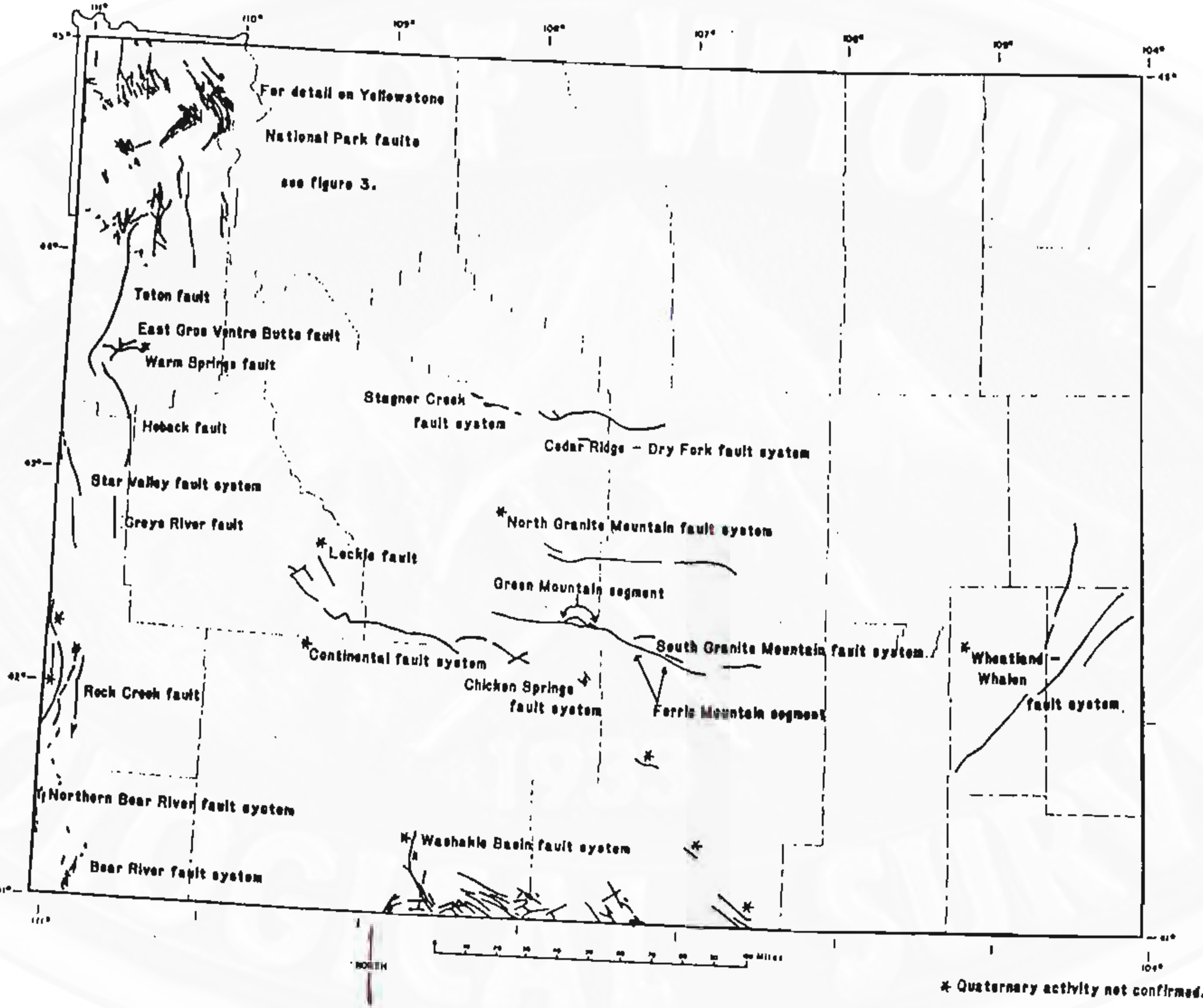

Figure 2. Suspected active faults in Wyoming.

Yellowstone National Park

Exact dates of movement have not been generated for fault systems in Yellowstone National Park (YNP). Recurrence intervals or estimates of maximum credible earthquakes have also not been calculated for active faults in the park. There are a number of fault systems, however, that have shown activity in the Quaternary era (Figure 3).

Ruppel (1972) described active faults in northern YNP. Faults with active segments bound the eastern and western flanks of the Gallatin Range. The main movement on the East Gallatin fault occurred before the eruption of the Pleistocene age rhyolites to the south of the Gallatin Range although a very slight offset of the rhyolites has been observed. Ruppel (1972) also noted that in the vicinity of the Gallatin Range, glacial deposits were cut by the fault. The U.S. Geological Survey (1972) shows fault scarps breaking a significant expanse of Quaternary age deposits from Mount Holmes in the south to the northern park boundary.

The West Gallatin fault also had most of its movement occurring before the eruption of the Pleistocene age rhyolites in the park although Ruppel (1972) observed that the rhyolites have been offset "a few tens of feet, if at all". Distinct fault scarps breaking Quaternary deposits are shown west of Crowfoot Ridge by the U.S. Geological Survey (1972).

Near Mammoth Hot Springs, there are a series of faults that have exhibited Quaternary age displacement. The Mammoth fault, which is shown by Ruppel (1972) to exhibit Quaternary displacement, has four faults directly to the east that have broken hot spring deposits and landslides in the area (Ruppel, 1972). Between the Mammoth fault and Sepulcher Mountain to the west, there

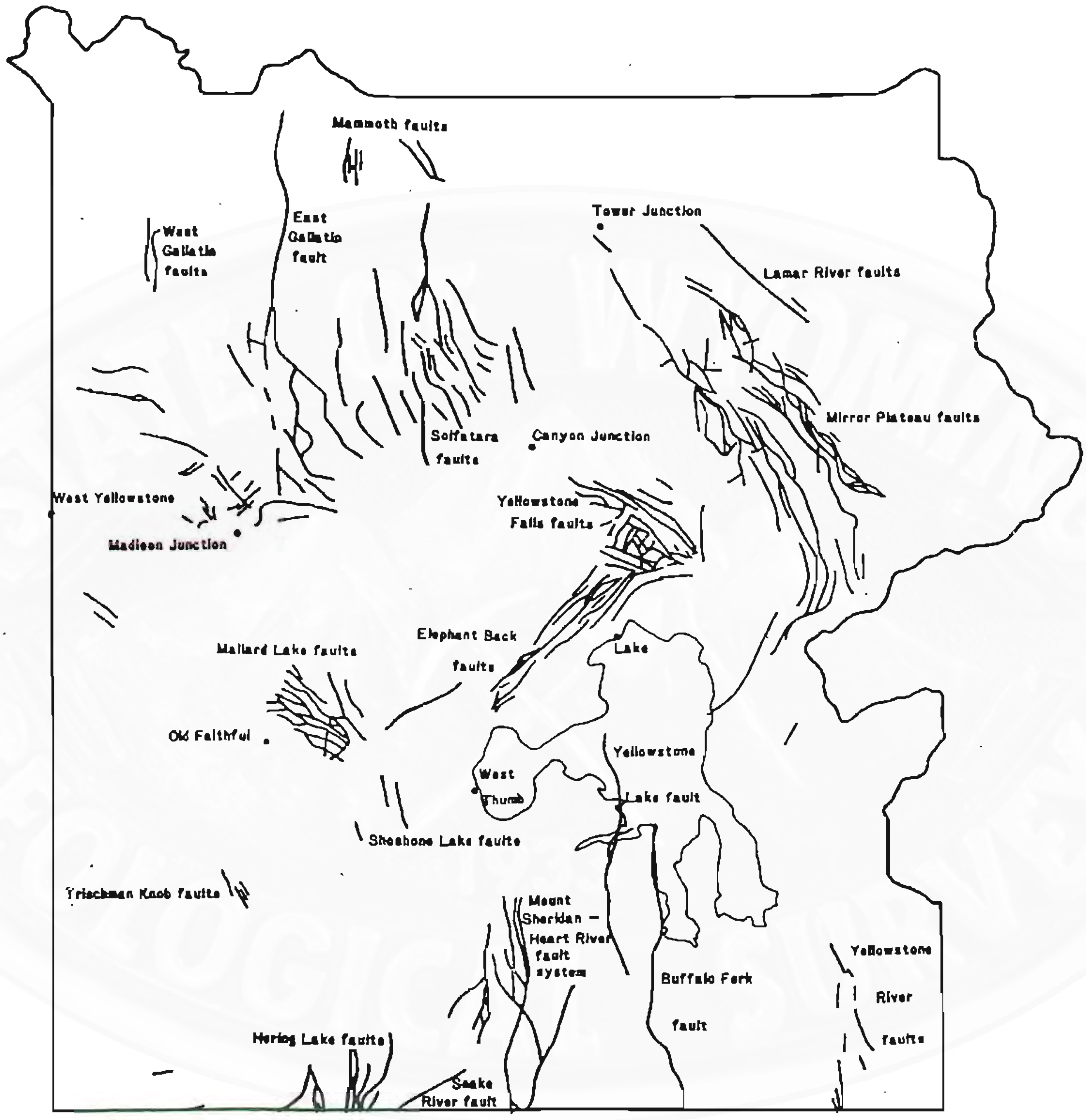

Figure 3. Active faults in Yellowstone National Park.

are also a number of fault traces that have broken the Huckleberry Ridge Tuff or Quaternary age deposits (U.S. Geological Survey, 1972).

Love (1961) described a number of extensive fault systems in the north-central, northeastern, and southern portions of the park. The Solfatara fault system is present north and northwest of the Solfatara Plateau, and is composed of a series of faults, some of which are up to ten miles in length. Maximum Quaternary displacement is approximately 200 feet, with displacements most commonly in the 40- to 140-foot range (Love, 1961). The U.S. Geological Survey (1972) shows a number of faults in the Solfatara fault system breaking the Quaternary-aged Lava Creek Tuff. To the east, along the Mirror Plateau, there are a series of northwest-trending faults. Many of the faults cut the Quaternary-aged Lava Creek Tuff (U.S. Geological Survey, 1962), as well as ice-scoured surfaces. Displacements on the ice-scoured surfaces range from 20 to 350 feet (Love, 1961). Northeast of the Mirror Plateau, along the Lamar River Valley between Lamar Canyon and Cache Creek, there are a few active fault traces that have shown significant Quaternary movement. The Lamar fault, located southwest of the Lamar River, is over nine miles long. Ice-scoured surfaces cut by the fault indicate that as much as 1,000 feet of movement may have occurred on the fault in the Quaternary (Love, 1961). The U.S. Geological Survey (1972) has mapped another active fault segment northeast of the Lamar River between Cache Creek and Soda Butte Creek. The segment, which is approximately one mile long, breaks Quaternary deposits.

Love (1961) described a series of active faults in an area east of the Yellowstone River, south of Sour Creek, and north of Pelican Creek. Faults in that area, named the Yellowstone Falls fault system by Love (1961), are up to nine miles long. The faults cut the Quaternary-aged Lava Creek Tuff (U.S. Geological Survey, 1972). Love (1961) reports up to 300 feet of Quaternary displacement along several of the faults in the system. In some areas, over 200 feet of post-glacial movement has been inferred. To the west of the Yellowstone Falls fault system there are a series of northeast-trending faults in the vicinity of Elephant Back Mountain. The faults break the Quaternary-aged Elephant Back flow, and in a few localities break Quaternary deposits (U.S. Geological Survey, 1972). West of the Elephant Back fault system, in the vicinity of Mallard Lake, there are a series of faults that break the Quaternary-aged Mallard Lake Member of the Plateau Rhyolite. The younger Elephant Back flow to the north is apparently not broken by the Mallard Lake faults (U.S. Geological Survey, 1972).

There are also a number of fault systems that exhibit evidence of Quaternary activity in the southern portions of YNP. West of Shoshone Lake, near Trischman Knob, there are a few northwest-trending faults that break the Quaternary-aged Bechler River flow (U.S. Geological Survey, 1972). Along the northeast portions of Shoshone Lake, there are also a few faults that break the Quaternary-aged Spring Creek flow, Dry Creek flow, and the Shoshone Lake Tuff Member of the Plateau Rhyolite. To the east, there are two fault systems found in the southern portions of Yellowstone Lake. One of the faults, which trends from Dot Island in Yellowstone Lake to Overlook Mountain to the south, breaks lacustrine deposits associated with Yellowstone Lake as well as portions of the Quaternary-aged Lava Creek Tuff and Mount Jackson Rhyolite (U.S. Geological Survey, 1972). The Buffalo Fork fault begins on the west side of the South Arm of Yellowstone Lake, and extends southward to the vicinity of Gravel Mountain in Teton National Forest (Love and Christiansen, 1985). The fault system is a reverse fault along which later normal faulting occurred. The Quaternary-aged Lava Creek Tuff has been broken by normal movement along segments of the fault near Channel Mountain in YNP (U.S. Geological Survey, 1972). East of the Buffalo Fork fault, and along the east and west valley margins of the Yellowstone River, there are a series of Quaternary-age faults that in part define the Yellowstone River Valley. Faults that break Quaternary deposits and alluvium are present along the east valley margin from Cabin Creek in the north to Cliff Creek in the south. The faults are normal, with the western block (Yellowstone River Valley) downdropped. Faults that break Quaternary deposits and alluvium are also present along the west valley margin from Badger Creek in the north to the park boundary in the south. The faults along the west valley margin are normal, with the eastern block (Yellowstone River Valley) downdropped.

Southwest of Yellowstone Lake, from the Heart Lake Geyser Basin south to the vicinity of Bobcat Ridge in the Bridger-Teton National Forest, there are a complex of faults that, for the purposes of this report, are called the Mount Sheridan-Heart River fault system. The system, composed of faults that roughly trend north-south, breaks numerous deposits of the Huckleberry Ridge Tuff in the Mount Sheridan-Red Mountain area, along the Heart River, and in the vicinity of Bobcat Ridge south of YNP (U.S. Geological Survey, 1972; Love, 1974b; Love and Keefer, 1975). The top of the Huckleberry Ridge Tuff marks the Pleistocene-Pliocene boundary (Love and Christiansen, 1985). The Snake River fault system has also offset the Huckleberry Ridge Tuff along portions of the Snake River (Love, personal communication, 1990). The Snake River fault extends northward from the Teton fault, with the juncture being present west of Steamboat Mountain (Love, 1974a). West of the Snake River fault, there are a series of faults present in the vicinity and east of Hering Lake. Those faults extend from that area south across the YNP boundary, and they appear to be an extension of the Teton fault system to the south. The faults break the Huckleberry Ridge Tuff and Lewis Canyon Rhyolite within YNP (U.S. Geological

Survey, 1972) and the Lewis Canyon Rhyolite west of Flagg Ranch (Love, 1974a). Love (1961) described up to 200 feet of displacement on portions of that fault system.

Teton Fault

The 44 mile-long-Teton fault extends along the eastern side of the Teton Range near Jackson, Wyoming. Historically, no significant earthquake epicenters have been associated with the Teton fault. In fact, many researchers consider the Teton fault to be a seismic gap in the Intermountain Seismic Belt. Historic earthquake epicenters shown on Plate 1 indicate that there has been little or no significant seismic activity on the fault in over 100 years.

Three segments of the fault have been defined-northern, central, and southern (Smith and others, 1990a; Susong and others, 1987). Quaternary fault scarps, up to 157 feet high, are present along significant portions of the fault system (Smith and others, 1990a). Smith and others (1990a) have found that there is an average of 33 feet of Quaternary surface offset observable along the northern and southern portions of the fault with a maximum of 98 feet observable along the central portion. Between 6,900 and 9,200 feet of total Quaternary displacement has occurred on the Teton fault (Gilbert and others, 1983).

In 1989, the University of Utah excavated a portion of the southern segment of the Teton fault near the mouth of Granite Canyon. What may be a single event with a displacement of approximately 13 feet was documented (Byrd and Smith, 1990b). Radiocarbon dates of approximately 7,200 years are associated with the event. If the displacement represents one event, a magnitude 7.2-7.5 earthquake would have resulted. If, however, the 13-foot displacement represents two events, two magnitude 6.3-6.9 events would have resulted (Smith and others, 1990b). Gilbert and others (1983) estimated a maximum recurrence interval of 3,600 years for magnitude 7.5 events on the Teton fault system while Doser and Smith (1983) estimated a recurrence interval of 800 to 1,800 years for a similar event. Combining the two sets of data results in a range of 800-3,600 years for the recurrence interval for a magnitude 7.5 event on the Teton fault. A maximum credible earthquake of magnitude 7.5 has been postulated for the fault system (Gilbert and others, 1983). Based upon the data published to date, it appears that the Teton fault may be at or beyond the expected return for a large, magnitude 7.5 event. Smith and others (1990c) suggest that as many as ten magnitude 7.0 or five magnitude 7.5 events may have occurred along the middle segment of the Teton fault in the last 15,000 years.

Jackson Hole Faults

A number of active faults have been described in the Jackson Hole area. The faults are located near East Gros Ventre Butte on the Flat Creek fan area, on a plateau south of Blacktail Butte, and near Mount Reid and Pilgrim Mountain. Other active fault systems may be present in the area, but are not described in this report.

Love and Taylor (1962) described the East Gros Ventre Butte fault system, which trends north-northeast from Jackson, Wyoming, past the Jackson National Fish Hatchery to Peterson Springs, approximately five miles in distance. From Peterson Springs, the fault system trends east-northeast along the northern edge of the Flat Creek alluvial fan for approximately five miles (Love, 1985). Love and Taylor (1962) estimated that 500 feet of Quaternary displacement occurred along the fault segment from Jackson to Peterson

Springs with the east side down. Near the Fish Hatchery, a scarp with approximately 150 feet of displacement was inferred by Love and Taylor (1962). Love and Love (1983) estimated that the 150 feet of displacement has occurred in the last 12,000 years Love (1975) indicated that the fault system offsets loess, glacial, and alluvial fan deposits east of Peterson Springs. Gastropods from several loess localities have a C-14 age ranging from 13,000 to 19,000 years before present (Love, 1975).

Gilbert and others (1983) described a series of right stepping, en echelon scarps in the Flat Creek fan, east and south of the East Gros Ventre Butte fault system. The northeast trending scarps are present in Sections 5, 6, and 7, T41N, R115W, as well as in Section 32, T42N, R115W, and in Section 12, T41N, R116W, . A large alluvial fan surface formed by Flat Creek is offset by the scarps. Vertical surface displacement along the main scarp is 2 to 3 feet, down to the west. The scarps, while believed to be fault controlled, could have formed as a result of compaction of the alluvial fan materials during an earthquake.

Love (1975) and Love and Love (1988) mapped a series of suspected active faults in the Blacktail Butte area. Subsequent field mapping in the area by Gilbert and others (1983) defined a series of north-trending, en echelon scarps in a relatively flat plateau south of Blacktail Butte. The faults, which are down to the west, are located in Sections 7 and 18, T42N, R115W. Vertical surface displacement across the main scarp is 2 feet (Gilbert and others, 1983).

Love (1973), Love and Reed (1973), and Love (1974a) mapped a series of faults that offset the Huckleberry Ridge Tuff in the northern portion of Jackson Hole. Love and Reed (1973) mapped a short east-west trending fault on the southern flank of Mount Reid. Love (1973) and Love (1974a) mapped a series of north-south trending faults south of Bailey Meadows near the boundary separating Grand Teton National Park and Teton National Forest. Love (1973) also mapped a series of east-west trending faults that offset the Huckleberry Ridge Tuff on Pilgrim Mountain. Gilbert and others (1983) estimated that vertical displacement of the tuff by the active fault systems present between Mount Reid on Pilgrim Mountain ranges from 100 to 200 feet.

Hoback Fault

The Hoback fault extends southward from the town of Jackson for approximately 35 miles. Love and Montagne (1956) described an area southeast of Jackson and northeast of the confluence of Flat Creek and Game Creek where loess and silt were displaced as much as 50 feet by the Hoback fault. Glacial debris and colluvium were also broken by the fault in the same vicinity (Love and Love, 1978). Gilbert and others (1983) estimated a maximum credible earthquake of magnitude 7.5 with a maximum recurrence interval of 71,000 years for such an event. They noted that geologic evidence suggests a substantially shorter return period. Doser and Smith (1983) suggest a return period of 1550 to 2360 years for a magnitude 7.5 event.

Star Valley/Grand Valley Fault

The Star Valley fault is part of an 85-mile-long fault complex. The Star Valley fault bounds the eastern side of the Star Valley in Lincoln County, Wyoming. The portion of the fault complex found in the Grand and Swan Valleys in Idaho and Wyoming (Anders and others, 1990) is called the Grand Valley fault. The Star Valley fault has been subdivided into two segments, the northern Star Valley fault and the southern Star Valley fault (McCalpin and others, 1990; Piety and others, 1986). Based upon specific geomorphic features present along both fault segments, Piety and others (1986) determined that latest Quaternary displacement rates are higher on the southern segment than the northern segment.

The southern Star Valley fault has Holocene offsets intermittently observable from Cottonwood Creek in the south to an area north of Grover, Wyoming, to the north (Piety and others, 1986). The northern Star Valley fault has a few Holocene-late Pleistocene offsets present between Grover, Wyoming, in the south and Prater Canyon in the north (Piety and others, 1986). No offsets of Quaternary deposits are found north of Prater Canyon although the northern portion of the Star Valley fault extends to the vicinity of the Greys River.

Measured vertical surface displacements on the southern Star Valley fault are 37.7 feet north of Dry Creek and 16.4 feet south of Dry Creek. Maximum vertical displacements of 36.1 feet and 29.5 feet are found at Swift Creek and Phillips Creek, respectively (McCalpin and others, 1990; Piety and others, 1986). Along the northern Star Valley fault, vertical surface displacements have been determined for scarps at Willow Creek and near Prater Canyon. At Willow Creek, late Quaternary-Holocene displacements have a maximum vertical offset of 38 feet (McCalpin and others, 1990). Near Prater Canyon, late Pleistocene-age displacements have a maximum vertical offset of 20.6 feet (Piety and others, 1986). Many of the measured scarps along the entire Star Valley fault are thought to represent multiple events. For example, three faulting events may have occurred since the late Pleistocene-early Holocene at Swift Creek (McCalpin, 1990). Three 10- to 13-foot events may have formed the larger 36.1-foot scarp at that locality.

A maximum credible earthquake of magnitude 7.5 with a recurrence interval of 5,000 to 7,000 years was assigned to a portion of the Star Valley fault by Piety and others (1986). They assumed a maximum latest Quaternary rupture length of approximately 27 miles. McCalpin and others (1990), however, have suggested that the 27-mile rupture length may generate a maximum event of magnitude 7.2. Based upon a recent excavation of the fault along Swift Creek, near Afton, McCalpin (1990) has estimated a maximum credible earthquake of magnitude 7.3 with a recurrence interval of 2,550-6,000 years. Approximately 5,500 years (radiocarbon age) has elapsed since the latest event on the fault system at the Afton locality. Based upon this evidence, the Star Valley fault system is near the maximum limit for the recurrence interval assigned to the system.

Greys River Fault

Rubey (1973) identified a Quarternary age fault east of the Greys River in Lincoln County with a northern terminus in Section 10, T33N, R116W. Pierce (1990) postulated that the fault has a lesser-Holocene-fault-length of approximately 25 miles. Aerial photographs examined by the Geological Survey of Wyoming in 1990 indicated that the north-south trending fault, hereafter referred to as the Greys River fault, has a northern segment that minimally extends from an area 0.5 mile south of the Sheep Creek south to the vicinity of South Twin Creek. This segment of the fault, which is located from 1 to 1.5 miles east of the Greys River, appears to offset alluvial deposits along Sheep Creek, Buck Creek, and North Twin Creek. McCalpin (Utah State University, personal communication, 1990) indicates that approximately 26 feet of offset, representing multiple events, has occurred in alluvial deposits along Sheep Creek.

Aerial photographs examined by the Geological Survey of Wyoming in 1991 indicate that alluvium may also be offset farther to the south. Specifically, alluvium may be offset between Broad Canyon to the north and Marten Creek to the south. Alluvium may also be offset in an area located between 2 and 2.5

miles north of the Corral Creek Guard Station and 0.5 mile east of the confluence of North Corral Creek and Greys River. Further field investigation is required in order to determine the full extent of Quaternary-age offset on the fault system.

Rock Creek Fault

The Rock Creek fault is a north-trending normal fault located approximately 15 miles west of Kemmerer, Wyoming, near Fossil Butte National Monument, and east of the southerly flowing Rock Creek. The fault, which has scarps present along 24 miles of its length, was first described by Rubey and others (1975) as offsetting alluvial fans and gravel deposits by as much as 50 feet. Chambers (1988) profiled Holocene fault scarps at seven localities along the fault, from which he inferred an age of from 2,000 to 6,000 years before present for the most recent event. Carbon 14 age dating of a charcoal sample from a buried soil horizon at Cook Canyon provides a maximum age for the most recent faulting event of approximately 4,760 years (Chambers, 1988). Chambers also estimated that the magnitude of the most recent seismic event on the fault was between 6.9 and 7.2 ± 1.2 ML. He also estimated that if a magnitude 7.0 earthquake occurred on the Rock Creek fault, it would be felt as an intensity IX event at Evanston, Kemmerer, and Cokeville, and an intensity VI event at Jackson Lake and Flaming Gorge Reservoir.

Bear River Fault System

The Bear River fault system, named by West (1984), was first mapped by Gibbons and Dickey (1983). Located approximately 12 miles southeast of

Evanston, Wyoming, the system extends northward from the North Flank fault of the Uinta Mountains in Utah to Aspen Creek in Wyoming. The faults in Wyoming are primarily located on the east side of Hilliard Flat.

The fault system is composed of a series of north-northwest to north-northeast trending scarps arranged in a right en echelon pattern. West (1989) trenched ten faults in or near the Bear River fault system. He determined net vertical tectonic displacements for those faults through analysis of scarp profiles, measurement of stratigraphic offsets in trench exposures, and interpretation of colluvial wedge stratigraphy. In Wyoming, West investigated faults near Sulphur Creek (Section 35, T13N, R119W), Lester Ranch (Section 24, T13N, R119W), Austin Reservoir (Section 36, T13N, R119W), La Chapelle Creek (Sections 18 and 19, T13N, R118W), and Martin Ranch (western portion of T13N, R119W). In Utah, West investigated faults near Big Burn (T2N, R10E), Little Burn (T2N, R10E), and Elizabeth Ridge (T2N, R11E).

West (1989) defined two distinct episodes of Holocene surface rupture in the fault system with radiocarbon dates of 4,120 ± 510 and 2,320 ± 860 years before present. The movements occurred in Pleistocene to Holocene till, outwash, and alluvium, as well as in the Wasatch Formation. West combined data derived from scarp profile measurements, stratigraphic offset measurements, and colluvial wedge analysis in order to determine mean vertical tectonic displacement per event. Mean vertical tectonic displacements per event are 6.9 feet at La Chapelle Creek, 15.4 feet (maximum) at Lester Ranch, 4.5 feet at Austin Reservoir, 16.4 feet (maximum) at Sulphur Creek, 16.7 feet at Big Burn, and 19.7 feet (maximum) at Little Burn (West, 1989). Multiple scarp profiles were constructed at Lester Ranch, Sulphur Creek, and Little Burn. The mean vertical tectonic displacements described above represent the maximum for all the profiles constructed at each of those sites. A single event was documented by West at Martin Ranch. That site has a mean net vertical tectonic displacement of 4.6 feet (West, 1989).

West (1989) calculated total net vertical tectonic displacements from scarp profile data at a number of sites. The total net vertical displacements were determined to be 16.7 feet at La Chapelle Creek, 37 feet at Lester Ranch, 28.2 feet at Sulphur Creek, 41.7 feet at Big Burn, and 23.6 feet at Little Burn (West, 1989). The figures used above represent the maximum of a range of values generated by West. The values for total net vertical tectonic displacement do not always directly correlate with the values for mean vertical tectonic displacement per event. Total net vertical tectonic displacements are derived from scarp profile data. Mean vertical tectonic displacements per event are derived from a combination of scarp profile, stratigraphic offset, and colluvial wedge analysis data.

A maximum credible earthquake of magnitude 7.5 has been estimated for the Bear River fault system. Surface ruptures extending over distances of from 21 to 25 miles have been assumed for the system (West, 1989). A minimum recurrence interval of 1,800 years can be inferred for the Bear River fault system. Since 2,320± years have elapsed since the last event, the system may be at or beyond the expected return for a large event.

Northern Bear River Fault System

Gibbons and Dickey (1983) mapped a series of faults that extend north of Evanston, Wyoming, to the vicinity of the Woodruff Narrows Reservoir. For the purposes of this report, the faults, which occur along the margins of the Bear River Valley, are considered to be in what is called the Northern Bear River fault system.

Southeast of the Woodruff Narrows Reservoir and east of the Bear River, there is a northerly trending fault approximately two miles long that crosses the floor of Whitney Canyon. Alluvium has been offset by the fault which is downthrown to the west. One post-fault sample and two pre-fault samples were radiocarbon dated in order to estimate dates of the last movement on the fault. The post-fault sample was dated at 1,260 ± 70 years, and the pre-fault samples were dated at 2,360 ± 60 years and 1,400 ± 300 years before present (Gibbons and Dickey, 1983). Gibbons and Dickey (1983) estimated that last movement on the Whitney Canyon fault occurred between 1,200 and 2,400 years ago.

Other fault traces identified by Gibbons and Dickey (1983) are west of the Bear River in T15N and T16N, R121W. The faults are downthrown to the east, and offset erosion surfaces of probable Quaternary age (Gibbons and Dickey, 1983).

Stagner Creek Fault System

Geomatrix Consultants, Inc. (1988a) investigated the Stagner Creek fault which trends roughly east-west in the vicinity of Boysen Reservoir on the south flank of the Owl Creek uplift. The maximum length of the fault is 24 miles, with Quaternary displacement found along a 17-mile segment of the fault (Geomatrix, 1988a). Holocene to late Pleistocene surfaces that were offset in the Birdseye Creek and Jewell Creek areas, were examined in some detail. Multiple events were suggested for some localities. Based upon the studies done in those areas, Geomatrix (1988a) has suggested an average displacement of over 1.5 feet per event with an average recurrence interval of between 8,000 to 20,000 years. A surface with an estimated age of 1,000 to 7,000 years in the Birdseye Creek area has not been offset. Geomatrix (1988a) estimated a maximum credible earthquake of magnitude 6.75 for the Stagner Creek fault system.

Cedar Ridge/Dry Fork Fault Systems

The Cedar Ridge/Dry Fork fault system, located along the south flank of the Bridger and Bighorn Mountains was investigated by Geomatrix (1988a). The Cedar Ridge/Dry Fork fault system is approximately 50 miles long. Geomatrix (1988a) investigated three sites along the fault system, finding one location with Pleistocene-age movement (NE Section 10, T39N, R92W.). Another of their locations (SW Section 10, T39N, R85W) has a 6.5-foot high, 1,300-foot-long scarp present, but a lack of sufficient surficial materials or Quaternary surfaces prevented a determination of possible Quaternary displacement. The scarp at a third locality (Sections 29 and 32, T39N, R88W) was reportedly due to differential erosion (Geomatrix, 1988a).

South Granite Mountain Fault System

The South Granite Mountain fault system trends west-northwest along the northern flanks of the Seminoe Mountains, Ferris Mountains, Green Mountain, and Crooks Mountain. The entire fault system is approximately 85 miles long and has been divided into five segments by Geomatrix (1988b). The segments, from east to west, are the Seminoe Mountain segment, the Ferris Mountain segment, the Muddy Gap segment, the Green Mountain segment, and the Crooks Mountain segment. Geomatrix (1988b) investigated the South Granite Mountain system in some detail and reported considerable late

Pleistocene to Holocene displacement in the Green Mountain and Ferris Mountain areas, and minor Quaternary displacement in the Muddy Gap area.

The Ferris Mountain segment is approximately 11 miles long and is defined by Sand Creek Canyon on the east to Cherry Creek on the west (Geomatrix, 1988b). The segment is present on the north flank of the Ferris Mountains. Total vertical surface displacements range from 3.25 to 20 feet, and scarp heights range from 9.5 to 40 feet among the scarps that were profiled. Multiple events are represented by those offsets. Trench analyses indicate approximately 1.5 feet of vertical offset per event has occurred in the late Quaternary. A maximum credible earthquake of magnitude 6.5-6.75 with a recurrence interval of 5,000 to 13,000 years was assigned to the Ferris Mountain segment by Geomatrix (1988b).

The Muddy Gap segment is approximately 14 miles long and is present on the northern flanks of the Red Hills and the western portion of the Ferris Mountains (Geomatrix, 1988b). The eastern boundary of the segment is Cherry Creek and the western boundary is the eastern edge of Green Mountain. Geomatrix (1988b) describes a series of low, discontinuous scarps along the eastern portion of the segment.

The Green Mountain segment is 15 miles long and extends from Willow Creek on the east to Crooks Creek on the west along the north flank of Green Mountain (Geomatrix, 1988b). Total vertical surface displacements are from 13 to over 67 feet, and scarp heights range from 22 to 86 feet among the scarps that were profiled. Additional vertical surface displacements of 1.5 to 3.25 feet were noted on scarps that were not profiled. Multiple events are represented by the majority of the offsets, which have occurred in late Quaternary deposits. A maximum credible earthquake of magnitude 6.75 with a recurrence interval of

2,000 to 6,000 years has been suggested for the Green Mountain segment (Geomatrix, 1988b).

Chicken Springs Fault System

The Chicken Springs fault system is present in the Red Desert, approximately 10 miles southwest of Bairoil, Wyoming, and 15 miles south of Green Mountain. The fault system was briefly investigated in 1987 by personnel from the Geological Survey of Wyoming and the Department of Geology and Geophysics at the University of Wyoming. Displaced soil horizons and alluvium were observed as were multiple east-west trending scarps. At one locality, an abandoned stream channel was exposed on the upthrown (northern) block of a prominent fault trending east-west. No evidence of the north-south trending stream channel was found on the downthrown (southern) block. Due to the features observed, the fault is considered to be Holocene in age. Additional research is required in order to confirm the age of faulting.

FAULTS RECURRENTLY ACTIVE OVER LAST 20 MILLION YEARS

A number of the fault systems shown on Plate 1 and Figure 2 have been recurrently active over the last 20 million years, but have shown no evidence or poorly-documented evidence of activity in the Quaternary. Those fault systems are the Continental fault system, the North Granite Mountain fault system, the Leckie fault, the Washakie Basin fault system, and the Wheatland-Whalen fault system as well as a number of unnamed faults (Figure 2).

The Continental fault is located along the southern flank of the Wind River Mountains. Geomatrix (1988a) investigated a prominent lineament along the Continental fault in the vicinity of Pacific Creek, North Pacific Creek, and Mitchell Creek. They reported that no evidence of late Quaternary offset was observed, and they concluded that the lineament was a fault-line scarp. Zeller and Stephens (1969) report that one high-level terrace appeared to be displaced across the fault, but detailed descriptions and analysis were lacking. Anders and LaForge (1983) investigated the fault as part of a seismotectonic study of the Big Sandy and Eden Dams and reported no evidence of Quaternary movement. In fact, they reported that no evidence of post-Miocene fault movements were observed.

Witkind (1975) reports that the Washakie Basin fault system has been recurrently active over the last 20 million years, but he did not suggest Quaternary activity. As part of an investigation of the proposed Little Sandstone Dam and Reservoir north of Savery, Wyoming, a few fault traces along Savery Creek near the proposed dam site were investigated by the Geological Survey of Wyoming (Case and Ver Ploeg, 1986). No evidence for Quaternary movements were observed in the study area. Detailed investigations on the majority of the faults in the Washakie Basin fault system are lacking.

Geomatrix (1988a) investigated what they named the Leckie fault, which is located north of the northwest portion of the Continental fault, near the town of Leckie. Richmond (1983) noted that a Tertiary-age boulder fanglomerate west of Leckie was displaced by normal faults. He suspected that some of the faults may have been active in the Quaternary. Geomatrix (1988a) reported that the fault trace was covered by undisturbed glacial deposits of probable late Pleistocene (Pinedale) age in Section 31, T31N, R105W. Geomatrix (1988a) also reported no offset or diplacement of latest Pleistocene or Holocene colluvium along the fault trace. Additional investigations are needed before Quaternary displacement can be ruled out on this fault system.

The North Granite mountain fault system is located along the northern margin of the Granite Mountains. Witkind (1975) suggested that the fault has been recurrently active over the last 20 million years, but he did not suggest Quaternary activity. Geomatrix (1988b) investigated the fault and reported finding no evidence for Quaternary activity. Quaternary surfaces were not found to be offset.

The Wheatland-Whalen fault system is a southwest to northeast trending series of normal faults that extend from the Laramie Range in southwestern Platte County, Wyoming, to the northeastern corner of Goshen County, Wyoming. McGrew (1961) stated that primary faulting on the system occurred in the late Miocene or Pliocene with minor faulting continuing into the late Quaternary. In 1985, the Earth Technology Corporation (1986) investigated the system for the U.S. Air Force. Aerial reconnaissance and field investigations did not reveal evidence of Quaternary displacement on the fault system. Scarps present in the area were identified as fault-line scarps resulting from differential erosion along the zone of faulting, and no offset was observed in Quaternary terraces that overlie the fault trace (Earth Technology Corporation, 1986). This conclusion is supported by Witkind (1975), who classified the fault system as being recurrently active over the last 20 million years, but did not suggest Quaternary activity.

QUATERNARY SCARPS RELATED TO FAULTING OR EROSION

There are several scarps described in the Jackson Hole area that may be either Quaternary faults or erosional features. Those scarps are located near Blacktail Butte, on Antelope Flats, along Spread Creek, and near the Potholes. Additional investigation, including trenching, may be required in order to definitively determine the origin of the above scarps. There are other poorly documented scarps in the Jackson Hole area and the rest of the State that are not described in this report.

Love (1975) and Love and Love (1988) mapped an apparent 5.5-mile-long active fault trace that forms a distinctive scarp along the western margin of Blacktail Butte. The suspected fault serves as a contact between glacial outwash gravel and loess to the east and terrace gravels to the west. (Gilbert and others (1983), however, postulated that the scarp strongly resembles other river-cut terraces in the area. The Geological Survey of Wyoming examined aerial photographs of the area in 1991. The scarp did not exhibit characteristics similar to other well-defined active fault scarps in the region. The possibilty of Quaternary faulting cannot be eliminated or confirmed without additional field and geophysical investigations.

Gilbert and others (1983) mapped a series of scarps on the Antelope Flats outwash in Section 34, T44N, R115W, and Sections 3 and 10, T43N, R115 W. Although the scarps were profiled in four areas, no displacement of the outwash surface was observed. Gilbert and others (1983) concluded that the scarps are of tectonic origin, but may have formed as a result of dynamic consolidation of deposits during an earthquake. The Geological Survey of Wyoming examined aerial photographs of the area in 1991. The scarps were not distinctive enough on photographs to assign a fault-related origin. Further field investigation, including trenching, is necessary to make a definitive determination.

Love and Love (1983) described a markedly linear scarp north of Spread Creek as being a Quaternary fault. The scarp, which is present in Sections 9, 10, 11, and 12, T44N, R114W, forms the southern margin of what has been informally called Spread Creek Hill (Gilbert and others, 1983). While Gilbert and others (1983) suggest that the scarp may be fault-related, they are uncertain as to the age of movement. A series of short, hanging valleys originate at the crest of Spread Creek Hill and terminate approximately halfway down the scarp. Love and Love (1983) postulate that the hanging valleys represent two episodes of Quaternary-age movement. Gilbert and others (1983) postulate that the hanging valleys may be related to stagnant ice to the south during Late Pleistocene glaciation. They also suggest that if the fault was active in the Holocene, the rate of displacement would be comparable to or exceed that of the Teton fault, which may not be credible for such a short fault. Additional investgation is required on the scarp to determine it's origin and age.

Gilbert and others (1983) described a series of short en echelon scarps in the Potholes' region, Section 6, T44N, R114W. The scarps, which have an average height of 2.5 feet, are similar to outwash channel banks. While Gilbert and others (1983) suspect that the scarps are related to tectonic activity, other non-tectonic causes could not be entirely eliminated. The most likely non-tectonic explanation is that the scarps are related to early Snake River terraces. Further investigation, including trenching, is required to determine the origin of the scarps.

SUMMARY

Earthquakes have been felt in all counties in Wyoming. The historic record in Wyoming is rather short with the first recorded event dating from the 1870's in Yellowstone National Park. In 1959, a magnitude 7.5, Intensity X earthquake near Hebgen Lake, Montana, resulted in the loss of life. Features in Yellowstone National Park were greatly altered by that event. Seismic activity in the Jackson Hole area in 1925 may well have been partially responsible for the initiation of a large landslide which dammed the Gros Ventre River. Lives were lost in Kelly, Wyoming, when a portion of the landslide dam failed in 1927.

Homes and businesses across the State have been damaged by earthquakes. In 1930, an Intensity VI earthquake in the Star Valley area cracked brick buildings. Portions of mines in the Rocks Springs area may have collapsed in 1910 and 1930 due to seismic activity. Buildings were cracked in 1934 in Lander due to an Intensity V event. In the 1890s, earthquakes in the Casper area severely damaged a hotel and also caused the Platte River to become reddish and thick with mud. Most recently, a magnitude 5.5, Intensity VI event in northern Albany County caused widespread concern in 1984. In southereastern Wyoming, numerous buildings and homes were cracked and a few underground pipes were reportedly broken near Casper.

In the eastern three-quarters of Wyoming, Algermissen and others (1982) suggest that a maximum of one intensity V earthquake may occur every 2.2 years. In the western quarter of the State, a maximum of one intensity V earthquake may occur every 1.5 years. Algermissen and others (1982) also suggest that magnitude 6.1 events are the largest that should be expected in the eastern three-quarters of the State and that magnitude 7.3 events are the largest that should be expected in the western quarter. Recent research, however, indicates that there are a series of fautls in the western quarter of the State that have the potential to generate magnitude 7.5 earthquakes.

However, potential earthquakes with maximum magnitudes of 7.5 are associated with a series of faults in the western quarter of the State. A series of faults in central Wyoming have had maximum credible earthquakes of magnitude 6.75 assigned to them. Therefore, magnitude 7.5 events are the largest that should be expected in the western quarter of the State; magnitude

6.75 events are the largest that should be expected in the Owl Creek to Granite Mountains portion of the State; and magnitude 6.1 events are the largest that should be expected in the rest of the State.

Not all active fault systems in the State have been identified or investigated in sufficient detail to assign recurrence intervals or maximum credible earthquakes. In some cases, the age of last movement has not been defined. In the Jackson Hole area, there are a number of scarps that have an unknown or questionable origin. There is very little data on the active fault systems in Yellowstone National Park, and the entire Washakie Basin Fault system needs investigation.

Field investigations, including fault trenching, are needed in many areas. In the Jackson Hole area, additional geophysical exploration would be desirable. In short, the future earthquake risk in large parts of Wyoming is still poorly defined. The true earthquake potential and risk can only be identified through field investigations.

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