Data for Quaternary faults in western Montana

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ALPHABETIC LISTING

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National Earthquake Hazard Reduction Program (NEHRP) project on
UNITED STATES MAP OF QUATERNARY FAULTS AND FOLDS
In cooperation with the International Lithosphere Program's
Task Group II-2, World Map of Major Active Faults
Michael N. Machette, Co-chairman

A collaborative effort of the U.S. Geological Survey,
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INTRODUCTION

The "World Map of Major Active Faults" Task Group is compiling published fault data, developing a digital database of the fault data, and preparing a series of maps for the United States and other countries in the western Hemisphere. The data is intended to portray the locations, ages, and activity rates of major earthquake-related features such as faults, folds, and liquefaction features that have geologic evidence of Quaternary (1.6 Ma) deformation. The Western Hemisphere effort is sponsored by International Lithosphere Program (ILP) Task Group II-2; the data compilation, database, and map for the United States is funded largely by the National Earthquake Hazard Reduction Program (NEHRP) through the U.S. Geological Survey. The ILP effort in the Western Hemisphere is coordinated by Michael N. Machette, the digital database is designed and managed Kathleen M. Haller, and map data are digitized and manipulated by Richard L. Dart. In addition to meeting the goals of the Task Group II-2, this effort represents a key contribution to the new Global Seismic Hazards Assessment Program (ILP Task Group II-0) for the International Decade for Natural Disaster Reduction.

This compilation, which documents the published data on Quaternary surface faulting in western Montana, is one of many similar state or regional compilations that are planned for the project. Compilations for Arizona (Pearthree, 1998 #2945), Colorado (Widmann and others, 1998 #3441), New Mexico (Machette and others, 1998), and West Texas (Collins and others, 1996 #993) are currently available and the compilation for features east of the Rocky Mountain front will be available in early 2000 (Crone and Wheeler, in press). All are primarily a catalog of data that includes a variety of geographic, geologic, and paleoseismologic parameters for known or assumed Quaternary faults. These data compilations, the digital database, and the companion maps summarize the published information on known tectonic features and present the information in an internally consistent format. The compilations will be available in digital database format on the WorldWide Web in the near future, which will greatly improve their utility. Release of data for individual states and regions within the United States in this text-based format was necessary because of the time required to develop the national database.

STRATEGY FOR DATA COMPILATION

The primary purpose of this compilation is to provide geologic input to models for seismic-hazard evaluations; combining geologic evidence of Quaternary movement on faults with historical seismicity better characterizes the hazard than using seismicity alone. The correlation between historical seismicity and Quaternary faults is highly variable. In regions where faults have high slip rates, historical seismicity commonly images the youngest faults. In regions where faults have low slip rates, most small- to moderate-magnitude earthquakes do not appear to be located on known Quaternary faults (Stickney and others, 1999 #3942). Thus, historical seismicity is an imperfect indicator of hazard. Paleoseismology investigations, which document the history of surface faulting or deformation on a specific structure through several seismic cycles, can provide a long-term perspective that augments the relatively short historical record of seismicity. The frequency and location of large-magnitude earthquakes in many parts of the United States are poorly defined by the historical record and are commonly seismologically unanticipated because the time between major earthquakes on many of these faults is much longer than the 200- to 300-yr-long historical record. Thus, an understanding of the seismogenic characteristics of prehistoric (Quaternary) faults can provide a vital key to improving seismic-hazard assessments in many regions. It is important to stress here that this compilation includes only faults that have a history of earthquakes large enough to result in permanent surface deformation such as surface faulting, folding, or produced wide-spread liquefaction. The more frequent small- and moderate-magnitude earthquakes do not alter the surface and are therefore below the level of detection in the geologic sense; however, they still can result in a considerable amount of property damage and loss of life.

We define four classes in order to categorize faults that are identified as Quaternary in the literature. Class A faults have evidence that at least one large-magnitude earthquake has occurred on that fault during the Quaternary. Class B faults include those that might not extend deeply enough to host large-magnitude earthquakes or the evidence for Quaternary slip is too weak to consider the fault as Class A. Both Class A and B faults are fully described here and are shown on the published map for western Montana (Stickney and others, 1999 #3942). Class C faults are those faults previously identified as Quaternary but the evidence does not support Quaternary movement, in other words, movement on the fault is probably pre-Quaternary. Class D "faults" are likely not faults at all, but may be other geomorphic or geologic features. We describe Class C and D features in much less detail; by providing a description in our compilation, we furnish a comprehensive list of all features that we have evaluated. We do not show either of the latter two classes of faults on any map.

Even though there have been considerable advances in paleoseismology in recent years, segmentation of faults remain controversial. In a paleoseismologic sense, the terms segment or segmentation apply to the part(s) of a long fault that ruptures in individual earthquakes. These terms have specific genetic connotations relating to the seismogenic or structural nature of the fault. The terms also appear in the literature to describe much shorter lengths of the fault (geometric or structural segments) or used with no specific meaning at all. It is because of this confusion that we have abandoned the use of "segment" in this compilation. We do not wish to promote a genetic interpretation when the author intended something completely different because of unclear usage of the terms. Our strategy, instead, is to describe parts of a fault or fault zone that have similar timing, slip rate, and or recurrence interval data and call them "sections". This term is not intended to impart any genetic implication. However, faults that are sectioned herein usually are understood better that those described as a single entity. Sectioned faults are distinguished from the rest of the faults by an additional lower-case alphabetic character following the fault number (*e.g.*, 648a). A unique alphabetic character is assigned for each of the fault's sections; "a" to the northernmost or westernmost section and the last letter in the sequence to the southernmost or easternmost section.

EXPLANATION OF PRIMARY DATA FIELDS

Compilations such as this provide a useful tool for comparing spatial and temporal patterns of faulting at local, regional, and continental scales. However, a database is a powerful tool only if it is a systematic collection of data. With this in mind, we have attempted to include only data that is currently in print and reference all data sources. We have incorporated as much pertinent data as possible, especially where conflicts apparently exist.

In order to achieve some consistency where multiple interpretations are published, we established a hierarchy that defines what data are preferred and subsequently presented in the primary data field (indicated in bold and defined below). We give highest priority to fault-related studies, particularly those focusing on the Quaternary history of a fault and lower priority to general geologic studies. In most cases, more recent studies are given priority over less recent ones. A more detailed scale of mapping (*e.g.*, 1:24,000 scale) has higher priority over a less detailed scale (*e.g.*, 1:250,000 scale). Even though we give the most weight to recent studies of Quaternary faulting, we include information about alternative interpretations in the "Comments" that follow the data field. By providing these alternative interpretations, users can test alternate scenarios in their seismic-hazard assessment. However, the above hierarchy determines the data we present in the primary data fields. No field studies were conducted to specifically address conflicting interpretations that became apparent during the compilation effort.

The database is designed to accommodate the wide range of data available for well-studied faults in the United States. However, most potentially seismogenic structures have received limited study; therefore, some fault discussions will appear incomplete. Nevertheless, the design of the database permits (1) the identification of faults that may be considered potentially hazardous and (2) the addition of new data as studies are completed.

The primary data fields are defined below and represent the type of data of interest in seismic-hazard analysis or to paleoseismologists. We include fields that contain information on timing of the most recent displacement(s) on the fault, slip-rate category, recurrence interval, and other descriptive, geographic, geologic, and paleoseismologic data. These were developed to permit searches on the database for faults with specific parameters.

The most recent prehistoric movement is divided into five age categories: historic, latest Quaternary (<15 ka), late Quaternary (<130 ka), late and middle Quaternary (<750 ka), or Quaternary (<1.6 Ma). These age categories define a maximum time of movement but do not constrain the minimum time. For example, if Holocene (<10 ka) movement is suspected on a fault but only late Pleistocene (10-130 ka) movement can be firmly documented, then we use the inclusive late Quaternary (<130 ka) category for the time of the most recent movement. The broad age categories also permit us to categorize faults, even those for which the published literature contains conflicts concerning the timing of fault movements. On the map, suspected or inferred Quaternary faults are shown as dotted lines; structures with known late Tertiary (or older) movement are not shown unless there is published documentation of Quaternary movement (geomorphology, offset surficial deposits, etc.).

The slip rate of mapped faults is grouped into broad categories that serve as a proxy for fault activity rates, which can be applied at a National scale. We divided possible slip rates into four categories: less than 0.2 mm/yr, 0.2 to less than 1 mm/yr, 1-5 mm/yr, and greater than 5 mm/yr using the traditional method of portraying slip rates in millimeters per year. These broad categories separate most intraplate structures (with rates of <5 mm/yr) from major plate-bounding structures (rate generally >5 mm/yr). The 1-5 mm/yr slip-rate category is typical of major intraplate faults such as the Garlock fault in California and Wasatch fault zone in Utah. If no published slip rate exists for a fault, the compiler assigns the fault to a category on the basis of his or her impression of the structure and its role in the regional tectonics; the slip-rate category value is preceded by "unknown". The absence or presence of recent movement during a specific time interval can be the basis for estimating a slip rate; one can use a variety of geomorphic and geologic relations to place a fault in its appropriate age and slip-rate categories. For example if a fault does not cut latest Quaternary (<15 ka) deposits, it probably has a slip rate of less than 1 mm/yr because at least 15 m of slip would have accumulated during this time if the rate was 1 mm/yr or greater. If strain corresponding to a slip rate of 1 mm/yr had accumulated on the fault, then some of that strain would probably have been released during one or more large surface-faulting earthquakes.

The database includes several fields that provide supporting information about the previously mentioned parameters, as well as additional descriptive, geologic, and paleoseismologic parameters. Included are fault name and number, a brief synopsis describing how well studied the fault is, date of compilation and compiler's name, and information about the location of the fault. Because the project integrates data from the entire United States, the database requires that each seismogenic structure have a unique number (where cited in the text, a fault’s number is enclosed in square brackets). In general, most of the structures in a given state or region are sequentially numbered. Names are derived from the literature and from common usage, and although some structures in different regions may have the same name, each has a unique number so we did not attempt to avoid duplicate names. Geologic data in the database include geologic setting, geomorphic expression, and the age of faulted deposits, all in descriptive form are included to provide additional information that is of interest to only part of our intended audience. Additional paleoseismologic data presented include brief descriptions of trenching studies and results.

HISTORICAL SEISMICITY

The historical seismicity in western Montana defines the northern part of the Intermountain seismic belt and the eastern part of the Idaho seismic zone (Smith and Sbar, 1974 #160). The Intermountain seismic belt is a broad generally north-trending zone of seismicity that follows the boundary between the Great Basin and Colorado Plateau in Arizona and Utah, extends through the Yellowstone Plateau northward into the Northern Rocky Mountains, and continues to the Flathead Lake area of northern Montana. It is about 1300 km long and about 100 km wide. The Idaho seismic zone (or the Centennial tectonic belt of Qamar and Stickney, 1983 #58) extends from the Yellowstone area westward into central Idaho and contains the highest level of historical seismicity in the state (Stickney and Bartholomew, 1987 #85).

Western Montana is no stranger to earthquakes. Over 13,000 separate recorded events occurred between 1982 and 1998 (Stickney and others, 1999 #3942). The vast majority of these earthquakes were not felt but some in Montana's history have had devastating effects on the population. Remarkably, in the past 40 years no destructive earthquakes have occurred in the state; in contrast, four significant earthquake sequences occurred in the previous 40 years (1920-1960). On June 27, 1925 the second largest historical earthquake in the state occurred near Clarkston. It had an estimated magnitude of 6.8 (Qamar and Stickney, 1983 #58). Pardee (1927 #469) reported no deaths resulting from the earthquake but damage occurred in the nearby towns of Three Forks, Logan, Manhattan, and Deer Park. Although ground cracks were observed after the earthquake, they were attributed to failure due to shaking. Ten years later and about 80 km to the northwest, a large earthquake occurred in Helena valley on October 18, 1935. No deaths were reported, but about half of the buildings in Helena were damaged during the 6.3 magnitude earthquake, which was located just north of the city (Qamar and Stickney, 1983 #58). In 1947, an earthquake, known as the Virginia City earthquake, occurred in the Madison Valley. The largest historical earthquake to occur in Montana occurred twelve years later and was large enough to result in surface rupture. The Hebgen Lake earthquake occurred in the middle of a summer night. Because the earthquake occurred during the height of the tourist season, it resulted in numerous deaths caused by a massive landslide that dammed the Madison River creating Earthquake Lake.

Hebgen Lake earthquake

The M_S 7.5 Hebgen Lake earthquake (Abe, 1981 #650) on August 17,1959 at 11:37 p.m. MST (08/18/1959 06:37:15.0 GCT) resulted in surface rupture on several faults covering 540 square kilometers. The principle faults that ruptured include part of the Hebgen fault [656a], the Red Canyon fault [657]; smaller and shorter ruptures occurred on part of the West Fork fault [658], part of the Madison fault [a short part of 655b], and numerous unnamed faults in the Hebgen Lake basin [659]. The earthquake probably consisted of two sub-events separated by 5 sec (Ryall, 1962 #635; Doser, 1985 #22); magnitudes for the sub-events are reported to be 6.0 and 7.1 (Doser, 1985 #22).

The earthquake was located near the Montana-Wyoming state line north of West Yellowstone, Mont. Doser (1985 #22) provides locations for the two sub-events; the first was located at 44.880° N, 111.113° W and the second at 44.838° N, 111.026° W. However, the locations are probably shifted to the northeast by about 5-10 km, which when corrected would place them near the southwestern end of surface faulting. Additional locations were documented by the U.S. Coast and Geodetic Survey (1959 #630), Ryall (1962 #635), and Trimble and Smith (1975 #89). Ryall did not attempt to resolve the locations of each sub-event, but did note that the second shock was located south of the first. Stewart and others (1964 #246) speculate that main shock occurred at intersection of Hebgen and Red Canyon faults and a N. 18° E. lineament defined by 20 aftershocks that occurred 3-6 days after the Hebgen Lake earthquake. Generally, the earthquake is thought to have occurred at a depth of 10-15 km (Murphy and Brazee, 1964 #245; Doser, 1985 #22).

Surface displacements and slip indicators on free faces indicate no lateral slip (Myers and Hamilton, 1961 #636; Witkind and others, 1962 #633; Witkind, 1964 #247) on steeply dipping faults. Much of the surface rupture follows the surface trace of preexisting thrust faults. Focal mechanisms from wave-form modeling are discordant with the trend of the surface faulting (Doser, 1989 #194). Fault-plane solution defines a plane striking N 80° ± 10° W and dipping 54° ± 8° SW (Ryall, 1962 #635; Abe, 1981 #650). Short-period polarities indicate fault plane dips 60°±5° S and moment-tensor solutions from long-period data suggests a dip of 42° ± 5° S (Doser, 1985 #22). Based on seismicity with focal depths from near surface to 15 km recorded in 1972, the fault is assumed to dip 70° SW (Trimble and Smith, 1975 #89). Modeling of geodetic data indicates a dip of 45° for the Hebgen fault and 50° for the Red Canyon fault (Barrientos and others, 1987 #269). Published dips of the fault at the surface include 55° SW on Red Canyon fault at mouth of Red Canyon (Witkind and others, 1962 #633), 60-85° SW and locally vertical on Hebgen fault (Witkind, 1964 #247), and 50°-85° on Red Canyon fault in Red Canyon (Witkind, 1964 #247).

The cumulative length of surface rupture was about 49 km. This length was distributed in the following manner: 18.1 km on Red Canyon fault [657], 12.9 km on Hebgen fault [656], 12.5 km on unnamed intrabasin faults [659], 2.8 km on West Fork fault [658], and 3.1 km on Madison fault [655]. Doser (1985 #22) indicates northwestward, unilateral propagation of ruptures of 6 km and 21 km for the two sub-events. dePolo and others (1991 #187) indicate a 28-km-long surface rupture (measured end to end).

The maximum slip at the surface was about 55-83 percent of the average slip determined from geophysical data. Although numerous authors cite various values for maximum slip at the surface, their values are from the original work of Myers and Hamilton (1961 #636; 1964 #250) and Witkind and his colleagues (Witkind 1961 #637; Witkind and others, 1962 #633; 1964 #247). The maximum corrected scarp height on the Hebgen fault [656] was 5.5 m, on the Red Canyon fault [657] was 4.6 m, on the West Fork fault [658] was 1.2 m, on the intrabasin scarps [659] was 0.7 m, and on part of the Madison fault [655] was 0.9 m. Doser (1985 #22) indicates that the average displacement on the Red Canyon fault was 2.4 m compared to average of 1.6 m on the Hebgen fault; Hall and Sablock (1985 #640) suggest average vertical displacement on Red Canyon was 2.3 m and on Hebgen fault was 2.0 m. Both of these averages are probably based on scarp-height data of Witkind (1964 #247) and Myers and Hamilton (1964 #250). In contrast, first-order leveling data suggest a maximum subsidence of 6.7 m near the northern end of Hebgen Lake; an area of about 150 km^2 subsided more than 3.0 m (1961 #636; Myers and Hamilton, 1964 #250). The reported maximum increase in elevation was about 0.2 m (Witkind and others, 1962 #633). More recent interpretations of geodetic data defines slip on two fault planes (one 18 km long and 12 km wide and the other 18 km long and 15 km wide) with slip of 7.8 m and 7.0 m, respectively (Barrientos and others, 1987 #269). Doser (1985 #22) suggests average displacements of 1.0 m and 6.6 m for the two sub-events based on body-wave analysis. Savage and Hastie (1966 #651) calculate the vertical displacement of the free surface to be 10 m on a single planar fault dipping 54° SW ±8° with dimensions of 30 km long by 15 km wide. Geodetic data indicate contemporary doming at a rate of 3-5 mm/yr in region for at least 25 yr prior of Hebgen Lake earthquake and continuing at least 1 yr after the earthquake. This was possibly due to magma intrusion (Reilinger and others, 1977 #479); however, Barrientos and others (1987 #269) offer an alternate interpretation.

SYNOPSIS OF QUATERNARY FAULTING IN WESTERN MONTANA

Most of the 69 known or suspected Quaternary faults in western Montana have not been studied in detail. Many are defined herein by a single time of most recent movement and single slip-rate category. Thirteen faults have been studied in sufficient detail to recognize different faulting histories along their length. Other state and regional compilations include fault related folds and liquefaction features, neither of these are known to occur in the State of Montana in the absence of more direct geologic information; therefore, these two indicators of potentially seismogenic features are not described with in this report.

Earlier published compilations of Quaternary faults in western Montana provided a minimum list of faults thought to be Quaternary in age and key data for this effort. The first comprehensive compilation of late Cenozoic faults was by Pardee (1950 #46), and for many faults, this report is still the only source of information. The earliest compilations that included fault locations on a topographic base maps were by Witkind (1975 #320; 1975 #819; 1975 #317) for Montana and adjacent states; these maps were subsequently incorporated into the National compilation of Howard and others (1978 #312). Later, Johns and others (1982 #259) compiled data for most of the southern part of the State of Montana and maps of Stickney and Bartholomew (1987 #242; written commun. 1992 #556) covered the same area as this compilation. The compilation by Johns and others (1982 #259) was based on aerial photo reconnaissance followed by little or no field checking. The maps by Stickney and Bartholomew (1987 #242; written commun. 1992 #556) were a derivative product showing those faults in Johns and others that demonstrated evidence of late Quaternary movement (*i.e.,* field reconnaissance suggested scarps on alluvium were present). The faults that Witkind (1975 #320; 1975 #819; 1975 #317) interpreted to be late Cenozoic in age are not included in this compilation because they generally lack evidence of movement young enough to meet the standards of this compilation. However, the structure is included in this report if more recent studies suggest that the fault was active during the Quaternary. Quaternary faults listed in previous compilations but shown to be pre-Quaternary by more recent work are designated either Class C or Class D and are not shown on any of the map products. We provide the basis for the class designation in the appropriate fault description.

The style of Quaternary faulting in western Montana is similar to the extensional deformation in the Basin and Range province. Because of this, western Montana has commonly been referred to as part of the Montana-Idaho Basin and Range or the northern Basin and Range, even though it is entirely within the Northern or Middle Rocky Mountains physiographic provinces of Fenneman and Johnson (1946 #461). Most faults in the western part of the state are roughly subparallel and strike north to northwest. However, small differences in dominant strike do exist. South of the Lewis and Clark line, the preferred strike is northwest; and northwest- and north-striking (225°-45°) faults comprise three-fourths of all the structures. Within the Lewis and Clark line, two-thirds of the faults trend northwest (225°-315°). North of the Lewis and Clark line, the preferred strike is north, and northwest- and north-striking (225°-45°) faults comprise three-fourths of all the structures. Thus, the faults north of the Lewis and Clark line have a more northerly trend that those to the south.

Generally the time of most recent prehistoric movement for faults of western Montana is poorly constrained, and usually, it is inferred based on assuming ages of faulted deposits for younger events and by range-front morphology and topographic expression of the range for older events. Part or all of 11 western Montana faults are believed to have ruptured during the past 15 k.y., including the four faults that ruptured during the Hebgen Lake earthquake. Eighteen other faults probably have had surface ruptures along their length in the past 130 k.y. Detailed information of the remaining 40 faults is not available; these faults are considered herein to have ruptured in the past 1.6 m.y. However, future detailed studies may indicate otherwise and the fault may assigned to a lower class (C or D). The spatial distribution of the most recent faulting ages across the state makes it appear that the youngest faulting is almost exclusively confined to the southern part of the state, but this may be due to lack of data in the north rather than a true depiction of the tectonic conditions. It long has been thought that young surface faulting did not exist north of the Lewis and Clark line, which extends southeasterly roughly from the Coeur d'Alene Mountains to Helena Valley (Reynolds, 1977 #61). However, recent studies in northern Montana have clearly documented not only Holocene rupture of the Mission fault [699], which is north of the Lewis and Clark line, but also a history of recurrent movement on at least the southern part of the fault (Ostenaa and Levish, 1994 #1013; Ostenaa and others, 1995 #912). Other nearby faults may have similar histories as suggested by the precipitous nature of their associated range fronts that were first noted by Pardee (1950 #46).

Few slip rates have been published for western Montana faults, and most published or inferred rates are low (<0.2 mm/yr). However, six faults have published or inferred slip rates of 0.2-1 mm/yr, and three have rates of 1-5 mm/yr. Only seven of the 69 faults discussed here have published rates, and most of those are not well constrained. The absence of one critical piece of information, such as the time between of two or more surface-rupturing earthquakes, which provides a reliable recurrence interval, or the amount of slip released within that interval of time yields suspect slip rates.

Understanding and appropriately characterizing a region's seismic hazard is paramount. To reach this end, future studies are needed to better define the paleoseismologic history of most faults in western Montana. It is critical that we begin systematic reconnaissance, detailed mapping, and site studies that are designed to provide reasonable data that are needed to incorporate into seismic-hazard assessment models. The most critical pieces of data are time of most recent movement and slip rate. The time of most recent movement is used in seismic-hazard assessments to define those faults that are considered potentially seismogenic. In some cases only Holocene faults may be considered, in other cases a longer time period is considered. But more critical is slip-rate data because it serves as a proxy for fault activity. In order to arrive at a reasonable slip rate one needs to know an appropriate recurrence interval and the amount of slip associated with that interval. Most studies to date have not documented slip rates because many times the author believes the data presented are not suitable for determining slip rates. In some cases, someone else then evaluates that data and slip rates are documented without the appropriate caveats. Thus, it is important that future studies clearly document recurrence intervals, amounts of slip, and attempt to determine an acceptable slip rate with explanations to prevent misinterpretation.

We expect to maintain this compilation through periodic updates because of its expected contribution in future national and regional seismic-hazard assessments. In order to make this possible, please send notification or copies of publications that address any aspect of this database to the first author (see Appendix C).

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DEFINITION OF DATABASE TERMS

Specialized fields (shown in bold letters) provide abstracted data, most of which will be in searchable fields when the digital database is released. Fields are based on the general guidelines for the project (Haller and others, 1993 #655). In addition to the searchable fields, more detailed information is provided in the "Comments" section. If no pertinent information was found in the published literature for a field, we show "none" or "not reported". The following provides definitions of fields (in alphabetic order) and indicates where various information, if known, can be found. In-text citations of references are presented in a standard format with the exception of the addition of a reference-specific number at the end. This reference number allows us to omit the traditional alpha character for authors having multi-year publications (*e.g.*, 1988a, 1988b). All fault numbers cited in the text are bounded by brackets [ ] to differentiate them from reference numbers.

Age of faulted surficial deposits This field includes the ages of faulted deposits *at the surface*. In general, these data are from surficial geologic mapping, but in a few cases they may be from descriptions in referenced work. In some cases, the age of faulted deposits may not agree with the timing of the most recent prehistoric deformation. This apparent inconsistency may arise because of the manner in which particular studies are given preferable citation based on recency and scope of the study.

Average strike The value presented is the length-weighted average strike of the trace of the structure in azimuthal degrees The azimuthal values are confined to the northwest and northeast quadrants of the compass (*i.e*., 0°-90° and 271°-359°).

Compiler and affiliation The name and affiliation of the person(s) primarily responsible for compilation of data presented for the structure. Full names and address of these compilers are shown in the list of contributors.

County and State (if other than Montana) If the structure is in more than one county, we list the county in which the majority of the structure is located, followed by county name(s) for the remainder of the structure. State name is provided in parenthesis if the fault extends outside of Montana.

Date of compilation This field shows when data were compiled for this project in a month/day/year format (*e.g*., 03/13/98).

Dip This field contains measured dip or range of dip values from a variety of geologic studies. In some cases, these data are near-surface measurements at specific locations; in other cases the data comes from published cross sections or other subsurface investigations. Additional pertinent information is included in "Comments".

Dip direction Predominant down-dip direction(s) of the structure defined by compass quadrants: north (N), west (W), south (S), east (E), northwest (NW), northeast (NE), southwest (SW), southeast (SE), or vertical (V). If individual faults dip in different directions, multiple directions may be indicated.

Geologic setting This statement provides a generalized perspective of the fault in terms of its regional geologic setting, amount of total offset, and general age of offset strata.

Geomorphic expression General description of the structure's geomorphic expression including the presence or absence of fault scarps, offset streams, monoclines, shutter ridges, associated landslides, *etc*. is provided in this field.

Length This field specifies two types of length data. The first is the end-to-end length of the Quaternary-age fault as measured from the most distal ends of the digital data. The ends of overlapping or echelon traces are projected to a line defined by the average strike and the length is then determined from those projected end points. The second type of length is the trace length. This length is the sum of lengths of the actual map traces. Faults or fault zones with multiple (overlapping) strands typically have cumulative trace lengths that exceed the end-to-end length by a factor of 1.5 or more.

Name (**Structure name** or **Section name**) The earliest referenced name for a fault generally is given preference, except in cases where a more commonly accepted name is widely used in the recent literature. Section names are commonly derived from fault or segment names already established in the geologic literature. Thus, minor changes in original name may have been made for reasons of clarity or consistency (such as segment to section) where appropriate. The "Comments" field contains other published names and references in which they are used, the geographic limits of the structure, north to south or west to east, as shown in this compilation; various geographic limits that are different in other studies are also included.

Number

Structure number The fault is assigned a number within the predetermined limits for the State. References to the same structure shown in compilations by others are included in "Comments". The three principle compilations of Quaternary faults in Montana include Witkind (1975 #317), Johns and others (1982 #259), and Stickney and Bartholomew (1987 #242) and are cited extensively through this compilation.

Section number A lower-case alpha character is appended to the fault number with "a" assigned to the northernmost or westernmost section of a fault (*i.e.*, fault 207 has three sections: 207a, 207b, 207c).

Number of sections (only included in descriptions of faults with sections) Number of sections (*e.g.*, 4) that require a separate discussion. Usually based on differences in the timing of the most recent surface rupturing earthquake or change in slip rate along strike. "Comments" include reference in which sections are discussed; if the term "segment" is used in the literature, an explanation of why "section" is used in the database is provided.

1° x 2° sheet This field aids in the geographic location of the fault. If the structure is mapped in more than one 1° x 2° sheet (standard USGS 1:250,000-scale topographic map series), the name of the sheet in which the majority of the structure is located is listed first, followed by sheet name(s) for the remainder of the structure.

Paleoseismology studies This field includes a synopsis of detailed site-specific studies, typically those involving exploratory trenching, but may also include natural exposures or other man-made exposures. Sites of morphologic studies or detailed mapping (without trenching) are not included in this discussion. Study sites are numbered sequentially from north to south or west to east in the format of fault number, section letter, and site number (*e.g.*, 601c-3). Paleoseismic data from these studies are included in appropriate fields that document recurrence interval, slip rate, and timing of most recent prehistoric deformation.

Physiographic Province Field contains physiographic province names defined by Fenneman and Johnson (1946 #461). Although the western part of Montana is informally referred to as part of the Basin and Range, it lies beyond the physiographic limits of the Basin and Range Province defined by Fenneman and Johnson. However, the style of faulting in Montana is reminiscent of that observed in the Basin and Range Province. The majority of western Montana is within the Northern Rocky Mountains Province, with a small part of the State north of Yellowstone National Park being part of the Middle Rocky Mountains and the rest of the State in the Great Plains Province.

Recurrence interval Published time interval between surface faulting events. The interval is followed by (1) yr if time interval is based on historic data, calendric or calibrated radiocarbon dates, (2) ^{14}C yr if time interval is based on uncalibrated radiocarbon dates, or (3) k.y. if time interval is based on less precise dating methods such as stratigraphy or geomorphology. "Not reported" is used if a time interval is not specifically documented; however, related information may follow in the "Comments". Also included is the time interval () for which this recurrence interval is valid in parenthesis. Alternative published recurrence intervals are included in "Comments".

References A complete bibliographic citation (in USGS style) is included for all references for each structure, and collectively for all structures in the database at the end of this document. In-text citations of references are presented in a standard format with the exception of the addition of a reference-specific number at the end. This reference number allows us to omit the traditional alpha character for authors having multi-year publications (*e.g.*, 1988a, 1988b). All fault numbers cited in the text are bounded by brackets, for example [2015], to differentiate them from reference numbers.

Reliability of location Reliability of location (Good or Poor) is related to the scale of the source map for the trace of the structure and to the method by which the trace of the structure was mapped. To qualify for a "Good" location, the trace of the structure must have been published on a topographic base map at a scale of 1:250,000 or more detailed and have been accurately located on original map using photogrammetry or similar methods, or the trace of the structure was published on a topographic base map at a scale of 1:100,000 or more detailed, but transferred without photogrammetric methods. Traces that do not meet the above standards (less detailed scale, planimetric base, transfer by inspection, *etc*.) constitute a "Poor" location. Judgments of reliability may not directly relate to line symbols (solid, dashed, dotted) that are used; however, concealed or inferred faults are usually considered poorly located.

Section name (see **Name**)

Section number (see **Number**)

Sense of movement Includes thrust, less than 45° dip; reverse, greater than 45° dip; dextral, right lateral; sinistral, left lateral; or normal. For oblique slip, principle sense of movement is followed by secondary sense. Ratios of the slip components are included, where known, to better characterize sense of movement (*e.g.*, dextral/normal 3:1).

Slip-rate category The primary field shows one of four slip-rate categories use in visually depicting relative activity on a map. The four categories established for the national compilation are: (1) <0.2 mm/yr, (2) 0.2-<1 mm/yr, (3) 1-5 mm/yr, and (4) >5 mm/yr. In Montana, all published or assumed slip rates fall within the first three categories. "Unknown" precedes the suspected slip-rate category if no published slip rate is known. "Comments" include a synopsis of published slip rates and pertinent documentation. Generally speaking, there are two types of slip rates. The first type is termed a "geologic slip rate" and is typically derived from the age and amount of offset of surficial geologic deposits. These rates are not precise, but allow one to place broad limits on possible slip rates, and hence can help characterize the fault in one of the above-mentioned categories. The second type of slip rate is termed a "paleoseismic slip rate" and is derived from the timing of faulting events and amounts of offset of geologic datums or piercing point for each event. This type of slip rate is more precise, but are rare owing to the extensive amount of work involved (*i.e.*, detailed paleoseismologic studies involving trenching and numeric dating). Most of the published or assumed slip rates for faults in Montana are based on the geologic type.

Structure name **(**see **Name)**

Structure number **(**see **Number)**

Synopsis This field provides a short summary that describes the level of study, and provides a snapshot of the scope of data that follows in the database.

Most recent prehistoric deformation The primary field shows one of the four time categories: (1) latest Quaternary (Holocene and latest Pleistocene, <15 ka), (2) late Quaternary (Holocene and late Pleistocene, <130 ka), (3) middle and late Quaternary (<750 ka), or (4) Quaternary (<1.6 Ma). This field is intended to document only prehistoric surface faulting; if the fault has had historical deformation then "year of historic rupture" is included.

Year of historic rupture This field contains the four digit year that an earthquake that resulted in surface rupture in historic time. The only earthquake in Montana large enough to result in surface rupture occurred in 1959 in the southwest part of the State. (See description of Hebgen Lake earthquake in introductory remarks.)

FAULT AND FOLD DATABASE

The following discussion of Quaternary faults and folds in Montana are organized by the number we have assigned to the structure. If a fault is present in more than one state, the number was assigned from that state in which the majority of the structure lies. For example, fault [746] (East Gallatin Reese Creek fault system) is primarily in Wyoming and was assigned a number from that state; thus, there is a break in numbers from 706-746 herein.

606, Deadman fault (Class A)

Structure Number 606

Comments: Refers to number 104 (unnamed fault) of Witkind (1975 #320) and number 11 (Deadman fault) of Witkind (1975 #317).

Structure Name Deadman fault

Comments: An early reference to the Deadman fault is Scholten and others (1955 #69) who showed the fault extending from east of Island Butte south to Black Canyon. Ostenaa and Wood (1990 #318) showed the fault as being longer and is the source for trace shown here. Skipp (1984 #452) mapped part of the fault (called Deadman fault zone) in detail and is the source of the complex, echelon traces between 44°15' and 44°30' latitude.

Synopsis The Deadman fault is a high-angle range-front and intrabasin fault along the southwest side of the Tendoy Mountains. Its Quaternary history is poorly understood and Quaternary movement is not demonstrably proven, no known studies have been completed at time of this compilation.

Date of compilation 03/29/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Clark (ID); Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Most of fault as shown is from 1:700,000-scale map of Ostenaa and Wood (1990 #318); well located part of fault is between 44°15' and 44°30' latitude from 1:62,000-scale map of Skipp (1984 #452).

Geologic setting High-angle, down-to-southwest, range-front and intrabasin normal fault bounding southwest side of Tendoy Mountains. Total stratigraphic offset unknown; however, tuff that predates 5 Ma is offset more than 150 m.

Sense of movement normal

Comments: (Scholten and others, 1955 #69)

Dip not reported

Dip direction SW

Geomorphic expression Scholten and others (1955 #69) report remnants of triangular facets.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Details of age of faulting are incomplete. Witkind (1975 #320) suggested Idaho part of fault probably has Quaternary movement but indicates that Montana part is Tertiary or Quaternary (Witkind, 1975 #317). Skipp (1984 #452) shows the fault crossing upper Quaternary deposits, which led Ostenaa and Wood (1990 #318) to speculate that at least part is Pleistocene or possibly Holocene. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Bartholomew and Stickney examined several sites along the part of the fault in Montana and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997). Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred based on Edie School rhyolite, shown as Tuff of Blacktail Butte (>5 Ma) by Skipp (1984 #452), displaced more than 150 m by late Tertiary or Quaternary movement (Scholten and others, 1955 #69).

Length End to end (km) 70.8
Cumulative trace (km) 104.1

Average strike (azimuth) 306°

References

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#69 Scholten, R., Keenmon, K.A., and Kupsch, W.O., 1955, Geology of the Lima region, southwestern Montana and adjacent Idaho: Geological Society of America Bulletin, v. 66, p. 345-404.

#452 Skipp, B., 1984, Geologic map and cross sections of the Italian Peak and Italian Peak Middle Roadless Areas, Beaverhead County, Montana, and Clark and Lemhi Counties, Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF-1601-B, 1 sheet, scale 1:62,500.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

#320 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in Idaho: U.S. Geological Survey Open-File Report 75-278, 71 p. pamphlet, 1 sheet, scale 1:500,000.

614, Unnamed fault near Monida (Class A)

Structure Number 614

Comments: Fault is shown on map of Witkind (1975 #320), but is not described and therefore has no documentation.

Structure Name Unnamed fault near Monida

Comments: Fault, as shown by Witkind, extends from northwest of Monida, Montana, southeastward to northeast of Humphrey, Idaho.

Synopsis No known studies have been completed at time of this compilation. Sole source of data is from earlier compilation of active faults by Witkind (1975 #320).

Date of compilation 03/17/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Clark (ID); Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location is based on unpublished Dubois quadrangle (1:250,000-scale) map of Witkind. Witkind shows fault on Idaho compilation (Witkind, 1975 #320), but not on the Montana compilation (Witkind, 1975 #317).

Geologic setting High-angle, down-to-southwest, normal fault east of I-15 in the western Centennial Range. Total offset unknown.

Sense of movement normal

Comments: (Witkind, 1975 #320)

Dip not reported

Dip direction SW

Geomorphic expression not reported

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Witkind (1975 #320) indicates fault is Quaternary in age.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred due to lack of data to indicate late Quaternary slip.

Length End to end (km) 13.7
Cumulative trace (km) 14.5

Average strike (azimuth) 302°

References

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

#320 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in Idaho: U.S. Geological Survey Open-File Report 75-278, 71 p. pamphlet, 1 sheet, scale 1:500,000.

641, Red Rock fault (Class A)

Structure Number 641

Comments: Refers to number 8 (Red Rock fault zone) of Witkind (1975 #317); number 4 (Red Rock fault) of Stickney and Bartholomew (1987 #85); and Timber Butte and Sheep Creeks segments of Red Rock fault in Montana Bureau of Mines and Geology digital database (Stickney, written comm., 1992) and Stickney and Bartholomew (1987 #242).

Structure Name Red Rock fault

Comments: The source of the name Red Rock fault is probably Pardee (1950 #46), who defined the fault as extending from near Clark Canyon Reservoir to southwest of Lima, Montana, along the east flank of the Tendoy Mountains. Pardee also referred to this structure as the Lima fault, whereas Scholten and others (1955 #69) used Red Rock fault zone. The fault, as shown here, extends from about 2 km north of Limekiln Canyon southward to near Birch Creek. Other compilations show only the southern two-thirds of the fault shown here (Witkind, 1975 #317; Stickney and Bartholomew, 1987 #242; Stickney and Bartholomew, written commun. 1992 #556).

Synopsis Trenching at one site on the southern part of the fault, along with clear differences in fault-scarp morphology and geologic relations between faulted and unfaulted deposits, three parts of the fault with probable different faulting histories. The northern part, as defined here by a valleyward echelon step in the fault at its southern end, has received little study.

Date of compilation 11/12/92

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Geologic setting High-angle, down-to-northeast, range-front normal fault bounding northeast side of Tendoy Mountains. There is no evidence of young faulting south of mapped trace even though the mountain front extends further south. Total vertical separation may be 1 km based on gravity data (Johnson, 1981b #313). Hurlow (1995 #1063) also suggests about 1 km of structural relief.

Number of sections 3

Comments: Sections are defined by the apparent differences in the timing of the most recent prehistoric deformation. The two southern sections are named following the names provided by Stickney and Bartholomew (1987 #85). They defined their segments on geomorphic data of Johnson (1981 #30). Johnson (1981 #30), however, discussed four segments of fault, but it is unclear if he meant seismogenic segments.

Length End to end (km) 40.7
Cumulative trace (km) 39.2

Average strike (azimuth) 326°

641a, Unnamed (north) section

Segment number 641a

Segment name Unnamed (north) section

Comments: Section extends from northern end of Tendoy Mountains, north of Limekiln Canyon, southeast to near Kelmbeck Creek. Southern end of the section is at a prominent echelon step in the range front.

Reliability of location Poor

Comments: Location of fault generally based on range-front topography, scarps on alluvium have not been observed.

Sense of movement normal

Comments: Sense of movement assumed to be same as is to the south as indicated by Witkind (1975 #317).

Dip not reported

Dip direction NE

Geomorphic expression Northern section characterized by straight mountain front and absence of recognizable fault scarps on alluvium (Johnson, 1981 #30).

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Faulting history of segment poorly known; reconnaissance studies indicate no evidence of scarps on uppermost Quaternary deposits (Johnson, 1981 #30; Haller, 1988 #27). The timing of the most recent event is inferred here to be possibly Quaternary based on the young movement to the southeast. No studies to date have addressed this section of the fault.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred based on absence of scarps.

Length End to end (km) 14.4
Cumulative trace (km) 14.7

Average strike (azimuth) 337°

641b, Timber Butte section

Segment number 641b

Segment name Timber Butte section

Comments: Named and defined as the Timber Butte segment by Stickney and Bartholomew (1987 #85; 1987 #242) based on geomorphic data of Johnson (1981 #30). Extends from near Kelmbeck Creek southeastward to about midway between Big Sheep Creek and Dry Canyon (Haller, 1988 #27). The part of fault Johnson (1981 #30) defined that most closely coincides with Timber Butte segment extends from Kelmbeck Creek to Garr Canyon, about 6 km south of southern segment boundary given here. Bartholomew (1989 #294) believes the Timber Butte-Sheep Creeks segment boundary is farther north than Haller's based on a Holocene scarp at Little Water Canyon. Crone and Haller (1991 #186) argue that this young scarp is small and uncharacteristic of older scarps at this site and is probably result of partly ineffective barrier to ruptures at the segment boundary.

Reliability of location Good

Comments: Location based on 1:250,000-scale maps of Haller (1988 #27), original mapping at 1:24,000 scale.

Sense of movement normal

Comments: (Witkind, 1975 #317)

Dip not reported

Dip direction NE

Geomorphic expression Section is characterized by steep, composite fault scarps with well-preserved triangular-faceted bedrock spurs (Pardee, 1950 #46; Scholten and others, 1955 #69). Pardee (1950 #46) recognized that the young fault scarps, which characterize most of Red Rock fault, are result of recent movement because of their steep slopes (30°-33°). Scarps on alluvium are discontinuous; single-event scarps are 1-3 m high and multiple-event scarps are as much as 20-25 m high.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Most authors agree that most recent faulting occurred at about or prior to 15 ka. Because there is no definitive data, we use a conservative estimate of less than 130 ka. Most recent faulting event occurred between 10 and 15 ka according to Haller (1988 #27) and Crone and Haller (1991 #186), based on morphology of scarps and inferred ages of faulted and unfaulted deposits. Stickney and Bartholomew (1987 #85) suggest latest Pleistocene deposits are not faulted and, thus, faulting might predate 12-15 ka. Johnson (1981 #30) believed youngest faulting may be as old as 100 ka.

Recurrence interval 12-25 k.y. (<25 ka)

Comments: Recurrence interval from Ostenaa and Wood (1990 #318); time for which this interval is valid (25 k.y.) is assumed from their discussion.

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred based on 1- to 3-m-high scarps on upper Pleistocene deposits (Stickney and Bartholomew, 1987 #85).

Length End to end (km) 9.3
Cumulative trace (km) 9.4

Average strike (azimuth) 327°

641c, Sheep Creeks section

Segment number 641c

Segment name Sheep Creeks section

Comments: Named and defined as the Sheeps Creek section by Stickney and Bartholomew (1987 #85; 1987 #242). Extends from about midway between Big Sheep Creek and Dry Canyon southeastward to southern end of the scarps southwest of Lima, Montana (Haller, 1988 #27). The parts of the fault Johnson defined that most closely coincides with the section described here include part from Garr Canyon to Little Sheep Creek and the east-trending part south of Little Sheep Creek. Bartholomew (1989 #294) believes Timber Butte-Sheep Creeks segment boundary is farther north than Haller's based on a Holocene scarp at Little Water Canyon. Crone and Haller (1991 #186) argue that this young scarp is small and uncharacteristic of older scarps at this site and is probably result of partly ineffective barrier to ruptures at the segment boundary.

Reliability of location Good

Comments: Location based on 1:250,000-scale maps of Haller (1988 #27), original mapping at 1:24,000 scale.

Sense of movement normal

Comments: (Witkind, 1975 #317)

Dip not reported

Dip direction NE

Geomorphic expression Section is characterized by nearly continuous, morphologically young fault scarps on alluvium and well preserved, triangular-faceted bedrock spurs (Pardee, 1950 #46; Scholten and others, 1955 #69). Locally multiple-event scarps are as much as 40 m high (Johnson, 1981 #30) and single-event scarps are as much as 6 m high (Haller, 1988 #27). Pardee (1950 #46) recognized that the young fault scarps, which characterize most of the Red Rock fault, are the result of recent movements because their steep slopes (30°-33°).

Age of faulted surficial deposits not reported

Paleoseismology studies One trench across 5-m-high scarp exposed evidence of two post-glacial (<12-15 ka) faulting events with the most recent event occurring during the late Holocene. Trench 641c-1 excavated by Bartholomew, Stickney, and Wilde in 1986 (Bartholomew and Stickney, 1987 #9; Stickney and others, 1987 #295), approximately 50 m north of Little Sheep Creek access road. Results discussed in Haller (1988 #27) and simplified trench log is in Bartholomew (1989 #294).

Most recent prehistoric deformation latest Quaternary (<15 ka)

Comments: Bartholomew (1989 #294) provides a simplified trench log and indicated an approximate time of faulting of 3,000 ± 800 yr. Scarps along this segment also are estimated to be Holocene in age based on morphology (Haller, 1988 #27). In contrast, Witkind (1975 #317) suggested historic movement along this part of the fault.

Recurrence interval 5-15 k.y. (<15-22 ka)

Comments: Recurrence interval from Ostenaa and Wood (1990 #318); time for which this interval is valid (15-22 k.y.) is assumed from their discussion. Haller (1988 #27) suggests a similar recurrence interval (5-7 k.y.) for past 12-15 k.y. Mason (1992 #463) indicates recurrence interval of 12±7 k.y. for an unspecified period of time. The compiler believes all to be based on trenching studies of Stickney and Bartholomew.

Slip-rate category unknown; probably 0.2-1.0 mm/yr

Comments: Data as presented by Ostenaa and Wood (1990 #318), based on trenching of Stickney and Bartholomew, indicate that slip during the most recent event was about 2.5 m, and the recurrence interval between the past two events was 5-15 k.y., which yields a slip rate that would fall within the assigned slip-rate category.

Length End to end (km) 14.8
Cumulative trace (km) 15.2

Average strike (azimuth) 316°

References

#294 Bartholomew, M.J., 1989, The Red Rock fault and complexly deformed structures in the Tendoy and Four Eyes Canyon thrust sheets—Examples of late Cenozoic and late Mesozoic deformation in southwestern Montana: Northwest Geology, v. 18, p. 21-35.

#9 Bartholomew, M.J., and Stickney, M.C., 1987, Late Quaternary faulting in southwestern Montana: Geological Society of America Abstracts with Programs, v. 19, p. 258-259.

#186 Crone, A.J., and Haller, K.M., 1991, Segmentation and the coseismic behavior of Basin and Range normal faults—Examples from east-central Idaho and southwestern Montana, *in* Hancock, P.L., Yeats, R.S., and Sanderson, D.J., eds., Characteristics of active faults: Journal of Structural Geology, v. 13, p. 151-164.

#27 Haller, K.M., 1988, Segmentation of the Lemhi and Beaverhead faults, east-central Idaho, and Red Rock fault, southwest Montana, during the late Quaternary: Boulder, University of Colorado, unpublished M.S. thesis, 141 p., 10 pls.

#1063 Hurlow, H.A., 1995, Late Pliocene or younger paleostress directions from fractured clasts, Sixmile Creek Formation, lower Red Rock Valley, SW Montana: Geological Society of America Abstracts with Programs, v. 27, no. 4, p. 16.

#30 Johnson, P.P., 1981, Geology of the Red Rock fault and adjacent Red Rock valley, Beaverhead County, Montana: Missoula, University of Montana, unpublished M.S. thesis, 88 p., 2 pls.

#313 Johnson, P.P., 1981b, Geology of the Red Rock fault and adjacent Red Rock valley, Beaverhead County, Montana, *in* Tucker, T.E., ed. Guidebook to southwest Montana: Montana Geological Society, 1981 Field Conference and Symposium, p. 245-251.

#463 Mason, D.B., 1992, Earthquake magnitude potential of active faults in the Intermountain seismic belt from surface parameter scaling: Salt Lake City, University of Utah, unpublished M.S. thesis, 110 p.

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#69 Scholten, R., Keenmon, K.A., and Kupsch, W.O., 1955, Geology of the Lima region, southwestern Montana and adjacent Idaho: Geological Society of America Bulletin, v. 66, p. 345-404.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

#295 Stickney, M.C., Bartholomew, M.J., and Wilde, E.M., 1987, Trench logs across the Red Rock, Blacktail, Lima Reservoir, Georgia Gulch, Vendome and Divide faults, Montana: Geological Society of America Abstracts with Programs, v. 19, p. 336-337.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

642, Emigrant fault (Class A)

Structure Number 642

Comments: Refers to number 15 (Emigrant fault) of Witkind (1975 #317); numbers 70 (Emigrant fault), 71 (Deep Creek fault), and 72 (Deep Creek West fault) of Johns and others (1982 #259); number 17 (Emigrant fault) of Stickney and Bartholomew (1987 #85); and Emigrant fault of Stickney and Bartholomew (1987 #242; written commun. 1992 #556).

Structure Name Emigrant fault

Comments: One of the earliest references to name the Emigrant fault is Pardee (1950 #46), who describes the fault as extending from Pine Creek southwestward to Yankee Jim Canyon. Also referred to as the Deep Creek fault (Bonini and others, 1972 #265; Personius, 1982 #241; 1982 #244; 1986 #252) and Emigrant Valley fault (U.S. Coast and Geodetic Survey, 1959 #630). Fault, as shown here, extends from Suce Creek southwestward to Yankee Jim Canyon.

Synopsis Detailed mapping and reconnaissance studies of scarp morphology are the sole source of data for this fault; segmentation model has not been proposed based on these data. No trenching has been conducted.

Date of compilation 10/06/92

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Park

1° x 2° sheet Bozeman

Physiographic province Middle Rocky Mountains

Geologic setting High-angle, down-to-the-northwest, range-front normal fault bounding the west side of the Beartooth uplift. Fault is generally several hundreds of meters west of the topographic range front (Bonini and others, 1972 #265; Personius, 1982 #241). Pierce and Morgan (1992 #539) indicate that the fault was active between 8 and at least 15 Ma and since 0.5 Ma with an interval of quiescence between, based on regressing displacement at a late Quaternary rate to fit the observed tilt in 5.4 and 8 Ma basalts in the valley. Units below the basalts suggest displacement totaling >1 km during the Miocene. Gravity data of Bonini and others (1972 #265) indicate total displacement of 5.6-6.1 km.

Number of sections 2

Comments: Seismogenic segments are not defined for this fault. The fault is marked by short discontinuous scarps that have similar morphologic characteristics (Personius, 1982 #241). According to Personius (1982 #244), scarp-morphology data do not clearly define of segmentation of this fault, even though, the fault's geometry has abrupt bend and left-stepping echelon pattern in the central part of the fault that could be interpreted as a possible segment boundary. Sections discussed here are based on an apparent difference in timing (shown by Personius, 1982 #241) of the most recent faulting event along strike.

Length End to end (km) 52.0
Cumulative trace (km) 56.0

Average strike (azimuth) 41°

642a, Unnamed (north) section

Section number 642a

Section name Unnamed (north) section

Comments: Section includes Strong's Ranch scarp and Pool Creek scarp of Personius (1982 #241; 1982 #244; 1986 #252); Pool Creek scarp of Stickney and Bartholomew (1987 #85; 1987 #242); and Deep Creek segment of Stickney and Bartholomew (written commun. 1992 #556). Johns and others (1982 #259) show this part of the fault as number 71 (Deep Creek fault) but the description provided for number 72 (Deep Creek West fault) appears to be more applicable to this section.

Reliability of location Good

Comments: Location based on 1:125,000-scale map of Personius (1982 #241). Solid lines are scarps on Quaternary deposits mapped by Personius, dotted lines are location of fault inferred by compiler.

Sense of movement normal

Comments: (Bonini and others, 1972 #265)

Dip 80° W

Comments: Location of dip, from Bonini and others (1972 #265), probably along the northernmost part of the fault that Personius (1982 #241) describes as being in bedrock. Bonini and others (1972 #265) indicate that modeling a vertical fault best fits the gravity data.

Dip direction W

Geomorphic expression Faceted spurs are preserved only locally, remnant pediments are absent, scarps on alluvium are discontinuous and up to 50 m high (Personius, 1982 #241). Hot springs occur along trace (Witkind, 1975 #317).

Age of faulted surficial deposits Upper Pleistocene (Pinedale?) glacial drift, upper Pleistocene alluvium, and undifferentiated upper Pleistocene glacial deposits; Paleozoic-Mesozoic and Precambrian bedrock at northern end (Personius, 1982 #241). Much of the length of the fault is thought to be continuous through deposits of late Quaternary age but scarps are not preserved in many locations (parts shown by dotted line).

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Personius (1982 #241) estimates that a reasonable time of faulting for the Strong's Ranch scarp is 100-200 ka. Due to the morphology of this scarp, an age of <130 ka seems reasonable and is used here. However, the Pool Creek scarp might possibly be 20-50 k.y. old (Personius, 1982 #244).

Recurrence interval 15±10 k.y.

Comments: Mason (1992 #463) indicates this recurrence interval for unspecified period of time based on data of Personius (1982 #241; 1982 #244) and Stickney and Bartholomew (1987 #85).

Slip-rate category unknown, probably 0.2-1.0 mm/yr

Comments: Short-term slip rate is higher than the apparent long-term rate. Late to middle Quaternary deposits (100,000-200,000 yr) have scarps as much as 35 m high. Displacement since early Pleistocene possibly 200-300 m based on elevations of displaced glacial till (Personius, 1982 #241).

Length End to end (km) 12.9
Cumulative trace (km) 13.6

Average strike (azimuth) 21°

642b, Unnamed (south) section

Section number 642b

Section name Unnamed (south) section

Comments: Section includes Barney Creek, Strawberry Creek, Elbow Creek, Count's Ranch, and Gray's Ranch scarps of Personius (1982 #241; 1982 #244; 1986 #252); Barney Creek, Strawberry Creek, Mill Creek, Sixmile Creek, and Dailey Lake scarps of Stickney and Bartholomew (1987 #85; 1987 #242); and Barney Creek, Strawberry Creek, Elbow Creek, Sixmile Creek, Dailey Lake, and Dome Mountain segments of Stickney and Bartholomew (written commun. 1992 #556).

Reliability of location Good

Comments: Location is based on 1:125,000-scale map of Personius (1982 #241). Solid lines are scarps on Quaternary deposits mapped by Personius, dotted lines are location of fault inferred by compiler.

Sense of movement normal

Comments: (Bonini and others, 1972 #265)

Dip 50°-60° W

Comments: Personius (1982 #241) reports 60° W. dip from exposure 4 km northeast of Sixmile Canyon in unconsolidated alluvium. Pardee (1950 #46) reports 50° W dip in 6-m-deep artificial exposure that was probably in unconsolidated alluvium, exact location unknown but was somewhere along the southernmost part of the fault. Bonini and others (1972 #265) indicate that modeling a vertical fault best fits the gravity data.

Dip direction NW

Geomorphic expression Faceted spurs are preserved only locally, remnant pediments are absent, scarps on alluvium are discontinuous and as much as 50 m high (Personius, 1982 #241). Hot springs occur along trace (Witkind, 1975 #317).

Age of faulted surficial deposits Holocene and upper Pleistocene alluvium, upper Pleistocene (Pinedale) glacial drift, Precambrian metamorphic bedrock (Personius, 1982 #241).

Paleoseismology studies none

Most recent prehistoric deformation latest Quaternary (<15 ka)

Comments: Scarps are on upper Pleistocene (Pinedale) deposits and scarp-morphology data of Personius (1982 #241) suggest age of 10-12 ka.

Recurrence interval 15±10 k.y.

Comments: Mason (1992 #463) indicates this recurrence interval for unspecified period of time based on data of Personius (1982 #241; 1982 #244) and Stickney and Bartholomew (1987 #85).

Slip-rate category 0.2-1.0 mm/yr

Comments: Pierce and Morgan (1992 #539) document a slip rate of 0.25 mm/yr based on data of Personius (1982 #241) , which is inferred here to be a late Quaternary rate.

Length End to end (km) 40.0
Cumulative trace (km) 42.4

Average strike (azimuth) 48°

References

#265 Bonini, W.E., Kelley, W.N., Jr., and Hughes, D.W., 1972, Gravity studies of the Crazy Mountains and the west flank of the Beartooth Mountains, Montana, *in* Lynn, J., Balster, C., and Warne, J., eds., Crazy Mountains Basin: Montana Geological Society, 21st Annual Geological Conference, September 22-24, 1972, Guidebook, p. 119-127.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#463 Mason, D.B., 1992, Earthquake magnitude potential of active faults in the Intermountain seismic belt from surface parameter scaling: Salt Lake City, University of Utah, unpublished M.S. thesis, 110 p.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#241 Personius, S.F., 1982, Geologic setting and geomorphic analysis of Quaternary fault scarps along the Deep Creek fault, upper Yellowstone valley, south-central Montana: Bozeman, Montana State University, unpublished M.S. thesis, 77 p., 1 sheet, scale 1:125,000.

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#252 Personius, S.F., 1986, Quaternary faulting along the Deep Creek fault upper Yellowstone valley, southwestern Montana, *in* Locke, W.W., ed. Quaternary geomorphic evolution of the Yellowstone region: Rocky Mountain Cell, Friends of the Pleistocene, September 6-8, 1986, Guidebook, p. 3-30.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

#630 U.S. Coast and Geodetic Survey, 1959, Preliminary report—Hebgen Lake, Montana earthquakes, August 1959: U.S. Department of Commerce, 15 p.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

643, Centennial fault (Class A)

Structure Number 643

Comments: Refers to fault number 4 (Centennial fault) of Witkind (1975 #317); fault numbers 1 (Centennial fault-Centennial Valley segment) and 35 (Centennial fault-Red Rock Pass-Henrys Lake segment) of Johns and others (1982 #259); fault number 9 (Centennial fault) of Stickney and Bartholomew (1987 #85); and Centennial fault of Stickney and Bartholomew (1987 #242; written commun. 1992 #556).

Structure Name Centennial fault

Comments: The source of the name is probably Pardee (1950 #46), who describes the fault as extending from near Monida, Montana, eastward to Henrys Lake basin. Fault, as shown here, extends from about 1 km south of Mud Lake eastward to 2 km south of southern shore of Henrys Lake. Extent of fault has been shown in various forms in previous compilations.

Synopsis This description, as well as more recent published discussions on this fault referenced here, are based on the data of Witkind (1975 #296). Scarps on Holocene and upper Pleistocene deposits are locally preserved along entire length of the Centennial fault; however, with the exception of the westernmost part of the fault, further evidence of young faulting (such as scarp continuity) is not reported. Thus, a conservative estimate of the age of the eastern part of the fault is used here. Most published data provide conflicting evidence about the recency and rate of activity of this fault.

Date of compilation 07/21/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead (MT); Fremont (ID)

1° x 2° sheet Ashton; Dubois

Physiographic province Northern Rocky Mountains

Geologic setting High-angle, down-to-the-north, range-front normal fault bounding north side of Centennial Mountains. Ross and Nelson (1964 #249) speculate that this fault is continuous with the east-trending intrabasin scarps formed during the Hebgen Lake earthquake south of Hebgen Lake [659] through Targhee Pass, which they contend is a modified structural depression; however, Fraser and others (1964 #628) argue to the contrary, citing the diminishing amount of displacement from west to east that appears to die out near Henrys Lake. Available gravity data suggest that the Centennial fault terminates in the Madison Valley (Schofield, 1981 #314). Sonderegger and others (1982 #297) report a minimum offset of 1.5-1.8 km of the 2-Ma Huckleberry Ridge Tuff and possibly 3 km vertical displacement in past 10 m.y.

Number of sections 4

Comments: Witkind (1975 #296) showed 3 segments of the Centennial fault in his original mapping, and other authors (Johns and others, 1982 #259; Stickney and Bartholomew, 1987 #85; Ostenaa and Wood, 1990 #318) have retained the nomenclature. However, it is unclear if the original intent was to identify independent seismogenic segments. Thus, sections of the fault that have similar characteristics are discussed here. Section boundaries are located where scarps on distinctly different age deposits occur or where echelon steps of the fault trace occur. The Centennial Valley segment of Witkind (1975 #296) is herein divided into 2 sections and his Red Rock Pass and Henrys Lake segments are discussed as 2 additional sections.

Length End to end (km) 62.5
Cumulative trace (km) 86.1

Average strike (azimuth) 282°

643a, Western Centennial Valley section

Section number 643a

Section name Western Centennial Valley section

Comments: Shown as the Western Centennial Valley segment by Stickney and Bartholomew (1987 #242) and Centennial Valley and East Centennial Valley segments in Stickney and Bartholomew (written commun. 1992 #556). Preference is given here to earlier name. Section includes approximately the western half of Centennial Valley segment of Witkind (1975 #296) and number 1 (Centennial Valley segment) of Johns and others (1982 #259). Extends from 1 km south of Mud Lake eastward to near 7 L Ranch (0.6 km east of Curry Creek), beyond which the fault is mostly buried (Witkind, 1975 #296).

Reliability of location Good

Comments: Location based on 1:62,500-scale map of Witkind (1975 #296).

Sense of movement normal

Comments: (Witkind, 1975 #296)

Dip not reported

Dip direction N

Geomorphic expression East-west trending, nearly continuous scarps, which are 5-22 m high (generally 12 m high) with steep 22°-54° maximum slope angles, on alluvial deposits (Witkind, 1975 #296). Ostenaa and Wood (1990 #318) and Gilbert and others (1983 #434) indicate that scarps are more extensive than shown by Witkind (1975 #296). Numerous springs are present along the trace of the fault (Honkala, 1960 #654).

Age of faulted surficial deposits Unknown, all deposits are shown in fault contact with the exception of an echelon scarp on Holocene alluvium (Witkind, 1975 #296).

Paleoseismology studies none

Most recent prehistoric deformation latest Quaternary (<15 ka)

Comments: Stickney and Bartholomew (1987 #85; 1987 #242; written commun. 1992 #556) indicate that the most recent faulting event occurred in the early Holocene based on stratigraphic relations. Ostenaa and Wood (1990 #318) also suggest Holocene faulting based on brief reconnaissance of the western part of the fault. Faulting of this section of the Centennial fault may be temporally related to that on the Lima Reservoir fault [646] (Ostenaa and Wood, 1990 #318).

Recurrence interval 2-25 k.y. (<25 ka)

Comments: Ostenaa and Wood (1990 #318) indicate two events occurred in the past 25 k.y. The most recent event is Holocene, and the penultimate event occurred between 12 and 25 ka based on stratigraphic relations. Recurrence interval given here is assumed from their discussion. Mason (1992 #463) indicates recurrence interval is >7±3 k.y. for an unspecified period of time based on data from Stickney and Bartholomew (1987 #85); however, supporting documentation in Mason (1992 #463) suggests that this is the interval of time since the most recent event.

Slip-rate category unknown; probably 0.2-1.0 mm/yr

Comments: There are no published slip rates for this part of the fault. The low topographic relief across the fault indicates that a low slip rate is reasonable. Reilinger and others (1977 #479) show a vertical crustal velocity of approximately 1 mm/yr in this area based on leveling data from 1934 and 1964 surveys. Gravity data suggest 3 km of vertical movement presumed to have occurred in the past 10 m.y. (Sonderegger and others, 1982 #297), which yields a long-term vertical slip rate that would fall within the assigned category.

Length End to end (km) 23.2
Cumulative trace (km) 25.2

Average strike (azimuth) 87°

643b, Red Rock Lakes section

Section number 643b

Section name Red Rock Lakes section

Comments: Shown as the Red Rock Lakes segment of Stickney and Bartholomew (1987 #242; written commun. 1992 #556). Section includes approximately the eastern half of Centennial Valley segment of Witkind (1975 #296) and number 1 (Centennial Valley segment) of Johns and others (1982 #259). Extends from near 7 L Ranch (0.6 km east of Curry Creek) eastward to Tom Creek.

Reliability of location Good

Comments: Location based on 1:62,500-scale map of Witkind (1975 #296); however, most of the fault is mapped as buried.

Sense of movement normal

Comments: (Witkind, 1975 #296)

Dip not reported

Dip direction N

Geomorphic expression Most of the fault is buried along this section (Witkind, 1975 #296), but scarps that are shown by Witkind are 3-10 m high with 35° maximum slope angles.

Age of faulted surficial deposits Lower Holocene (?) alluvial-fan deposits (Witkind, 1975 #296) at eastern end of section, but no other Quaternary deposits are shown as faulted.

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: A conservative estimate of age is used here because of conflicting data even though various authors regard movement on this part of the fault as being Holocene (Johns and others, 1982 #259; Pierce and Morgan, 1990 #222; 1992 #539) or late Quaternary (Stickney and Bartholomew, 1987 #85; 1987 #242; written commun. 1992 #556). Holocene (?) alluvium is shown as faulted; however, nearby upper Pleistocene (Pinedale) till is unfaulted and scarps are poorly preserved along this part of the fault (Witkind, 1975 #296). Myers and Hamilton (1964 #250) state that shorelines near Upper Red Rock Lake, thought to be altithermal (1800 B.C.) but certainly late Pleistocene (post-Pinedale) are faulted and warped by at least 18 m.

Recurrence interval >65±45 k.y.

Comments: Mason (1992 #463) suggests this recurrence interval for unspecified period of time based on data from Stickney and Bartholomew (1987 #85). However, this recurrence interval and the published slip rate seem to be incompatible.

Slip-rate category 1.0-5.0 mm/yr

Comments: Pierce and Morgan (1992 #539) report a maximum slip rate of 1.3 mm/yr in the past 15 k.y. for the eastern and central parts of the fault based on as much as 20 m of offset of 15 ka deposits from data of Witkind (1975 #296). A slip rate of >0.75 mm/yr in the past 2 Ma (Pierce and Morgan, 1992 #539) is based on 1.5-1.8 km minimum offset of Huckleberry Ridge Tuff. Sonderegger and others (1982 #297) indicate that an average displacement rate of 0.3 mm/yr is reasonable for this part of the fault. Reilinger and others (1977 #479) show a vertical crustal velocity of approximately 1 mm/yr in this area based on leveling data from 1934 and 1964 surveys.

Length End to end (km) 20.0
Cumulative trace (km) 20.2

Average strike (azimuth) 280°

643c, Red Rock Pass section

Section number 643c

Section name Red Rock Pass section

Comments: Shown as Red Rock Pass segment in Witkind (1975 #296), which extends from near Tom Creek to Rock Creek.

Reliability of location Good

Comments: Location based on 1:62,500-scale map of Witkind (1975 #296); however, most of the fault is mapped as buried.

Sense of movement normal

Comments: (Witkind, 1975 #296)

Dip not reported

Dip direction NE, SW

Geomorphic expression Northwest-trending en echelon faults in the bedrock high that separates Centennial Valley from Henrys Lake basin; trace is marked by aligned springs, marshes, and seeps (Witkind, 1975 #296).

Age of faulted surficial deposits Precambrian crystalline rocks (Witkind, 1975 #296)

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Pierce and Morgan (1990 #222; 1992 #539) show this section as Holocene and Johns and others (1982 #259) show it as late Pleistocene, but there is no compelling evidence to indicate late Quaternary faulting. No data are available to constrain time of most recent faulting; thus, a conservative estimate is offered here

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Scarps are not present on alluvial deposits, thus, the slip rate is assumed to be low. Reilinger and others (1977 #479) show a vertical crustal velocity of 2-5 mm/yr in this area, with rates decreasing to the west, based on leveling data from 1934 and 1964 surveys.

Length End to end (km) 9.9
Cumulative trace (km) 28.4

Average strike (azimuth) 308°

643d, Henrys Lake section

Section number 643d

Section name Henrys Lake section

Comments: Witkind (1975 #296) calls this the Henrys Lake segment but the part denoted as such extends well beyond the western limit of the mapped fault, which extends from Rock Creek eastward to near Henrys Lake at Bootjack Pass. Myers and Hamilton (1964 #250) also suggest that the fault continues eastward into the southern Madison Range. There are some south-stepping echelon scarps near the southeast shore of Henrys Lake (Stickney, oral commun., 1996) that may be unmapped fault scarps.

Reliability of location Good

Comments: Location based on 1:62,500-scale map of Witkind (1975 #296); however, most of the fault is mapped as buried.

Sense of movement normal

Comments: (Witkind, 1975 #296)

Dip not reported

Dip direction N

Geomorphic expression Fault is mostly concealed but probably consists of a single, east-trending trace (Witkind, 1975 #296). Stickney and Bartholomew (1987 #85) report a 1-km-long scarp on Holocene deposits along this part of the fault. Witkind (1975 #296) shows a scarp on Rock Creek moraine, which he inferred to be latest Pleistocene in age.

Age of faulted surficial deposits uppermost Pleistocene till (Witkind, 1975 #296), but Witkind notes that other nearby tills of comparable age are unfaulted.

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Although limited evidence exists that post-glacial (<15 ka) faulting has occurred (Witkind, 1975 #296), conflicting relations indicate that a more conservative estimate be used here. Pierce and Morgan (1990 #222; 1992 #539) show faulting on this section as Holocene and Johns and others (1982 #259) show it as late Pleistocene. Stickney and Bartholomew (1987 #85) document a 1-km-long Holocene scarp on this section.

Recurrence interval not reported

Slip-rate category 1.0-5.0 mm/yr

Comments: 1.3 mm/yr (<15 ka). Pierce and Morgan (1992 #539) report this value as the maximum slip rate for the eastern and central parts of the fault based on as much as 20 m of offset of 15 ka deposits from data of Witkind (1975 #296). A long-term (<2 Ma) slip rate of >0.75 mm/yr (Pierce and Morgan, 1992 #539) is based on 1.5-1.8 km minimum offset of Huckleberry Ridge Tuff (Sonderegger and others, 1982 #297). Reilinger and others (1977 #479) show a vertical crustal velocity of 5 mm/yr in this area based on leveling data from 1934 and 1964 surveys.

Length End to end (km) 10.2
Cumulative trace (km) 12.3

Average strike (azimuth) 78°

References

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#222 Pierce, K.L., and Morgan, L.A., 1990, The track of the Yellowstone hotspot—Volcanism, faulting, and uplift: U.S. Geological Survey Open-File Report 90-415, 68 p., 1 pl.

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#479 Reilinger, R.E., Citron, G.P., and Brown, L.D., 1977, Recent vertical crustal movements from precise leveling data in southwestern Montana, western Yellowstone National Park, and the Snake River Plain: Journal of Geophysical Research, v. 82, p. 5349-5359.

#249 Ross, C.P., and Nelson, W.H., 1964, Regional seismicity and brief history of Montana earthquakes, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-E, p. 25-30.

#314 Schofield, J.D., 1981, Structure of the Centennial and Madison Valleys based on gravitational interpretation, *in* Tucker, T.E., ed. Guidebook to southwest Montana: Montana Geological Society, 1981 Field Conference and Symposium, p. 275-283.

#297 Sonderegger, J.L., Schofield, J.D., Berg, R.B., and Mannick, M.L., 1982, The upper Centennial Valley, Beaverhead and Madison Counties, Montana: Montana Bureau of Mines and Geology Memoir 50, 53 p., 4 pls.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

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#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

644, Blacktail fault (Class A)

Structure Number 644

Comments: Refers to feature number 13 (Blacktail fault) of Witkind (1975 #317), number 5 (Blacktail fault) of Stickney and Bartholomew (1987 #85), and Blacktail fault of Stickney and Bartholomew (1987 #242; written commun. 1992 #556).

Structure Name Blacktail fault

Comments: The original source of the name Blacktail fault is probably Scholten and others (1955 #69), who describe it as extending at least 24 km northwestward from near Deer Creek. Pardee (1950 #46) shows it on his map and discusses it in his section on faults along the Beaverhead-Jefferson basin but does not give it a name. The fault shown here is based on descriptions provided by Stickney and Bartholomew (1987 #85) and the Montana Bureau of Mines and Geology digital data (Stickney and Bartholomew, written commun. 1992 #556) and extends from 1.5 km northwest of U.S. Highway 91 southeast to 1 km southeastward of Teddy Creek.

Synopsis In general, published information about the nature, timing, or extent of displacement is limited. Published maps reveal significant differences even in the location of the fault. One trench was excavated across the more recently active part of the range-front fault, but a younger fan surface about 1 km to the east has short scarp.

Date of compilation 10/19/92

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Dillon; Dubois

Physiographic province Northern Rocky Mountains

Geologic setting High-angle, down-to-the-northeast, range-front normal fault bounding the northeast side of the Blacktail Range. Amount of structural throw is not known; Scholten and others (1955 #69) indicate a throw of >750 m based on the height of the range-front escarpment. Hurlow (1995 #1063) indicates about 1 km of structural relief across fault.

Number of sections 2

Comments: Sections are based on distinctly different faulting histories along the fault; segments have been discussed in the literature but the level of detail is insufficient to define segments for the purpose of this database. The northwesternmost 12 km of the Blacktail fault [644a], described in Stickney and Bartholomew (1987 #85) as inactive, is the only part that has a recognizably different faulting history. The rest of the fault discussed by Stickney and Bartholomew (1987 #85) as the Cottonwood Creek scarp includes the three segments shown in the Montana Bureau of Mines and Geology digital data (Stickney and Bartholomew, written commun. 1992 #556); they are named the Northwest, Southeast, and Cottonwood segments. Detailed studies have not been completed to identify differences in timing of faulting events, and thus these parts of the fault are discussed collectively as a single section [644b]. Ostenaa and Wood (1990 #318) suggest the presence of more than one segment based on discontinuities in the fault trace and slightly better preserved scarps along the southeastern part of the fault, but they also note the absence of firm supporting evidence.

Length End to end (km) 39.7
Cumulative trace 42.3

Average strike (azimuth) 311°

644a, Unnamed (northwest) section

Section number 644a

Section name Unnamed (northwest) section

Comments: Section extends from 1.5 km northwest of U.S. Highway 91 southeastward to 1.5 km northwest of Sheep Creek.

Reliability of location Poor

Comments: Location of fault inferred from description of Stickney and Bartholomew (1987 #85).

Sense of movement normal

Comments: (Pierce and Morgan, 1990 #222; Ostenaa and Wood, 1990 #318)

Dip not reported

Dip direction NE

Geomorphic expression No scarps are known along this section of the fault. The morphology of the range-front is significantly more subdued than that to the southeast.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Stickney and Bartholomew (1987 #85) describe a 12-km-long part of the Blacktail fault as being inactive based on their classification scheme; that is they considered it to have been inactive since about 130 ka. The timing of the most recent event is inferred here to be possibly Quaternary based on the young movement to the southeast [644b]. Reconnaissance studies suggest possible Pleistocene displacement (M.J. Bartholomew, written commun. 1997).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the lack of evidence of slip in the past 130 k.y.

Length End to end (km) 11.8
Cumulative trace (km) 11.9

Average strike (azimuth) 310°

644b, Cottonwood section

Section number 644b

Section name Cottonwood section

Comments: Stickney and Bartholomew (1987 #85) discuss this part of the fault as the Cottonwood scarp; the geographic name is used here. The Northeast, Southwest, and Cottonwood segments in the Montana Bureau of Mines and Geology digital data (Stickney and Bartholomew, written commun. 1992 #556) are the three strands shown here; the Cottonwood segment is the short strand south of Cottonwood Creek. Section extends from 1.5 km northwest of Sheep Creek southeast to 1 km southeastward of Teddy Creek.

Reliability of location Poor

Comments: Location of fault is based on Montana Bureau of Mines and Geology digital data (Stickney and Bartholomew, written commun. 1992 #556), 1:500,000-scale map of Stickney and Bartholomew (1987 #242), and description of the fault given by Stickney and Bartholomew (1987 #85). Trace of fault shown by approximately 1:700,000-scale map of Ostenaa and Wood (1990 #318) differs significantly from what is portrayed here.

Sense of movement normal

Comments: (Pierce and Morgan, 1990 #222; Ostenaa and Wood, 1990 #318)

Dip not reported

Dip direction NE

Geomorphic expression No known detailed discussion of scarps exists, but Ostenaa and Wood (1990 #318) indicate there are at least some scarps on alluvium.

Age of faulted surficial deposits not reported

Paleoseismology studies Trench 644b-1, located on a terrace approximately 10 m above and south of Cottonwood Creek on rangeward strand of fault, was excavated in 1986. Data are published in Bartholomew and Stickney (1987 #9) and Stickney and others (1987 #295). Trench did not expose the fault but did expose at least one colluvial wedge (Stickney, oral commun. 1994).

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Stickney and Bartholomew (1987 #85; 1987 #242; written commun. 1992 #556) indicate that the most recent faulting event on this fault occurred between 13 and 150 ka, supported by trenching south of Cottonwood Creek (Bartholomew and Stickney, 1987 #9; Stickney and others, 1987 #295). Stickney and others (1987 #295) document that contact between inferred upper Quaternary (Bull Lake) outwash and upper Pleistocene mud flow is offset 5 m. Bartholomew and Stickney (1987 #9) indicate the scarp formed during one or more late Pleistocene faulting events. Ostenaa and Wood (1990 #318) estimate that the most recent event occurred between 15 and 35 ka based on a 2-m-high scarp on upper Pleistocene (inferred to be contemporaneous with the last glacial cycle, Pinedale) fan near Cottonwood Creek. The short piedmont scarp south of Cottonwood Creek is designated post-latest glacial (<13 ka) in Stickney and Bartholomew (1987 #242). Pierce and Morgan (1990 #222) show the Blacktail fault on their regional map as having post-glacial (<15 ka) movement; however, the fault is designated as late Pleistocene (<100 ka) in the text. We use a conservative estimate for the most recent movement because the faulting history is poorly understood.

Recurrence interval 15-30 k.y.

Comments: Ostenaa and Wood (1990 #318) suggest this preliminary and speculative recurrence interval based on trenching data (Stickney and others, 1987 #295) and surficial relations along this section. They note that recurrence intervals on this fault may be longer than that for other faults in this area and that the given interval is probably a minimum. The time interval for which this recurrence is valid is not documented.

Slip-rate category unknown; probably <0.2 mm/yr

Comments: No published slip rates exist for this section, an inferred low slip rate is based on the small (4-5 m) amount of offset of inferred upper (<150-ka) Quaternary deposits (Stickney and Bartholomew, 1987 #85).

Length End to end (km) 27.6
Cumulative trace (km) 30.4

Average strike (azimuth) 320°

References

#9 Bartholomew, M.J., and Stickney, M.C., 1987, Late Quaternary faulting in southwestern Montana: Geological Society of America Abstracts with Programs, v. 19, p. 258-259.

#1063 Hurlow, H.A., 1995, Late Pliocene or younger paleostress directions from fractured clasts, Sixmile Creek Formation, lower Red Rock Valley, SW Montana: Geological Society of America Abstracts with Programs, v. 27, no. 4, p. 16.

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#222 Pierce, K.L., and Morgan, L.A., 1990, The track of the Yellowstone hotspot—Volcanism, faulting, and uplift: U.S. Geological Survey Open-File Report 90-415, 68 p., 1 pl.

#69 Scholten, R., Keenmon, K.A., and Kupsch, W.O., 1955, Geology of the Lima region, southwestern Montana and adjacent Idaho: Geological Society of America Bulletin, v. 66, p. 345-404.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

#295 Stickney, M.C., Bartholomew, M.J., and Wilde, E.M., 1987, Trench logs across the Red Rock, Blacktail, Lima Reservoir, Georgia Gulch, Vendome and Divide faults, Montana: Geological Society of America Abstracts with Programs, v. 19, p. 336-337.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

645, Sweetwater fault (Class A)

Structure Number 645

Comments: Refers to number 6 (Sweetwater fault) of Stickney and Bartholomew (1987 #85) and Sweetwater fault of Stickney and Bartholomew (1987 #242; written commun. 1992 #556).

Structure Name Sweetwater fault

Comments: Source of name is probably Schmidt and Hendrix (1981 #1070), who show the fault on a map but do not describe it. Also referred to as the Timber Hill fault by Fritz and Sears (1993 #1235). Stickney and Bartholomew (1987 #85; 1987 #242) show this fault south of and parallel to Sweetwater Creek and extending along the northern flank of Timber Hill.

Synopsis Much of the fault has been studied by reconnaissance investigations. In general, little specific evidence is published about the nature, timing, or extent of displacement.

Date of compilation 05/05/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison; Beaverhead

1° x 2° sheet Dillon

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location of fault is based on Montana Bureau of Mines and Geology digital data (Stickney and Bartholomew, written commun. 1992 #556) and 1:500,000-scale map of Stickney and Bartholomew (1987 #242).

Geologic setting High-angle, down-to-the-northeast, range-front normal fault bounding the south side of the Sweetwater Basin. The Sweetwater fault appears to be more or less coincident with a thrust fault shown on the geologic map of Dillon (Ruppel and others, 1993 #646). Vertical, normal separation is about 20 m in past 6 m.y. (Fritz and Sears, 1993 #1235).

Sense of movement normal

Comments: (Pierce and Morgan, 1990 #222; Ostenaa and Wood, 1990 #318)

Dip not reported

Dip direction NE

Geomorphic expression Well-preserved scarps are present at the mouths of most small drainages (Ostenaa and Wood, 1990 #318). Scarps are absent on Holocene deposits, and 1- to 2-m-high scarps are present on upper Pleistocene deposits (Stickney and Bartholomew, 1987 #85).

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Stickney and Bartholomew (1987 #85; 1987 #242; written commun. 1992 #556) indicate that the most recent faulting event occurred 13-150 ka. Pierce and Morgan (1990 #222), however, show this fault as having post-glacial (<15 ka) movement. Ostenaa and Wood (1990 #318) indicate that the most recent event occurred <15-25 ka on Table 1-1 and <12-25 ka on Table 2-1, but they state that no clearly recognizable Holocene deposits are displaced. Thus, we use a conservative estimate for the most recent movement because the faulting history is poorly understood.

Recurrence interval 10-40 k.y.

Comments: Ostenaa and Wood (1990 #318) infer this average recurrence interval based on the late Quaternary slip rate (0.05-0.1 mm/yr) and slip of 1-2 m per event, as indicated by the height of single-event scarps. A recurrence interval of 10-20 k.y. is shown on Table 1-1 and 10-40 k.y. on Table 2-1; however, they refer to the later recurrence interval in the text.

Slip-rate category <0.2 mm/yr

Comments: Stickney and Bartholomew (1987 #85) document 250 m of offset of the 4 Ma Timber Butte basalt (Kreps and others, 1992 #1236) across the Sweetwater fault, from which they state that the average slip rate is 0.06 cm/yr. However, these data yield a slip rate of 0.06 mm/yras noted by Ostenaa and Wood (1990 #318); who also suggest a similar late Quaternary slip rate (0.05-0.1 mm/yr) based on the 1- to 2-m-high scarps on upper Pleistocene deposits. Long-term slip rate is significantly less than 0.04 mm/yr if revised age of Timber Hill basalt is taken into account. Fritz and Sears (1993 #1235) indicate that the basalt is offset 200 m, which further reduces the long-term slip rate.

Length End to end (km) 13.2
Cumulative trace (km) 13.2

Average strike (azimuth) 307°

References

#1235 Fritz, W.J., and Sears, J.W., 1993, Tectonics of the Yellowstone hotspot wake in southwestern Montana: Geology, v. 21, p. 427-430.

#1236 Kreps, J., Fritz, W.J., Sears, J.W., and Wampler, J.M., 1992, The 6 Ma Timber Hill basalt flow—Implications for late-Cenozoic drainage systems and the onset of Basin-and-Range style faulting, southwestern Montana: Geological Society of America Abstracts with Programs, v. 24, no. 6, p. 22.

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#222 Pierce, K.L., and Morgan, L.A., 1990, The track of the Yellowstone hotspot—Volcanism, faulting, and uplift: U.S. Geological Survey Open-File Report 90-415, 68 p., 1 pl.

#646 Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1° x 2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1803-H, 1 sheet, scale 1;250,000.

#1070 Schmidt, C.J., and Hendrix, T.E., 1981, Tectonic controls for thrust belt and Rocky Mountain foreland structures in the northern Tobacco Root Mountains—Jefferson Canyon area, southwestern Montana, *in* Tucker, T.E., ed. Guidebook to southwest Montana: Montana Geological Society, 1981 Field Conference and Symposium, p. 167-180.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

646, Lima Reservoir fault (Class A)

Structure Number 646

Comments: Refers to feature number 10 (Lima Reservoir graben) of Stickney and Bartholomew (1987 #85). Shown as North Shore scarps, one of three sets of scarps defining the Lima Reservoir graben of Stickney and Bartholomew (1987 #242) and Lima graben of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Lima Reservoir fault

Comments: Earliest reference to this fault is Myers and Hamilton (1964 #250). However, the original source of name is Bartholomew and Stickney (1987 #9), who also called this feature Lima Reservoir graben (Stickney and Bartholomew, 1987 #85; Stickney and Bartholomew, 1987 #242) and Southwest, Middle, and Northeast segments of the Lima graben in Montana Bureau of Mines and Geology digital database (Stickney and Bartholomew, written commun. 1992 #556).

Synopsis Little is known about these three, short, subparallel fault scarps, but one has been trenched. Trenching data and stratigraphic relations suggest multiple faulting events in post-glacial (<15 ka) time.

Date of compilation 04/20/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Trace is from digital data of Stickney and Bartholomew (written commun. 1992 #556) compiled at scale of 1:250,000.

Geologic setting Fault, as shown, consists of three intrabasin scarps forming a horst (on the north) and graben (on the south). The middle of the three scarps is the highest, about 3-4 m. Amount of total throw unknown.

Sense of movement normal

Comments: (Stickney and Bartholomew, 1987 #242)

Dip not reported

Dip direction S; N

Geomorphic expression Myers and Hamilton (1964 #250) indicate presence of 6-m-high scarps.

Age of faulted surficial deposits Pleistocene fluvial deposits (Bartholomew and Stickney, 1987 #9)

Paleoseismology studies A trench (646-1) was excavated in 1986 across the middle, down-to-south scarp (Bartholomew and Stickney, 1987 #9; Stickney and others, 1987 #295). Site was located in the western one-third of the scarp; digital location given here is approximate. Evidence indicates at least two faulting events resulting in more than 7 m of offset of Pleistocene deposits and at least 5 m of offset of upper Quaternary? (pre-Pinedale) deposits. The earlier faulting event generated sandblows.

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Stickney and Bartholomew (1987 #242) indicate the northern of the three scarps is late Quaternary; however, the southern two were shown as post-glacial, as supported by trenching data (Bartholomew and Stickney, 1987 #9; Stickney and others, 1987 #295). Conversely, Stickney and Bartholomew (1987 #85; written commun. 1992 #556) assign a Holocene age for all three scarps. We use the conservative estimate here. Ostenaa and Wood (1990 #318) contend that these scarps may be subsidiary to the Centennial fault [643], which is thought to be Holocene along its western section.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on 1- to 2-m-high scarps on lower Holocene deposits and 6- to 8-m-high scarps on upper Quaternary deposits (Stickney and Bartholomew, 1987 #85).

Length End to end (km) 2.9
Cumulative trace (km) 6.4

Average strike (azimuth) 289°

References

#9 Bartholomew, M.J., and Stickney, M.C., 1987, Late Quaternary faulting in southwestern Montana: Geological Society of America Abstracts with Programs, v. 19, p. 258-259.

#250 Myers, W.B., and Hamilton, W., 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-I, p. 55-98.

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

#295 Stickney, M.C., Bartholomew, M.J., and Wilde, E.M., 1987, Trench logs across the Red Rock, Blacktail, Lima Reservoir, Georgia Gulch, Vendome and Divide faults, Montana: Geological Society of America Abstracts with Programs, v. 19, p. 336-337.

647, Kissick fault (Class A)

Structure Number 647

Comments: Refers to number 12 (Kissick fault) of Witkind (1975 #317).

Structure Name Kissick fault

Comments: Name is possibly from Scholten and others (1955 #69), who showed it as extending a few kilometers north of location shown in this compilation. Fault extends from approximately the latitude of confluence of Hansen Creek and Medicine Lodge Creek southeastward to near head waters of Warm Springs Creek.

Synopsis Fault is poorly understood, no known studies have been completed at time of this compilation. Age is poorly constrained, movement on fault may be entirely Tertiary in age.

Date of compilation 03/31/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Fault trace is from 1:700,000-scale map of Ostenaa and Wood (1990 #318).

Geologic setting High-angle, down-to-southwest, normal fault that traverses irregular topography on western side of northern part of Tendoy Range (Ostenaa and Wood, 1990 #318).

Sense of movement normal

Comments: (Scholten and others, 1955 #69)

Dip not reported

Dip direction SW

Geomorphic expression Fault has no geomorphic expression, faceted spurs, or scarps on Tertiary basin fill or Quaternary alluvium, which has limited aerial extent (Ostenaa and Wood, 1990 #318).

Age of faulted surficial deposits Unknown; Scholten and others (1955 #69) described the fault as juxtaposing Tertiary and Precambrian allochthonous rocks.

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Fault has no characteristics of being active in the late Quaternary, but is considered it to be potential seismic source (Ostenaa and Wood, 1990 #318). Fault was active at least as recently as Miocene time (Scholten and others, 1955 #69). Witkind (1975 #317) showed fault as late Cenozoic in age. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Absence of scarps indicates a low slip rate.

Length End to end (km) 14.2
Cumulative trace (km) 14.4

Average strike (azimuth) 337°

References

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.
#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.
#69 Scholten, R., Keenmon, K.A., and Kupsch, W.O., 1955, Geology of the Lima region, southwestern Montana and adjacent Idaho: Geological Society of America Bulletin, v. 66, p. 345-404.
#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

648, Red Rock Hills fault (Class A)

Structure Number 648

Structure Name Red Rock Hills fault

Comments: An early reference to Red Rock Hills fault is Scholten and others (1955 #69), who described the discontinuous fault as extending from near southern end of Clark Canyon Reservoir (north) to northeast of Lima, Montana (south). Northern part of fault described by Scholten is an older structure (Quaternary?) and not coincident with Monument Hill (Ostenaa and Wood, 1990 #318) section [648a] described here. Discontinuous fault shown here extends from Maurer Creek southeastward to Red Rock River.

Synopsis This feature is virtually unstudied. Johnson (1981 #30) discussed but did not map fault, and Ostenaa and Wood (1990 #318) question some of his conclusions.

Date of compilation 02/09/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Geologic setting Fault consists of several widely separated northwest-trending, down-to-southwest normal faults bounding southwest side of Red Rock Hills. Johnson (1981 #30) considered it to be an antithetic to the Red Rock fault [641], which bounds the west side of Red Rock graben, and to have an equivalent amount of total throw of 1 km (Johnson, 1981b #313).

Number of sections 3

Comments: Sections are based on presumed age difference between northern section and other two sections, and lack of continuous expression between southern two sections.

Length End to end (km) 337.5
Cumulative trace (km) 35.8

Average strike (azimuth) 314°

648a, Monument Hill section

Section number 648a

Section name Monument Hill section

Comments: Defined as Monument Hill segment by Ostenaa and Wood (1990 #318). Extends about 11 km southeastward from Maurer Creek.

Reliability of location Good

Comments: Location of scarps based on 1:24,000-scale map of Ostenaa and Wood (1990 #318).

Sense of movement normal

Comments: (Scholten and others, 1955 #69). Orientation of extension fractures in clasts associated with presently inactive northwestern extension of this section suggests post-late Pliocene sinistral or sinistral-oblique movement (Hurlow, 1995 #1063).

Dip not reported

Dip direction SW

Geomorphic expression Characterized by 3- to 4-m-high scarps on alluvium, aligned springs, and faceted spurs along much of trace.

Age of faulted surficial deposits Upper Pleistocene alluvium (Ostenaa and Wood, 1990 #318).

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Time is based on morphology of one scarp profile and inferred age of faulted deposit, which is based on position of deposits in landscape (Ostenaa and Wood, 1990 #318). Scarp profile suggests that faulting might be contemporaneous with most recent faulting on Timber Butte segment [641B] of Red Rock fault. Profiled scarp may be the result of 1 or 2 faulting events.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on data presented by Ostenaa and Wood (1990 #318) of 3-4 m of offset of late Pleistocene fan thought to be 12-35 ka. If offset of fan is result of 2 events, then minimum rate is falls within the assigned slip-rate category; however if single event, a maximum rate could fall within the next higher slip-rate category.

Length End to end (km) 10.7
Cumulative trace (km) 9.8

Average strike (azimuth) 324°

648b, Unnamed (central) section

Section number 648b

Section name Unnamed (central) section

Comments: Section consists of two subparallel fault scarps north of Sage Creek.

Reliability of location Poor

Comments: Location based on 1:200,000-scale mapping of Scholten and others (1955 #69).

Sense of movement normal

Comments: (Scholten and others, 1955 #69)

Dip not reported

Dip direction SW

Geomorphic expression Fault is defined by "linear swales at base of high angle slopes," triangular faces (dipping 18°-20°), and series of springs (Johnson, 1981b #313).

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Most recent event is suspected to be Quaternary; although no definitive estimate of age has been reported.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on lack of data to indicate late Quaternary slip.

Length End to end (km) 6.8
Cumulative trace (km) 6.7

Average strike (azimuth) 307°

648c, Unnamed (south) section

Section number 648c

Section name Unnamed (south) section

Comments: Section includes subparallel lineaments northeast of Lima, Montana.

Reliability of location Poor

Comments: Location based on 1:200,000-scale mapping of Scholten and others (1955 #69).

Sense of movement normal

Comments: (Scholten and others, 1955 #69)

Dip not reported

Dip direction SW

Geomorphic expression Characterized by 1- to 3-km-long, prominent, subparallel lineaments (Ostenaa and Wood, 1990 #318).

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Fault is not known to displace Quaternary deposits (Ostenaa and Wood, 1990 #318), but section is suspected to be Quaternary in age.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on lack of data to indicate late Quaternary slip.

Length End to end (km) 5.4
Cumulative trace (km) 19.3

Average strike (azimuth) 311°

References

#1063 Hurlow, H.A., 1995, Late Pliocene or younger paleostress directions from fractured clasts, Sixmile Creek Formation, lower Red Rock Valley, SW Montana: Geological Society of America Abstracts with Programs, v. 27, no. 4, p. 16.

#30 Johnson, P.P., 1981, Geology of the Red Rock fault and adjacent Red Rock valley, Beaverhead County, Montana: Missoula, University of Montana, unpublished M.S. thesis, 88 p., 2 pls.

#313 Johnson, P.P., 1981b, Geology of the Red Rock fault and adjacent Red Rock valley, Beaverhead County, Montana, *in* Tucker, T.E., ed. Guidebook to southwest Montana: Montana Geological Society, 1981 Field Conference and Symposium, p. 245-251.

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#69 Scholten, R., Keenmon, K.A., and Kupsch, W.O., 1955, Geology of the Lima region, southwestern Montana and adjacent Idaho: Geological Society of America Bulletin, v. 66, p. 345-404.

649, Tobacco Root fault (Class A)

Structure Number 649

Comments: Refers to number 53 (unnamed fault along east side of Jefferson valley) of Witkind (1975 #317), number 6 (Tobacco Root Mountains western border fault) of Johns and others (1982 #259).

Structure Name Tobacco Root fault

Comments: Pardee (1919 #765; 1950 #46), as well as Tansley and others (1933 #768), speculated about the existence of a range-front fault along the Beaverhead-Jefferson basin, but neither named the fault. Source of the name may be Berg (1959 #761) as cited by Chadwick and Leonard (1979 #762). Fault extends from 2 km east of Renova, Montana, southward to 6.5 km east of Twin Bridges, Montana. The southern part of the fault coincides with the trace of the Georgia Gulch fault [667]. Johns and others (1982 #259) show a longer fault, which extends from north of the Jefferson River southward, across the Ruby River and joins the intersection of Ruby Range western [665] and northern [666] border faults.

Synopsis Most of the fault has only received preliminary reconnaissance investigation. In general, little detailed evidence is published about the nature, timing, or extent of displacement. Published maps reveal significant differences even in the location of the fault.

Date of compilation 05/09/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Dillon

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Trace is compiled, with minor modifications, from 1:250,000-scale geologic map of Ruppel and others (1993 #646). Location of fault presented here differs significantly from that of Witkind (1975 #320) and Johns and others (1982 #259).

Geologic setting High-angle, down-to-the-west, range-front normal fault bounding the western side of the Tobacco Root Mountains. Pardee (1950 #46) suggests displacement may be 1.5-1.8 km based on projection of offset erosional surfaces, and Johns and others (1982 #259) cite a personal communication with Schofield who suggested that the Tertiary fill may be 4-5 km thick near the southern end of the fault based on gravity data. Kuenzi and Fields (1971 #757) estimate about 1.8 km of post-mid-Pliocene stratigraphic throw based on comparison of dips for Sixmile Creek strata, but concede that separation may only be about 0.9 km.

Sense of movement normal

Comments: (Witkind, 1975 #317; Johns and others, 1982 #259)

Dip not reported

Dip direction W

Geomorphic expression Slightly eastward tilted range block, abrupt and imposing range front, faceted spurs with aligned bases (Pardee, 1950 #46). No scarps on alluvium are reported.

Age of faulted surficial deposits Miocene-Pliocene Sixmile Creek Formation (Johns and others, 1982 #259)

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Johns and others (1982 #259) inferred Quaternary movement on this fault, but provide no substantiating data. Witkind (1975 #320) indicated this fault is probably late Cenozoic but does not rule out Quaternary activity. Pardee (1950 #46) suggested that the majority of faulting may have been completed during the Tertiary, but the degree of faceted-spur preservation suggests Pleistocene displacement. Kuenzi and Fields (1971 #757) suggest that faulting ceased prior to the late Pleistocene. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Bartholomew and Stickney examined several sites along the fault and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997). Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned herein. The timing of the most recent event is inferred here to be possibly Quaternary based on the young movement to the south, on the nearby Georgia Gulch fault [667]. No studies to date have addressed the fault described here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on the absence of scarps.

Length End to end (km) 32.4
Cumulative trace (km) 33.7

Average strike (azimuth) 20°

References

#761 Berg, A.B., 1959, The geology of the northwestern corner of the Tobacco Root Mountains, Madison County, Montana: Minneapolis, University of Minnesota, unpublished M.S. thesis, 75 p.

#762 Chadwick, R.A., and Leonard, R.B., 1979, Structural controls of hot-spring systems in southwestern Montana: U.S. Geological Survey Open-File Report 79-1333, 25 p.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#757 Kuenzi, W.D., and Fields, R.W., 1971, Tertiary stratigraphy, structure, and geologic history, Jefferson basin, Montana: Geological Society of America Bulletin, v. 82, p. 3373-3393.

#765 Pardee, J.T., 1919, Some manganese deposits in Madison County, Montana, *in* Contributions to economic geology 1918: U.S. Geological Survey Bulletin 690, p. 131-143.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#646 Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1° x 2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1803-H, 1 sheet, scale 1;250,000.

#768 Tansley, W., Schaefer, P.A., and Hart, L.H., 1933, A geological reconnaissance of the Tobacco Root Mountains, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 9, 57 p.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

#320 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in Idaho: U.S. Geological Survey Open-File Report 75-278, 71 p. pamphlet, 1 sheet, scale 1:500,000.

650, South Horse Prairie basin fault (Class A)

Structure Number 650

Comments: Not shown in any previous compilation.

Structure Name South Horse Prairie basin fault

Comments: Fault shown in Ostenaa and Wood (1990 #318). Fault extends from northern end of bedrock spur in Beaverhead Mountains, west of Horse Prairie Creek, to south of Cruikshank Creek.

Synopsis History of fault is poorly known, no detailed studies have been completed. Sole source of data is Ostenaa and Wood (1990 #318).

Date of compilation 03/31/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead; Lemhi (ID)

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Fault trace is from 1:700,000-scale map of Ostenaa and Wood (1990 #318).

Geologic setting High-angle, down-to-west, normal fault along eastern side of Horse Prairie basin in the northern Beaverhead Mountains. No known estimates of total displacement exist.

Sense of movement normal

Comments: (Ostenaa and Wood, 1990 #318)

Dip not reported

Dip direction W

Geomorphic expression Ostenaa and Wood (1990 #318) report no evidence of late Quaternary movement but Quaternary deposits have limited aerial extent along the fault.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Fault has no characteristics of being active in the late Quaternary, but it cuts Miocene basin fill and is considered to be potential seismic source (Ostenaa and Wood, 1990 #318). They show fault as Cenozoic with possible or inferred Quaternary movement.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of evidence for late Quaternary movement.

Length End to end (km) 24.8
Cumulative trace (km) 21.7

Average strike (azimuth) 2°

References

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

651, East Muddy Creek fault (Class A)

Structure Number 651

Comments: Refers to number 9 (East Muddy Creek fault) of Witkind (1975 #317).

Structure Name East Muddy Creek fault

Comments: An early reference to East Muddy Creek fault is Scholten and others (1955 #69), and might be source of name. Fault extends from approximately the latitude of north fork of McKnight Canyon southward to Shearing Pen Gulch.

Synopsis History of fault is poorly known; no detailed work has been completed. There is little general agreement in the time of most recent movement. Fault is complimentary basin-bounding fault to the West Muddy Creek fault [652].

Date of compilation 04/01/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Fault trace is from 1:700,000-scale map of Ostenaa and Wood (1990 #318).

Geologic setting High-angle, down-to-west, normal fault bounding northeast side of Muddy Creek basin.

Sense of movement normal

Comments: (Scholten and others, 1955 #69)

Dip not reported

Dip direction SW

Geomorphic expression Scholten and others (1955 #69) comment that fault is a distinctive feature for more than 15 mi but do not describe its characteristics.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Fault has no features indicative of late Quaternary movement, but is considered it to be a potential seismic source (Ostenaa and Wood, 1990 #318). Witkind (1975 #317) shows fault as late Cenozoic but suggests that it might not have been active since Oligocene. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. M.J. Bartholomew (written commun. 1997) found no evidence suggesting late Quaternary faulting with the exception of a single scarp of indeterminable origin. Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on lack of data to indicate late Quaternary slip.

Length End to end (km) 18.2
Cumulative trace (km) 18.6

Average strike (azimuth) 337°

References

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#69 Scholten, R., Keenmon, K.A., and Kupsch, W.O., 1955, Geology of the Lima region, southwestern Montana and adjacent Idaho: Geological Society of America Bulletin, v. 66, p. 345-404.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

652, West Muddy Creek fault (Class A)

Structure Number 652

Comments: Refers to number 10 (West Muddy Creek fault) of Witkind (1975 #317).

Structure Name West Muddy Creek fault

Comments: Scholten and others (1955 #69) is an early reference to West Muddy Creek fault and might be source of its name. Fault extends from south of Warm Springs Creek southward to near headwaters of Williamson Wood Canyon.

Synopsis History of fault is poorly known, no detailed work has been completed. There is little general agreement in the time of most recent movement. Fault is complimentary basin-bounding fault to the East Muddy Creek fault [651].

Date of compilation 04/01/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Fault trace is from 1:700,000-scale map of Ostenaa and Wood (1990 #318).

Geologic setting High-angle, down-to-east, normal fault bounding southwest side of Muddy Creek basin.

Sense of movement normal

Comments: (Scholten and others, 1955 #69)

Dip not reported

Dip direction E

Geomorphic expression Scholten and others (1955 #69) state that fault forms distinctive scarp separating Madison Group from Tertiary sedimentary and volcanic basin fill in Muddy Creek basin.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Fault has no features indicative of late Quaternary movement, but is considered it to be potential seismic source (Ostenaa and Wood, 1990 #318). Witkind (1975 #317) shows fault as late Cenozoic but suggests it might not have been active since Oligocene. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Bartholomew and Lewis examined several sites along the fault and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997). Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on lack of data to indicate late Quaternary slip.

Length End to end (km) 19.7
Cumulative trace (km) 20.3

Average strike (azimuth) 341°

References

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#69 Scholten, R., Keenmon, K.A., and Kupsch, W.O., 1955, Geology of the Lima region, southwestern Montana and adjacent Idaho: Geological Society of America Bulletin, v. 66, p. 345-404.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

653, Unnamed fault near Trail Creek (Class A)

Structure Number 653

Comments: Not shown on any previous compilation.

Structure Name Unnamed fault near Trail Creek

Comments: Short scarp named Trail Creek scarp by Stickney and Bartholomew (1987 #242). The 2-km-long scarp is centered on Trail Creek at the southwest end of Snowcrest Range. Scarp is one of three sets of scarps north of Lima Reservoir. This feature was not included in the Montana Bureau of Mines and Geology digital database (Stickney and Bartholomew, written commun. 1992 #556).

Synopsis Fault is poorly known, no detailed work has been completed. Sole source of data is Stickney and Bartholomew (1987 #242).

Date of compilation 04/15/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Trace of scarp from 1:24,000-scale map of Stickney (written comm., 1992).

Geologic setting High-angle, down-to-southwest normal fault.

Sense of movement normal

Comments: (Stickney and Bartholomew, 1987 #242)

Dip not reported

Dip direction SW

Geomorphic expression A narrow graben is preserved along part of the main scarp.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation latest Quaternary (<15 ka)

Comments: Age estimate is from Stickney and Bartholomew (1987 #242), who did not provide substantiating data. Narrow graben is still visible along part of the main scarp (Stickney, oral commun., 1996).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred based on lack of data to indicate otherwise.

Length End to end (km) 2.3
Cumulative trace (km) 2.4

Average strike (azimuth) 308°

References

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

654, Unnamed fault near Middle Creek (Class A)

Structure Number 654

Comments: Not shown on any previous compilation.

Structure Name Unnamed fault near Middle Creek

Comments: Short scarp named Middle Creek scarp by Stickney and Bartholomew (1987 #242). The scarp extends 3 km westward from Middle Creek southeast of Peterson Basin near southern end of Snowcrest Range. Scarp is one of three sets of scarps north of Lima Reservoir. This feature was not included in the Montana Bureau of Mines and Geology digital database (Stickney and Bartholomew, written commun. 1992 #556).

Synopsis Fault is poorly understood, no known work has been completed at time of compilation. Sole source of data is Stickney and Bartholomew (1987 #242).

Date of compilation 04/15/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Dubois

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Trace of scarp from 1:24,000-scale map of Stickney (written commun. 1992).

Geologic setting High-angle, down-to-south normal fault.

Sense of movement normal

Comments: (Stickney and Bartholomew, 1987 #242)

Dip not reported

Dip direction S

Geomorphic expression not reported

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Age estimate is from Stickney and Bartholomew (1987 #242), who do not provide substantiating data.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on lack of data to indicate otherwise.

Length End to end (km) 2.4
Cumulative trace (km) 3.0

Average strike (azimuth) 284°

References

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

655, Madison fault (Class A)

Structure Number 655

Comments: Refers to fault number 5 (Madison Range fault) of Witkind (1975 #317); fault numbers 45 (Madison Range fault-southern segment), 46 (Madison Range fault-middle segment), and 47 (Madison Range fault-northern segment) of Johns and others (1982 #259); fault number 11 (Madison fault) of Stickney and Bartholomew (1987 #85); Jack Creek, Cedar Creek, Burger Creek, Bear Creek, and Indian Creek scarps and Madison Canyon segment of the Madison fault of Stickney and Bartholomew (1987 #242); and Jordan Creek, Jack Creek, Cedar Creek, Burger Creek, Bear Creek, Indian Creek, Madison Canyon, and Northern Henrys Lake segments of the Madison fault of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Madison fault

Comments: Pardee (1950 #46) is an early reference to this fault, who called it the Madison Range fault. Most of the early literature followed this nomenclature; however, the name "Madison fault" is commonly used now. Also shown as "Madison Valley fault" (U.S. Coast and Geodetic Survey, 1959 #630). The fault extends from north of Saint Joe Creek southwestward to Garner Canyon. Witkind and others (1964 #629) described the fault as extending farther south to near Big Springs, but did not show it as such on their map. Young (1985 #690) shows this fault extending farther north (at least another 2 km) to the edge of her map and states that its trace may coincide with the Madison River near the Madison Powerhouse.

Synopsis Detailed mapping and reconnaissance studies of scarp morphology along the northern two sections of the fault are the primary source of data for this fault; segmentation models have been proposed based on these data. No single study has examined the entire fault, and no detailed site studies, such as trenching, have been conducted. Short parts of the fault ruptured during the 1959 Hebgen Lake earthquake with displacements of less than 1 m. No known published investigations of the southern section of the fault are available.

Date of compilation 02/09/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison; Fremont (ID)

1° x 2° sheet Bozeman; Ashton

Physiographic province Northern Rocky Mountains

Geologic setting High-angle, down-to-west, range-front normal fault bounding western side of Madison Range. Maximum depth to basement in northern Madison Valley is about 2.1 km, in central Madison Valley the depth may be in excess of 4.5 km, and in southern Madison Valley about 1.2 km (Schofield, 1981 #314; Rasmussen and Fields, 1985 #481). Maximum total throw is probably more than 8 km according to Locke and Schneider (1990 #253).

Number of sections 3

Comments: Several reports discuss the right-stepping echelon nature of this fault as evidence of separate tectonic blocks with Pardee (1950 #46) being the earliest, and further discussed by Shelden (1960 #478). Young (1985 #690) describes 12 segments along the northern 10-12 km of the fault, but each are defined based on parts of the fault having a similar strike. Johns and others (1982 #259) and Schneider (1985 #319) defined three segments; the latter discussed the northern two in detail. These previously published boundaries roughly coincide with the section boundaries shown here. Even though sections, as shown here, are nearly coincident with "segments" of Johns and others (1982 #259), they assign a single age (Holocene) to the whole fault based on the short ruptures from the 1959 Hebgen Lake earthquake south of Madison Canyon (Witkind, 1964 #247; Myers and Hamilton, 1964 #250). Available data suggests timing of the most-recent faulting event does differ along strike; however, the published data do not meet our minimum requirements for defining segments for this database.

Length End to end (km) 98.7
Cumulative trace (km) 109.7

Average strike (azimuth) 341°

655a, Unnamed (north) section

Section number 655a

Section name Unnamed (north) section

Comments: Although Schneider (1985 #319) discusses and defines segments of the Madison fault based on morphologic studies, he did not assign names. Section shown herein is probably same as northern segment of Schneider, which extends from Jack Creek to south of Indian Creek. Scarps north of Jack Creek from Kellogg (1992 #433; 1993 #565) are not included.

Reliability of location Good

Comments: Trace is compiled from 1:24,000-scale (Kellogg, 1992 #433; 1993 #565; 1993 #566) and 1:62,500-scale (Hadley, 1969 #572) geologic maps. Mapped traces of scarps from these sources are shown as solid lines, dotted lines are traces inferred by compiler.

Sense of movement normal

Comments: (Witkind, 1975 #317). Predominant sense of movement is probably normal; however, Young (1985 #690) documents slickensides that suggest sinistral, dextral, and normal movement on the variously oriented parts of the fault.

Dip not reported

Comments: Dip is inferred to be steep (Johns and others, 1982 #259); however, Rasmussen and Fields (1985 #481) suggest that the fault is listric and soles into a Laramide thrust based on seismic data.

Dip direction W

Geomorphic expression Fault is expressed as discontinuous, high (locally in excess of 35 m) scarps on alluvium with steep (20°-40°, with mode around 30°) maximum slope angles (Schneider, 1985 #319).

Age of faulted surficial deposits Holocene and upper Pleistocene alluvium, colluvium, and debris flows (Kellogg, 1992 #433; Kellogg, 1993 #565) upper Pleistocene till, and locally, Cretaceous bedrock (Hadley, 1969 #572; Tysdal, 1990 #573).

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Age assignment is from Stickney and Bartholomew (1987 #85; 1987 #242; written commun. 1992 #556); however, parts of this section (Burger Creek segment and Indian Creek segment) are thought to be Holocene. Geologic mapping indicates the majority of scarps are on Holocene and upper Pleistocene alluvium, colluvium, and debris flows (Kellogg, 1992 #433; 1993 #565). In contrast, earlier studies by Schneider (1985 #319) indicated that the fault does not appear to displace upper Pleistocene (Pinedale and possibly not Bull Lake) deposits. The time of most recent movement along this part of the fault does not appear to be well constrained; thus, a conservative estimate is used here.

Recurrence interval >10 k.y.

Comments: Schneider (1985 #319) provides this recurrence interval for an unspecified period of time. Mason (1992 #463) indicates recurrence interval is 15±5 k.y. for an unspecified period of time based on data of Stickney and Bartholomew (1987 #85).

Slip-rate category unknown; probably <0.2 mm/yr

Comments: No known published slip rate exists for this section of the fault; low slip rate is inferred. Schneider (1985 #319) suggests this section of fault appears to have been less active and have a lower late Quaternary slip rate than sections to the south. Comparison of 1923 second-order and 1960 first-order leveling data indicate uplift rate between 1 and 3 mm/yr in this area, with the higher rates to the south (Reilinger and others, 1977 #479).

Length End to end (km) 38.8
Cumulative trace (km) 43.0

Average strike (azimuth) 352°

655b, Madison Canyon section

Section number 655b

Section name Madison Canyon section

Comments: Bartholomew and Stickney (1987 #85; 1987 #242) refer to this part of the fault as Madison Canyon segment. Schneider (1985 #319) also discussed and defined segments of the Madison fault based on morphologic studies, but did not assign names. Section as defined here extends from about 2 km south of Corral Creek southward to headwaters of Mile Creek. Mathieson (1983 #1065) shows a scarp at the southern end that extends about 140 m southwest of Mile Creek, makes a 50° change in trend, and extends into the mountain block at west edge of a Pinedale moraine. She believes that the strand that trends up Mile Creek accommodated earlier Holocene movement than that on the valleyward strand shown on her map. Section is longer than middle segment of Schneider, which extends from Indian Creek to Madison Canyon. We exclude area between Indian Creek and Corral Creek where no scarps are mapped (Hadley, 1969 #572) but include about 9 km of scarps south of Madison Canyon and the extension up Mile Creek. Part of this section ruptured during the 1959 Hebgen Lake earthquake. Section as defined here roughly coincides with unnamed segment defined by Lundstrom (1986 #457); he suggests that the northern boundary is somewhere between Wolf and Corral Creeks and southern boundary is at Mile Creek where the continuity of the range-front scarp ends.

Reliability of location Good

Comments: Trace is compiled from 1:24,000-scale geologic maps (O'Neill, in prep. 1992 #569; O'Neill, in prep. 1992 #570) and 1:24,000-scale Quaternary geologic map (Lundstrom, 1986 #457). Location of fault between 44°52'30" and 44°45' is from Lundstrom; location of fault north of 44°52'30" is poorly located and inferred from topography. Southern extension of section is from Witkind and others (1964 #629).

Sense of movement normal

Comments: (Witkind, 1975 #317). No significant component of horizontal movement was recognized by Mathieson (1983 #1065).

Dip 60° W.

Comments: Dip of slickensided surface at the third canyon south of Sheep Creek (Mathieson, 1983 #1065). Dip is inferred to be steep or possibly vertical (Johns and others, 1982 #259). Rasmussen and Fields (1985 #481) suggest fault is listric and soles into a Laramide thrust based on seismic data; however, Alexander and Leeder (1990 #458) state that the characteristics of surface deformation of fluvial terraces at the mouth of the Madison River are inconsistent with listric faulting.

Dip direction W

Geomorphic expression Fault is expressed as nearly continuous, high (locally >35 m) scarps on alluvium with steep (30°-45°, with mode around 35°) maximum slope angles (Gary, 1980 #695; Schneider, 1985 #319). Lundstrom (1986 #457) indicates most scarps are 7-14 m high and cluster into two groups of about 7 m and 11 m high. A short (about 3 km long) part of this section ruptured during the 1959 Hebgen Lake earthquake, with vertical offsets <1 m (Myers and Hamilton, 1964 #250). One continuous scarp, about 0.1 km long, is centered on Sheep Creek, the other about 2.4 km long is north of Little Mile Creek. Doser (1985 #22) states that it is difficult to determine if the historical movement was related to tectonic movement along the fault or some other mechanism such as settlement. Wallace (1980 #657) reoccupied two sites photographed in 1959 and describes the post-1959 scarp degradation. Locally, nick points in streams crossing the fault are only a few tens of meters from the scarp (Gary, 1980 #695).

Age of faulted surficial deposits Upper Quaternary alluvium and colluvium, glacial till, and landslide deposits, nearly all are <40 ka. Gary (1980 #695) shows that scarps are on some late Pleistocene (Pinedale) moraines but not all. Much of the length of the fault coincides with the bedrock-alluvium contact.

Paleoseismology studies none

Most recent prehistoric deformation latest Quaternary (<15 ka)

Comments: Based on diffusion-equation modeling of scarp-morphology data, Lundstrom (1986 #457) estimates the timing of the most recent event to be 4 k.y. A late Holocene age is also suggested by Schneider (1985 #319, whose best estimate is 3-5 k.y. Leveling data indicate fluvial terraces at mouth of Madison River have been tilted in the past few hundred years (Alexander and Leeder, 1990 #458. Mathieson (1983 #1065) also recognized the most recent movement to be Holocene but also points out that prominent prehistoric facets (bevels) are absent on the scarp; she suggests this is due to high degradation rates rather that absence of young movement to be the cause.

Recurrence interval 10-25 k.y. (<2 Ma)

Comments: Lundstrom (1986 #457) determined this recurrence interval based on assuming a nearly constant rate of tilting (0.05 µrad/yr) of the valley floor across a 5.5-km-wide valley, with displacements of 3-7 m per event. He assumes the 7-m-high scarps are the result of 1-2 events and constrain the amounts of offset per event. Mathieson indicates that the average recurrence interval could be as long as 7.5-10 k.y. during the past 15-30 k.y., if displacements were 3 m per event, or as short as 1.9-3.8 k.y. during the same interval, if displacements were 1 m per event. Schneider (1985 #319) speculates the recurrence interval may be 1-2 k.y. Ritter and others (1995 #882) suggest a recurrence interval of less than 1000 yr, but the basis for this estimate is not clear.

Slip-rate category 0.2-1.0 mm/yr

Comments: Based on 6- to 8-m offsets of deposits thought to be 20-40 ka, Lundstrom (1986 #457) reports a slip rate of 0.15-0.4 mm/yr for this part of the fault. He also indicates that the rate of valley floor tilting has been 0.05 µrad/yr for the past 2 Ma bight be episodic, and determined a 0.2-0.6 mm/yr slip rate for post-Pinedale slip (<11-20 ka), with 0.3-0.4 mm/yr being a preferred rate. Slip rate during the Sangamon interglacial might be about one order of magnitude less, and a late Quaternary rate may be about 0.1 mm/yr. In another publication, Mathieson (1983 #764) documented a slip rate of 0.4-0.7 mm/yr for the past 30 k.a. based on a 11-m-high scarp on Pinedale or younger debris-flow deposits; she also cites previous investigators that show a similar (0.5 mm/yr) slip rate for post-Huckleberry Ridge Tuff displacement. Vertical displacement of the 2-Ma Huckleberry Ridge Tuff is 800-900 m (Pierce and Morgan, 1992 #539), which suggests a comparable long-term slip through the Quaternary. Schneider (1985 #319) suggests that this section of fault appears to have been more active and have a higher late Quaternary slip rate than section to the north. Comparison of 1923 second-order and 1960 first-order leveling data indicate uplift rate of 2 to >5 mm/yr in this area, with the higher rates to the south (Reilinger and others, 1977 #479).

Length End to end (km) 37.9
Cumulative trace (km) 2106

Average strike (azimuth) 338°

655c, Unnamed (south) section

Section number 655c

Section name Unnamed (south) section

Comments: Although Schneider (1985 #319) discusses and defines segments of the Madison fault based on morphologic studies, he did not assign names. The section as defined here extends from Mile Creek southwestward to Garner Canyon. This section is shorter than the southern segment of Schneider and likewise, Johns and others (1982 #259), which extends from Madison Canyon southwestward to possibly west of Reas Pass.

Reliability of location Poor

Comments: Fault trace based 1:62,500-scale geologic map showing inferred location (Witkind, 1972 #534).

Sense of movement normal

Comments: (Witkind, 1975 #317)

Dip not reported

Comments: Dip is inferred to be steep or possibly vertical (Johns and others, 1982 #259); however, Rasmussen and Fields (1985 #481) suggest fault is listric and soles into a Laramide thrust based on seismic data.

Dip direction SW

Geomorphic expression not reported

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Age is from Stickney and Bartholomew (1987 #85; written commun. 1992 #556) based on three scarps on deposits inferred to be late Pleistocene (Pinedale to post-Bull Lake and Bull Lake to pre-Bull Lake) in age. Pierce and Morgan (1992 #539) also indicate late Pleistocene age. The Holocene faulting documented by Johns and others (1982 #259) is along the part of the fault included in the Madison section [655b].

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: No published slip rate is known for this section. Inferred low slip rate based on lack of evidence to indicate otherwise. Comparison of 1923 second-order and 1960 first-order leveling data indicate uplift rate of 3 to >5 mm/yr in this area, with the higher rates to the north of this section (Reilinger and others, 1977 #479).

Length End to end (km) 22.3
Cumulative trace (km) 25.3

Average strike (azimuth) 327°

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656, Hebgen fault (Class A)

Structure Number 656

Comments: Refers to number 6 (Hebgen fault) of Witkind (1975 #317), number 42 (Hebgen fault) of Johns and others (1982 #259), number 13 (Hebgen fault) of Stickney and Bartholomew (1987 #85), and Hebgen fault of Stickney and Bartholomew (1987 #242; written commun. 1992 #556).

Structure Name Hebgen fault

Comments: Pardee (1950 #46) noted a strong indication of a fault-controlled range front along the northeast side of Hebgen Lake but did not cite a fault name. The earliest use of the name for fault was probably in the numerous publications following the 1959 Hebgen Lake earthquake (Myers and Hamilton, 1961 #636; Witkind and others, 1962 #633; Witkind, 1964 #247; Myers and Hamilton, 1964 #250; Witkind and others, 1964 #629; Witkind, 1969 #468). An earlier publication refers to the fault as Hebgen Lake fault (U.S. Coast and Geodetic Survey, 1959 #630). Fault, as defined by 1959 surface rupture, extends from Beaver Creek southeastward to 2.3 km west of Canyon Creek.

Synopsis Even though the largest historic earthquake in Montana caused surface rupture of this fault, little is known about its paleoseismic history. The majority of published data are in reports dating from the early 1960s, from studies initiated due to the 1959 Hebgen Lake earthquake.

Date of compilation 11/17/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Ashton

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Location based on 1:62,500-scale map (Witkind, 1964 #247; Myers and Hamilton, 1964 #250).

Geologic setting High-angle, down-to-southwest, range-front normal fault bounding northeastern side of main body of Hebgen Lake. Fault generally parallels the strike of the bedrock and has a close spatial relation to the surface trace of the Laramide-age Johnson thrust fault (Witkind, 1964 #247; Myers and Hamilton, 1964 #250). Witkind and others (1964 #629) indicate that Cambrian strata are on both sides of the fault for much of its length suggesting that the total stratigraphic throw is small. Witkind (1964 #247) indicates net cumulative throw is about 305 m.

Sense of movement normal

Comments: Based on slip indicators with rakes of 90° resulting from the Hebgen Lake earthquake (Witkind and others, 1962 #633).

Dip 60°-80° SW

Comments: Range in dip is from Witkind (1975 #317) and Johns and others (1982 #259). Witkind and others (1964 #629) suggests a dip of 75° SW. Geodetic data suggests fault dips 45° SW (Barrientos and others, 1987 #269).

Dip direction SW

Geomorphic expression The fault is characterized by 0.3- to 6-m-high (generally 3-m-high) historical scarps (Witkind, 1964 #247) that are locally superimposed on 3- to 30-m-high prehistoric scarps, monoclinal folds, and linear bedrock outcrops (Witkind, 1964 #247; Myers and Hamilton, 1964 #250; Witkind and others, 1964 #629). Wallace (1980 #657) details significant degradation of scarp at two locations.

Age of faulted surficial deposits Upper Quaternary (Pinedale and Bull Lake) alluvium (~30%); Precambrian, Cambrian, Devonian, and Mississippian bedrock (~70%) based on mapping shown on plate 5 of USGS Professional Paper 435 (1964).

Paleoseismology studies none

Year of historic rupture 1959

Most recent prehistoric deformation not reported

Comments: Some early papers on this fault suggest there is no evidence of previous faulting (Witkind, 1975 #317) or provide inconclusive evidence of prior faulting (Myers and Hamilton, 1964 #250). However, more recent morphologic studies by Nash (1984 #343) estimate the age of prehistoric faulting on nearby intrabasin scarps [659] to be 2.8 ± 1.0 k.y. Doser (1985 #22) reports a date of 3,250±850 yr B.P. attributed to Nash. Alexander and others (1994 #1252) suggest that the migration of the South Fork of the Madison River meander belt to the east is due to recurrent Holocene faulting. No data are available for scarps on the Hebgen fault.

Recurrence interval 5.4-29.8 k.y. (<0.6-2.0 Ma)

Comments: Wheeler and Krystinik (1992 #608) suggest this recurrence interval considering the maximum age of the fault zone (including Red Canyon fault) to be 0.6-2.0 m.y., net cumulative throw of 305 m from Witkind's data (1964 #247), and slip events with displacement similar to 1959 Hebgen Lake earthquake. Ostenaa and Wood (1990 #318) indicate the recurrence interval is <10 k.y. for an unspecified time interval. Pierce and Friedman (1996 #3941) indicate that no more that three surface faulting events including the 1959 earthquake have occurred in approximately the past 30 k.y. They further suggest that the recurrence interval is 10 k.y. or greater for one or both of the major faults involved in the Hebgen Lake earthquake. Data are poorly constrained and data on individual faults affected by the Hebgen Lake earthquake are not available.

Slip-rate category 1.0-5.0 mm/yr

Comments: The only known slip rate published for this fault zone is by Doser (1985 #641) whose estimate is 0.8-2.5 mm/yr for an unspecified time interval. However, based on the data of Wheeler and Krystinik (1992 #608) to determine recurrence intervals, a lower long-term (<0.6-2.0 Ma) is suggested for the fault zone, which includes the Red Canyon fault. Data are poorly constrained and data on individual faults affected by the Hebgen Lake earthquake are not available.

Length End to end (km) 12.9
Cumulative trace (km) 13.3

Average strike (azimuth) 307°

References

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657, Red Canyon fault (Class A)

Structure Number 657

Comments: Refers to number 7 (Red Canyon fault) of Witkind (1975 #317), number 43 (Red Canyon fault) of Johns and others (1982 #259), number 14 (Red Canyon fault) of Stickney and Bartholomew (1987 #85), and Red Canyon fault of Stickney and Bartholomew (1987 #242; written commun. 1992 #556).

Structure Name Red Canyon fault

Comments: Pardee (1950 #46) noted a strong indication of a fault-controlled range front along the northeastern side of Hebgen Lake but did not report a fault name. The earliest use of this fault name was probably in the numerous publications resulting from the 1959 Hebgen Lake earthquake (Woodard, 1960 #653; Witkind and others, 1962 #633; Witkind, 1964 #247; Myers and Hamilton, 1964 #250; Witkind and others, 1964 #629; Witkind, 1969 #468). Myers and Hamilton (1964 #250) refer to the part of this fault southeast of the mouth of Red Canyon as the "Corey Spring fault zone." Fault extends from about 1 km northeast of the intersection of Kirkwood Creek and Hebgen fault [656] southeastward beyond the Yellowstone Park boundary to Maple Creek.

Synopsis Even though the largest historic earthquake in Montana resulted in surface rupture of part of this fault, little is known about its paleoseismic history. The Hebgen Lake earthquake (Mw 7.5) of 1959 occurred on this fault trend, but was centered in Montana (Murphy and Brazee, 1964 #245). The majority of published data are in reports dating from the early 1960s, from studies initiated due to the 1959 Hebgen Lake earthquake. Sections cited herein are defined by distinct changes in the timing of the most recent event along the strike of the fault.

Date of compilation 06/03/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey; Kenneth L. Pierce, U.S. Geological Survey

Geologic setting This high-angle, down-to-southwest, arcuate fault is one in a belt of active faults that extends westward from Yellowstone and that Pierce and Morgan (1992 #539) relate to the easterly track of the Yellowstone hotspot. Fault extends along the southwest flank of Kirkwood Ridge, continuing south along northeastern side of Red Canyon, northern side of Grayling Arm of Hebgen Lake, and extends into the glacial outwash plain east of Yellowstone basin. Fault generally parallels strike of bedrock (Witkind, 1964 #247; Myers and Hamilton, 1964 #250) and locally follows contact between massive limestone and thin-bedded shale (Doser, 1985 #22) along the western section. Witkind (1964 #247) indicates net cumulative throw is several thousand feet along central part of fault, but exact amount is indeterminable.

Number of sections 3

Comments: Sections defined herein based on distinct differences in timing of most recent surface faulting along the strike of the fault. The westernmost section ruptured in the 1959 Hebgen Lake earthquake; the other two sections are in Wyoming. The central section [751b] has post-glacial offset, and the easternmost section displaces 0.63 Ma Lava Creek Tuff.

Length End to end (km): 28.8
Cumulative trace (km): 58.0

Average strike (azimuth) 298

657a, Unnamed (northwestern) section

Section number 657a

Section name Unnamed (northwestern) section

Reliability of location Good

Comments: Location based on 1:62,500-scale map of 1959 deformation (Witkind, 1964 #247; Myers and Hamilton, 1964 #250). Plate 5 of U.S. Geological Survey Professional Paper 435 (1964) suggests that the fault continues eastward from southern terminus shown here.

County and State (if other than Montana) Gallatin

1° x 2° sheet Ashton

Physiographic province Northern Rocky Mountains

Sense of movement normal

Comments: Based on slip from the Hebgen Lake earthquake (Witkind, 1964 #247; Witkind and others, 1964 #629).

Dip 50°-85° SW

Comments: Range in dips from exposures of fault plane (Witkind, 1964 #247); Johns and others (1982 #259) indicate dip is nearly vertical. Geodetic data suggests that the fault dips 50° SW (Barrientos and others, 1987 #269).

Main dip direction SW

Geomorphic expression The fault is characterized by 0.1- to 4.6-m-high historical scarps that are locally superimposed on prehistoric scarps (Witkind, 1964 #247; Myers and Hamilton, 1964 #250). Wallace (1980 #657) details significant degradation of scarp at two locations.

Age of faulted surficial deposits Witkind (1964 #247) indicates scarps are all on unconsolidated sediments. Based on mapping, shown on plate 5 of USGS Professional Paper 435 (1964), about 30% of the length of the scarps are on upper Quaternary (Pinedale and Bull Lake) alluvium and 70% on Precambrian, Cambrian, Devonian, and Mississippian bedrock.

Paleoseismology studies none

Year of historic rupture 1959

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Woodard (1960 #653) provides detailed descriptions of scarps on this fault. He indicates evidence of post-glacial faulting at several locations, and thus, the conservative estimate of <130 ka is used here. Other early papers discussing this fault suggest that there is local evidence of prior faulting (Witkind and others, 1962 #633; Witkind, 1964 #247; Myers and Hamilton, 1964 #250) suggesting at least two pre-1959 surface-faulting events at Blarneystone Ranch. No data are available on pre-1959 scarps on the Red Canyon fault; however, morphologic studies by Nash (1984 #343) estimate the age of prehistoric faulting on nearby intrabasin scarps [659] to be 2.8 ± 1.0 k.y. Doser (1985 #22) reports a date of 3,250±850 yr B.P. attributed to Nash. Alexander and others (1994 #1252) suggest that the migration of the South Fork of the Madison River meander belt to the east is due to recurrent Holocene faulting.

Recurrence interval 5.4-29.8 k.y. (<0.6-2.0 Ma)

Comments: Wheeler and Krystinik (1992 #608) suggest this recurrence interval by considering the maximum age of the fault zone (including Hebgen fault) to be 0.6-2.0 m.y., the net cumulative throw of 305 m from Witkind's data (1964 #247), and slip events having displacements similar to 1959 Hebgen Lake earthquake. Ostenaa and Wood (1990 #318) indicate the recurrence interval is <10 k.y. for an unspecified time interval. Pierce and Friedman (1996 #3941) indicate that no more that three surface faulting events including the 1959 earthquake have occurred in approximately the past 30 k.y. They further suggest that the recurrence interval is 10 k.y. or greater for one or both of the major faults involved in the Hebgen Lake earthquake. Data are poorly constrained and data on individual faults affected by the Hebgen Lake earthquake are not available.

Slip-rate category 1.0-5.0 mm/yr

Comments: The only known slip rate published for this fault zone is by Doser (1985 #641) whose estimate is 0.8-2.5 mm/yr for an unspecified time interval. However, based on the data of Wheeler and Krystinik (1992 #608) to determine recurrence intervals, a lower long-term (<0.6-2.0 Ma) slip rate is suggested for the fault zone, which includes Hebgen fault. Data are poorly constrained and data on individual faults affected by the Hebgen Lake earthquake are not available.

Length End to end (km) 18.1
Cumulative trace (km) 46.8

Average strike (azimuth) 300°

657b, Richards Creek section

Section number 657b

Section name Richards Creek section

Comments: Named for Richards Creek that flows parallel to fault trace. Extends about 4 km eastward from Montana into Wyoming.

Reliability of location Good

Comments: Fault traces from surficial geology mapped at 1:62,500 by Pierce (1973 #3805) and bedrock volcanic geology mapped by R.L. Christiansen and compiled at 1:125,000 (in press #1784) and U.S. Geological Survey (1972 #639).

County Park (Wyo.), Gallatin (Mont.)

1° x 2° sheet Ashton

Physiographic Province Northern Rocky Mountains

Sense of movement normal

Dip not reported

Dip direction S

Geomorphic expression A 3-m-high scarp is formed on the surface of Pinedale outwash gravels (Pierce, 1973 #3805). A fault scarp about 10 feet (3 m) high is formed on Pinedale fan gravel, and further east down faulting appears to have controlled the shallow lakes along Richards Creek.

Age of faulted deposits Offsets an alluvial fan formed by Pinedale outwash gravel.

Detailed studies none

Most recent prehistoric deformation latest Quaternary (<15 ka)

Comments: Offsets glacial outwash deposited at glacial maximum, which is estimated to be about 20-30 ka.

Recurrence interval not reported

Comments: At least one offset in past 20-30 k.y.

Slip-rate category unknown, probably <0.2 mm/yr

Comments: Offset of 3 m in past 20-30 k.y. yields maximum slip rate that falls within the assigned category.

Length End to end (km): 5.2
Cumulative trace (km) 5.4

Average strike (azimuth) 278°

657c, Maple Creek section

Section number 657c

Section name Maple Creek section

Comments: Named for Maple Creek, which the fault crosses just east of the floor of West Yellowstone basin. Mapped extent is only about 4 km.

Reliability of location Good

Comments: Mapped at 1:125,000 scale where it offsets the 0.63 Ma Lava Creek Tuff (U.S. Geological Survey, 1972 #639; Christiansen, in press #1784). Surficial geology mapped by Pierce (1973 #3805).

County Park (Wyo.)

1° x 2° sheet Ashton

Province Northern Rocky Mountains

Sense of movement normal

Dip not reported

Dip direction S

Geomorphic expression Bedrock escarpments developed on 0.63 Ma Lava Creek Tuff; fault is mapped as not offsetting Pinedale glacial till (Pierce, 1973 #3805).

Age of faulted deposits 0.63 Ma Lava Creek Tuff

Detailed studies none

Most recent prehistoric deformation middle and late Quaternary (<750 ka)

Comments: Youngest offset not well constrained, and possibly might be post-glacial (<15 ka).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Lava Creek Tuff (0.63 Ma) is offset as much as 100 m, which yields a maximum long-term slip rate that falls within this category.

Length End to end (km) 4.0
Cumulative trace (km) 5.8

Average strike (azimuth) 285°

References

#1252 Alexander, J., Bridge, J.S., Leeder, M.R., Collier, R.E.L., and Gawthorpe, R.L., 1994, Holocene meander-belt evolution in an active extensional basin, southwestern Montana: Journal of Sedimentary Research, v. B64, p. 542-559.

#269 Barrientos, S.E., Stein, R.S., and Ward, S.N., 1987, Comparison of the 1959 Hebgen Lake, Montana and the 1983 Borah Peak, Idaho, earthquakes from geodetic observations: Bulletin of the Seismological Society of America, v. 77, p. 784-808.

#1784 Christiansen, R.L., in press, The Quaternary and Pliocene Yellowstone Plateau Volcanic Field of Wyoming, Idaho, and Montana: U.S. Geological Survey Professional Paper 729-G, 1 pl., scale 1:125,000.

#22 Doser, D.I., 1985, Source parameters and faulting processes of the 1959 Hebgen Lake, Montana, earthquake sequence: Journal of Geophysical Research, v. 90, no. B6, p. 4537-4555.

#641 Doser, D.I., 1985, The 1983 Borah Peak, Idaho and 1959 Hebgen Lake, Montana earthquakes—Models for normal fault earthquakes in the Intermountain seismic belt, *in* Stein, R.S., and Bucknam, R.C., eds., Proceedings of workshop XXVIII on the Borah Peak, Idaho, earthquake: U.S. Geological Survey Open-File Report 85-290, v. A, p. 368-384.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

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#250 Myers, W.B., and Hamilton, W., 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-I, p. 55-98.

#343 Nash, D.B., 1984, Morphologic dating of fluvial terrace scarps and fault scarps near West Yellowstone, Montana: Geological Society of America Bulletin, v. 95, p. 1413-1424.

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#3805 Pierce, K.L., 1973, Surficial geologic map of the Mount Holmes quadrangle and parts of the Tepee Creek, Crown Buttes, and Miner quadrangles, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey Miscellaneous Geologic Investigations I-640, 1 sheet, scale 1:62,500.

#3941 Pierce, K.L., and Friedman, I., 1996, Obsidian hydration dating of Quaternary events, *in* Noller, J.S., Sowers, J.M., and Lettis, W.R., eds., Quaternary geochronology—Applications in Quaternary geology and paleoseismology: U.S. Nuclear Regulatory Commission NUREG/CR-5562, p. 2-363—2-382.

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#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

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#657 Wallace, R.E., 1980, Degradation of the Hebgen Lake fault scarps of 1959: Geology, v. 8, p. 225-229.

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#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

#629 Witkind, I.J., Hadley, J.B., and Nelson, W.H., 1964, Pre-Tertiary stratigraphy and structure of the Hebgen Lake area, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-R, p. 199-207.

#633 Witkind, I.J., Myers, W.B., Hadley, J.B., Hamilton, W., and Fraser, G.D., 1962, Geologic features of the earthquake at Hebgen Lake, Montana, August 17, 1959: Bulletin of the Seismological Society of America, v. 52, p. 163-180.

#653 Woodard, F.W., 1960, Red Canyon fault Hebgen Lake, Montana, earthquake August 17,1959, *in* Campau, D.E., and Anisgard, H.W., eds., West Yellowstone—Earthquake area: Billings Geological Society, 11th Annual Field Conference, September 7-10, 1960, p. 49-55.

658, West Fork fault (Class A)

Structure Number 658

Comments: Refers to number 44 (West Fork fault scarp) of Johns and others (1982 #259), number 15 (West Fork fault) of Stickney and Bartholomew (1987 #85), and West Fork fault of Stickney and Bartholomew (1987 #242; written commun. 1992 #556). Witkind (1975 #317) did not include this fault in his compilation.

Structure Name West Fork fault

Comments: The earliest use of the name for this fault was probably by Witkind and others (1962 #633); however, in later publications, the common reference was to the West Fork fault scarps (Witkind, 1964 #247). Fault, as defined by 1959 surface rupture, parallels the northern part of Red Canyon fault [657] and is located about 1.5 km to northwest.

Synopsis Even though the largest historic earthquake in Montana resulted in surface rupture of this short fault, little is known about its paleoseismic history. Witkind provides only brief discussions in reports dating from the early 1960s.

Date of compilation 01/12/93

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Ashton

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Location based on 1:62,500-scale map (Witkind, 1964 #247; Myers and Hamilton, 1964 #250).

Geologic setting High-angle, down-to-southwest, normal fault that is small and inconspicuous both structurally and topographically (Witkind and others, 1962 #633). Witkind and others (1964 #629) indicate that similar bedrock occurs on both sides of the fault for much of its length indicating that total stratigraphic throw is small.

Sense of movement normal

Comments: (Witkind, 1964 #247)

Dip not reported

Comments: Johns and others (1982 #259) indicate that fault is nearly vertical.

Dip direction SE

Geomorphic expression Fault is generally characterized by 0.9 m historical scarps with net displacements of 0.3-0.6 m (Witkind, 1964 #247).

Age of faulted surficial deposits Unconsolidated sediments along its entire length (Witkind, 1964 #247); bedrock is near surface in at least some of the locations.

Paleoseismology studies none

Year of historic rupture 1959

Most recent prehistoric deformation not reported

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: The poor topographic expression of this fault suggests low slip rates, and thus, the lowest slip-rate category is assigned here.

Length End to end (km) 2.8
Cumulative trace (km) 2.8

Average strike (azimuth) 64°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

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#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

#247 Witkind, I.J., 1964, Reactivated faults north of Hebgen Lake, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-G, p. 37-50.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

#629 Witkind, I.J., Hadley, J.B., and Nelson, W.H., 1964, Pre-Tertiary stratigraphy and structure of the Hebgen Lake area, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-R, p. 199-207.

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659, Unnamed faults in Hebgen Lake basin

Structure Number 659

Comments: Refers to number 16 (Hebgen Lake graben) of Stickney and Bartholomew (1987 #85), Hebgen Lake graben of Stickney and Bartholomew (1987 #242), and Madison Arm graben of Stickney and Bartholomew (written commun. 1992 #556). Johns and others (1982 #259) discuss these faults (number 34, Hebgen Lake basin) but do not show them on a map. Witkind (1975 #317) does not include these faults in his compilation.

Structure Name Unnamed faults in Hebgen Lake basin

Comments: The numerous intrabasin faults south of the Madison Arm of Hebgen Lake that ruptured during the Hebgen Lake earthquake have been referred to by several names in the literature, but no name has widespread popular usage. Some individual features have been referred to as "scarps near Ranger Basin station" (Ross and Nelson, 1964 #249), "Madison Arm fault" (Myers and Hamilton, 1964 #250), "graben involving faulted bedrock" (Myers and Hamilton, 1964 #250), and "faults at Horse Butte" (Myers and Hamilton, 1964 #250). Alexander and others (1994 #1252) call one of these faults the Hope Ranch fault. These faults are discussed collectively for convenience.

Synopsis Even though the largest historic earthquake in Montana resulted in surface rupture of these faults, only slightly more is known about some of them than the other faults that slipped during the Hebgen Lake earthquake. The majority of published data are in reports dating from the early 1960s.

Date of compilation 01/12/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Ashton

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Location based on 1:62,500-scale map (Witkind, 1964 #247; Myers and Hamilton, 1964 #250).

Geologic setting Predominately west-trending scarps, which broadly define a graben in the Upper Madison Valley south of Hebgen Lake. Ross and Nelson (1964 #249) speculate that these structures are continuous with the Centennial fault [643] through Targhee Pass, which they contend is a modified structural depression; however, available gravity data do not support this conclusion (Schofield, 1981 #314).

Sense of movement normal

Comments: (Myers and Hamilton, 1964 #250)

Dip not reported

Dip direction NE; SW; NW

Geomorphic expression Faults are expressed as small (<0.6-0.8 m), short (<3.5 km), discontinuous historical scarps locally superimposed on prehistoric scarps (<6 m) and local monoclinal warping (Myers and Hamilton, 1964 #250). Myers and Hamilton (1964 #250) describe some of these features in detail, as abstracted in following discussion. "Madison Arm fault and monocline" has the greatest local relief, with north-facing surface rupture expressed as <0.7 m offsets that locally grade into warped sediments. Deformation in 1959 was superimposed on a prehistoric scarp along the western end; the eastern part of the fault has no evidence of a prehistoric event. "Faults at Horse Butte" are composed of multiple scarps having varying orientations and apparently are not associated with prehistoric scarps; however, Myers and Hamilton do suggest Horse Butte does appear to be fault controlled. "Graben involving faulted bedrock," which is near Basin Ranger Station, has small (<0.3 m), discontinuous scarps with the northernmost graben-bounding scarp on south side of a rhyolite horst. The 1959 scarps are superimposed on 1.5- to 4.6-m-high scarps.

Age of faulted surficial deposits Upper Pleistocene (<40 ka) outwash (Nash, 1984 #343).

Paleoseismology studies none

Year of historic surface rupture 1959

Most recent prehistoric deformation latest Quaternary (<15 ka)

Comments: Nash (1984 #343) estimates prehistoric faulting event occurred 2.8 ± 0.1 ka based on morphologic modeling of scarps southeast of confluence of Denny Creek and South Fork Madison River. Doser (1985 #22) reports a date of 3,250±850 yr B.P. attributed to Nash.

Recurrence interval not reported

Comments: Although not stated as such, data from Nash (1984 #343) suggests a recurrence interval of 2.8±0.1 k.y. between the past two surface-faulting events.

Slip-rate category unknown; probably 0.2-1.0 mm/yr

Comments: The poor topographic expression of these faults suggests low slip rates or recent inception of faulting. The largest multiple-event scarps (4.5-6 m) on upper Pleistocene deposits (15-40 ka) also support a low slip rate as well as small historic slip (<0.6-0.8 m) with implied recurrence interval of 2.8 k.y.

Length End to end (km) 12.5
Cumulative trace (km) 23.3

Average strike (azimuth) 284°

References

#1252 Alexander, J., Bridge, J.S., Leeder, M.R., Collier, R.E.L., and Gawthorpe, R.L., 1994, Holocene meander-belt evolution in an active extensional basin, southwestern Montana: Journal of Sedimentary Research, v. B64, p. 542-559.

#22 Doser, D.I., 1985, Source parameters and faulting processes of the 1959 Hebgen Lake, Montana, earthquake sequence: Journal of Geophysical Research, v. 90, no. B6, p. 4537-4555.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#250 Myers, W.B., and Hamilton, W., 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-I, p. 55-98.

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#314 Schofield, J.D., 1981, Structure of the Centennial and Madison Valleys based on gravitational interpretation, *in* Tucker, T.E., ed. Guidebook to southwest Montana: Montana Geological Society, 1981 Field Conference and Symposium, p. 275-283.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

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#247 Witkind, I.J., 1964, Reactivated faults north of Hebgen Lake, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-G, p. 37-50.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

660, Unnamed fault near Mile Creek (Class A)

Structure Number 660

Comments: Fault not shown on any previous compilation.

Structure Name Unnamed fault near Mile Creek

Comments: Section extends southwestward about 4 km from about 1 km southwest of Mile Creek.

Synopsis Fault is expressed as a short (4-km-long) scarp on Quaternary alluvium in the Madison Valley. Recent studies conclude that the origin of this feature is faulting; earlier studies indicate that this feature is fluvial.

Date of compilation 04/11/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison; Beaverhead

1° x 2° sheet Ashton

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Location of scarp based on 1:24,000-scale map of Lundstrom (1986 #457).

Geologic setting Short, low, northwest-facing scarp in Madison Valley. Along trend to the southwest is a mapped fault that offsets Huckleberry Ridge Tuff (2 Ma) about 40 m (Gary, 1980 #695).

Sense of movement normal

Comments: (Lundstrom, 1986 #457)

Dip not reported

Dip direction NW

Geomorphic expression Scarps are 2-3 m high with low to moderate (10-15°) maximum slope angles on undifferentiated Quaternary fan gravels, probably 15-30 k.y. old. Inferred offset of older gravels is 25 m (Lundstrom, 1986 #457). In contrast, Myers and Hamilton (1964 #250) regarded this as a fluvial scarp in their reconnaissance of Madison Valley.

Age of faulted surficial deposits Upper Quaternary alluvium, undifferentiated Quaternary fan gravels, Pliocene Huckleberry Ridge Tuff (Lundstrom, 1986 #457).

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Lundstrom (1986 #457) indicates the most recent event occurred between 15-30 ka based on differential faulting of Pinedale channels and suggestion that a silt cap and fan gravels locally drape over scarp.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on small scarps on upper Quaternary deposits.

Length End to end (km) 3.9
Cumulative trace (km) 3.9

Average strike (azimuth) 39°

References

#695 Gary, S.D., 1980, Quaternary geology and geophysics of the upper Madison Valley, Madison County, Montana: Missoula, University of Montana, unpublished M.S. thesis, 76 p., 2 plates.

#457 Lundstrom, S.C., 1986, Soil stratigraphy and scarp morphology studies applied to the Quaternary geology of the southern Madison Valley, Montana: Arcata, California, Humboldt State University, unpublished M.S. thesis, 53 p., 1 pl., scale 1:24,000.

#250 Myers, W.B., and Hamilton, W., 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435-I, p. 55-98.

661, Wolf Creek graben

Structure Number 661

Comments: Possibly refers to part of number 51 (Wolf Creek Hot Springs fault), number 55 (Wolf Creek fault A), and number 56 (Wolf Creek fault B) of Johns and others (1982 #259); number 12 (Wolf Creek graben) of Stickney and Bartholomew (1987 #85); Wolf Creek graben of Stickney and Bartholomew (1987 #242); and Madison graben of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Wolf Creek graben

Comments: Source of name is Stickney and Bartholomew (1987 #85; 1987 #242). Johns and others (1982 #259) refer to each strand with an individual fault name. Stickney and Bartholomew (written commun. 1992 #556) call these faults the Madison graben. Weinheimer (1979 #696; 1982 #656) probably first documented the name "Wolf Creek Hot Spring fault". All of the faults are discussed collectively because the known information indicates that they do not behave independently during large magnitude earthquakes.

Synopsis Little is known about these short subparallel fault scarps. Most of the data cited here is from Stickney and Bartholomew (1987 #85; 1987 #242).

Date of compilation 04/11/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Ashton; Bozeman

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Source of trace is digital data of Stickney and Bartholomew (written commun. 1992 #556) compiled at scale of 1:250,000.

Geologic setting Fault, as shown, consists of three subparallel intrabasin scarps forming a graben on the east side of the Madison River. The eastern two scarps are down to the west and the western scarp is down to the east.

Sense of movement normal

Comments: (Johns and others, 1982 #259)

Dip not reported

Dip direction W; E

Geomorphic expression Weinheimer (1979 #696) documents the morphology of the scarps on a fault that he calls the Wolf Creek Hot Springs fault, but it is uncertain if the structure he describes is shown in this compilation. The fault, as he shows it, should be east of those shown here and is down to the range front at least along part of its length (this sense of movement is opposite to the easternmost fault shown here). He describes the scarps as being 1- to 1.5-m-high, east-facing scarps along the southern 2 km and about 2-m-high, west facing scarps between 3-5 km north of Wolf Creek, with presumably a 1 km gap between.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Timing of most recent event is from Stickney and Bartholomew (1987 #85; 1987 #242; written commun. 1992 #556). Johns and others (1982 #259) indicate Holocene faulting (Weinheimer, 1982 #656) on fault number 51 (Wolf Creek Hot Springs fault) which might, in part, be the east-facing scarp shown here. Scarps on fault number 55 (Wolf Creek fault A) of Johns and others (Johns and others, 1982 #259) are restricted to the Cameron surface (Schneider, 1985 #319). The other fault is shown as Quaternary by Johns and others (1961 #766).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate is indicated by presence of scarps generally less than 2 m high on upper Quaternary deposits (Johns and others, 1982 #259).

Length End to end (km) 4.0
Cumulative trace (km) 8.2

Average strike (azimuth) 341°

References

#766 Johns, W.M., 1961, Geology and ore deposits of the southern Tidal Wave mining district Madison County, Montana: Montana Bureau of Mines and Geology Bulletin 24, 53 p., 1 pl.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#319 Schneider, N.P., 1985, Morphology of the Madison Range fault scarp, southwest Montana—Implications for fault history and segmentation: Oxford, Ohio, Miami University, unpublished M.S. thesis, 131 p.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

#696 Weinheimer, G.J., 1979, The geology and geothermal potential of the upper Madison Valley between Wolf Creek and the Missouri Flats, Madison County, Montana: Bozeman, Montana State University, unpublished M.S. thesis, 108 p., 1 plate.

#656 Weinheimer, G.J., 1982, Madison Valley thermal springs, *in* The upper Centennial Valley, Beaverhead and Madison Counties, Montana: Montana Bureau of Mines and Geology Memoir 50, p. 20-26.

662, Bradley Creek fault (Class A)

Structure Number 662

Comments: Refers to number 76 (Bradley Creek fault) of Johns and others (1982 #259).

Structure Name Bradley Creek fault

Comments: Source of the name is Johns and others (1982 #259). Fault extends from about 2 km northwest of Hot Springs Creek southeastward to about 1.5 km northwest of U.S. Highway 287.

Synopsis The age of this fault is highly suspect. The sole reference to this feature is Johns and others (1982 #259), who assign a Holocene age to the fault; other compilations of late Quaternary structures in Montana (Stickney and Bartholomew, 1987 #85; 1987 #242; written commun. 1992 #556) do not include this feature because they believe it to be a fault-line scarp (M.J. Bartholomew, written commun. 1997). The Bradley Creek fault appears to be the southern extension of the Carmichael fault (part of which is discussed in 695).

Date of compilation 04/21/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Bozeman

Physiographic province Northern Rock Mountains

Reliability of location Poor

Comments: Source of trace is from 1:500,000-scale map of Johns and others (1982 #259).

Geologic setting High-angle, down-to-northeast normal (?) fault bounding part of the east side of the southern part of Tobacco Root Mountains. No known estimates of depth to basement or stratigraphic offset exist.

Sense of movement normal

Comments: Johns and others (1982 #259) indicate the presence of a possible scarp; however, they also note that the northern part of the scarp is down to the southwest and the southern part is down to the northeast. Possible normal movement is inferred here because of evidence of a vertical component, but left lateral movement is also a possibility. In addition, dip direction is inferred based on better expressed topography at the north end of fault compared to south end and the indicated dip of nearby Carmichael fault [695].

Dip not reported

Dip direction NE

Geomorphic expression Johns and others (1982 #259) indicate the presence of scarps and "interception of drainage," these are the only comments offered.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Johns and others (1982 #259) believe that the geomorphic evidence indicates Holocene movement; however, the omission of this feature in other compilations makes a Holocene age suspect. Thus, a conservative age estimate is used here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the poor expression of fault.

Length End to end (km) 9.6
Cumulative trace (km) 9.7

Average strike (azimuth) 329°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

663, Bitterroot fault (Class A)

Structure Number 663

Comments: Refers to number 88 (Bitterroot fault) of Witkind (1975 #317).

Structure Name Bitterroot fault

Comments: Name is probably from Lindgren (1904 #769); even though he discusses this fault at length, he uses the name only in passing on p. 115. Fault, as shown here, extends from about 4 km northwest of Lolo, Montana, southward to about 2.2 km southeast of West Fork of Bitterroot River.

Synopsis Little is known about the Quaternary history of this fault. Ross (1947 #772) speculated that no range-front fault is present along the eastern flank of the Bitterroot Mountains. The majority of studies (a few of which are cited here) have focused on the prominent mylonite zone along the range front. Isolated scarps on predominately upper Quaternary deposits are known (Barkmann, 1984 #809); however, scarps are not recognized on adjacent older deposits.

Date of compilation 06/14/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Ravalli; Missoula

1° x 2° sheet Hamilton; Elk City

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Trace compiled from 1:500,000-scale map of Witkind (1975 #317). The extent and character of the fault is shown in a variety of ways by different authors. Lindgren (1904 #769) and Pardee (1950 #46) indicate that the fault extends from near Lolo Peak at least as far south as Grantsdale, Montana, or possibly to Boulder Creek, a tributary of West Fork Bitterroot River. McMurtrey and others (1972 #770) show four left-stepping echelon traces that extend along and into the range from near Florence to south of Victor, Montana. Toth (1983 #776) shows the fault extending from west of Darby, Montana, southward to West Fork Bitterroot River, and continuing westward parallel to that river and the Nez Perce Fork to about 5 km west of Watch Tower Creek; even though this map extends north of Florence, Montana, the fault is not shown in the northern part of the map area. Barkmann (1984 #809) documents the presence of two scarps on alluvium (neither of which are shown here), one near Lake Como and the other at the mouth of Bear Creek.

Geologic setting High-angle, down-to-east, range-front normal fault bounding the east side of Bitterroot Mountains. No recent estimates of depth to basement and stratigraphic throw are known, but Lindgren (1904 #769) suggests a minimum vertical offset of 1.2-1.8 km. Old gravity data suggest that the valley fill is about 600 m thick (Manghnani and Hower, 1961 #773); however, more recent data suggest that magnetic basement is 1.6 km deep (Lankston, 1975 #811). Generalized bedrock topography derived from data of Lankston suggests a maximum throw is approximately 3.3 km (Barkmann, 1984 #809).

Sense of movement normal

Comments: (Lindgren, 1904 #769)

Dip 45°-90° E

Comments: Lindgren (1904 #769) reports the fault dipping 45° E at a depth of 150 m in the Curlew Mine. McMurtrey and others (1972 #770) indicate the fault dips from 45° to vertical but do not document where or on what measurements were obtained.

Dip direction E

Geomorphic expression In general, fault is poorly expressed. Quaternary scarps include a 2-km-long scarp near the mouth of Bear Creek, a 5-km-long scarp south of Lake Como (Barkmann, 1984 #809), and a short, "historic" scarp near the Curlew Mine (Lindgren, 1904 #769). The range-front morphology is generally characterized by 18-26° slopes (Lindgren, 1904 #769) on mylonite that is as much as 1 km thick (Chase and others, 1983 #771). Various authors speculate that mylonitization may be related to early extension (Garmezy and Sutter, 1983 #774; House and others, 1993 #775). Lindgren (1904 #769) indicates that streams draining the Bitterroot Range have a notable increase in gradient (from about 40 m/km to 80 m/km) within 1.6 km of the fault on upthrown block that is related to faulting.

Age of faulted surficial deposits Locally pre-Bull Lake and Bull Lake till (Barkmann, 1984 #809)

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: A conservative estimate is used here, even though localized historical and late Quaternary displacement is reported in the literature. Lindgren (1904 #769) documents historical (1898) movement along nearly 500 m of the fault near the Curlew Mine (Witkind, 1975 #317). However, local newspapers make no mention of a significant earthquake occurring at that time (Qamar and Stickney, 1983 #58), thus, ground failure due to some nonseismogenic cause is possible (Barkmann, 1984 #809). Surficial slip was 30-60 cm and, in places, the disrupted ground surface has a partly open fissure (Lindgren, 1904 #769). The interpretation of historical seismically induced movement is questionable; therefore, it is not indicated in this compilation. Witkind (1975 #317) shows the rest of the fault as late Cenozoic on his map, but his accompanying text suggests that parts of the fault are Quaternary. Barkmann (1984 #809) indicates the presence of a 70-m-high scarp on middle Quaternary (pre-Bull Lake) till and 7-m-high scarp on upper Quaternary (Bull Lake) till; no scarps are known on ~15 ka (Pinedale) deposits. These relations are apparent at two locations (near Bear Creek and south of Lake Como); however, the lack of continuous scarps justifies a conservative estimate.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on ~7 m slip on upper Quaternary (<130 ka) deposits.

Length End to end (km) 98.4
Cumulative trace (km) 103.1

Average strike (azimuth) 1°

References

#809 Barkmann, P.E., 1984, A reconnaissance investigation of active tectonism in the Bitterroot Valley, western Montana: Missoula, University of Montana, unpublished M.S. thesis, 84 p., 5 pls.

#771 Chase, R.B., Bickford, M.E., and Arruda, E.C., 1983, Tectonic implications of Tertiary intrusion and shearing within the Bitterroot dome, northeastern Idaho batholith: Journal of Geology, v. 91, p. 462-470.

#774 Garmezy, L., and Sutter, J.F., 1983, Mylonitization coincident with uplift in an extensional setting, Bitterroot Range, Montana-Idaho: Geological Society of America Abstracts with Programs, v. 15, p. 578.

#775 House, M.A., Isachsen, C.E., Hodges, K.V., and Bowring, S.A., 1993, Geochronologic evidence for a complex, post-extensional thermal structure in the Bitterroot dome metamorphic complex, MT.: Geological Society of America Abstracts with Programs, v. 25, p. A-411.

#811 Lankston, R.W., 1975, Depth to magnetic basement in the northern Bitterroot Valley and Sapphire Mountains in western Montana: Geological Society of America Abstracts with Programs, v. 7, no. 5, p. 620.

#769 Lindgren, W., 1904, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U.S. Geological Survey Professional Paper 27, 123 p.

#773 Manghnani, M.H., and Hower, J., 1961, Structural significance of a gravity profile in the Bitterroot Valley, Ravalli County, Montana [abs.]: Geological Society of America Special Paper 68, p. 93.

#770 McMurtrey, R.G., Konizeski, R.L., Johnson, M.V., and Bartells, J.H., 1972, Geology and water resources of the Bitterroot Valley, southwestern Montana: U.S. Geological Survey Water-Supply Paper 1889, 80 p., 1 pl., scale 1:125,000.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#58 Qamar, A.I., and Stickney, M.C., 1983, Montana earthquakes, 1869-1979—Historical seismicity and earthquake hazard: Montana Bureau of Mines and Geology Memoir 51, 79 p., 3 pls.

#772 Ross, C.P., 1947, Eastern front of the Bitterroot Range near Hamilton, Montana: Geological Society of America Bulletin, v. 58, p. 1222.

#776 Toth, M.I., 1983, Reconnaissance geologic map of the Selway-Bitterroot Wilderness, Idaho County, Idaho, and Missoula and Ravalli Counties, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-1495-B, 1 sheet, scale 1:125,000.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

664, Unnamed fault near Cliff Lake (Class A)

Structure Number 664

Comments: Fault not shown on any previous compilation.

Structure Name Unnamed fault near Cliff Lake

Comments: This approximately 3-km-long fault south of the town of Cliff Lake, Montana, is shown on map of Lundstrom (1986 #457) but is not named.

Synopsis: Little is known about this scarp in the Madison Valley. Sole source of data is Lundstrom (1986 #457).

Date of compilation 04/11/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Ashton

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Source of trace is 1:24,000-scale geologic map of Lundstrom (1986 #457).

Geologic setting Single, down-to-southwest scarp along west side of Missouri flats. Presence of fault is suggested by the elevated Huckleberry Ridge Tuff.

Sense of movement normal

Dip not reported

Dip direction SW

Geomorphic expression Scarp is 3-5 m high with moderate maximum slope angles (Lundstrom, 1986 #457), but Lundstrom indicates that scarp may have been erosionally modified during the deposition of younger gravels on the downthrown side.

Age of faulted surficial deposits Scarp bounds late Pleistocene terrace (inferred Bull Lake equivalent). Fault is buried by younger upper Pleistocene fan gravel.

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Lundstrom (1986 #457) indicates that upper Pleistocene deposits are faulted.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate is indicated by height of scarps on upper Quaternary deposits.

Length End to end (km) 2.7
Cumulative trace (km) 2.8

Average strike (azimuth) 304°

References

#457 Lundstrom, S.C., 1986, Soil stratigraphy and scarp morphology studies applied to the Quaternary geology of the southern Madison Valley, Montana: Arcata, California, Humboldt State University, unpublished M.S. thesis, 53 p., 1 pl., scale 1:24,000.

665, Ruby Range western border fault (Class A)

Structure Number 665

Comments: Refers to number 52 (unnamed fault at east edge of Beaverhead valley) of Witkind (1975 #317) and number 3 (Ruby Range western border fault) of Johns and others (1982 #259).

Structure Name Ruby Range western border fault

Comments: Name is from Johns and others (1982 #259). Fault extends from 4 km south of Ruby River southwestward to about 5.5 km east of Blacktail Creek.

Synopsis Little is known about the Quaternary history of this fault. All data are based on compilation of Johns and others (1982 #259). Published maps reveal significant differences in the location and extent of the fault.

Date of compilation 05/05/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison; Beaverhead

1° x 2° sheet Dillon

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location based on 1:500,000-scale map of Witkind (1975 #317). Geologic map of Ruppel and others (1993 #646) shows trace of the northeastern half (northeast of Stone Creek) within 1 km of location given here; however, the southwestern half is up to 2.5 km valleyward of the trace shown here. The fault is shown to extend southwestward beyond the map area of Johns and others (1982 #259), but at least as far as the Blacktail River.

Geologic setting High-angle, down-to-the-northwest, range-front normal fault bounding the northwest side of the Ruby Range. Amount of structural throw is unknown.

Sense of movement normal

Comments: (Witkind, 1975 #317; Johns and others, 1982 #259)

Dip not reported

Dip direction NW

Geomorphic expression Pardee (1950 #46) indicates that there are no scarps along this fault. The morphology of the southwestern half of the range front is generally subdued and deeply embayed; the range is generally low. The northeastern half of the range is higher and the range front is more abrupt and has a somewhat linear character (Ostenaa and Wood, 1990 #318).

Age of faulted surficial deposits Tertiary lake beds (Pardee, 1950 #46). Map of Ruppel and others suggests that the southern half of the fault is buried by Tertiary (Pliocene-Eocene) Bozeman Group, but the fault offsets the same unit at the northeastern end and may displace Quaternary fan deposits. However, Tysdal (1976 #767) shows the northern part of the fault buried by Quaternary deposits.

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Timing of faulting is poorly constrained. Johns and others (1982 #259) suggest that the most recent event occurred during the late Pleistocene based on a genetic response of fan building to faulting; they do not report evidence of scarps on alluvial deposits. The only hint of some surficial reflection of recent faulting is their reference to the change in gradient and sinuosity of the Ruby River. Pardee (1950 #46) documents that Tertiary deposits are faulted. Witkind (1975 #317) assigns a late Cenozoic age to this structure, but does not rule out possible Quaternary movement. Ostenaa and Wood (1990 #318) found no indication of late Quaternary displacement based on air photo and limited field reconnaissance. However, some evidence points to possible early to mid-Quaternary activity along at least the northeastern half of the fault, but the majority of movement may have been completed by the end of the Pliocene (Ostenaa and Wood, 1990 #318). Because of the conflicting interpretations, this fault is tentatively assigned a Quaternary age; although there is no constraining data.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the absence of scarps.

Length End to end (km) 38.0
Cumulative trace (km) 38.4

Average strike (azimuth) 37°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#646 Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1° x 2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1803-H, 1 sheet, scale 1;250,000.

#767 Tysdal, R.G., 1976, Geologic map of northern part of Ruby Range, Madison County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-951, 1 sheet, scale 1:24,000.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

666, Ruby Range northern border fault (Class A)

Structure Number 666

Comments: Refers to number 4 (Ruby Range northern border fault) of Johns and others (1982 #259).

Structure Name Ruby Range northern border fault

Comments: Name is from Johns and others (1982 #259). Fault extends from Ruby Range western border fault [665] southeastward to Williams Creek.

Synopsis Little is known about the Quaternary history of this fault. All data are based on compilation of Johns and others (1982 #259). Published maps reveal significant differences in the location and extent of the fault.

Date of compilation 05/05/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Dillon

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location based on 1:500,000-scale map of Johns and others (1982 #259). Only the southeastern 13 km of the fault is shown on the geologic map of Ruppel and others (1993 #646), but the location agrees with the trace shown here except for the part east of the Ruby River. Ruppel and others (1993 #646) show this part of the fault 0.5 km to the south.

Geologic setting High-angle, down-to-the-northeast, range-front normal fault bounding the northern side of the Ruby Range. Amount of structural throw is unknown.

Sense of movement normal

Comments: (Johns and others, 1982 #259)

Dip not reported

Dip direction NE

Geomorphic expression No scarps are reported along this fault; the range front is abrupt.

Age of faulted surficial deposits The fault defines the contact between Quaternary alluvium and bedrock (Ruppel and others, 1993 #646).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Timing of faulting is poorly constrained. Johns and others (1982 #259) suggest that the most recent event occurred during the late Pleistocene based on a genetic response of fan building to faulting; they do not report scarps on alluvial deposits. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Bartholomew and Stickney examined several sites along the fault and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997). Because details are lacking, the fault is included in this compilation. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Bartholomew and Stickney examined several sites along the fault and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997). Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the absence of scarps.

Length End to end (km) 21.8
Cumulative trace (km) 23.9

Average strike (azimuth) 310°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#646 Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1° x 2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1803-H, 1 sheet, scale 1;250,000.

667, Georgia Gulch fault (Class A)

Structure Number 667

Comments: Refers to number 7 (Georgia Gulch fault) of Stickney and Bartholomew (1987 #85), Georgia Gulch fault of Stickney and Bartholomew (1987 #242), and Georgia Gulch fault and North Georgia Gulch fault of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Georgia Gulch fault

Comments: Source of name is Stickney and Bartholomew (1987 #85; 1987 #242). The Georgia Gulch fault is inferred herein to include the piedmont scarps shown by Ruppel and others (1993 #646) and, thus, extends from 3 km south of Dry Boulder Creek southward to 1 km north of Wisconsin Creek. The northern 6.5 km of echelon faults, which are in Tertiary sediments (M.J. Bartholomew, written commun. 1997) have not been included in previous discussions (Stickney and Bartholomew, 1987 #85; Bartholomew and others, 1990 #243) or shown on other compilations (Johns and others, 1982 #259; Stickney and Bartholomew, 1987 #242; written commun. 1992 #556). The northern 10 km of this fault is west of the southern part of the Tobacco Root fault [649], and the southern part of the fault coincides with the southern part of the Tobacco Root fault.

Synopsis Much of the fault has only received preliminary reconnaissance investigation. In general, little specific evidence is published as to the nature, timing, or extent of displacement. Published maps reveal significant differences even in the location of the fault. Two trenches have been excavated on the more recently active part of the fault.

Date of compilation 05/09/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Dillon

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Source of the trace is 1:250,000-scale geologic map of Ruppel and others (1993 #646) with minor modifications. Location of trenched scarp is from Bartholomew and others (1990 #243).

Geologic setting High-angle, down-to-the-west, normal fault near the southwestern side of the Tobacco Root Mountains. There is no known data on the amount of total stratigraphic throw.

Sense of movement normal

Comments: (Witkind, 1975 #317; Johns and others, 1982 #259)

Dip not reported

Comments: Near-vertical faults exposed in trench 667-1 all dip slightly eastward, but Bartholomew and others (1990 #243) suggested that this may be a near-surface phenomenon and that the fault dips to the west at depth.

Dip direction W

Geomorphic expression Scarps on alluvium are present at least locally. Holocene deposits have no scarps, approximately 1-m-high scarps are on uppermost Pleistocene (Pinedale?) deposits, and 4-m-high scarps are on upper Quaternary (Bull Lake?) deposits (Stickney and Bartholomew, 1987 #85).

Age of faulted surficial deposits Quaternary alluvial fan deposits, Tertiary sediments. Source of data is Bartholomew and others (1990 #243) generalized map of Jefferson basin. They show the fault at the bedrock-alluvial contact along the southern part of the section; continuing northward, it displaces Quaternary alluvium. Tertiary sediments shown by Bartholomew and others (1990 #243) should be offset based on the location of scarps defining the northern end of the section from Ruppel and others (1993 #646). Ruppel and others (1993 #646) show only Quaternary alluvium along this section of the fault; however, M.J. Bartholomew (written commun. 1997) believes the deposits are Tertiary.

Paleoseismology studies Trench 667b-1, located approximately 2 km south of Goodrich Gulch on valleyward strand of fault, was excavated in 1986 (Bartholomew and Stickney, 1987 #9). Trench was across a 0.5-m-high scarp on the youngest faulted alluvial fan deposit; however, displacement of inferred upper Quaternary (Bull Lake) mud flow deposit is 1 m (Bartholomew and others, 1990 #243), which may reflect multiple movements. Post-glacial (Pinedale) displacement is thought to be 0.5 m. Another trench, located a few hundred meters south of trench 667b-1 was excavated in 1990 by Bartholomew and Stickney, but no published information is available at this time.

Most recent prehistoric deformation latest Quaternary (<15 ka)

Comments: Relations in trench 667b-1 suggest that the most recent event post-dated deposition associated with the most recent glacial cycle (Bartholomew and others, 1990 #243), but Holocene deposits near the trench site are not faulted. The same age is assigned to the rest of the piedmont scarps, even though there is no supporting data. Stickney and Bartholomew (1987 #85; 1987 #242; written commun. 1992 #556) indicate that the timing of the most recent event is late Pleistocene for the range-bounding part of this fault.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the small amount of documented slip in the past 130 k.y. However, the available data are for a single strand of the fault and does not represent the cumulative slip across the numerous nearby splays.

Length End to end (km) 14.2
Cumulative trace (km) 28.0

Average strike (azimuth) 12°

References

#9 Bartholomew, M.J., and Stickney, M.C., 1987, Late Quaternary faulting in southwestern Montana: Geological Society of America Abstracts with Programs, v. 19, p. 258-259.

#243 Bartholomew, M.J., Stickney, M.C., and Wilde, E.M., 1990, Late Quaternary faults and seismicity in the Jefferson basin, *in* Hall, R.D., ed. Quaternary geology of the western Madison Range, Madison Valley, Tobacco Root range, and Jefferson valley: Rocky Mountain Cell, Friends of the Pleistocene, August 15-19, 1990, Guidebook, p. 238-244.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#646 Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1° x 2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1803-H, 1 sheet, scale 1;250,000.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.
#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

668, Vendome fault (Class A)

Structure Number 668

Comments: Refers to number 8 (Vendome horst) of Stickney and Bartholomew (1987 #85), Vendome horst of Stickney and Bartholomew (1987 #242), and Vendome fault of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Vendome fault

Comments: Name is from Bartholomew and Stickney (1987 #9). Fault, as shown, extends southward about 11 km from near Pipestone Hot Springs; however, the part of the fault north of Little Pipestone Creek may be suspect (M.C. Stickney, oral commun. 1992) because the scarp is low (1-2 m) and subdued (M.J. Bartholomew, written commun. 1996).

Synopsis Most of the fault has been studied only by preliminary reconnaissance. Little published evidence discusses the nature, timing, or extent of displacement. Two trenches have been excavated across the southern part of the fault.

Date of compilation 05/12/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet Dillon

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Trace of fault compiled from 1:500,000-scale map of Stickney and Bartholomew (1987 #242).

Geologic setting Fault expressed as short, discontinuous intrabasin scarps, locally forming a horst, on western side of Jefferson basin. Total amount of structural displacement is unknown.

Sense of movement normal

Comments: (Stickney and Bartholomew, 1987 #242)

Dip not reported

Dip direction E; W

Geomorphic expression Scarps are generally 3-4 m high on alluvium and locally form a horst at the southern end of the scarps (Bartholomew and others, 1990 #243).

Age of faulted surficial deposits Scarps are on upper Quaternary (Bull Lake?) deposits; Holocene and uppermost Pleistocene (Pinedale) deposits are not faulted. According to Bartholomew and others (1990 #243), scarps terminate at the contact between Bull Lake and Pinedale deposits.

Paleoseismology studies Trench 668-1 was excavated in 1986 (Bartholomew and Stickney, 1987 #9) across the middle (down-to-the-east) scarp on the horst block at the southern end of the scarps (Bartholomew and others, 1990 #243) about 7 km west of Renova, Montana (1.6 km south of railroad). Downthrown block at this site is locally covered by Holocene alluvium, and scarp is about 4 m high. Three faulting events were recognized indicating 7 m of total displacement during the late Pleistocene (Bartholomew and others, 1990 #243). Displacement is documented to be 9 m by Bartholomew and Stickney (1987 #9). Two additional short trenches were excavated in 1990 about 0.5 km to the north of trench 668-1 (Stickney, written commun. 1993), but no published data are currently available.

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: The scarps on upper Quaternary deposits and their absence on uppermost Pleistocene and Holocene deposits indicate faulting occurred between about 13 and 150 k.y. ago (Stickney and Bartholomew, 1987 #85; Stickney and Bartholomew, 1987 #242; Stickney and Bartholomew, written commun. 1992 #556). Lenses of volcanic ash were found at different stratigraphic positions in the upper colluvial wedge, but Bartholomew and others (1990 #243) do not report the age of this ash to further constrain the timing of the most recent event.

Recurrence interval not reported

Comments: Three faulting events between about 13 and 150 k.y. ago is indicated by trenching studies (Bartholomew and others, 1990 #243), but no constraining data are available for the timing of any of these events.

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Approximately 7-9 m of offset (Bartholomew and Stickney, 1987 #9; Bartholomew and others, 1990 #243) since about 150 ka suggests a slip rate of much less than 0.2 mm/yr.

Length End to end (km) 11.4
Cumulative trace (km) 10.8

Average strike (azimuth) 347°

References

#9 Bartholomew, M.J., and Stickney, M.C., 1987, Late Quaternary faulting in southwestern Montana: Geological Society of America Abstracts with Programs, v. 19, p. 258-259.

#243 Bartholomew, M.J., Stickney, M.C., and Wilde, E.M., 1990, Late Quaternary faults and seismicity in the Jefferson basin, *in* Hall, R.D., ed. Quaternary geology of the western Madison Range, Madison Valley, Tobacco Root range, and Jefferson valley: Rocky Mountain Cell, Friends of the Pleistocene, August 15-19, 1990, Guidebook, p. 238-244.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

669, Rocker fault (Class A)

Structure Number 669

Comments: Refers to number 71 (unnamed fault along east side Deer Lodge Pass—Divide Creek) and number 81 (unnamed fault along east side Melrose valley) of Witkind (1975 #317), and number 25 (Rocker fault) of Johns and others (1982 #259).

Structure Name Rocker fault

Comments: Name is from Johns and others (1982 #259). Bartholomew and Stickney (1987 #9) and Stickney and others (1987 #295) referred to the southern part of this fault as the Divide fault because of change in trend. We use the earlier name here. The fault extends from about 6 km north of Highway 90 (west of Butte) southward to about 5 km southeast of Camp Creek.

Synopsis Preliminary reconnaissance studies have been conducted along some of the fault. Little information has been published concerning the nature, timing, or extent of displacement on the fault, but one trench was excavated on the southern part of the fault.

Date of compilation 05/17/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Silver Bow; Madison

1° x 2° sheet Dillon; Butte

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Trace of fault from 46° N. to 45°45' N. is from 1:24,000-scale geologic map of Smedes (1967 #574), but fault is approximately located on original source. The location of the northern and southern parts of the fault are inferred from the local topography and constrained by the trace on the 1:500,000-scale map of Witkind (1975 #317) and generalized on the approximately 1:70,000-scale map of Ostenaa and Wood (1990 #318).

Geologic setting High-angle, down-to-the-west, range-front normal fault bounding the east side of Divide Creek valley. Amount of structural throw is unpublished.

Sense of movement normal

Comments: (Johns and others, 1982 #259)

Dip not reported

Dip direction W

Geomorphic expression Range front has aligned spurs that are slightly oversteepened at their bases and are separated by narrow valleys (Pardee, 1950 #46).

Age of faulted surficial deposits unknown, fault coincides with the bedrock-alluvium contact or is buried by Quaternary deposits (Ruppel and others, 1993 #646). Pardee (1950 #46) reports that Tertiary lake beds are faulted.

Paleoseismology studies Trench 669-1, located about 200 m north of Moose Creek, was excavated across projection of fault in 1986 (Bartholomew and Stickney, 1987 #9). Trench showed no evidence of late Quaternary (<130 ka) offset (Bartholomew and Stickney, 1987 #9).

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Trenching studies do not preclude Quaternary movement. However, they do exclude the possibility of Pleistocene movement reported by Johns and others (1982 #259). Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the absence of scarps on upper Quaternary deposits and faulted late Quaternary deposits in the trench.

Length End to end (km) 43.5
Cumulative trace (km) 48.6

Average strike (azimuth) 0°

References

#9 Bartholomew, M.J., and Stickney, M.C., 1987, Late Quaternary faulting in southwestern Montana: Geological Society of America Abstracts with Programs, v. 19, p. 258-259.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#646 Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1° x 2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1803-H, 1 sheet, scale 1;250,000.

#574 Smedes, H.W., 1967, Preliminary geologic map of the Butte South quadrangle, Montana: U.S. Geological Survey Open-File Report 67-203, 5 pls., scale 1:24,000.

#295 Stickney, M.C., Bartholomew, M.J., and Wilde, E.M., 1987, Trench logs across the Red Rock, Blacktail, Lima Reservoir, Georgia Gulch, Vendome and Divide faults, Montana: Geological Society of America Abstracts with Programs, v. 19, p. 336-337.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

670, Central Park fault (Class A)

Structure Number 670

Comments: Refers to number 100 (Central Park fault) of Johns and others (1982 #259).

Structure Name Central Park fault

Comments: Name is probably from Hackett and others (1960 #267). Fault extends from about 0.5 km east of Madison River east-northeastward to parallel the lower reach of Reese Creek.

Synopsis Little is known about the Quaternary history of this fault because of its poor surficial expression, and most evidence of its existence and age is circumstantial.

Date of compilation 03/14/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Bozeman

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location is based on trace from 1:250,000-scale map of Hackett and others (1960 #267), but location is speculative because fault is buried.

Geologic setting High-angle, down-to-south normal (?) intrabasin fault in Three Forks Basin. Brodowy and others (1991 #257) suggest that the fault follows the Perry line and may accommodate Basin-and-Range-style extension by dextral oblique slip. Vertical slip on fault is about 60 m based on position of Pliocene(?) gravel on either side of fault (Hackett and others, 1960 #267).

Sense of movement normal

Comments: Johns and others (1982 #259) suggest normal(?) slip on this fault; however, cross sections in Hackett and others (1960 #267) indicate reverse slip.

Dip not reported

Dip direction S

Geomorphic expression Fault is inferred from the presence of an east-trending monoclinal fold in Tertiary strata in the northern part of Gallatin Valley. Folding is thought to be the result of movement on a subjacent fault.

Age of faulted surficial deposits Pliocene(?) gravels (Hackett and others, 1960 #267)

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Timing of last movement is from Johns and others (1982 #259) as suggested by Hackett and others (1960 #267). Bartholomew and Stickney examined several sites along the fault and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on absence of scarps on upper Pleistocene deposits and apparent maximum vertical movement of 60 m since Pliocene time (Hackett and others, 1960 #267).

Length End to end (km) 30.3
Cumulative trace (km) 30.6

Average strike (azimuth) 77°

References

#257 Brodowy, J.M., Lageson, D.R., Ryan, C., and Snyder, B., 1991, Structure and neotectonics of the eastern Three Forks Basin, northern Intermountain seismic belt, southwest Montana: Geological Society of America Abstracts with Programs, v. 23, no. 5, p. A233-A234.

#267 Hackett, O.M., Visher, F.N., McMurtrey, R.G., and Steinhilber, W.L., 1960, Geology and ground-water resources of the Gallatin Valley, Gallatin County, Montana: U.S. Geological Survey Water Supply Paper 1482, 282 p., 1 pl., scale 1:63,360.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

671, Canyon Ferry fault (Class A)

Structure Number 671

Comments: Refers to fault 42 (unnamed echelon faults that for west side of Big Belt Mountains) of Witkind (1975 #317); fault 125 (Canyon Ferry-Duck Creek fault) of Johns and others (1982 #259); fault 18 (Canyon Ferry fault) of Stickney and Bartholomew (1987 #85); Confederate Gulch, Duck Creek and Gurnett Creek scarps of Stickney and Bartholomew (1987 #242); and Confederate Gulch fault of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Canyon Ferry fault

Comments: Although Pardee (1950 #46) was probably the first to mention this fault as a tectonically young structure (late Cenozoic), it remained unnamed in the literature until Johns and others (1982 #259) referred to it as the Canyon Ferry-Duck Creek fault. Stickney and Bartholomew (1987 #85) were first to document Quaternary movement and call it the Canyon Ferry fault, a usage that we follow here. The fault has two sections and extends from Cave Gulch southward to 2 km south of Gurnett Creek.

Synopsis Although poorly studied, the fault has been shown on several regional neotectonic maps. The heights of scarps on upper Quaternary deposits are reported Stickney and Bartholomew (1987 #85).

Date of compilation 04/16/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Broadwater; Lewis and Clark

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Geologic setting High-angle, down-to-the-southwest, range-front normal fault that bounds the southwestern side of Big Belt Mountains. The fault reportedly has 450-1200 m of late Cenozoic displacement (Johns and others, 1982 #259). As shown by Witkind (1975 #317), the Canyon Ferry fault continues farther to the southeast along the subdued front of the Big Belt Mountains (Pardee, 1950 #46) and would include the Ray Creek and Deep Creek faults of Johns and others (1982 #259). However, the southern extension of the Canyon Ferry fault (south of Gurnett Creek) is not included in this compilation based on the absence of evidence suggesting Quaternary movement.

Number of sections 2

Comments: Sections chosen herein are based on the presence or absence of fault scarps.

Length End to end (km) 35.0
Cumulative trace (km) 38.6

Average strike (azimuth) 321°

671a, Unnamed (north) section

Section number 671a

Section name Unnamed (north) section

Comments: Defined herein as the range-front fault that extends along the Big Belt Mountains from Cave Gulch southeastward to about 3 km north of Confederate Gulch.

Reliability of location Poor

Comments: Trace compiled from 1:500,000 scale map of Witkind (1975 #317) and unpublished data of Stickney and Bartholomew (written commun. 1992 #556).

Sense of movement normal

Comments: Largely inferred from topographic and structural setting (Pardee, 1950 #46; Mertie and others, 1951 #520; Nelson, 1963 #521; Johns and others, 1982 #259).

Dip not reported

Dip direction SW

Geomorphic expression Impressive, steep front of the Big Belt Mountains along northern half of Canyon Ferry Lake. Pardee (1950 #46) reported truncated faceted spurs 300-600 m high. However, the fault trace appears to be buried everywhere by Quaternary alluvial and colluvial deposits.

Age of faulted surficial deposits Mertie and others (1951 #520) showed Tertiary deposits as both faulted and in fault contact with Precambrian bedrock.

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Stickney and Bartholomew (1987 #85) indicated that movement on this part of the fault has not occurred in the past 130 k.y.; Witkind (1975 #317) and Johns and others (1982 #259) reported only late Cenozoic movement. Pardee (1950 #46) speculated on young movement based on the prominent range front, but could only demonstrate post-Miocene displacement. However, the strong, fault-controlled range-front morphology and fault's lateral continuity with Quaternary scarps on the southern section [671b] suggest Quaternary movement.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on lack of scarps preserved on Quaternary deposits.

Length End to end (km) 18.2
Cumulative trace (km) 20.3

Average strike (azimuth) 308°

671b, Unnamed (south) section

Section number 671b

Section name Unnamed (south) section

Comments: Defined herein as the range-front fault that extends from about 3 km north of Confederate Gulch to about 1 km south of Duck Creek, and a piedmont scarp that extends from 2 km south of Duck Creek to about 2 km south of Gurnett Creek. This section consists of the Confederate Gulch scarp (Stickney and Bartholomew, 1987 #85) and the Duck Creek and Gurnett Creek scarps (Stickney and Bartholomew, 1987 #242), all of which are named for local streams. Also included are the intervening short parts of the fault that are buried by Quaternary deposits. Because the section described here consists of individual previously named parts of the fault, we do not use a preferential name.

Reliability of location Poor

Comments: Trace is from 1:500,000 scale map of Stickney and Bartholomew (1987 #242), but modified to conform to topography at 1:63,360 scale (Stickney, oral commun. 1992).

Sense of movement normal

Comments: Scarps on Quaternary deposits show down-to-the-west offset of alluvial surfaces (Witkind, 1975 #317).

Dip not reported

Dip direction SW

Geomorphic expression Forms prominent, but discontinuous fault scarps along base of Big Belt Mountains and on piedmont, east of Canyon Ferry Lake. Scarp at Confederate Gulch is 6 km long, and is 15-20 m high on middle Quaternary deposits and 1-2 m high on upper Quaternary (post-Bull Lake) alluvium (Stickney and Bartholomew, 1987 #85). Further south, short (2-3 km long) scarps are preserved on both sides of Duck Creek and Gurnett Creek (Stickney and Bartholomew, 1987 #242).

Age of faulted surficial deposits Upper Quaternary (post-Bull Lake) alluvium at Confederate Gulch (Stickney and Bartholomew, 1987 #85).

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Confederate Gulch scarp is suspected to be >15 ka (present on Bull Lake but not Pinedale deposits) according to Stickney and Bartholomew (1987 #85), but the remainder of the scarp to the south also is considered late Quaternary (Stickney, oral commun., 1993). Early compilations (Witkind, 1975 #317; Johns and others, 1982 #259) only indicated late Cenozoic movement.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: A low slip rate is assumed based on 1-2 m high scarps on upper Quaternary deposits and 15-20 m high scarps on middle Quaternary deposits (Stickney and Bartholomew, 1987 #85).

Length End to end (km) 17.8
Cumulative trace (km) 18.3

Average strike (azimuth) 335°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#520 Mertie, J.B., Jr., Fischer, R.P., and Hobbs, S.W., 1951, Geology of the Canyon Ferry quadrangle, Montana: U.S. Geological Survey Bulletin 972, 97 p., 2 pls., scale 1:48,000.
#521 Nelson, W.H., 1963, Geology of the Duck Creek Pass quadrangle Montana, *in* Contributions to general geology 1960: U.S. Geological Survey Bulletin 1121, p. J1-J56, 1 pl., scale 1: 62,500.
#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.
#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.
#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.
#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.
#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

672, Lower Duck Creek fault (Class A)

Structure Number 672

Comments: Corresponds to fault 127 (Lower Duck Creek fault) of Johns and others (1982 #259).

Structure Name Lower Duck Creek fault

Comments: Named by Johns and others (1982 #259) because of a possible fault scarp between Duck Creek and Gurnett Creek, on the east side of Canyon Ferry Lake. We use Johns and others (1982 #259) trace, which extends from near the latitude of Confederate Gulch southeastward to about 2 km north of Gurnett Creek. They reported a length of 10.5 km, which is at about 3 km longer than the trace shown on their map.

Synopsis Suspected fault scarp was identified from aerial photographs and is coincident with geologic contact between Quaternary units as mapped by Nelson (1963 #521). Fault origin for scarp is not confirmed.

Date of compilation 04/16/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Broadwater

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Shown on Johns and others (1982 #259) map at 1:500,000 scale, but trace is from coincident geologic contact shown on 1:62,500 map of Nelson (1963 #521).

Geologic setting Reported as suspected fault with down-to-the-southwest movement. Lies along distal piedmont that flanks western side of Big Belt Mountains. Subparallel to but west of the southern part of Canyon Ferry fault [671b].

Sense of movement normal

Comments: Inferred from geologic setting.

Dip not reported

Dip direction SW

Geomorphic expression Escarpment and linear tone contrast detected from aerial photos (Johns and others, 1982 #259); however, the compiler believes that the feature could be geologic (fluvial?) contact related to former margin of Missouri River.

Age of faulted surficial deposits Fault(?) separates Quaternary younger alluvium and Quaternary mantle deposits according to map of Nelson (1963 #521).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Johns and others (1982 #259) indicate possible Quaternary movement, but also speculate that the scarp may not be tectonic. If this really is a fault, movement may be as young as late Quaternary based on low topographic position of faulted(?) alluvium in valley.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on obscure scarps.

Length End to end (km) 6.8
Cumulative trace (km) 6.8

Average strike (azimuth) 317°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#521 Nelson, W.H., 1963, Geology of the Duck Creek Pass quadrangle Montana, *in* Contributions to general geology 1960: U.S. Geological Survey Bulletin 1121, p. J1-J56, 1 pl., scale 1: 62,500.

673, Indian Creek faults (Class A)

Structure Number 673

Comments: Refers to fault 114 (Indian Creek faults) of Johns and others (1982 #259), fault 19 (Townsend graben) of Stickney and Bartholomew (1987 #85), and West Canyon Ferry faults of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Indian Creek faults

Comments: Named by Johns and others (1982 #259) for fault scarps on alluvial fans of local drainage. Also referred to as Townsend graben by Stickney and Bartholomew (1987 #85; 1987 #242) and West Canyon Ferry faults by Stickney and Bartholomew (written commun. 1992 #556). Indian Creek name is preferred because of prior usage and reference to a specific nearby locality. The fault scarps are north of Indian Creek on the piedmont between the Elkhorn Mountains and Canyon Ferry Lake.

Synopsis Series of short, echelon, east- and west-facing fault scarps recognized from aerial photos and later confirmed by ground reconnaissance.

Date of compilation 04/16/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Broadwater

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: From detailed mapping used to compile map by Stickney and Bartholomew (1987 #242).

Geologic setting Intrabasin, high-angle normal faults that form graben on piedmont east of Elkhorn Mountains, northwest of Townsend, Montana. Stickney and Bartholomew (1987 #85) reported that these faults are part of a 7-km-long by 2-km-wide graben that trends N 35° W, 2-3 km east of the range front. The predominant sense of movement is down to the northeast, but some secondary faults are down to the southwest thus forming the graben reported by Stickney and Bartholomew (1987 #85).

Sense of movement normal

Dip not reported

Dip direction NE; SW

Geomorphic expression Six-km-long zone of 0.5- to 1-km-long echelon and parallel scarps on Quaternary surfaces. An additional 3 km of older (pre-late Quaternary) faults are present according to Stickney and Bartholomew (1987 #85), although these are not shown on a map.

Age of faulted surficial deposits Pleistocene according to mapping of Freeman and others (1958 #526); Johns and others (1982 #259) suspect that these faults may cut an upper Quaternary (early? Wisconsin) alluvial fan. Stickney and Bartholomew (1987 #85) report that upper Quaternary (<130 ka) deposits have 1- to 2-m-high scarps.

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Based on geologic relations of scarps on deposits thought to be about 15-130 ka (Stickney and Bartholomew, 1987 #85).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred slip rate based on 1- to 2-m-high scarps considered to be on deposits that are 15-130 ka (Stickney and Bartholomew, 1987 #85).

Length End to end (km) 3.9
Cumulative trace (km) 4.8

Average strike (azimuth) 322°

References

#526 Freeman, V.L., Ruppel, E.T., and Klepper, M.R., 1958, Geology of part of the Townsend Valley Broadwater and Jefferson Counties, Montana, *in* Contributions to economic geology: U.S. Geological Survey Bulletin 1042-N, p. 481-556, 1 pl., scale 1:48,000.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

674, Hilger fault (Class A)

Structure Number 674

Comments: Refers to fault 44 (Hilger fault along northeast side Hilger Valley) of Witkind (1975 #317) and fault 31 (Hilger Valley fault) of Johns and others (1982 #259).

Structure Name Hilger fault

Comments: Pardee (1950 #46) probably first named this range-front fault for its location near Hilger, a small town along the Missouri River. Witkind (1975 #317) followed the same usage, but Johns and others (1982 #259) refer to it as the Hilger Valley fault. The original name is used here.

Synopsis Poorly studied, range-bounding, normal fault; estimates of its most recent movement are based on qualitative statements about rates of stream incision versus uplift. The fault is inferred to lie at the range margin, and to project beneath the abutment of Upper Holter Lake on the Missouri River.

Date of compilation 04/19/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark

1° x 2° sheet Butte; White Sulphur Springs

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Transferred from figure 15 (scale approximately 1:200,000) of Pardee (1950 #46) to 1:250,000 sheet, trace was then adjusted to topography.

Geologic setting Range-bounding, down-to-the-southwest, high-angle(?) normal fault that forms 3- to 5-km wide, 20-km-long "trenchlike" depression (Hilger Valley) (Pardee, 1950 #46). Limits and location of fault are poorly known; as shown on figure 15 of Pardee (1950 #46), fault extends from about 2 km west of Little Prickly Pear Creek near Sieben, east to Spring Gulch, about 2 km southeastward of the Missouri River.

Sense of movement normal

Comments: Witkind (1975 #317)

Dip >55°

Comments: Johns and others (1982 #259). Witkind (1975 #317) also suggests that the fault has a high angle (dip).

Dip direction SW

Geomorphic expression Forms linear escarpment with aligned truncated spurs (facets) at base of Big Belt Mountains (Pardee, 1950 #46). At the western end of fault (near Sieben), the lower 30 m of the escarpment (in shale) is steeper (40°) than the remainder of mountain front. Valleys of Little Prickly Pear Creek and Missouri River, which cross the fault’s projection, have steep lower gorges about 200 m deep. Upper canyon walls are less steep and wider, suggesting lower (younger) gorges were formed mostly by a phase of accelerated incision since early to middle Pleistocene time (Pardee, 1950 #46). However, there are no scarps along the projection of fault according to Witkind (1975 #317).

Age of faulted surficial deposits Bregman (1981 #530) mapped undifferentiated Quaternary deposits across the trace of the fault, but Johns and others (1982 #259) note that these deposits could be as young as Holocene. Fault cuts Cambrian strata and Precambrian Belt Group rocks in hangingwall block.

Paleoseismology studies none

Most recent prehistoric deformation middle or late Quaternary (<750 ka)

Comments: Timing based on qualitative assessments of Pardee (1950 #46) and lack of fault scarps (Witkind, 1975 #317). However, Pardee (1950 #46) stated that most of the 200 m of postulated uplift that stranded the ancient paleovalleys must have been accomplished by early or middle Pleistocene time. Johns and others (1982 #259) cite late Pleistocene as time of latest movement.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Lack of fault scarps (Witkind, 1975 #317) supports interpretation of low slip rate.

Length End to end (km) 20.5
Cumulative trace (km) 21.1

Average strike (azimuth) 299°

References

#530 Bregman, M.L., 1981, Structural geology of the Sheep Creek and Rattlesnake Mountain quadrangles, Lewis and Clark County, Montana: Montana Bureau of Mines and Geology Geologic Map 26, 19 p. pamphlet, 1 sheet, scale 1:24,000.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

675, Soup Creek fault (Class A)

Structure Number 675

Comments: Refers to fault 124 (Soup Creek fault) of Johns and others (1982 #259).

Structure Name Soup Creek fault

Comments: Johns and others (1982 #259) use this name, which is a small creek near the middle of the fault, and cite Schaffer (1971 #529) as their sole reference. Limits of fault are poorly known; as shown on Johns and others (1982 #259), fault extends from about Beaver Creek (near Nelson) southwest through York to the Canyon Ferry fault [671]. However, south of York Creek, the fault's location is poorly known; therefore we only the fault south to York Creek.

Synopsis Poorly studied, range-bounding, normal fault inferred to be at base of Big Belt Mountains. Included here because it may be part of an en echelon system that is comprised of the Hilger [674], Soup Creek, and Canyon Ferry [671] faults. This fault may have had earlier Pleistocene displacement as similarly suggested for the Hilger fault.

Date of compilation 04/20/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Transferred from Johns and others (1982 #259) 1:500,000 scale map to 1:250,000 sheet; then adjusted to fit topography. Trace of fault south of York Canyon to junction with Canyon Ferry fault [671] is conjectural and thus not shown.

Geologic setting Range-bounding, down-to-the-southwest, high-angle(?) normal fault that bounds southwestern flank of Middleman Mountain in northern part of Big Belt Mountains. Schaffer (1971 #529) reported about 300 m of unknown age offset on this fault.

Sense of movement normal

Dip not reported

Dip direction SW

Geomorphic expression No known scarps; fault is probably inferred on basis of aligned faceted spurs on bedrock of Big Belt Mountains. Johns and others (1982 #259) indicate a low confidence in the fault's existence.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Considered to be a Quaternary structure by Johns and others (1982 #259). Bartholomew and Stickney (1987 #9) found no evidence of late Quaternary movement.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the absence of fault scarps.

Length End to end (km) 12.9
Cumulative trace (km) 13.2

Average strike (azimuth) 329°

References

#9 Bartholomew, M.J., and Stickney, M.C., 1987, Late Quaternary faulting in southwestern Montana: Geological Society of America Abstracts with Programs, v. 19, p. 258-259.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#529 Schaffer, W.L., 1971, Geology of the Hogback Mountain area, northern Big Belt Mountains, Montana: Albuquerque, University of New Mexico, unpublished M.S. thesis, 66 p., 2 pls., scale 1:24,000.

676, Boulder River valley western border fault (Class A)

Structure Number 676

Comments: Refers to fault 26 (Boulder River valley western border fault) of Johns and others (1982 #259).

Structure Name Boulder River valley western border fault

Comments: Johns and others (1982 #259) is the source of the name, although, the fault is on the piedmont of the Bull Mountain, rather than along the Boulder River. Stickney and Bartholomew (written commun. 1992 #556) used the name Bull Mountain fault for its location along an unnamed range that is south of Bull Mountain. Fault extends from 2.5 km southeast of Boulder Hot Springs southward to 1.5 km north of U.S. Highway 10 near the Jefferson River.

Synopsis Poorly studied range-bounding fault on eastern side of an unnamed range south of Bull Mountain and west of the Boulder River. The medial part of the fault has Quaternary scarps (Stickney and Bartholomew, written commun. 1992 #556), whereas the extent and location of the distal portions are inferred based on local topography.

Date of compilation 04/20/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet White Sulphur Springs; Bozeman; Butte

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: In general, location is poor. Part of fault having Quaternary scarps is well located and is from digital compilation of Stickney and Bartholomew (written commun. 1992 #556). Remainder of fault was transferred from 1:500,000 scale map of Johns and others (1982 #259).

Geologic setting High-angle, down-to-the-east, range-bounding normal fault on east flank of Bull Mountain and adjacent unnamed range, which form an elongate north-trending fault block. Although Johns and others (1982 #259) made no mention of actual fault scarps, they show a high confidence in the fault's existence and report a length of 32 km for the structure. Johns and others (1982 #259) argue that late Pleistocene faulting induced the incision and deposition of alluvial fans and inferred as much as 120 m of offset of the piedmont surface.

Sense of movement normal

Comments: Johns and others (1982 #259).

Dip about 75° E

Comments: Johns and others (1982 #259) provide this approximate dip but do not report its location or basis.

Dip direction E

Geomorphic expression Stickney and Bartholomew (written commun. 1992 #556) mapped a 3- to 4-km-long fault scarp that crosses the alluvial piedmont southeast of Bull Mountain along the medial part of the fault from about Brady Creek southward to Dunn Creek. North and south of the medial part, no obvious fault scarps are preserved.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation middle and late Quaternary (<750 ka)

Comments: Stickney and Bartholomew (written commun. 1992 #556) showed the fault scarp as middle to late Quaternary on their unpublished digital map. This generally agrees with the late Pleistocene age inferred by Johns and others (1982 #259).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on 120 m of offset in deposits that could be as old as middle Pleistocene (<750 ka).

Length End to end (km) 33.5
Cumulative trace (km) 36.3

Average strike (azimuth) 349°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

677, Beaver Creek fault (Class A)

Structure Number 677

Comments: Refers to fault 115 (Beaver Creek-Townsend faults) of Johns and others (1982 #259) and the Beaver Creek fault of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Beaver Creek fault

Comments: This name is used by Stickney and Bartholomew (written commun. 1992 #556) on their digital fault map of southwestern Montana. Johns and others (1982 #259) use the names Beaver Creek and Townsend for their two fault segments. The name used herein applies to the northern part of their fault, whereas the southern part is not included owing to a lack of demonstrable Quaternary movement. The fault extends from the southern margin of the alluvial fan of Beaver Creek southward to a point about 2 km north of Indian Creek, where it enters Cretaceous bedrock (Kinoshita and others, 1964 #532).

Synopsis This poorly understood basin-margin fault on the east flank of the Elkhorn Mountains appears to have middle Quaternary or younger movement on the basis of aerial photography. Even though Johns and others (1982 #259) discuss two segments of the fault, their term segments was probably refers to two en echelon traces that they included in their compilation.

Date of compilation 04/21/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Broadwater

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Trace is from digital fault map of Stickney and Bartholomew (written commun. 1992 #556), but we extended it several kilometers further south on basis of Johns and others (1982 #259) trace fitted to geology mapped by Kinoshita and others (1964 #532).

Geologic setting Range-bounding, down-to-the-east, high-angle(?) normal fault along eastern margin of the Elkhorn Mountains, west of the southern half of Canyon Ferry Lake. Along most of its trace, the Beaver Creek fault places Quaternary and Tertiary sediments on the east against Cretaceous bedrock on the west.

Sense of movement normal

Dip not reported

Dip direction E

Geomorphic expression Johns and others (1982 #259) report six distinct scarps on bedrock are visible on aerial photographs of the northern section of the fault.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation middle and late Quaternary (<750 ka)

Comments: Age is from Stickney and Bartholomew (written commun. 1992 #556) based on field studies of scarp morphology. In contrast, Johns and others (1982 #259) speculate that scarps along northern part may be Holocene because they are fresh looking, but reported late Cenozoic movement.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on small scarps and subdued morphology.

Length End to end (km) 12.3
Cumulative trace (km) 12.5

Average strike (azimuth) 346°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#532 Kinoshita, W.T., Davis, W.E., Smedes, H.W., and Nelson, W.H., 1964, Bouguer gravity, aeromagnetic, and generalized geologic map of Townsend and Duck Creek Pass quadrangles, Broadwater County, Montana: U.S. Geological Survey Geophysical Investigations Map GP-439, 6 p. pamphlet, 2 sheets, scale 1:62,500.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

678, Helena valley fault (Class A)

Structure Number 678

Comments: Refers to fault 50 (St. Mary's fault) of Witkind (1975 #317), fault 121 (Helena Valley fault) of Johns and others (1982 #259), fault 20 (Helena Valley fault) of Stickney (1987 #251) and Stickney and Bartholomew (1987 #85) (written commun. 1992 #556), and Thorton Ranch and East of I-15 segments of Helena Valley fault of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Helena valley fault

Comments: According to Schmidt (1986 #533), this fault was first mapped by Bregmen and Robinson (no reference given). The first name applied to the structure appears to be St. Mary's fault (Witkind, 1975 #317), which was a previously mapped fault to the northwest of Helena (Schmidt, 1986 #533). The name Helena valley fault, which is now preferred in the literature, has been applied to combinations of various faults in the Helena valley. However, recent mapping by Schmidt (1986 #533) and Stickney (1987 #251) support restricting the name to the range-bounding fault along the northern margin of the Helena valley. The part of the fault having demonstrable or suspected Quaternary movement extends from 5 km west of Interstate Highway 15 at the bedrock divide with Silver Valley to 3 km east of the southeastern shore of Lake Helena.

Synopsis This fault has been mapped as a bedrock structure for more than 20 years, but considerable doubt has existed about its sense and recency of movement. Stickney (1987 #251) was the first to find offset Quaternary deposits along two short parts of the fault, although the majority of its mapped trace seems to be represented by a fault-line scarp.

Date of compilation 04/22/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark

1° x 2° sheet White Sulphur Springs, Butte

Physiographic province Northern Rocky Mountains

Geologic setting High-angle, down-to-the-southwest, normal(?) fault along northern margin of the Helena valley (as restricted from previous usage). The fault extends from the bedrock divide with Silver Valley eastward to Lake Helena. Witkind (1975 #317) extended the fault farther west to Canyon Creek, and both Witkind (1975 #317) and Johns and others (1982 #259) extended the fault southeastward along the base of the Spokane Hills. Schmidt (1986 #533) mapped the fault (inferred trace) eastward into the Townsend Valley, although Stickney (1987 #251) found no evidence for Quaternary movement in the low divide between Lake Helena and Hauser Lake. The zone formed by the St. Marys fault, Helena valley fault, and its extension to the east are considered to be the northern boundary of the Lewis and Clark line, which is thought to be a Tertiary dextral-slip fault zone (Reynolds, 1979 #223). Reynolds (1979 #223) and Schmidt (1986 #533) reported several kilometers of Tertiary dextral movement on the Helena valley fault, although this amount of offset is not well documented.

Number of sections 2

Comments: The two sections consist of the main range-bounding trace of the Helena valley fault and a second minor section comprised of two 1-km-long scarps that are on the piedmont south of the range. The piedmont scarps are clearly related to young movement, which may be associated with the main fault at depth.

Length End to end (km) 19.9
Cumulative trace (km) 24.2

Average strike (azimuth) 294°

678a, Unnamed (main range-bounding) section

Section number 678a

Section name Unnamed (main range-bounding) section

Reliability of location Good

Comments: Shown on maps by Schmidt (1986 #533) and Stickney (1987 #251), the fault is either entirely within bedrock or bounds bedrock.

Sense of movement normal

Comments: As reported by Stickney (1987 #251), although Reynolds (1979 #223) considered its recent (Tertiary) phase of movement to have primarily dextral slip.

Dip not reported

Dip direction SW

Geomorphic expression Main fault is defined by the linear bedrock margin (fault-line scarp) at the northern edge of Helena valley. Neither Schmidt (1986 #533) nor Stickney (1987 #251) found scarps on unconsolidated sediments along this section.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Inferred Quaternary movement based on age estimates (early Quaternary or late Tertiary) of Stickney and Bartholomew (1987 #85) and the fault's spatial association with nearby post-middle Pleistocene scarps [678b].

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of scarps on upper Quaternary deposits.

Length End to end (km) 19.9
Cumulative trace (km) 22.4

Average strike (azimuth) 295°

678b, Unnamed (piedmont) section

Section number 678b

Section name Unnamed (piedmont) section

Comments: Includes the Thorton Ranch scarp and the East of I-15 scarp of Stickney and Bartholomew (1987 #85). The scarps are parallel to and slightly basinward (south) of the range-bounding section of the Helen valley fault [678a].

Reliability of location Good

Comments: Based on 1:50,000-scale map of Stickney (1987 #251).

Sense of movement normal

Dip not reported

Dip direction S

Geomorphic expression This section consists of two 1-km-long fault scarps on alluvial-fan deposits. The scarps are about 1 m high, have a gentle slope (angle not specified), and appear to be highly degraded (Stickney, 1987 #251). They have been incised by streams and are buried in part by upper Quaternary deposits.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation middle or late Quaternary (<750 ka)

Comments: Based on age estimates of Stickney and Bartholomew (1987 #85) and supported by the implied high degree of degradation of the fault scarps.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred from absence of scarps on upper Quaternary alluvium.

Length End to end (km) 4.7
Cumulative trace (km) 1.8

Average strike (azimuth) 284°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#223 Reynolds, M.W., 1979, Character and extent of Basin-Range faulting, western Montana and east-central Idaho, *in* Newman, G.W., and Goode, H.D., eds., Basin and Range symposium and Great Basin field conference: Rocky Mountain Association of Geologists and Utah Geological Association, p. 41-54.

#533 Schmidt, R.G., 1986, Geology, earthquake hazards, and land use in the Helena area, Montana—A review: U.S. Geological Survey Professional Paper 1316, 64 p., 3 pls., scale 1:48,000 and 1:25,000.

#251 Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, 1 pl., scale 1:50,000.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.
#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

679, Spokane Hills fault (Class A)

Structure Number 679

Comments: Refers to parts of fault 50 (St. Mary's fault) of Witkind (1975 #317), fault 121 (Helena Valley fault) of Johns and others (1982 #259), and fault 24 (Spokane Hills fault) of Stickney (1987 #251) and Stickney and Bartholomew (1987 #85; 1987 #242; written commun. 1992 #556).

Structure Name Spokane Hills fault

Comments: The first use of this name appears to have been by Schmidt (1986 #533). The faults were included as the southwestern part of the Helena Valley (St. Marys) fault by Witkind (1975 #317) and Johns and others (1982 #259). The structure consists of two range-bounding splays and a piedmont scarp that together extend from about 1 km northwest of Hauser Lake where Spokane Creek enters southward to a point about 1 km north of U.S. Highway 287.

Synopsis The range-bounding normal faults [679a] form a prominent escarpment on Tertiary bedrock along the eastern margin of Helena valley and locally show evidence of late Quaternary movement. The piedmont scarp [679b] shows clear evidence of late Quaternary movement. Johns and others (1982 #259) indicate that a splay of the Helena Valley fault extends about 6 km southward along Spokane Creek and is a structural control for the creek. This splay is not included here because it lacks evidence of Quaternary movement.

Date of compilation 04/23/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark; Broadwater

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Geologic setting This zone of subparallel, generally down-to-the-southwest, range-bounding and piedmont normal faults form the western margin of the Spokane Hills along the eastern side of Helena valley. The main fault [679a] has two echelon parts that place pre-Tertiary bedrock on the east against Tertiary sedimentary rocks and Quaternary sediment on the west. A subsidiary fault, on the piedmont, cuts Tertiary and perhaps Quaternary sediment.

Number of sections 2

Comments: Sections defined here are the main range-bounding faults [679a] and a short piedmont scarp [679b]

Length End to end (km) 13.6
Cumulative trace (km) 13.6

Average strike (azimuth) 321°

679a, Unnamed (range-bounding) section

Section number 679a

Section name Unnamed (range-bounding) section

Comments: This section is the main range-bounding trace of the fault and consists of two scarps that form a right-stepping echelon pattern. The northern scarp extends from a bedrock knob about 1 km west of Spokane Creek at its entry into Hauser Lake, southeastward about 6 km into the Spokane Hills. The northern end of the southern scarp is about 2.5 km to the south and extends south-southeastward along the base of the main part of the Spokane Hills for a distance of about 5 km.

Reliability of location Good

Comments: Based on 1:50,000-scale map of Stickney (1987 #251).

Sense of movement normal

Dip not reported

Dip direction SW

Geomorphic expression Forms prominent escarpment along the western edge of the Spokane Hills. No fault scarps on unconsolidated material have been reported.

Age of faulted surficial deposits Stickney (1987 #251) showed the fault cutting Pleistocene loess and Tertiary deposits, both of which are in juxtaposition with pre-Tertiary bedrock in the footwall along most of this section. The fault cuts middle Pleistocene piedmont gravel at one locality (Stickney, 1987 #251).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Stickney (1987 #251) reports this section of the fault as having early Quaternary or late Tertiary movement, although middle Pleistocene piedmont gravel appears to be offset at one locality.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred from absence of Quaternary scarps.

Length End to end (km) 13.8
Cumulative trace (km) 12.3

Average strike (azimuth) 320°

679b, Unnamed (piedmont) section

Section number 679b

Section name Unnamed (piedmont) section

Comments: Comprised of a single short piedmont scarp about 4 km east of Louisville and 1 km north of U.S. Highway 285. This scarp is parallel to and about 1 km west of the main trace of the fault [679a].

Reliability of location Good

Comments: Based on 1:50,000-scale geologic map of Stickney (1987 #251).

Sense of movement normal

Dip not reported

Dip direction SW

Geomorphic expression Johns and others (1982 #259) mention offset deposits that are probably associated with the 4- to 5-m-high fault scarp (Stickney and Bartholomew, 1987 #85) that was mapped on the piedmont by Stickney (1987 #251).

Age of faulted surficial deposits Johns and others (1982 #259) stated that upper Pleistocene loess and Quaternary pediment deposits are offset about 6 m (T. 4 N., R. 1 W. Sec. 4 and 9). Stickney (1987 #251) and Stickney and Bartholomew (1987 #85) cite offset of upper to middle Pleistocene deposits, but Holocene to upper Pleistocene sediment extends across the trace of the fault on their map.

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Based on geomorphic expression (presence of scarp) and age of faulted deposits.

Recurrence interval not reported

Slip-rate category unknown, probably 0.2-1 mm/yr

Comments: Slip rate is inferred on the basis of a 4- to 5-m-high scarp and about 6 m of offset of deposits that are late Pleistocene (>10-130 ka) or older (Stickney and Bartholomew, 1987 #85). These data are not conclusive and indicate a maximum slip rate that could fall into either of the lower two categories. The higher of the two is selected here so as to not inadvertently lower the hazard.

Length End to end (km) 1.3
Cumulative (km) 1.3

Average strike (azimuth) 335°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#533 Schmidt, R.G., 1986, Geology, earthquake hazards, and land use in the Helena area, Montana—A review: U.S. Geological Survey Professional Paper 1316, 64 p., 3 pls., scale 1:48,000 and 1:25,000.

#251 Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, 1 pl., scale 1:50,000.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.
#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

680, Regulating Reservoir faults (Class A)

Structure Number 680

Comments: Refers to fault 122 (Helena Regulating Reservoir fault) of Johns and others (1982 #259) and Regulating Reservoir fault (Stickney and Bingler, 1981 #559; Stickney, 1987 #251; Stickney and Bartholomew, written commun. 1992 #556).

Structure Name Regulating Reservoir faults

Comments: Found in trench excavations by M.W. Reynolds in 1975 (Schmidt, 1986 #533); later mapped by Schmidt (1986 #533) and Stickney (1987 #251). Johns and others (1982 #259) use the term Helena Regulating Reservoir fault for the locality of its discovery, although the term Regulating Reservoir is shown on local maps and thus accepted as the fault's name (Stickney and Bingler, 1981 #559). The fault consists of three echelon scarps that extend across Spokane Bench.

Synopsis Comprised of three, echelon, intrabasin, normal faults that trend northwest and lie between the Spokane Hills fault (679a) and the Spokane Bench fault (681). Poorly studied, with the exception of a single trenching study for Regulating Reservoir.

Date of compilation 04/23/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Location from 1:50,000-scale map of Stickney (1987 #251). Also shown by Schmidt (1986 #533).

Geologic setting Three intrabasin, echelon, down-to-the-southwest, normal faults that form discontinuous and dissected scarps on Spokane Bench. The faults trend northwesterly between the Spokane Hills fault [679a] and the Spokane Bench fault [681] and have been considered as splays of the latter (Johns and others, 1982 #259). The westernmost fault projects beneath Regulating Reservoir.

Sense of movement normal

Comments: Johns and others (1982 #259)

Dip 60°-80° W

Comments: Determined from trenching study at the Regulating Reservoir (Schmidt, 1986 #533).

Dip direction SW

Geomorphic expression The central fault of three faults is marked by a dissected scarp that is 12 to 30 m high on Spokane Bench (Schmidt, 1986 #533). Locally, Spokane Bench is tilted to the east, adjacent to the fault. Locally, stream channels and young alluvium bury the trace of the fault.

Age of faulted surficial deposits Spokane Bench, which is faulted, is underlain by Tertiary(?) fluvial and lacustrine sediments, which are considered to be as old as Oligocene (Schmidt, 1986 #533) or as young as late Pliocene or early Pleistocene (Johns and others, 1982 #259). The bench may in fact be an erosional surface that is unconformable on the underlying materials (Pardee, 1950 #46), which are tilted. Reynolds reported that caliches formed in the sediment are brecciated along the projection of the fault (Schmidt, 1986 #533). Thus, although the faults are known to cut Tertiary sediment, they also deform Spokane Bench, which could be as young as early Pleistocene.

Paleoseismology studies Trenching at the Regulating Reservoir in 1977 (Schmidt, 1986 #533) revealed a narrow zone of high-angle normal faults that dip 60-80° W. Although no datable materials were found, caliches that are considered to be early Pleistocene or late Pliocene show evidence of local faulting.

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Witkind (1975 #317) showed the fault as Quaternary, Schmidt (1986 #533) considered it to be potentially active, and Reynolds, as cited in Johns and others (1982 #259), suggested possible Holocene movement on the basis of a spatial association with the 1935 Helena earthquake and the presence of clastic dikes in trench excavations. However, the latter argument is not definitive, and thus we use the conservative estimate of Quaternary.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate is inferred from the 12- to 30-m-high scarp on Spokane Bench, which could be as young as early Pleistocene.

Length End to end (km) 8.2
Cumulative (km) 11.9

Average strike (azimuth) 315°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#533 Schmidt, R.G., 1986, Geology, earthquake hazards, and land use in the Helena area, Montana—A review: U.S. Geological Survey Professional Paper 1316, 64 p., 3 pls., scale 1:48,000 and 1:25,000.

#251 Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, 1 pl., scale 1:50,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

#559 Stickney, M.C., and Bingler, E.C., 1981, Earthquake-hazard evaluation of the Helena valley area, Montana: Montana Bureau of Mines and Geology Open-File Report 83, 30 p., 1 pl., scale 1:24,000.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

681, Spokane Bench fault (Class A)

Structure Number 681

Comments: Refers to faults 152 (unnamed, extends south from Lake Helena) and 292 (unnamed fault near Helena) of Witkind (1975 #317), and fault 123 (Lake Helena fault) of Johns and others (1982 #259).

Structure Name Spokane Bench fault

Comments: Johns and others (1982 #259) referred to the northern part of this structure as the Lake Helena fault. First published use of the Spokane Bench name appears to have been by Schmidt (1986 #533) and is the name that is used here. The fault was unnamed in compilation of Witkind (1975 #317) and on maps by Stickney and Bingler (1981 #559) and Stickney (1987 #251). Fault extends from outlet of Lake Helena southerly and southeasterly to east of Clasoil, Montana.

Synopsis This intrabasin normal fault forms a prominent scarp on the western and southern edges of Spokane Bench, east of Helena. The northern section of the fault is mostly concealed beneath young unconsolidated deposits, whereas a scarp on Tertiary sediment is present along the south section.

Date of compilation 04/26/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark; Jefferson

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Geologic setting Down-to-the-west, intrabasin, normal fault that forms a prominent scarp at the western and southern margins of Spokane Bench. Johns and others (1982 #259) report 30 m of Quaternary displacement on the fault. At the northern end, there may be as much as 100 m of offset between Tertiary sediment and pre-Tertiary sedimentary bedrock (Schmidt, 1986 #533). Further south, the fault turns to the southeast and forms a down-to-the-southwest scarp that opposes the northward gradient between higher bedrock terrain and Spokane Bench.

Number of sections 2

Comments: Fault divided into two sections on the basis of trend and previous mapping that defined two separate faults.

Length End to end (km) 20.4
Cumulative (km) 20.1

Average strike (azimuth) 330°

681a, Unnamed (north) section

Section number 681a

Section name Unnamed (north) section

Comments: Refers to unnamed fault (#152) of Witkind (1975 #317) and to the Lake Helena fault (#123) of Johns and others (1982 #259). This section extends from the east side of Lake Helena southward to a point about 3 km northeast of East Helena, where it joins the southern section. Johns and others (1982 #259) considered it to be a continuation of the Regulating Reservoir fault [680] and (together) possibly a splay of their larger Helena valley fault [Spokane Hills fault, 679].

Reliability of location Good

Comments: Location based primarily on 1:48,000-scale map of Schmidt (1986 #533). Stickney (1987 #251) shows the fault as having two right-stepping echelon strands.

Sense of movement normal

Comments: Johns and others (1982 #259).

Dip not reported

Dip direction W

Geomorphic expression According to Schmidt (1986 #533), this fault follows the base of a escarpment that is about 30 m high along the western margin of Spokane Bench. The trace of the fault is probably covered by stream gravels (Schmidt, 1986 #533) and by local alluvial-fan deposits and colluvium shed from the scarp (Stickney, 1987 #251).

Age of faulted surficial deposits Fault displaces Spokane Bench and drops it down to the west, presumably beneath younger Quaternary material. Spokane Bench is underlain by Tertiary(?) fluvial and lacustrine sediments, which are considered to be as old as Oligocene (Schmidt, 1986 #533) to as young as late Pliocene or early Pleistocene (Johns and others, 1982 #259). The bench may in fact be an erosional surface that is unconformable on the underlying materials (Pardee, 1950 #46), which are tilted. Thus, although the faults are known to cut Tertiary sediment, they also deform Spokane Bench, which could be as young as early Pleistocene.

Paleoseismology studies In 1977, the Bureau of Reclamation excavated several trenches across the scarp, west of Regulating Reservoir. These trenches were about 2 m deep and were logged by M.W. Reynolds (USGS) and M. McKeown (USBR) (Schmidt, 1986 #533). The trenches did not penetrate the primary trace of the fault, but exposed Tertiary sediment that dips as much as 70° in hanging wall of the fault and early(?) Quaternary sediment that is folded, slumped, locally shattered (sheared?) and invaded by sand dikes. Movement is presumed to have occurred on the main fault in middle or late Quaternary time (Schmidt, 1986 #533).

Most recent prehistoric deformation middle and late Quaternary (<750 ka)

Comments: Estimates range from middle or late Quaternary (Schmidt, 1986 #533) to early Quaternary or late Tertiary (Stickney, 1987 #251). Estimate of timing is based on deformation of early(?) Quaternary sediment (Schmidt, 1986 #533).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on 30 m of Quaternary displacement on the fault (Johns and others, 1982 #259).

Length End to end (km) 10.2
Cumulative (km) 10.4

Average strike (azimuth) 350°

681b, Unnamed (south) section

Section number 681b

Section name Unnamed (south) section

Comments: Refers to unnamed fault (#292) of Witkind (1975 #317). Fault extends from a point about 3 km northeast of East Helena southeastward to Clasoil, a small town about 10 km east of East Helena.

Reliability of location Good

Comments: Location based primarily on 1:50,000-scale map of Stickney (1987 #251), but modified to connect with the northern section of the fault [681a] as suggested by topography.

Sense of movement normal

Dip not reported

Dip direction SW

Geomorphic expression This fault is marked by a southwest-facing scarp that opposes the northerly gradient between high bedrock terrain (to the south) and Spokane Bench. The scarp is very small at Clasoil, but is progressively larger to the west. It reaches 20 m in height at Diehl Lane, where it is coincident with a northwesterly trending stream channel. Along most of its length, the scarp deflects or controls the path of streams.

Age of faulted surficial deposits Fault displaces Spokane Bench and drops it down to the west, presumably beneath younger Quaternary material. Spokane Bench is underlain by Tertiary(?) fluvial and lacustrine sediments, which are considered to be as old as Oligocene (Schmidt, 1986 #533) to as young as late Pliocene or early Pleistocene (Johns and others, 1982 #259). The bench may in fact be an erosional surface that is unconformable on the underlying materials (Pardee, 1950 #46), which are tilted. Thus, although the faults are known to cut Tertiary sediment, they also deform Spokane Bench, which could be as young as early Pleistocene.

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Stickney (1987 #251) reported early Quaternary to late Tertiary movement, whereas Witkind (1975 #317) considered the fault to be Quaternary.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred from the 20-m-high fault scrap on Spokane Bench.

Length End to end (km) 11.8
Cumulative trace (km) 9.7

Average strike (azimuth) 309°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#533 Schmidt, R.G., 1986, Geology, earthquake hazards, and land use in the Helena area, Montana—A review: U.S. Geological Survey Professional Paper 1316, 64 p., 3 pls., scale 1:48,000 and 1:25,000.

#251 Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, 1 pl., scale 1:50,000.
#559 Stickney, M.C., and Bingler, E.C., 1981, Earthquake-hazard evaluation of the Helena valley area, Montana: Montana Bureau of Mines and Geology Open-File Report 83, 30 p., 1 pl., scale 1:24,000.
#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

682, Diamond Springs fault (Class A)

Structure Number 682

Comments: Refers to fault 23 (Diamond Springs fault) of Stickney and Bartholomew (1987 #85); Diamond Springs scarp of Stickney and Bartholomew (1987 #242).

Structure Name Diamond Springs fault

Comments: Mapped and named by Stickney (1987 #251) for local drainage (Diamond Springs Gulch). Fault extends from Diamond Springs Gulch southward about 1 km.

Synopsis Poorly studied, down-to-the-east, normal fault that bounds pre-Tertiary bedrock at northwestern corner of Helena valley. Trend is nearly perpendicular to the northern section Helena valley fault [678a].

Date of compilation 04/27/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark

1° x 2° sheet Butte

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: From digital map of Stickney and Bartholomew (written commun. 1992 #556).

Geologic setting One-km-long, down-to-the-east, normal fault that forms scarp on Quaternary deposits and bounds pre-Tertiary bedrock at the northwestern corner of Helena valley.

Sense of movement Normal

Comments: Stickney (1987 #251).

Dip not reported

Dip direction E

Geomorphic expression Scarp on piedmont is dissected by streams that have terraces of Holocene to late Pleistocene age. No scarp heights or amounts of offset are mentioned by Stickney (1987 #251) or Stickney and Bartholomew (1987 #85).

Age of faulted surficial deposits Stickney (1987 #251) showed the fault cutting Holocene and middle Pleistocene alluvium, but the depicted displacement of Holocene alluvium is a drafting error (Stickney, oral commun. 1993).

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Stickney and Bartholomew (1987 #85; 1987 #242) show the fault as having late Pleistocene movement, but referenced by Stickney (1987 #251).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred from absence of scarps on Holocene and upper Quaternary deposits.

Length End to end (km) 0.7
Cumulative trace (km) 0.7

Average strike (azimuth) 6°

References

#251 Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, 1 pl., scale 1:50,000.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

683, Iron Gulch fault (Class A)

Structure Number 683

Comments: Refers to fault 22 (Iron Gulch fault) of Stickney and Bartholomew (1987 #85) and Stickney (1987 #251), part of fault 45 (unnamed fault at eastern end of Scratchgravel Hills) of Witkind (1975 #317), and part of fault 120 (Prickly Pear fault) of Johns and others (1982 #259). Also refers to Silver Creek fault of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Iron Gulch fault

Comments: Pardee (1950 #46) first recognized this fault, but did not give it a name. The fault was named for Iron Gulch, a small stream that crosses the scarp at northeastern margin of Scratchgravel Hills, on western side of Helena valley, by Stickney (1987 #251). This structure, which has been mapped higher on the slope, was referred to as part of the Prickly Pear fault zone by Johns and others (1982 #259), the Scratchgravel Hills fault by Schmidt (1986 #533), and the Silver Creek fault by Stickney and Bartholomew (written commun. 1992 #556).

Synopsis This fault bounds the northeastern side of the Scratchgravel Hills and may be the northwestern part of a more continuous fault zone that strikes southeasterly across Helena valley. The fault forms a scarp at the base of middle to upper Pleistocene piedmont-slope deposits.

Date of compilation 04/28/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark

1° x 2° sheet Butte

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: From digital map of Stickney and Bartholomew (written commun. 1992 #556).

Geologic setting Northeast-trending, basin-margin, normal fault at western side of Helena valley. As mapped by Stickney (1987 #251), the trace of the fault is entirely within Quaternary deposits. Schmidt (1986 #533) mapped a similar basin-margin fault higher on the eastern slope of the Scratchgravel Hills, but showed it entirely within bedrock. Conversely, Johns and others (1982 #259) showed the Prickly Pear fault extending from East Helena northwestward as a concealed fault beneath the Helena valley; its northwestern end is largely coincident with the Iron Gulch fault.

Sense of movement Normal
Comments: Johns and others (1982 #259)

Dip not reported

Comments: Steep (but with no specific dip angles reported) according to Johns and others (1982 #259).

Dip direction NE

Geomorphic expression Forms a 4-km-long, 4- to 5-m-high scarp on middle to late Pleistocene alluvial fans, but is dissected and (or) covered by Holocene to upper Pleistocene alluvium (Stickney, 1987 #251). The fault is parallel to Silver Creek and the downdropped side is covered by Holocene alluvium. It is possible that the scarp has been trimmed (or formed) by lateral erosion from Silver Creek.

Age of faulted surficial deposits Fault truncates middle to upper Pleistocene alluvium (Stickney and Bartholomew, 1987 #85).

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Stickney (1987 #251) reported that middle to late Pleistocene alluvial fans are displaced, but on the digital map of Stickney and Bartholomew (written commun. 1992 #556) they show the fault as being late Quaternary (late Pleistocene or Holocene). The Prickly Pear fault was considered to be Holocene (Johns and others, 1982 #259) on the basis of its spatial association with the 1935-36 earthquake epicenters. However, there is no evidence of historic surface rupturing or Holocene movement along the Iron Gulch fault or the inferred trace of the Prickly Pear fault.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on small scarps (4-5 m high) on deposits that could be as young as 130 ka.

Length End to end (km) 3.9
Cumulative trace (km) 3.9

Average strike (azimuth) 327°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#533 Schmidt, R.G., 1986, Geology, earthquake hazards, and land use in the Helena area, Montana—A review: U.S. Geological Survey Professional Paper 1316, 64 p., 3 pls., scale 1:48,000 and 1:25,000.

#251 Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, 1 pl., scale 1:50,000.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

684, Franklin Mine Road fault (Class A)

Structure Number 684

Comments: Refers to fault 21 (Franklin Mine Road fault) of Stickney and Bartholomew (1987 #85) and the northern part of fault 37 (Scratchgravel Hills-Fort Harrison faults) of Johns and others (1982 #259)

Structure Name Franklin Mine Road fault

Comments: First recognized and mapped by Stickney and Bingler (1981 #559), it was later shown by Johns and others (1982 #259) as a collection of fault scarps in the northern part of a zone that they called the Scratchgravel Hills-Fort Harrison fault. Stickney and Bartholomew (written commun. 1992 #556) use the name Scratchgravel Hills fault on their digital map. We adopt the name used by Stickney (1987 #251), which refers to a local access road. The Franklin Mine Road fault is between bedrock hills at the southern margin of the Scratchgravel Hills, northwest of Helena.

Synopsis The Franklin Mine Road fault forms two parallel scarps that bound the southern side of Scratchgravel Hills, northwest of Helena. The scarps are both short and surrounded by bedrock, which suggests they are not part of a longer range-bounding structure. Little detailed information exists about this structure.

Date of compilation 04/29/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark

1° x 2° sheet Butte

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: From digital map of Stickney and Bartholomew (written commun. 1992 #556).

Geologic setting Northeast-trending, down-to-the-southwest, normal fault that forms two parallel scarps on an old element of the piedmont within an erosional valley on the southern side of the Scratchgravel Hills. As mapped by Stickney (1987 #251), the traces of the fault are short, entirely within Quaternary deposits and surrounded by bedrock, which suggests they are not part of a longer range-bounding structure.

Sense of movement normal

Comments: Johns and others (1982 #259).

Dip not reported

Comments: Nearly vertical according to Johns and others (1982 #259).

Dip direction SE

Geomorphic expression Has two 1-km-long scarps on older alluvial fans, but the scarps are covered by upper Pleistocene alluvium (Stickney and Bartholomew, 1987 #85). Johns and others (1982 #259) showed as many as eight scarps in this area, but most are associated with joints in bedrock.

Age of faulted surficial deposits Fault displaces a late Pleistocene pediment (piedmont) surface, whereas the scarps are covered by uppermost Pleistocene (Pinedale) alluvial-fan deposits (Stickney and Bartholomew, 1987 #85). However, Stickney (1987 #251) mapped the upper of the two scarps as crossing uppermost Pleistocene (Pinedale) alluvium.

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Johns and others (1982 #259) show the fault as Quaternary, whereas Stickney and Bartholomew (1987 #242; written commun. 1992 #556) indicate that the fault is late Quaternary. Since the latter compilations focused on recent faults, we use their age assignment.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is from the apparent small height of the scarps and the fact that they appear to be older than latest Pleistocene.

Length End to end (km) 1.1
Cumulative (km) 1.9

Average strike (azimuth) 53°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#251 Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, 1 pl., scale 1:50,000.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

#559 Stickney, M.C., and Bingler, E.C., 1981, Earthquake-hazard evaluation of the Helena valley area, Montana: Montana Bureau of Mines and Geology Open-File Report 83, 30 p., 1 pl., scale 1:24,000.

685, Fort Harrison fault (Class A)

Structure Number 685

Comments: Refers to southern part of fault 37 (Scratchgravel Hills-Fort Harrison faults) of Johns and others (1982 #259).

Structure Name Fort Harrison fault

Comments: Pardee (1950 #46) first recognized the presence of a range-bounding fault (unnamed) at the southern margin of Prickly Pear basin (Helena valley). Stickney and Bingler (1981 #559) mapped the fault, and later, Johns and others (1982 #259) show it as several faults in the southern part of a zone that they called the Scratchgravel Hills-Fort Harrison fault. We use the name of Stickney (1987 #251), which refers to Fort William Henry Harrison. The Fort Harrison fault is mapped from Cherry Creek eastward to Tenmile Creek.

Synopsis Little is known about the Fort Harrison fault other than it forms a prominent escarpment along the northern side of pre-Tertiary bedrock at the southwestern corner of the Helena valley. The scarp is relatively short, and may be part of a longer inactive fault system that bounds the southern side of the Helena valley.

Date of compilation 04/29/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Lewis and Clark

1° x 2° sheet Butte

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: From 1:50,000-scale map of Stickney (1987 #251).

Geologic setting West-trending, down-to-the-north, normal fault that forms a prominent escarpment at the southwestern corner of the Helena valley, southwest of Fort Harrison, which is due west of Helena. The fault is only about 1.5 km long, but may be part of the larger but inactive Prickly Pear fault system (Pardee, 1950 #46) that bounds the southern side of the Helena valley. For example, Johns and others (1982 #259) show a similar structure (State Capitol fault, no. 111) to the east that bounds bedrock south of Helena and has early Pleistocene scarps. However, Stickney (1987 #251) found no evidence to suggest that the State Capitol fault has demonstrable Quaternary movement.

Sense of movement normal

Comments: (Johns and others, 1982 #259)

Dip not reported

Comments: Nearly vertical (?) (Johns and others, 1982 #259)

Dip direction N

Comments: Stickney (1987 #251).

Geomorphic expression Has a single 1.5-km-long escarpment between Quaternary deposits and pre-Tertiary bedrock. Johns and others (1982 #259) showed as many as four scarps in this area and mention as many as 15 that are as much as 1.5 km long. However, only the longer east-west-trending scarp was shown by Stickney (1987 #251); it separates middle Pleistocene pediment gravel (on the north) from pre-Tertiary bedrock (on the south).

Age of faulted surficial deposits Stickney (1987 #251) showed faulted middle Pleistocene deposits, but this is a cartographic error. He found no evidence of displacement of these deposits (Stickney, oral commun., 1993).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Stickney (1987 #251) shows the fault as early Quaternary or late Tertiary. Johns and others (1982 #259) suggest Quaternary movement.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the absence of evidence for late or middle Quaternary movement along the fault.

Length End to end (km) 1.6
Cumulative (km) 1.6

Average strike (azimuth) 90°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#251 Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, 1 pl., scale 1:50,000.

#559 Stickney, M.C., and Bingler, E.C., 1981, Earthquake-hazard evaluation of the Helena valley area, Montana: Montana Bureau of Mines and Geology Open-File Report 83, 30 p., 1 pl., scale 1:24,000.

686, Camas Creek fault (Class A)

Structure Number 686

Comments: Refers to fault 130 (Camas Creek fault) of Johns and others (1982 #259).

Structure Name Camas Creek fault

Comments: Mentioned by this name in Johns and others (1982 #259), although Birkholz (1967 #560) may have named this fault for Camas Creek. Fault extends from 2 km south of the Smith River southward to Thompson Gulch Guard Station, which is about 2 km north of Gile Reservoir.

Synopsis Poorly studied fault that is inferred on the basis of the anomalously linear course of Camas Creek and the linear range front flanked by numerous alluvial fans, which appear to be unfaulted. There is little documentation of displacement of Quaternary deposits, and most of the inferred trace is within Miocene rocks. This structure should be considered suspect and may possibly be of non-tectonic origin.

Date of compilation 04/30/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Meagher

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Transferred from 1:500,000-scale map of Johns and others (1982 #259).

Geologic setting North-trending, down-to-the-east, inferred fault that may control the course of Camas Creek. According to Birkholz (1967 #560), the fault extends along Camas Creek for about 14 km, however Johns and others (1982 #259) show a fault trace that is about 20 km long.

Sense of movement normal

Comments: Johns and others (1982 #259).

Dip not reported

Dip direction E

Geomorphic expression According to Johns and others (1982 #259), Camas Creek appears to be a subsequent stream flowing along the trace of the fault in easily erodible Miocene deposits. No unequivocal fault scarps are known.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Age assignment is from Johns and others (1982 #259). Birkholz (1967 #560) suggests that movement on this fault began during the Pliocene and continued until post-Wisconsin (Holocene) time, although this assertion is not supported; thus, Johns and others age estimate is use here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on absence of fault scarps.

Length End to end (km) 19.2
Cumulative trace (km) 19.3

Average strike (azimuth) 2°

References

#560 Birkholz, D.O., 1967, Geology of the Camas Creek area, Meagher County, Montana: Butte, Montana College of Mineral Science and Technology, unpublished M. S. thesis, 68 p., 2 pls.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

687, Smith Valley fault (Class A)

Structure Number 687

Comments: Refers to fault 134 (Smith Valley fault) of Johns and others (1982 #259).

Structure Name Smith Valley fault

Comments: Apparently initially recognized and named by Johns and others (1982 #259) for fault on northeast flank of Smith Valley, northwest of White Sulphur Springs, Montana. Fault extends from about 1 km southeast of Newlan Creek to about 4 km northwest of the North Fork Smith River.

Synopsis Poorly studied fault recognized from aerial photographs. Quaternary movement is suggested by its relatively fresh-looking scarp, but no one has examined this structure on the ground.

Date of compilation 04/29/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Meagher

1° x 2° sheet White Sulphur Springs

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Transferred from 1:500,000-scale map of Johns and others (1982 #259).

Geologic setting Northwest-trending, normal fault(?) that bounds the southwestern side of low hills, 4-10 km north of White Sulphur Springs. Fault inferred to be near prominent break in slope between hills and the gently sloping piedmont that grades southwestward to the Smith River.

Sense of movement normal

Comments: Johns and others (1982 #259).

Dip not reported

Dip direction SW

Geomorphic expression Johns and others (1982 #259) concluded that this feature is a fault scarp, rather than fault-line scarp, because it there is no change in vegetation at the scarp. They estimate about 30 m of displacement in the Quaternary, although no documentation was presented in their report.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Johns and others (1982 #259).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on Johns and others (1982 #259) estimate of 30 m of displacement in the Quaternary.

Length End to end (km) 6.5
Cumulative trace (km) 6.5

Average strike (azimuth) 307°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

688, Continental fault (Class A)

Structure Number 688

Comments: Refers to fault 54 (Continental fault) of Witkind (1975 #317) and fault 23 (Continental fault) of Johns and others (1982 #259).

Structure Name Continental fault

Comments: Weed (1912 #562) suggested the presence of this fault on the basis of abrupt range-front topography. Pardee (1950 #46) is an early reference to this fault name. The Continental fault bounds the western side of Rampart Mountain and "East Ridge" (a locally used name for ridge that extends south of Elk Park Pass along the Continental Divide) east of Butte. No other names have been found in our literature search. Witkind (1975 #317) showed the fault as extending from about 3 km north of East Butte southward to a point about 5 km due east of Janney, where the fault enters a valley between the foothills and East Ridge. This trace probably came from Pardee (1950 #46). Johns and others (1982 #259) showed the Continental fault as extending much farther north, to within 3 km of the Boulder River, although no references are listed to justify extending the fault in this area to the north.

Synopsis Poorly studied, but potentially young fault along western front of Rampart Mountain and East Ridge, just east of Butte. Most of the data associated with this fault is 40 or more years old.

Date of compilation 04/30/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Silver Bow

1° x 2° sheet Dillon, Butte

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location transferred from 1:500,000-scale map of Witkind (1975 #317).

Geologic setting Forms a prominent 600- to 900-m-high escarpment along the western front of Rampart Mountain and East Ridge, east and southeast of Butte. Pardee (1950 #46) made a convincing argument for late Cenozoic uplift and reversal of drainage in Elk Park, which appears to be a beheaded valley that lies about 400 m above East Butte on the footwall of the Continental fault. Pardee (1950 #46) reports exposures of faults that trend more or less parallel to the mountain front, and there are subparallel faults that dip steeply to the west in mine workings.

Sense of movement normal

Comments: Slickenlines along fault planes in mine tunnels show minor components of both dextral and sinistral slip (Pardee, 1950 #46).

Dip 70-75°

Comments: Dip measured on fault planes in mine tunnels (Pardee, 1950 #46). These faults are subparallel to the Continental fault and may or may not be associated with it.

Dip direction W

Geomorphic expression Forms prominent escarpment along western front of Rampart Mountain and East Ridge; the surface trace of the fault is characterized by springs and zones of altered rock. Pardee (1950 #46) suspected that the main trace of the fault is at the foot of the Rampart Range, although no one has reported fault scarps on unconsolidated material.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Weed (1912 #562) suspected historic movement (not associated with an earthquake) from comparison of probably unreliable leveling of two monuments in 1896 and 1906. Meinzer (1914 #563) suspected Holocene movement. Although neither of these studies demonstrated young movement, the abrupt, steep and linear front of the range and apparent reversal of drainage associated with hundreds of meters of Cenozoic uplift (Pardee, 1950 #46) suggest Quaternary movement on the Continental fault. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Bartholomew and Stickney examined several sites along the southern part of the fault and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997). Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on lack of scarps associated with the main (concealed?) trace of the fault.

Length End to end (km) 18.2
Cumulative trace (km) 18.3

Average strike (azimuth) 332°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#563 Meinzer, O.E., 1914, The water resources of Butte, Montana: U. S. Geological Survey Water Supply Paper 345-G, 78-125 p., 1 sheet, scale 1:62,500.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#562 Weed, W.H., 1912, Geology and ore deposits of the Butte district, Montana: U. S. Geological Survey Professional Paper 74, 262 p., 25 sheets.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

689, Whitetail Creek fault (Class A)

Structure Number 689

Structure Name Whitetail Creek fault

Comments: Source of name is probably Stickney and Bartholomew (1987 #242). Named for Whitetail Creek, the fault scarp is <1 km west of main north-south road in Whitetail Valley and extends between 5 and 12 km north of Whitehall.

Synopsis Newly recognized late Quaternary scarp formed by down-to-the-west fault that may be basinward splay of a range-bounding fault [690] along the western margin of the Bull Mountains.

Date of compilation 04/30/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet Dillon

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Transferred from 1:500,000-scale map of Stickney and Bartholomew (1987 #242). Bartholomew and Stickney (1990 #243) describe the fault as being 5 km long, it is shown here as a slightly longer feature.

Geologic setting Down-to-the-west, normal fault that forms piedmont scarp east of Whitetail Creek in Whitetail Valley. This fault is basinward of a longer, parallel, older(?) normal fault [690] that bounds the western margin of Bull Mountain. Total stratigraphic offset unknown.

Sense of movement normal

Comments: (Bartholomew and others, 1990 #243)

Dip not reported

Dip direction W

Geomorphic expression Fault scarp on alluvial valley floor, near western margin of piedmont from Bull Mountain. No information about the height or morphology of the scarp has been published.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Stickney and Bartholomew (1987 #242) report the most recent faulting event was between 13 and 150 ka.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on the absence of data that indicate late Quaternary slip.

Length End to end (km) 7.3
Cumulative (km) 7.5

Average strike (azimuth) 350°

References

#243 Bartholomew, M.J., Stickney, M.C., and Wilde, E.M., 1990, Late Quaternary faults and seismicity in the Jefferson basin, *in* Hall, R.D., ed. Quaternary geology of the western Madison Range, Madison Valley, Tobacco Root range, and Jefferson valley: Rocky Mountain Cell, Friends of the Pleistocene, August 15-19, 1990, Guidebook, p. 238-244.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

690, Bull Mountain western border fault (Class A)

Structure Number 690

Comments: Refers to fault 21 (Bull Mountain western border fault) of Johns and others (1982 #259) and fault 72 (unnamed fault, east side of Little Whitetail Valley) of Witkind (1975 #317).

Structure Name Bull Mountain western border fault

Comments: Although this fault was recognized by Pardee (1950 #46), it was first named the "Bull Mountain western border fault" by Johns and others (1982 #259). The fault extends along the west side of Bull Mountain from a point about 10 km south of Boulder, Montana, to about 5 km north of the Jefferson River.

Synopsis Poorly studied, down-to-the-west, normal fault that is largely inferred by the young morphologic appearance of the western margin of Bull Mountain. The fault is suspected as having young movement, but this assertion is not well supported.

Date of compilation 04/30/93

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet Butte, Dillon

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Trace is from 1:500,000-scale map of Witkind (1975 #317), transferred to 1:250,000-scale base.

Geologic setting Range-bounding, down-to-the-west, normal fault that is mapped along western margin of Bull Mountain. No other compilations (Witkind, 1975 #317; Johns and others, 1982 #259) or studies of active faulting (Stickney and Bartholomew, 1987 #85) have reported fault scarps on unconsolidated material in this area.

Sense of movement normal

Comments: Witkind (1975 #317) and Johns and others (1982 #259).

Dip not reported

Comments: Nearly vertical (?) according to Johns and others (1982 #259).

Dip direction W

Geomorphic expression No scarps noted, although Pardee (1950 #46) implied young fault control of the range front, which is steep, straight, and rises abruptly. Johns and others (1982 #259) inferred deposition on the dissected piedmont of Bull Mountain south of Black Butte owing to young (late? Pleistocene) movement of the fault.

Age of faulted surficial deposits Pardee (1950 #46) mentioned that Tertiary beds dip east toward Bull Mountain, suggesting young (late Cenozoic) movement.

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Although Johns and others (1982 #259) listed the fault's latest movement as late Pleistocene, their argument is based on anomalous stream gradients. Inasmuch as no scarps have been recognized on unconsolidated material, we use a more conservative estimate herein. Additionally, Stickney and Bartholomew (1987 #242) did not include this structure on their map. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Bartholomew and Stickney examined several sites along the fault and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997). Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of scarps along the structure.

Length End to end (km) 29.6
Cumulative (km) 30.3

Average strike (azimuth) 351°

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

691, Bridger fault (Class A)

Structure Number 691

Comments: Refers to number 38 (Bridger Creek-Bear Canyon fault) and south part of number 43 (Morgan fault) of Witkind (1975 #317) and number 98 (Bridger range-front fault) of Johns and others (1982 #259).

Structure Name Bridger fault

Comments: Source of the name is probably Pardee (1950 #46). Also referred to as Bridger Creek-Bear Canyon fault (McMannis, 1955 #513; Witkind, 1975 #317) Bridger frontal fault zone by Hackett and others (1960 #267), Bridger range-front fault by Lageson (1989 #261), and Bridger Range fault by Brodowy (1991 #257). Fault as shown here includes southern part of Morgan fault of Skipp and Peterson (1965 #472); ends of the fault are based on overall range-front morphology and are similar to those shown by Johns and others (1982 #259). Fault extends from Blacktail Creek southeastward to north of U.S. Highway 10.

Synopsis Little is known about the Quaternary history of this fault because of its poor surficial expression.

Date of compilation 03/14/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Gallatin; Broadwater

1° x 2° sheet Bozeman; White Sulphur Springs

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location is based on trace from 1:500,000-scale map of Witkind (1975 #317), but because the fault is not known to reach the surface, its location is speculative. Gravity data indicate the fault is about 2 km west of the range front (Davis and others, 1965 #263).

Geologic setting High-angle, down-to-the-west, normal fault bounding the western side of the Bridger Range. Fault may have a listric geometry based on proximal dip of Tertiary basin fill (Brodowy and others, 1991 #257). Segments discussed by Lageson (1989 #261) address parts of the fault that are bounded by intersecting structures, which may or may not be related to seismogenic segments. Lageson (1989 #261) documents the possibility of 2.2 km of throw across this fault since mid-Eocene to early Oligocene. McMannis (1955 #513) indicates faulting initiated during the Oligocene with an episode of quiescence during the Pliocene. Davis and others (1965 #263) suggest about 750 m of throw based on gravity data.

Sense of movement normal

Comments: (Witkind, 1975 #317)

Dip not reported

Dip direction W

Geomorphic expression No scarps on alluvium (McMannis, 1955 #513; Lageson, 1989 #261), fault is inferred from steep gravity gradient (Davis and others, 1965 #263), precipitous range front, and aligned faceted spurs (Pardee, 1950 #46; McMannis, 1955 #513).

Age of faulted surficial deposits No surficial deposits are displaced, but Tertiary lake beds dip toward the range (Pardee, 1950 #46).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Post-Tertiary movement is suggested by the rangeward dip of Tertiary lake beds; however, no data are available to provide better constraints. Pierce and Morgan (1992 #539) indicate that this fault was active during the Tertiary but do not preclude Quaternary movement. Bartholomew and Stickney examined several sites along the fault and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997). Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on absence of data that indicate late Quaternary slip.

Length End to end (km) 48.3
Cumulative (km) 54.1

Average strike (azimuth) 341°

References

#257 Brodowy, J.M., Lageson, D.R., Ryan, C., and Snyder, B., 1991, Structure and neotectonics of the eastern Three Forks Basin, northern Intermountain seismic belt, southwest Montana: Geological Society of America Abstracts with Programs, v. 23, no. 5, p. A233-A234.

#263 Davis, W.E., Kinoshita, W.T., and Robinson, G.D., 1965, Bouguer gravity, aeromagnetic, and generalized geologic map of the eastern part of the Three Forks Basin, Broadwater, Madison, and Gallatin Counties, Montana: U.S. Geological Survey Geophysical Investigations Map GP-498, 5 p. pamphlet, 2 pls., scale 1:62,500.

#267 Hackett, O.M., Visher, F.N., McMurtrey, R.G., and Steinhilber, W.L., 1960, Geology and ground-water resources of the Gallatin Valley, Gallatin County, Montana: U.S. Geological Survey Water Supply Paper 1482, 282 p., 1 pl., scale 1:63,360.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#261 Lageson, D.R., 1989, Reactivation of a Proterozoic continental margin, Bridger Range, southwestern Montana, *in* French, C.E., and Grabb, R.F., eds., Geologic resources of Montana: Montana Geological Society, 1989 Field Conference Guidebook, Montana Centennial Edition, v. 1, p. 279-298.

#513 McMannis, W.J., 1955, Geology of the Bridger Range, Montana: Geological Society of America Bulletin, v. 66, p. 1385-1430.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#472 Skipp, B., and Peterson, A.C., 1965, Geologic map of the Maudlow quadrangle southwestern Montana: U.S. Geological Survey Miscellaneous Geologic Investigations I-452, 2 sheets, scale 1:24,000.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

692, Gallatin Range fault (Class A)

Structure Number 692

Comments: Refers to number 92 (Gallatin range-front fault) of Johns and others (1982 #259) and Gallatin fault of Stickney and Bartholomew (written commun. 1992 #556).

Structure Name Gallatin Range fault

Comments: Source of the name is unknown. Fault extends from Gallatin River east-northeastward to near Bear Creek. Shown as Gallatin fault by Stickney and Bartholomew (written commun. 1992 #556).

Synopsis Little is known about the Quaternary history of this fault. Nowhere is the fault known to coincide with scarps on alluvium, but scarps would be difficult to identify because much of the Gallatin range front is heavily forested. Inferred Quaternary activity is based on the preservation of a precipitous, linear, range front.

Date of compilation 03/14/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Bozeman

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location is based solely on topography.

Geologic setting High-angle, down-to-the-northwest, normal fault bounding the northwestern side of the Gallatin Range. Fault may be associated with a subparallel, antithetic fault 4 km north of main fault that defines a deep, narrow graben (Davis and others, 1965 #263; Brodowy and others, 1991 #257). There may have been as much as 500 m of uplift since Miocene time (Johns and others, 1982 #259).

Sense of movement normal

Comments: (Johns and others, 1982 #259)

Dip not reported

Dip direction NW

Geomorphic expression No scarps on alluvium are known (M.J. Bartholomew, written commun. 1997); fault is inferred from steep gravity gradient (Davis and others, 1965 #263; Bonini and others, 1972 #265), precipitous range front, and aligned faceted spurs (Lageson, oral commun. 1992).

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Timing of last movement is from Johns and others (1982 #259) and Stickney and Bartholomew (written commun. 1992 #556). The morphologic characteristics of the range front indicate recurrent activity, but the timing of the last faulting event is highly speculative.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on the absence of data that indicate late Quaternary slip.

Length End to end (km) 26.9
Cumulative (km) 27.4

Average strike (azimuth) 63°

References

#265 Bonini, W.E., Kelley, W.N., Jr., and Hughes, D.W., 1972, Gravity studies of the Crazy Mountains and the west flank of the Beartooth Mountains, Montana, *in* Lynn, J., Balster, C., and Warne, J., eds., Crazy Mountains Basin: Montana Geological Society, 21st Annual Geological Conference, September 22-24, 1972, Guidebook, p. 119-127.

#257 Brodowy, J.M., Lageson, D.R., Ryan, C., and Snyder, B., 1991, Structure and neotectonics of the eastern Three Forks Basin, northern Intermountain seismic belt, southwest Montana: Geological Society of America Abstracts with Programs, v. 23, no. 5, p. A233-A234.

#263 Davis, W.E., Kinoshita, W.T., and Robinson, G.D., 1965, Bouguer gravity, aeromagnetic, and generalized geologic map of the eastern part of the Three Forks Basin, Broadwater, Madison, and Gallatin Counties, Montana: U.S. Geological Survey Geophysical Investigations Map GP-498, 5 p. pamphlet, 2 pls., scale 1:62,500.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

693, Unnamed fault near Sweet Grass Hills (Class A)

Structure Number 693

Comments: Not shown on any previous compilation.

Structure Name Unnamed fault near Sweet Grass Hills

Comments: Lopez (1995 #1062) first documented these faults, but did not name them. The two short, subparallel faults are north and northwest of Gold Butte, part of Middle Butte in the Sweet Grass Hills about 50 km northeast of Shelby, Montana.

Synopsis Little is known about the Quaternary history of these short faults. Sole source of data is Lopez (1995 #1062).

Date of compilation 04/01/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Toole

1° x 2° sheet Shelby

Physiographic province Great Plains

Reliability of location Good

Comments: Location from 1:100,000-scale geologic map of Lopez (1995 #1062).

Geologic setting Two short, subparallel, down-to-northwest, normal (?) faults along northwestern flank of Middle Butte. Amount of total offset not known.

Sense of movement normal

Comments: Lopez (1995 #1062) indicates down-to-northwest displacement, from which we infer normal movement. The southern fault may have had a history of left-lateral movement.

Dip not reported

Dip direction NW

Geomorphic expression The northern fault is expressed by a nearly continuous "fresh" scarp, and the southern by a "prominent" scarp (Lopez, 1995 #1062).

Age of faulted surficial deposits Upper Cretaceous bedrock, and forms contact between Quaternary pediment gravel and Quaternary glacial till (Lopez, 1995 #1062).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Lopez (1995 #1062) suggests Quaternary movement on both of these faults.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Low slip rate inferred; no substantiating data are available.

Length End to end (km) 5.7
Cumulative (km) 11.6

Average strike (azimuth) 58°

References

#1062 Lopez, D.A., 1995, Geology of the Sweet Grass Hills, north-central Montana: Montana Bureau of Mines and Geology Memoir 68, 35 p., 1 pl., scale 1:100,000.

694, Elk Creek fault (Class A)

Structure Number 694

Comments: Refers to number 84 (Elk Creek fault) of Johns and others (1982 #259).

Structure Name Elk Creek fault

Comments: Source of the name s probably Andretta and Alsup (1960 #419). This fault is the western extension of Salesville fault (Hackett and others, 1960 #267; Carl, 1970 #689). Feichtinger (1970 #456) indicates that the Elk Creek fault may extend from the Cherry Creek fault southeastward to the mouth of Gallatin Canyon, but its extent as shown here is from about 8 km northwest of Madison River southeastward to near Goose Creek.

Synopsis Little is known about the Quaternary history of this fault; however, most agree this is a reactivated Laramide structure. Various authors have inferred Holocene or "Recent" movement but evidence of this is inconclusive.

Date of compilation 03/21/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison; Gallatin

1° x 2° sheet Bozeman

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: The trace of the fault west of the Madison River is well located based on 1:24,000-scale map of Feichtinger (1970 #456), but east of the river the trace is poorly located and modified to fit topography based on map of Carl (1970 #689).

Geologic setting Cenozoic movement is normal, down to northeast on a steeply dipping preexisting structure demonstrating reverse (down-to-south) Laramide deformation and possibly similar style of deformation during Precambrian (Andretta and Alsup, 1960 #419; Feichtinger, 1970 #456). Amount of Quaternary throw not known due to complex history.

Sense of movement normal

Comments: (Andretta and Alsup, 1960 #419)

Dip not reported

Dip direction NE

Geomorphic expression West of the Madison River, a high, well-developed fluvial(?) surface (Madison bench) is displaced 60 m (Andretta and Alsup, 1960 #419). Expression of faulting east of the Madison River unknown.

Age of faulted surficial deposits Quaternary gravels, colluvium; Tertiary eolian and lacustrine deposits (Feichtinger, 1970 #456).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Fault is thought to deform a high Quaternary fluvial terrace(?) as shown by Feichtinger (1970 #456); however, this gravel-capped surface is inferred to be Pliocene by Hackett and others (1960 #267). Feichtinger (1970 #456) suggests faulting may have occurred during the Holocene ("Recent"), but Stickney (oral commun. 1992) believes there is no evidence for late Quaternary surface faulting. Due to lack of consensus, a conservative estimate for the timing of the most recent event is used here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on suggestion by Hackett and others (1960 #267) that Pliocene gravels are offset approximately 50 m.

Length End to end (km) 28.1
Cumulative (km) 28.6

Average strike (azimuth) 298°

References

#419 Andretta, D.B., and Alsup, S.A., 1960, Geology and Cenozoic history of the Norris-Elk Creek area, southwest Montana, *in* Campau, D.E., and Anisgard, H.W., eds., West Yellowstone—Earthquake area: Billings Geological Society, 11th Annual Field Conference, September 7-10, 1960, Guidebook, p. 185-190.

#689 Carl, J.D., 1970, Block faulting and development of drainage, northern Madison Mountains, Montana: Geological Society of America Bulletin, v. 81, p. 2287-2298.

#456 Feichtinger, S.H., 1970, Geology of a portion of the Norris quadrangle with emphasis on Tertiary sediments Madison and Gallatin Counties, Montana: Bozeman, Montana State University, unpublished M.S. thesis, 85 p., 2 pls.

#267 Hackett, O.M., Visher, F.N., McMurtrey, R.G., and Steinhilber, W.L., 1960, Geology and ground-water resources of the Gallatin Valley, Gallatin County, Montana: U.S. Geological Survey Water Supply Paper 1482, 282 p., 1 pl., scale 1:63,360.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

695, Carmichael fault (Class A)

Structure Number 695

Comments: Refers to number 7 (Carmichael fault) of Johns and others (1982 #259).

Structure Name Carmichael fault

Comments: Garihan and others (1983 #686) show this part of the fault zone as the Carmichael fault; however, Schmidt and Garihan (1983 #692) clearly show that the Carmichael fault terminates near Pony and the southern extension of this fault zone is the Pony fault. Earlier sources of the name are unknown. The part of the fault that is inferred to have Quaternary movement extends from Norwegian Creek southeastward to about 2 km northwest of Hot Springs Creek, but the Pony-Carmichael fault zone extends nearly 30 km farther northwest of trace shown here.

Synopsis Little is known about the Quaternary history of this fault; primary source of data is Johns and others (1982 #259).

Date of compilation 03/28/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Bozeman

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Even thought trace of fault is compiled from 1:250,000-scale map of Garihan and others (1983 #686), it is uncertain that this is the location of scarps documented by Johns and others (1982 #259). They show the fault having a more southerly strike, and thus, their trace is as much as 1 km south of trace shown here.

Geologic setting Inferred down-to-northeast, normal Cenozoic movement is confined to a short part of this long, steeply dipping Laramide-age structure that originally had reverse (down-to-south) sense of motion and possibly a similar style of deformation during the Precambrian. Amount of stratigraphic displacement unknown.

Sense of movement normal

Comments: (Johns and others, 1982 #259)

Dip not reported

Dip direction NE

Geomorphic expression Johns and others (1982 #259) document a scarp between Norwegian Creek and Hot Springs Creek, but Stickney and Bartholomew (1987 #242; written commun. 1992 #556) do not include it in their compilations because they found no evidence suggesting late Quaternary faulting. If this scarp is on the trace of the fault presented here, it opposes the general topography of the area.

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Johns and others (1982 #259) indicate this part of the fault is Holocene, based on the presence of a "fresh fault scarp" and the location of a 1980 earthquake. Bartholomew and Stickney examined several sites along the fault and found no evidence suggesting late Quaternary faulting (M.J. Bartholomew, written commun. 1997). Because details are lacking, the fault is included in this compilation. Due to the lack of agreement in the timing of the most recent movement, a Quaternary age is assigned here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on lack of detailed data indicating otherwise.

Length End to end (km) 4.9
Cumulative (km) 4.9

Average strike (azimuth) 311°

References

#686 Garihan, J.M., Schmidt, C.J., Young, S.W., and Williams, M.A., 1983, Geology and recurrent movement history of the Bismark-Spanish Peaks-Gardiner fault system, southwest Montana, *in* Lowell, J.D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colorado, Rocky Mountain Association of Geologists, p. 295-314.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#692 Schmidt, C.J., and Garihan, J.M., 1983, Laramide tectonic development of the Rocky Mountain foreland of southwestern Montana, *in* Lowell, J.D., ed., Rocky Mountain foreland basins and uplifts: Denver, Co., Rocky Mountain Association of Geologists, p. 295-314.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

696, Thompson Valley fault (Class A)

Structure Number 696

Comments: Not shown on any previous compilation.

Structure Name Thompson Valley fault

Comments: Source of name is Ostenaa and others (1990 #540). Mapped fault scarps shown here extend from Bear Creek southward to the Little Thompson River, but the fault may extend farther to the north approximately 3 km to near Semem Creek (1990 #540).

Synopsis Fault was first mapped and described by Ostenaa and others (1990 #540) based on photogeologic mapping and brief field reconnaissance.

Date of compilation 10/10/95

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Sanders

1° x 2° sheet Wallace

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Location based on trace from 1:48,000-scale map of Ostenaa and others (1990 #540). Ostenaa and others speculate that the fault extends at least 3 km north of the trace shown on their map and possibly as much as 20 km further to the north, based on the extent of the adjacent topographic basin, but they do not show its location.

Geologic setting Down-to-the-west, normal fault west of Cook Mountain and adjacent peaks to the south. The fault is nearly parallel to an elongate topographic basin and is located closer to the center of the basin than along the flanking mountains. Late Cenozoic displacement is inferred to be small because of the presence of bedrock outcrops and apparently thin alluvial fill in the adjacent valley (Ostenaa and others, 1990 #540).

Sense of movement normal

Comments: (Ostenaa and others, 1990 #540)

Dip not reported

Dip direction W

Geomorphic expression Nearly continuous, down-to-west, fault scarp characterizes the part of the fault shown here. Maximum observed surface offset is 6.4 m on surfaces that are early to mid-Wisconsin in age or older (Ostenaa and others, 1990 #540). Prominent faceted spurs have been noted along the mountain front to the east, but they may be nontectonic in origin (Ostenaa and others, 1990 #540).

Age of faulted surficial deposits upper Quaternary fan alluvium (Wisconsin in age)

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: Scarps are present on late Pleistocene surfaces but not on inferred Holocene surfaces. Scarps on this fault are morphologically older that equivalent-size scarps on the Mission fault [699b], which is assumed to have last ruptured about 8 k.y. ago (Ostenaa and others, 1995 #912).

Recurrence interval not reported

Comments: Multiple late Quaternary faulting events are indicated by different amounts of surface offset on surfaces of different ages; however, the ages of the displaced surfaces are poorly constrained, and Ostenaa and others (1990 #540) did not attempt to define recurrence intervals.

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on 6.4-m-high scarp on surfaces at least early to mid-Wisconsin in age.

Length End to end (km) 9.6
Cumulative (km) 9.7

Average strike (azimuth) 348°

References

#540 Ostenaa, D., Manley, W., Gilbert, J., LaForge, R., Wood, C., and Weisenberg, C.W., 1990, Flathead Reservation regional seismotectonic study—An evaluation for dam safety: U.S. Bureau of Reclamation Seismotectonic Report 90-8, 161 p., 7 pls.

#912 Ostenaa, D.A., Levish, D.R., and Klinger, R.E., 1995, Mission fault study: U.S. Bureau of Reclamation Seismotectonic Report 94-8, 111 p.

697, Pine Creek Valley fault (Class A)

Structure Number 697

Comments: Refers to number 195 (Pine Creek Valley fault) of Witkind (1975 #317).

Structure Name Pine Creek Valley fault

Comments: Fault as shown by Witkind (1975 #317) extends about 3 km west of Pine Creek.

Synopsis Fault is poorly studied, no known studies have been completed. Sole source of data is Witkind (1975 #317).

Date of compilation 03/05/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Lincoln

1° x 2° sheet Kalispell

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location of fault based on 1:500,000-scale map of Witkind (1975 #317).

Geologic setting Short, right-lateral, intrabasin fault.

Sense of movement dextral

Comments: (Witkind, 1975 #317)

Dip not reported

Dip direction not reported

Geomorphic expression not reported

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Witkind (1975 #317) cites W. Johns as the source of the data pertaining to this fault including the age assignment of late Pleistocene. We use a conservative age here based on the absence of published data.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the absence of data that indicate late Quaternary slip.

Length End to end (km) 3.3
Cumulative (km) 3.3

Average strike (azimuth) 85°

References

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

698, Jocko fault (Class A)

Structure Number 698

Comments: Refers to fault number 91 (Jocko fault) of Witkind (1975 #317).

Structure Name Jocko fault

Comments: The source of the name Jocko fault is probably Pardee (1950 #46) who described the fault as extending along the west flank of the Jocko Range (Rattlesnake Range). Fault extends from Big Knife Creek southwestward to near the headwaters of Finley Creek. A similar trace was shown by Witkind (1975 #317).

Synopsis Photogeologic mapping and brief field reconnaissance is sole source of data for this fault. No detailed studies have been conducted.

Date of compilation 10/11/95

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Missoula; Lake

1° x 2° sheet Wallace; Choteau

Physiographic province Northern Rocky Mountains

Reliability of location Good

Comments: Location based on trace from 1:48,000-scale map of Ostenaa and others (1990 #540).

Geologic setting High-angle, down-to-the-northwest, normal fault along the western flank of Rattlesnake Mountains. Amount of structural throw is unknown. Water-well data indicate that the depth to Precambrian Belt Supergroup rocks is more than 200 m. The thickness of valley fill decreases to the north (Ostenaa and others, 1990 #540) suggesting the greatest amount of throw is across the southern part of the fault.

Sense of movement normal

Comments: (Witkind, 1975 #317)

Dip not reported

Dip direction NW

Geomorphic expression Discontinuous scarps are present along 4 km of the southern part of the fault. The rest of the fault is characterized by steep faceted spurs dissected by narrow valley, which are perpendicular to the range front (Pardee, 1950 #46). Scarp at the northern end of the fault, near Big Knife Creek, was reported by Pardee (1950 #46), but reconnaissance by Ostenaa and others (1990 #540) did not locate the feature.

Age of faulted surficial deposits Most of the fault is located at the Precambrian-Quaternary contact, the southern end is at the Precambrian-Tertiary contact, and a short part extends into Tertiary bedrock (Ostenaa and others, 1990 #540).

Paleoseismology studies none

Most recent prehistoric deformation late Quaternary (<130 ka)

Comments: The scarps along the southern part of the fault are thought to be on late Quaternary surfaces (Ostenaa and others, 1990 #540). Surficial deposits north of the scarps are not faulted but are probably younger than the faulted surfaces to the south.

Recurrence interval not reported

Comments: Ostenaa and others (1990 #540) indicate evidence for three faulting events but the timing of those events is unknown.

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on small scarps on late Quaternary surfaces.

Length End to end (km) 15.8
Cumulative (km) 16.2

Average strike (azimuth) 23°

References

#540 Ostenaa, D., Manley, W., Gilbert, J., LaForge, R., Wood, C., and Weisenberg, C.W., 1990, Flathead Reservation regional seismotectonic study—An evaluation for dam safety: U.S. Bureau of Reclamation Seismotectonic Report 90-8, 161 p., 7 pls.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

699, Mission fault (Class A)

Structure Number 699

Comments: Refers to fault number 92 (Mission fault) of Witkind (1975 #317).

Structure Name Mission fault

Comments: First recognized by Wilson (1921 #1025), who suggested a late Cenozoic age. Fault, as shown here, extends from the Flathead River between Creston and Kalispell, Montana, southward to St. Marys Lake. Witkind (1975 #317) shows the location of the fault slightly different than shown here.

Synopsis The first reported Holocene surface rupture north of the Lewis and Clark line. Recurrent late Quaternary movement is apparent along the southern part of the fault based on geologic mapping, field reconnaissance, and numerous trench studies. The northern part is characterized by the absence of scarps on alluvium and thus is largely unstudied with the exception of geophysical investigations.

Date of compilation 11/29/95

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Lake; Flathead

1° x 2° sheet Wallace; Kalispell; Choteau

Physiographic province Northern Rocky Mountains

Geologic setting High-angle, down-to-west, normal fault bounding western side of Mission Range. Evidence of a dextral component of movement is present along some parts of the fault. Displacement across the Mission fault is smallest along the northern part of the fault and increases to a maximum near the southern end; however, the amount of total displacement is unclear. The Mission fault along the Flathead section [699a] consists of several subparallel strands, and in general, bedrock in the valley is buried by a thin (20- to 30-m-thick) alluvial cover (Ostenaa and others, 1990 #540; 1995 #912). LaPoint (1973 #1022) suggests 3-3.5 km of vertical displacement across the northern part of the fault. Pardee (1950 #46) suggested that late Cenozoic vertical offset across the southern part of the fault is at least 2.5 km assuming Tertiary peneplain correlation across the fault is correct. Based on gravity data, maximum depth to bedrock is generally 300 m but reaches a depth of about 600 m near the southern end of the fault (Ostenaa and others, 1995 #912), and 0.9-1.6 Ga Belt Supergroup rocks may be displaced more than 5 km (Ostenaa and others, 1990 #540).

Number of sections 2

Comments: Based on similar late Quaternary faulting histories at numerous trench sites along the southern (Mission Valley) section and the contrasting absence of scarps on alluvial deposits along the northern (Flathead Lake) section (Ostenaa and others, 1995 #912). Boundary between the two sections coincides with change in depth of bedrock-alluvial contact in adjacent basin (Ostenaa and others, 1990 #540).

Length End to end (km) 101.9
Cumulative (km) 213.2

Average strike (azimuth) 352°

699a, Flathead Lake section

Segment number 699a

Segment name Flathead Lake section

Comments: Defined and named the Flathead Lake segment by Ostenaa and others (1995 #912). Originally called the northern segment in earlier publication (Ostenaa and others, 1990 #540). Section as described herein consists of numerous subparallel traces (some of which are sublacustrine) that extend from the Flathead River southward to 6 km east of Pablo, Montana, south of Flathead Lake.

Reliability of location Poor

Comments: Source of traces is approximately 1:350,000-scale map without topography from Ostenaa and others (1995 #912) that was compiled from earlier geologic and geophysical mapping. Location of fault based on gross topography of range. Fault scarps on alluvium or glacial deposits are absent.

Sense of movement normal

Comments: (Witkind, 1975 #317)

Dip not reported

Dip direction W

Geomorphic expression The subparallel traces of the faults in this section as depicted by Ostenaa and others (1990 #540) do not have fault scarps on alluvium or glacial deposits. Most of the onshore traces are inferred from aligned ridge-crest saddles and linear side-hill depressions. Range front is linear. Elevation of range gradually increases from north to south.

Age of faulted surficial deposits Unknown because most of the traces of the fault are in Flathead Lake. Surficial, subaerial deposits (probably all younger than 13-16 ka) are unfaulted. Bedrock is buried by a thin (20-30 m) alluvial cover (Ostenaa and others, 1990 #540; 1995 #912).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Even though Ostenaa and others (1995 #912) could not find any clear evidence of Quaternary displacement, this part of the fault is considered to be Quaternary in age because of multiple post-glacial faulting events to the south. Pardee (1950 #46), and thus Witkind (1975 #317), indicated that the fault is early Quaternary or late Tertiary. More recent seismic studies (Kogan, 1981 #958; Wold, 1982 #957) suggested that displacement on this section has occurred during post-glacial (<15 ka) time. However, some or all of the features may be due to glacial erosion or post-glacial slumping because similar evidence of recent faulting is absent onshore (Ostenaa and others, 1990 #540; 1995 #912). Based on the same data, Qamar and others (1982 #516) and Ostenaa and others (1995 #912) concluded that the youngest displacement on this part of the fault is at least 10 ka and possibly older than the retreat of the Flathead lobe of the Cordilleran ice sheet from the Polson moraine. Thus, movement on the northern part of the fault is older than displacement on the south.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate is based on the absence of fault scarps on late Quaternary surfaces. Long-term slip rate is lower than on Mission Valley section based on lower topographic and structural relief.

Length End to end (km) 65.4
Cumulative (km) 171.7

Average strike (azimuth) 353°

699b, Mission Valley section

Segment number 699b

Segment name Mission Valley section

Comments: Defined and named the Mission Valley segment in Ostenaa and others (1995 #912). Originally called the southern segment in earlier publication (Ostenaa and others, 1990 #540). Section as defined herein extends from 6 km east of Pablo, Montana, southward to St. Marys Lake, and may extend 2-5 km further south (Ostenaa and Levish, 1994 #1013; Ostenaa and others, 1995 #912).

Reliability of location Good

Comments: Location primarily based on 1:48,000-scale map of Ostenaa and others (1990 #540) augmented by 1:24,000-scale site maps of Ostenaa and others (1995 #912).

Sense of movement normal

Comments: Sense of movement from Witkind (1975 #317). Along the fault north of Mission Reservoir, the sense of slip appears to normal based on displacement of geomorphic features (Ostenaa and Levish, 1994 #1013). Along the southern part of the segment, where the strike of the fault is N. 45° W., a significant component of dextral slip is reported (Ostenaa and Levish, 1994 #1013; Ostenaa and others, 1995 #912).

Dip not reported

Dip direction W

Geomorphic expression Fault is marked by nearly continuous, fault scarps that coincide with the western limit of bedrock outcrops, morphologically young scarps on Quaternary surfaces in drainage embayments, and aligned, linear, bedrock facets. Elevation of range increases from north to south.

Age of faulted surficial deposits Late Quaternary moraines, including those that have characteristics of deposition into Lake Missoula, and upper Quaternary alluvium (Ostenaa and others, 1995 #912).

Paleoseismology studies Seventeen trenches have been excavated at five sites on surfaces younger than the highstand of Lake Missoula (15-19 ka) by Ostenaa and others (1995 #912) and Ostenaa and Levish (1994 #1013). Many of the trenches were excavated on surfaces that record two displacement events and are near older surfaces that record several more events.

North Crow Creek. Trench 699b-1, located about 250 m north of North Crow Creek and about 600 m west of North Crow Creek campground, was excavated on an inset moraine thought to be 15-19 ka. The trenched scarp is 6-7 m high with a surface offset of 4-5 m; surface on older deposit nearby has 14-m-high scarp with possible lateral displacement of as much as 20 m.

South Crow Creek. Trench 699b-2, located south of South Crow Creek, about 9 km south of North Crow Creek site, was excavated on inset alluvial surface adjacent to the southern lateral moraine. Trench crosses 20-m-wide graben with estimated offset of 3.0-9.8 m (the preferred value is 4-6 m); surface on older deposit nearby has 12.4-m-high scarp.

Marsh Creek. Trench 699b-3, located north of Marsh Creek, about 3.7 km south of South Crow Creek site, trench was excavated on inset alluvial surface thought to be younger than 15-19 ka. Trenched scarp is about 4.0 m high with a surface offset of about 3.3 m. The complexity of deformation and the more northeasterly strike of the fault at this site might be evidence of a larger lateral component of movement at this site. A second trench was excavated at this site on inset surface that has no scarp, and was found to be unfaulted.

Mission Reservoir. Trenches 699b-4 and 5, located between Mission Creek access road and Mission Creek, about 19 km south of Marsh Creek site, trenches were excavated about 20 m apart on alluvium thought to be approximately 15-19 ka. Trenches extend across faulted deposits but there is no scarp present. The surface of the nearby southern lateral moraine (possibly 19-23 ka) has a 12.4-m-high scarp that may record possibly 20 m of lateral movement. Only movement during the most recent event is indicated by the relations of deposits in these two trenches, and the absence of a consistent sense of vertical displacement associated with individual faults in trench 699b-5 seems to indicate a significant lateral-slip component.

Tabor Dam. Eleven trenches were excavated at this site in 1993-1994 (Ostenaa and Levish, 1994 #1013). Three post-glacial faulting events are indicated by relations in trench 699b-6 (Ostenaa and Levish, 1994 #1013) and trench 699b-7 (Ostenaa and Levish, 1994 #1013); the other trenches at this site did not reveal evidence of faulting. Bedrock on the downthrown block is offset vertically 5-10 m, but lateral slip may be 15-30 m.

Most recent prehistoric deformation latest Quaternary (<15 ka)

Comments: Ostenaa and others (1995 #912) indicate that the most recent event on this part of the Mission fault occurred 7.7±0.2 ka. Primary Mazama ash (7.6 ka) is present in scarp-derived colluvium at trenches 699b-1 and 2. Unfaulted deposits near 699b-3 have an age of 6.7 k.y., and thus define an upper limit on the age of the most recent event. None of the relations in trench 699b-3 preclude the interpretation of a early Holocene event. Timing of the single event at trench sites 699b-4 and 5 is 7.6-8.7 ka, which is bracketed by Mazama ash (7.6 ka) and radiocarbon ages on samples from faulted and unfaulted deposits.

Recurrence interval <7.3-11.3 k.y. (<15-19 ka)

Comments: Trench sites 699b-1, 2, and 3 all contain evidence of an recurrent faulting event; however, the time of earlier faulting is unconstrained. The 11.3 k.y. recurrence interval assumes the penultimate event occurred immediately following oldest inferred time of stabilization of surfaces at these sites (19 ka), and the 7.3 k.y. interval assumes the penultimate event occurred midway between the youngest inferred time of stabilization of surfaces (15 ka) and the most recent event. A shorter average recurrence interval of 4-8 k.y. for the past 19-23 ka is suggested by Ostenaa and others (1995 #912) based on the assumption that the higher scarps on older deposits are the product of 3-4 events. Earlier estimates of recurrence intervals were significantly longer (Ostenaa and others, 1990 #540).

Slip-rate category unknown; probably 0.2-1 mm/yr

Comments: There are no known published slip rates for this part of the Mission fault. The slip data and recurrence intervals in Ostenaa and others (1995 #912) indicate that a vertical slip rate of 0.1-0.5 is reasonable. Most of the rates that can be calculated from the data are >0.2 mm/yr; therefore, the higher of the two possible slip-rate categories was selected here. In addition, no lateral-slip component is included in the calculated slip rate, and thus, calculated values may underestimate the slip rate.

Length End to end (km) 39.9
Cumulative (km) 41.5

Average strike (azimuth) 348°

References

#958 Kogan, J., 1981, A seismic sub-bottom profiling study of recent sedimentation in Flathead Lake, Montana: Missoula, University of Montana, unpublished M.S. thesis, 98 p.

#1022 LaPoint, D.J., 1973, Gravity survey and geology of the Flathead Lake region, Montana: Northwest Geology, v. 2, p. 13-20.

#540 Ostenaa, D., Manley, W., Gilbert, J., LaForge, R., Wood, C., and Weisenberg, C.W., 1990, Flathead Reservation regional seismotectonic study—An evaluation for dam safety: U.S. Bureau of Reclamation Seismotectonic Report 90-8, 161 p., 7 pls.

#1013 Ostenaa, D.A., and Levish, D.R., 1994, Surface faulting investigations for Tabor Dam: U.S. Bureau of Reclamation Seismotectonic Report 94-7, 30 p.

#912 Ostenaa, D.A., Levish, D.R., and Klinger, R.E., 1995, Mission fault study: U.S. Bureau of Reclamation Seismotectonic Report 94-8, 111 p.
#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.
#516 Qamar, A., Kogan, J., and Stickney, M.C., 1982, Tectonics and recent seismicity near Flathead Lake, Montana: Bulletin of the Seismological Society of America, v. 72, p. 1591-1599.
#1025 Wilson, R.A., 1921, Geology and physiography of the Mission Range, Montana: Chicago, Illinois, University of Chicago, unpublished Ph.D. dissertation, 107 p.
#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.
#957 Wold, R.J., 1982, Seismic reflection study of Flathead Lake, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-1433, 1 sheet.

700, Swan fault (Class A)

Structure Number 700

Comments: Refers to number 93 (Swan fault) of Witkind (1975 #317).

Structure Name Swan fault

Comments: An early reference to this fault is Clapp (1932 #997), who believed that movement was characterized by thrust or reverse slip on an east-dipping fault. Fault extends from midway along southwestern flank of Teakettle Mountain southward to Cottonwood Creek.

Synopsis Little is known about this long range-front fault. It is not marked by known scarps on alluvium but most of the deposits near the location of the inferred fault are probably post-glacial in age and, thus, may post-date the most recent faulting event. No detailed studies have been conducted.

Date of compilation 10/17/95

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Missoula; Lake; Flathead; Powell

1° x 2° sheet Choteau; Kalispell; Cut Bank

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location based on inferred trace from 1:250,000-scale map of Mudge and others (1982 #964), approximately 1:312,000-scale map of Ostenaa and others (1990 #540), and 1:500,000-scale map of Witkind (1975 #317). Earlier mapping (Johns and others, 1963 #1026) does not extend fault as far north as shown here.

Geologic setting Possible listric, down-to-the-west, normal fault between the western side of the Swan Range and Kalispell, Swan, and Clearwater Valleys. Near the central part of the fault, geophysical data indicate that the valley fill is about 2 km thick near Condon, Montana, and stratigraphic offset is more than 3.5 km (Mudge and others, 1982 #964; Crosby, 1984 #316). In Kalispell Valley, gravity data suggests the valley fill is about 1.5 km thick (Konizeski and McMurtrey, 1968 #965). Southern end of fault may be truncated by or merges with St Marys fault (Ostenaa and others, 1990 #540).

Sense of movement normal

Comments: (Johns, 1964 #1051)

Dip not reported

Dip direction SW

Geomorphic expression Range front is abrupt, linear, steep, and characterized by prominent faceted spurs. Especially prominent fault scarps near Lion Creek were reported by Crosby (1984 #316), but more recent work suggests scarps on alluvium are not present at this location (Ostenaa and others, 1990 #540). No other documentation of scarps on alluvium is known. The origin of the abrupt range front was attributed to glacial erosion by early reconnaissance studies in this area (Davis, 1920 #962).

Age of faulted surficial deposits not reported

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: No detailed studies have been published to document the displacement history of this fault. The Swan fault is known not to displace uppermost Pleistocene and Holocene surficial deposits at several locations; however, the occurrence of surface-faulting earthquakes prior to about 13 ka can not be precluded due to the absence of alluvium of that age at the surface (Ostenaa and others, 1990 #540). The Swan fault has characteristics similar to those of late Quaternary faults elsewhere in the region (Sullivan and LaForge, 1988 #541). Thus, we use a conservative estimate of age.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of data that indicate late Quaternary slip.

Length End to end (km) 155.9
Cumulative (km) 228.0

Average strike (azimuth) 337°

References

#997 Clapp, C.H., 1932, Geology of a portion of the Rocky Mountains of northwestern Montana: Montana Bureau of Mines and Geology Memoir 4, 30 p., 1 pl., scale 1:500,000.

#316 Crosby, G.W., 1984, Structural-geophysical interpretation of Swan Valley, Montana, *in* McBane, J.D., and Garrison, P.B., eds., Northwest Montana and adjacent Canada: Montana Geological Society, 1984 Field Conference and Symposium, p. 245-251.

#962 Davis, W.M., 1920, Features of glacial origin in Montana and Idaho: Annals of the Association of American Geographers, v. 10, p. 75-148.

#1051 Johns, W.M., 1964, Progress report on geologic investigations in the Kootenai-Flathead area, northwest Montana—6. Southeastern Flathead County and northern Lake County: Montana Bureau of Mines and Geology Bulletin 42, 66 p., 3 pls.

#1026 Johns, W.M., Smith, A.G., Barnes, W.C., Gilmour, E.H., and Page, W.D., 1963, Progress report on geologic investigations in the Kootenai-Flathead area, northwest Montana: Montana Bureau of Mines and Geology Bulletin 36, 68 p., 4 pls., scale 1:75,000.

#965 Konizeski, R.L., and McMurtrey, R.G., 1968, Geology and ground water resources of the Kalispell Valley, northwestern Montana: Montana Bureau of Mines and Geology Bulletin 68, 42 p., 5 pls.

#964 Mudge, M.R., Earhart, R.L., Whipple, J.W., and Harrison, J.E., 1982, Geologic and structure map of the Choteau 1° x 2° quadrangle, western Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1300, 2 sheets, scale 1:250,000.

#540 Ostenaa, D., Manley, W., Gilbert, J., LaForge, R., Wood, C., and Weisenberg, C.W., 1990, Flathead Reservation regional seismotectonic study—An evaluation for dam safety: U.S. Bureau of Reclamation Seismotectonic Report 90-8, 161 p., 7 pls.

#541 Sullivan, J.T., and LaForge, R.C., 1988, Seismic sources and maximum credible earthquakes for Willow Creek Dam, Sun River Project, Montana: U.S. Bureau of Reclamation Seismotectonic Report 88-12, 15 p., 2 pls.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

701, South Fork Flathead fault (Class A)

Structure Number 701

Comments: Refers to fault number 121 (unnamed fault southwest flank of Flathead Range) and fault number 122 (South Fork Flathead River fault) of Witkind (1975 #317).

Structure Name South Fork Flathead fault

Comments: Source of name is Ostenaa and others (1990 #540). Referred to as the Flathead fault in early work in the region (Clapp, 1932 #997; Erdmann, 1944 #987). Later referred to as the South Fork fault (Bryant and others, 1984 #1027; Sullivan and LaForge, 1988 #541). The most recently used name is preferred here to avoid any possible confusion with structural style attributed to the fault in early publications.

Synopsis Virtually nothing is known about this long range-front fault. No detailed studies have been conducted at this time. It is not marked by any reported scarps.

Date of compilation 02/01/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Flathead; Powell; Lewis and Clark

1° x 2° sheet Choteau; Cut Bank

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Source of trace is primarily 1:125,000-scale geologic map (without topography) of Johns (1970 #896). Northern and southern ends of fault is from 1:1,000,000-scale fault map of Ostenaa and others (1990 #540). Location of northern end of fault, from Riverside Creek northward, is indicated by Erdmann (1944 #987) to be nearer the present location of eastern shoreline of Hungry Horse Reservoir.

Geologic setting High-angle or possibly listric, down-to-west, range-front normal fault bounding the southwestern side of Flathead Range. Total displacement across the fault is unknown. Qamar and Stickney (1983 #58) suggest late Tertiary displacement is more than 100 m.

Sense of movement normal

Comments: (Johns, 1964 #1051). Early workers (Clapp, 1932 #997; Erdmann, 1944 #987) in this area speculated that movement on a east-dipping high-angle reverse fault (Flathead fault) was the origin of the basin and range topography; but Erdmann did not preclude that the fault might be normal.

Dip not reported

Dip direction SW

Geomorphic expression Erdmann (1944 #987) states that "actual scarps have not been observed". No more recent studies are known.

Age of faulted surficial deposits Johns (1970 #896) shows about 70% of the length of the fault at contact between bedrock (Precambrian and Cambrian) units or at or near the bedrock-alluvium contact, but he also indicates that the trace is not well located. Bryant and others (1984 #1027) indicate that Tertiary basin fill is displaced by the fault.

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Erdmann (1944 #987) suggests that there is widespread evidence that movement continued until Sangamon (?) interglacial stage based on the tilt of valley deposits, but deformation of gravels of this age was not reported. Because there is no definitive information on the timing of the most recent movement on this fault, we use a conservative estimate; however, it is possible that movement ceased in the Tertiary as indicated by Bryant and others (1984 #1027).

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of scarps.

Length End to end (km) 147.7
Cumulative (km) 153.3

Average strike (azimuth) 329°

References

#1027 Bryant, M.B., Garrison, P.B., Winston, D., Tucker, T., French, D.E., and Binda, P., 1984, 1984 Field Conference road logs—Kalispell—Waterton—Fernie Basin—Rocky Mountain trench, *in* McBane, J.D., and Garrison, P.B., eds., Northwest Montana and adjacent Canada: Montana Geological Society, 1984 Field Conference and Symposium, p. 331-338.

#997 Clapp, C.H., 1932, Geology of a portion of the Rocky Mountains of northwestern Montana: Montana Bureau of Mines and Geology Memoir 4, 30 p., 1 pl., scale 1:500,000.

#987 Erdmann, C.E., 1944, Part 2. Hungry Horse Dam and Reservoir site, South Fork Flathead River, Flathead County, Montana, *in* Geology of dam sites on the upper tributaries of the Columbia River in Idaho and Montana: U.S. Geological Survey Water-Supply Paper 866-B, p. 37-116, 4 pls.

#1051 Johns, W.M., 1964, Progress report on geologic investigations in the Kootenai-Flathead area, northwest Montana—6. Southeastern Flathead County and northern Lake County: Montana Bureau of Mines and Geology Bulletin 42, 66 p., 3 pls.

#896 Johns, W.M., 1970, Geology and mineral deposits of Lincoln and Flathead Counties, Montana: Montana Bureau of Mines and Geology Bulletin 79, 182 p., 3 pls., scale approx. 1:125,000.

#540 Ostenaa, D., Manley, W., Gilbert, J., LaForge, R., Wood, C., and Weisenberg, C.W., 1990, Flathead Reservation regional seismotectonic study—An evaluation for dam safety: U.S. Bureau of Reclamation Seismotectonic Report 90-8, 161 p., 7 pls.

#58 Qamar, A.I., and Stickney, M.C., 1983, Montana earthquakes, 1869-1979—Historical seismicity and earthquake hazard: Montana Bureau of Mines and Geology Memoir 51, 79 p., 3 pls.

#541 Sullivan, J.T., and LaForge, R.C., 1988, Seismic sources and maximum credible earthquakes for Willow Creek Dam, Sun River Project, Montana: U.S. Bureau of Reclamation Seismotectonic Report 88-12, 15 p., 2 pls.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

702, Bull Lake fault (Class A)

Structure Number 702

Comments: Refers to southern part of fault number 125 of Witkind (1975 #317).

Structure Name Bull Lake fault

Comments: Source of name is probably Calkins and MacDonald (1909 #1029), who describe the fault as a steeply dipping (45° W.) overthrust fault, which extends from Station Creek southward to the lower forks of the Bull River. Later mapping by Gibson (1948 #1030) shows the normal fault extending into bedrock at both its northern and southern ends. Fault is similarly shown by Johns (1970 #896) and Wells and others (1981 #1038), but not on subsequent compilation of 1° x 2° Kalispell sheet by Harrison and others (1983 #1032). Fault, as shown here, extends from Camp Creek, 3.5 km east of the range front, southward to 0.2 km northwest of East Fork Bull River.

Synopsis Virtually nothing is known about this fault. It does not have known scarps on alluvium, and its Quaternary history of displacement is inferred from equivocal relations at one location.

Date of compilation 02/29/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Lincoln; Sanders

1° x 2° sheet Kalispell

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Based on poorly located fault shown on 1:125,000-scale geologic map by Gibson (1948 #1030).

Geologic setting Steeply to moderately dipping, down-to-west, normal fault bounding the southern part of Lake Creek valley. Witkind (1975 #317) considered the basin-bounding parts of this fault, the Savage Lake fault [703], and O'Brien Creek fault [704] to be a single feature. This interpretation is not supported by recent work; thus, we depict the faults as originally mapped. Pardee (1950 #46) suggests that the cumulative displacement across this fault is about 1.5 km.

Sense of movement normal

Comments: (Gibson, 1948 #1030)

Dip 45° W

Comments: Dip of fault from exposure east of Bull Lake (Calkins and MacDonald, 1909 #1029; Pardee, 1950 #46).

Dip direction W

Geomorphic expression Range front is characterized by aligned faceted spurs. Scarps on alluvium are not known.

Age of faulted surficial deposits Unknown, fault is generally concealed by alluvium. Location of fault shown at or near bedrock-alluvial contact (Johns, 1970 #896). Wells and others (1981 #1038) show the fault entirely in bedrock.

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Based on limited evidence, movement on this fault has been regarded as "recent" since the early work of Calkins and MacDonald (1909 #1029); no subsequent detailed studies have been conducted. Gibson (1948 #1030) also described places where there may be evidence of young movement, but cautiously noted that the relations also could be erosional in origin. Although evidence is inconclusive, an erosional origin is preferred in a report by the U.S. Army Corps of Engineers (1978 #1028). Pardee (1950 #46) believed the range-front morphology indicated that most of the faulting is Pleistocene in age. A conservative estimate for the timing of the most recent movement is used here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on the absence of data that indicate late Quaternary slip.

Length End to end (km) 21.9
Cumulative trace (km) 23.6

Average strike (azimuth) 356°

References

#1029 Calkins, F.C., and MacDonald, D.F., 1909, A geological reconnaissance in northern Idaho and northwestern Montana: U.S. Geological Survey Bulletin 384, 112 p.

#1030 Gibson, R., 1948, Geology and ore deposits of the Libby quadrangle, Montana: U.S. Geological Survey Bulletin 956, 131 p., 2 pls.

#1032 Harrison, J.E., Cressman, E.R., and Whipple, J.W., 1983, Preliminary geologic and structure maps of part of the Kalispell 1° x 2° quadrangle, Montana: U.S. Geological Survey Open-File Report 83-502, 6 p. pamphlet, 2 sheets, scale 1:250,000.

#896 Johns, W.M., 1970, Geology and mineral deposits of Lincoln and Flathead Counties, Montana: Montana Bureau of Mines and Geology Bulletin 79, 182 p., 3 pls., scale approx. 1:125,000.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#1028 U.S. Army Corps of Engineers, 1978, Libby additional units and reregulating dam—Design memorandum 7: U.S. Army Corps of Engineers, Seattle District, v. 3.

#1038 Wells, J.D., Lindsey, D.A., and Van Loenen, R.E., 1981, Geology of the Cabinet Mountains Wilderness, Lincoln and Sanders Counties, Montana, *in* Mineral resources of the Cabinet Mountains Wilderness, Lincoln and Sanders Counties, Montana: U.S. Geological Survey Bulletin 1501-A, p. 9-19.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

703, Savage Lake fault (Class A)

Structure Number 703

Comments: Refers to middle part of fault number 125 of Witkind (1975 #317).

Structure Name Savage Lake fault

Comments: Source of name is probably Gibson (1948 #1030), who showed the fault joining the Bull Lake fault [702] east of Bull Lake and extending along the edge of Lake Creek valley northward almost to the Kootenai River. Fault, as shown here, extends from about 1 km south of Kootenai River southward to join with the Bull Lake fault [702] 1 km south of Crowell Creek.

Synopsis Virtually nothing is known about the Quaternary history of this fault. It is not known if scarps on alluvium are present. Its history of Quaternary displacement is inferred from equivocal relations.

Date of compilation 03/04/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Lincoln

1° x 2° sheet Kalispell

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Based on poorly located and mostly inferred fault shown on 1:125,000-scale geologic map of Gibson (1948 #1030). Northern extension of fault as shown by Johns (1970 #896) is not included because of its generally poor surface expression. Savage Lake fault is not shown in more recent compilation of 1° x 2° Kalispell sheet by Harrison and others (1983 #1032).

Geologic setting High-angle, down-to-west, normal fault bounding the northern part of Lake Creek valley. Witkind (1975 #317) considered this fault, the basin-bounding part of the Bull Lake fault [702], and O'Brien Creek fault [704] to be a single feature, but this interpretation is not supported by recent work. Thus, we depict the faults as originally mapped. Estimates of total throw are not known

Sense of movement normal

Comments: (Witkind, 1975 #317)

Dip 90°

Comments: Fault was reported to be vertical east of Savage Lake (Gibson, 1948 #1030).

Dip direction V

Geomorphic expression Range front is characterized by aligned faceted spurs. Scarps on alluvium are not known.

Age of faulted surficial deposits Unknown, but fault is generally buried by Quaternary alluvium. Location of fault is shown at or near the bedrock-alluvium contact (Johns, 1970 #896).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: J.T. Pardee (Gibson, 1948 #1030) inferred Holocene movement on the fault based on the interpretation that Kootenai Falls is a knickpoint resulting from the most recent movement. Since the knickpoint has migrated a short distance from the inferred location of the fault and bedrock along this reach of the river is not particularly resistant; the implication is that movement on the fault is geologically young. Additionally, recent movement is inferred from the spatial relations between topographic depressions and swamps and the inferred location of the fault (Gibson, 1948 #1030). Pardee (1950 #46) believed that the range-front morphology indicated that most of the faulting is Pleistocene in age. We use a conservative estimate for the timing of the most recent movement here.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of data that indicate late Quaternary slip.

Length End to end (km) 17.7
Cumulative (km) 18.8

Average strike (azimuth) 10°

References

#1030 Gibson, R., 1948, Geology and ore deposits of the Libby quadrangle, Montana: U.S. Geological Survey Bulletin 956, 131 p., 2 pls.

#1032 Harrison, J.E., Cressman, E.R., and Whipple, J.W., 1983, Preliminary geologic and structure maps of part of the Kalispell 1° x 2° quadrangle, Montana: U.S. Geological Survey Open-File Report 83-502, 6 p. pamphlet, 2 sheets, scale 1:250,000.

#896 Johns, W.M., 1970, Geology and mineral deposits of Lincoln and Flathead Counties, Montana: Montana Bureau of Mines and Geology Bulletin 79, 182 p., 3 pls., scale approx. 1:125,000.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

704, O'Brien Creek fault (Class A)

Structure Number 704

Comments: Refers to northern part of fault number 125 of Witkind (1975 #317).

Structure Name O'Brien Creek fault

Comments: Source of name is probably Gibson (1948 #1030), who showed the fault as extending from the northern shores of Savage Lake northward to the edge of the mapped area. Fault extends from near the 90° bend in O'Brien Creek near Yaak Mountain south to northern shores of Savage Lake.

Synopsis Virtually nothing is known about the Quaternary history of this fault. It is not known if scarps on alluvium are present. Its history of Quaternary displacement is inferred from equivocal relations at one location.

Date of compilation 03/04/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Lincoln

1° x 2° sheet Kalispell

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Based on poorly located fault shown on 1:125,000-scale geologic map of Gibson (1948 #1030); northern part of fault is from Witkind (1975 #317) and shows fault extending northwestward to edge of map area; this part of the trace not included because evidence for Quaternary movement is not documented. O'Brien Creek fault not shown on compilation of 1° x 2° Kalispell sheet by Harrison and others (1983 #1032).

Geologic setting High-angle, down-to-west, normal fault bounding the mountain front facing O'Brien Creek. Witkind (1975 #317) considered this fault, the basin-bounding part of the Bull Lake fault [702], and Savage Lake fault [703] as a single feature. This interpretation is not supported by recent work; thus, we depict the faults as originally mapped.

Sense of movement normal

Comments: (Gibson, 1948 #1030)

Dip not reported

Dip direction SW

Geomorphic expression Scarps on alluvium are not known.

Age of faulted surficial deposits Unknown. Location of fault shown at or near bedrock-alluvium contact (Johns, 1970 #896).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Gibson (1948 #1030) did not suggest recent movement on this fault as he did for the "related" faults [702 and 703] to the south. However, Witkind (1975 #317) included this as a Quaternary structure based on the description of the fault by Pardee (1950 #46). No recent work has been conducted to quantify the timing of the most recent movement on this fault, which we depict here as Quaternary.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of data that indicate late Quaternary slip.

Length End to end (km) 14.9
Cumulative (km) 15.5

Average strike (azimuth) 337°

References

#1030 Gibson, R., 1948, Geology and ore deposits of the Libby quadrangle, Montana: U.S. Geological Survey Bulletin 956, 131 p., 2 pls.

#1032 Harrison, J.E., Cressman, E.R., and Whipple, J.W., 1983, Preliminary geologic and structure maps of part of the Kalispell 1° x 2° quadrangle, Montana: U.S. Geological Survey Open-File Report 83-502, 6 p. pamphlet, 2 sheets, scale 1:250,000.

#896 Johns, W.M., 1970, Geology and mineral deposits of Lincoln and Flathead Counties, Montana: Montana Bureau of Mines and Geology Bulletin 79, 182 p., 3 pls., scale approx. 1:125,000.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

705, Ninemile fault (Class A)

Structure Number 705

Comments: Refers to fault number 89 (unnamed fault at northeastern edge of Missoula basin) of Witkind (1975 #317).

Structure Name Ninemile fault

Comments: Origin of the name not known. Fault is shown and discussed by Pardee (1950 #46), but no name was given. McMurtrey and others (1965 #1052) referred to this structure as the Clark Fork fault. The Ninemile fault in McMurtrey and others (1965 #1052) is shown as a thrust fault on the southern side of Ninemile Creek; they refer to a Ph.D. dissertation by F.W. Hall for their source. Wells (1974 #1044) mapped this structure as having multiple traces and called it the Ninemile fault zone; two of the traces are shown here but the commonly used name is retained. Fault extends from about 1 km southeast of the Sanders-Missoula County line near the headwaters of Ninemile Creek southeastward to the confluence of Marshall Creek and Clark Fork, northeast of Missoula.

Synopsis The Ninemile fault is a principle fault in the Lewis and Clark line. Little is known about its Quaternary history, but small earthquakes have occurred in the vicinity of this fault (Qamar and Stickney, 1983 #58). Although there is no definitive evidence of Quaternary movement, this fault is included herein because of the pronounced range-front morphology, which could be the result of Quaternary faulting. Significant movement on the Ninemile fault has occurred (Wells, 1974 #1044; Wallace and others, 1990 #1045). Tertiary deposits are clearly deformed (Wells, 1974 #1044; Harrison and others, 1986 #1046); all Quaternary surficial deposits near the fault are post-glacial in age and are undeformed (Ostenaa and others, 1990 #540).

Date of compilation 03/11/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Missoula; Sanders

1° x 2° sheet Wallace; Hamilton; Butte

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location is based on mostly concealed trace from 1:250,000-scale map of Harrison and others (1986 #1046), in part after Wells (1974 #1044). Southern part of fault is from 1:500,00-scale map of Witkind (1975 #317).

Geologic setting Down-to-south, normal (?) fault bounding the southwestern flank of the Squaw Peak and Jocko Ranges. Wells (1974 #1044) suggests that if movement is entirely dip slip, then 8.8-12.1 km of displacement is possible; however, structural relations do not preclude as much as 29 km of right-lateral displacement.

Sense of movement normal

Comments: Wells (1974 #1044) indicates that geologic relations of Tertiary beds indicate southwest side down, but dextral movement is also possible.

Dip not reported

Dip direction SW

Geomorphic expression Faceted spurs have long been recognized (Pardee, 1950 #46) along the fault but the origin may be due to differential erosion near the fault zone (Ostenaa and others, 1990 #540). No scarps are known to exist on alluvium; Ostenaa and others (1990 #540) briefly examined several sites along the fault and found no evidence of late Quaternary faulting.

Age of faulted surficial deposits Fault is shown as continuous in bedrock and buried by Quaternary deposits (Harrison and others, 1986 #1046).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: Pardee (1950 #46) speculated that movement on this fault was Pliocene or early Pleistocene in age. Witkind (1975 #317) included this structure in his compilation and indicated that the fault was probably Quaternary based on Pardee's statement. Limited reconnaissance by Ostenaa and others (1990 #540) found no evidence of Quaternary faulting, but scarps may not be preserved due to erosional conditions and the lack of deposits old enough to record the most recent movement.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of scarps on upper Quaternary deposits.

Length End to end (km) 70.1
Cumulative (km) 93.0

Average strike (azimuth) 305°

References

#1046 Harrison, J.E., Griggs, A.B., and Wells, J.D., 1986, Geologic and structure maps of the Wallace 1° x 2° quadrangle, Montana and Idaho: U.S. Geological Survey Miscellaneous Investigations Map I-1509-A, 2 sheets, scale 1:250,000.

#1052 McMurtrey, R.G., Konizeski, R.L., and Brietkrietz, A., 1965, Geology and ground water resources of the Missoula basin, Montana: Montana Bureau of Mines and Geology Bulletin 47, 35 p., 3 pls.

#540 Ostenaa, D., Manley, W., Gilbert, J., LaForge, R., Wood, C., and Weisenberg, C.W., 1990, Flathead Reservation regional seismotectonic study—An evaluation for dam safety: U.S. Bureau of Reclamation Seismotectonic Report 90-8, 161 p., 7 pls.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#58 Qamar, A.I., and Stickney, M.C., 1983, Montana earthquakes, 1869-1979—Historical seismicity and earthquake hazard: Montana Bureau of Mines and Geology Memoir 51, 79 p., 3 pls.

#1045 Wallace, C.A., Lidke, D.J., and Schmidt, R.G., 1990, Faults of the central part of the Lewis and Clark line and fragmentation of the Late Cretaceous foreland basin in west-central Montana: Geological Society of America Bulletin, v. 102, p. 1021-1037.

#1044 Wells, J.D., 1974, Geologic map of the Alberton quadrangle, Missoula, Sanders, and Mineral Counties, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-1157, 1 sheet, scale 1:62,500.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

706, Unnamed fault near Ovando (Class A)

Structure Number 706

Comments: Refers to fault number 94 (unnamed fault at northeast edge Blackfoot Valley) of Witkind (1975 #317).

Structure Name Unnamed fault near Ovando

Comments: This fault may be a reactivated part of the Cenozoic St. Marys fault zone, north of Ovando, Montana. Fault, as shown here, extends from Cottonwood Creek southeastward to the North Fork Blackfoot River.

Synopsis Virtually nothing is known about the Quaternary history of this fault. Although there is no definitive evidence of Quaternary movement, this fault is included here because it is associated with a pronounced range front.

Date of compilation 03/12/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Powell; Missoula

1° x 2° sheet Choteau

Physiographic province Northern Rocky Mountains

Reliability of location Poor

Comments: Location is based on mostly concealed trace on 1:250,000-scale map of Mudge and others (1982 #964), which closely follows mapping of Witkind (1977 #1048; 1977 #1049; 1977 #1053), and extent of the fault is based on 1:500,000-scale map of Witkind (1975 #317). Fault, as depicted by Witkind (1975 #317) after Pardee (1950 #46), extends southeastward along the hill between Ovando and Lincoln, Montana. This southern extension is not shown in later mapping by Witkind (1977 #1047) or Mudge and others (1982 #964), and is not included here.

Geologic setting High-angle, down-to-the-south, normal fault bounding the Blackfoot Mountains. According to Mudge and others (1982 #964), vertical displacement may be a few meters to more than 1.8 km. Pardee (1950 #46) suggested that the vertical offset is about 0.9 km assuming that correlation of a Tertiary peneplain across the fault is correct. Harrison and others (1974 #1050) suggest that horizontal displacement is 13 km on the St. Marys fault zone.

Sense of movement normal

Comments: From (Witkind, 1975 #317). However, St. Marys fault zone is described as having dextral and apparent vertical movement (Mudge and others, 1982 #964).

Dip not reported

Dip direction S

Geomorphic expression Prominent, bold, steep range front, which Pardee (1950 #46) characterized as an eroded fault scarp. No scarps on alluvium are reported.

Age of faulted surficial deposits Most of the trace of the fault is buried; by Quaternary alluvium fault is mapped as continuous feature through Proterozoic bedrock (Mudge and others, 1982 #964).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: The timing of the most recent movement on this fault is not known. We infer this feature to have Quaternary movement based on the prominent range front. Most Quaternary deposits near the fault are post-glacial in age and are younger than the most recent movement. Pardee (1950 #46) first recognized this fault as a late Cenozoic structure but made no statement about the age of most recent movement. Witkind (1975 #317) subsequently included this fault in his compilation. Mudge and others (1982 #964) suggest movement on this and related faults of the St. Marys fault zone to be younger than that on the nearby range-front faults.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of data that indicate late Quaternary slip.

Length End to end (km) 28.9
Cumulative (km) 30.6

Average strike (azimuth) 288°

References

#1050 Harrison, J.E., Griggs, A.B., and Wells, J.D., 1974, Tectonic features of the Precambrian Belt basin and their influence on post-Belt structures: U.S. Geological Survey Professional Paper 866, 15 p.

#964 Mudge, M.R., Earhart, R.L., Whipple, J.W., and Harrison, J.E., 1982, Geologic and structure map of the Choteau 1° x 2° quadrangle, western Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1300, 2 sheets, scale 1:250,000.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

#1047 Witkind, I.J., 1977, Preliminary map showing surficial deposits in the south half of the Coopers Lake quadrangle, Powell County, Montana: U.S. Geological Survey Open-File Report 77-466, 1 sheet, scale 1:24,000.

#1048 Witkind, I.J., 1977, Preliminary map showing surficial deposits in the south half of the Ovando Mountain quadrangle, Powell County, Montana: U.S. Geological Survey Open-File Report 77-465, 1 sheet, scale 1:24,000.

#1049 Witkind, I.J., 1977, Preliminary map showing surficial deposits in the south half of the Ovando quadrangle, Powell County, Montana: U.S. Geological Survey Open-File Report 77-196, 1 sheet, scale 1:24,000.

#1053 Witkind, I.J., 1977, Preliminary map showing surficial deposits in the Woodworth quadrangle, Powell County, Montana: U.S. Geological Survey Open-File Report 77-203, 1 sheet, scale 1:24,000.

746, East Gallatin Reese Creek fault system (Class C)

Structure Number 746

Comments: Refers to fault number 30 (Reese Creek fault) of Witkind (1975 #317; 1975 #819); and fault numbers 64 (Reese Creek fault), 65 (East Gallatin fault), and 66 (Devils Slide fault) of Johns and others (1982 #259).

Structure Name East Gallatin Reese Creek fault

Comments: The faults in this system, which form the high eastern front of Gallatin Range and extends northward along Reese Creek, have been referred to by various names. The name East Gallatin Reese Creek fault system is from Pierce and others (1991 #1055) and is preferred in this compilation because we group the structures for convenience. The three faults include the East Gallatin and the Devils Slide faults of Ruppel (1972 #470) and the Reese Creek fault of Wilson (1934 #1054). Ruppel (1972 #470) suggests that the faults may extend much further south, beyond Old Faithful and the Upper Geyser Basin and possibly join the Teton fault. The extent of the fault system shown here is from about 0.5 km east of Corwin Springs south to near the southern end of the Gallatin Range.

Synopsis The East Gallatin fault forms the >600-m-high eastern front of the Gallatin Range. At its southern end a strand of the fault offsets 0.63 Ma Lava Creek Tuff, but along the main range front, the tuff occurs only at the foot of the range in Gardners Hole and not present on the upthrown side of the fault. The northern extension of this fault, the Reese Creek section, is mapped as having as many as 6 strands. These extensional normal faults offset Eocene rocks and younger Cenozoic movement is suspected, but not demonstrated. No scarps are known on Quaternary deposits. La Duke Hot Springs are located along the projection of the Reese Creek section just north of the Yellowstone River.

Date of compilation 03/18/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey; Kenneth L. Pierce, U.S. Geological Survey

County and State (if other than Montana) Park (Wyo.), Park (Mont.) (Yellowstone National Park)

1° x 2° sheet Ashton, Bozeman

Physiographic Province Middle Rocky Mountains

Geologic setting High-angle to near-vertical, down-to-the-east, normal fault along the eastern side of the Gallatin Range and northern extension that is associated with a less prominent range front. The northern extension of this fault, the Reese Creek section, is mapped as having as many as 6 strands (Ruppel, 1972 #470; U.S. Geological Survey, 1972 #639). Various amounts of displacement across this fault is documented but all are less than 2 km. Hague and others (1899 #1058) suggests more than 1.2 km of offset across the fault system. Later, Iddings (1904 #1059) inferred 1.8 km of offset across the Reese Creek fault. Wilson (1934 #1054) suggested about 1.2 km of offset across the easternmost strand of the system. Fraser and others (1969 #467) suggest a similar amount of offset (1.3 km). Ruppel (1972 #470) summarized previous work suggesting more than 1200 m of post-Eocene stratigraphic displacement. At its southern end, the fault offsets 0.63 Ma Lava Creek Tuff; along the main range front, the tuff occurs only at the foot of the range in Gardners Hole and not present on the upthrown side of the fault.

Number of sections 2

Comments: Two sections are defined based on demonstrable Quaternary movement along the southern part of the fault (Gallatin Range section) and less definitive evidence of Quaternary movement along the northern part (Reese Creek section)

Length End to end (km): 40.0
Cumulative (km): 79.9

Average strike (azimuth) 356°

746a, Reese Creek section

Section number 746a

Section name Reese Creek section

Comments: Section name follows fault name established by Wilson (1934 #1054). Section extends from about 0.5 km east of Corwin Springs south to the Gallatin River.

Reliability of location Poor

Comments: All of the northern part of fault trace is mostly inferred and the location of about half of southern part is inferred on 1:125,000-scale geologic maps (U.S. Geological Survey, 1972 #639; 1972 #1057) based on mapping of Ruppel (1972 #470). The extreme northern end is from Pierce and others (1991 #1055).

Sense of movement normal

Comments: From (Witkind, 1975 #317; 1975 #819). Early movement on the fault may have been left lateral (Brown, 1961 #1056).

Dip not reported

Dip direction E

Geomorphic expression Much of the fault system is buried but is expressed in the topography from the flank of Little Quadrant Mountain southward to the flank of Mount Holmes (U.S. Geological Survey, 1972 #1057). The topographic difference across the fault along its northern part is less than that to the south as evidenced by the presence of Eocene rocks of Sepulcher Mountain east of the fault (downdropped side).

Age of faulted surficial deposits Mostly pre-Quaternary rocks, including Eocene. One of the strands is mapped as concealed by Lava Creek Tuff (U.S. Geological Survey, 1972 #639), but which has been remapped as the 2.0 Ma Huckleberry Ridge Tuff (R.L., Christiansen, written commun., 1998). The fault is reported only to be "topographically expressed" in Pinedale till but does not this offset unit on a companion map (U.S. Geological Survey, 1972 #1057). No offset of deposits was noted by Pierce (1973 #3805) and Pierce and others (1991 #1055).

Paleoseismology studies none

Most recent prehistoric deformation Quaternary (<1.6 Ma)

Comments: There is no definitive estimate of the time of most recent movement of this fault. Undine Falls Basalt (~600 ka) is probably not offset, within the resolution limits of about 50 m (Pierce and others, 1991 #1055). Ruppel (1972 #470) documented post-glacial movement and is the source of the Holocene age assignment in earlier compilations (Witkind, 1975 #317; 1975 #819; Johns and others, 1982 #259), but Pierce and others (1991 #1055) report that evidence to support post-glacial movement is absent. The age assignment of Quaternary is tentative, as its faulting history prior to 600 ka is not known.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: Inferred low slip rate based on absence of scarps on late Quaternary deposits.

Length End to end (km) 13.5
Cumulative Trace (km) 46.8

Average strike 3°

746b, East Gallatin section

Section number 746b

Section name East Gallatin section

Comments: Section name follows fault name established by Ruppel (1972 #470). Section extends from the Gallatin River south to beyond Winter Creek. Ruppel (p. A51-55, 1972 #470) and Pierce and others (p. C-18, 1991 #1055) summarized previous work and described the fault. .

Reliability of location Good

Comments: Ruppel (1972 #470) mapped the fault at 1:62,5000 scale and the U.S. Geological Survey (1972 #639; 1972 #1057) portrayed it at 1:125,000 scale

Sense of movement normal

Dip 50°-vertical

Comments: Ruppel (p. A51, 1972 #470) noted "The East Gallatin fault is vertical where it is exposed by the Gardner River, and its straight trace suggests that it remains vertical, or nearly so, both to the north and to the south." Pierce and others (p C18-21, 1991 #1055) suggested that at depth the fault may dip east at 50° and intercepts the Norris Mammoth corridor at 10-15 km depth so that extension that had occurred on the East Gallatin fault now occurs in the Norris-Mammoth corridor.

Dip direction E

Geomorphic expression The eastern front of the Gallatin Range is linear, moderately steep, and locally more than 600 m high. Although Ruppel (p. A54, 1972 #470) noted that glacial deposits are displaced minor amounts, Pierce and others (1991 #1055) could find no evidence of offset of glacial deposits.

Age of faulted deposits Mostly pre-Quaternary rocks, especially Paleozoic. At southern end of fault, one strand of the fault offsets 0.63 Ma Lava Creek Tuff.

Paleoseismology studies none

Most recent prehistoric deformation middle and late Quaternary (<750 ka)

Comments: The geomorphic expression of the range front suggests late Cenozoic activity. Offset Eocene rocks and younger Cenozoic movement is suspected, but not demonstrated. Uncertain, but near southern end, an eastern splay offsets Lava Creek Tuff (0.63 Ma). Near section boundary (on the north, the easternmost strand does not offset Lava Creek Tuff.

Recurrence interval not reported

Slip-rate category unknown; probably <0.2 mm/yr

Comments: No offset of glacial deposits has been observed (Pierce, 1973 #3805; Pierce and others, 1991 #1055); thus, the lowest slip-rate category is indicated.

Length End to end (km): 26.9
Cumulative trace (km): 33.0

Average strike (azimuth) 345°

References

#1056 Brown, C.W., 1961, Cenozoic stratigraphy and structural geology, northeast Yellowstone National Park, Wyoming and Montana: Geological Society of America Bulletin, v. 72, p. 1173-1194.

#467 Fraser, G.D., Waldrop, H.A., and Hyden, H.J., 1969, Geology of the Gardiner area, Park County, Montana: U.S. Geological Survey Bulletin 1277, 118 p., 1 pl., scale 1:24,000.

#1058 Hague, A., Iddings, J.P., Weed, W.H., Walcott, C.D., Girty, G.H., Stanton, T.W., and Knowlton, F.H., 1899, Geology of the Yellowstone National Park: U.S. Geological Survey Monograph 32, 882 p.

#1059 Iddings, J.P., 1904, A fracture valley system: Journal of Geology, v. 12, p. 94-105.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#3805 Pierce, K.L., 1973, Surficial geologic map of the Mount Holmes quadrangle and parts of the Tepee Creek, Crown Buttes, and Miner quadrangles, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey Miscellaneous Geologic Investigations I-640, 1 sheet, scale 1:62,500.

#1055 Pierce, K.L., Adams, K.D., and Sturchio, N.C., 1991, Geologic setting of the Corwin Springs Known Geothermal Resources Area-Mammoth Hot Springs Area in and adjacent to Yellowstone National Park, *in* Sorey, M.L., ed., Effects of potential geothermal development in the Corwin Springs Known Geothermal Resources Area, Montana, on the thermal features of Yellowstone National Park: U.S. Geological Survey Water-Resources Investigations Report 91-4052.

#470 Ruppel, E.T., 1972, Geology of pre-Tertiary rocks in the northern part of Yellowstone National Park, Wyoming: U.S. Geological Survey Professional Paper 729-A, 66 p., 1 pl., scale 1:62,500.

#639 U.S. Geological Survey, 1972, Geologic map of Yellowstone National Park: U.S. Geological Survey Miscellaneous Geologic Investigations I-711, 1 sheet, scale 1:125,000.

#1057 U.S. Geological Survey, 1972, Surficial geologic map of Yellowstone National Park: U.S. Geological Survey Miscellaneous Geologic Investigations I-710, 1 sheet, scale 1:125,000.

#1054 Wilson, C.W., 1934, Geology of the thrust fault near Gardiner, Montana: Journal of Geology, v. 42, p. 649-663.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

#819 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in Wyoming: U.S. Geological Survey Open-File Report 75-279, 35 p. pamphlet, 1 sheet, scale 1:500,000.

Antelope Creek fault (Class C)

Structure Name Antelope Creek fault

Comments: Fault may have been first named by Johns and others (1982 #259); fault is number 36 in their compilation.

Reason for Class designation Quaternary movement was inferred by Johns and others (1982 #259) based on the boundary between marshes of Red Rock Lakes and the higher alluvial plain to the north in Centennial Valley. Fault as shown follows the northern edges of Red Rock Lakes. Demonstrable Quaternary (<1.6 Ma) movement is not recognized. Part of this fault is shown by Schofield (1981 #314) based on gravity data, but his location seems to be north of that shown by Johns and others (1982 #259).

Date of compilation 04/11/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Ashton

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#314 Schofield, J.D., 1981, Structure of the Centennial and Madison Valleys based on gravitational interpretation, *in* Tucker, T.E., ed. Guidebook to southwest Montana: Montana Geological Society, 1981 Field Conference and Symposium, p. 275-283.

Black Butte fault (Class C)

Structure Name Black Butte fault

Comments: Fault may have first been named by Johns and others (1982 #259); fault is number 20 in their compilation.

Reason for Class designation Pleistocene movement was inferred by Johns and others (1982 #259) based on inferred contemporaneous movement with the Bull Mountain western border fault [690]. Quaternary (<1.6 Ma) movement has not been documented, and no scarps have been recognized. This feature is designated Class C herein based on the absence of compelling evidence for Quaternary slip.

Date of compilation 06/02/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet Dillon

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

Bone Basin Creek fault A (Class C)

Structure Name Bone Basin Creek fault A

Comments: Source of name is Johns and others (1982 #259); fault is number 8 in their compilation.

Reason for Class designation Johns and others (1982 #259) only reference for this fault is Kuenzi and Fields (1971 #757), who do not show or discuss a fault having the length, orientation, or location shown on map of Johns and others. Thus, this feature is designated Class C herein because the original study provides no compelling evidence that a fault exists at this location or that it has a Quaternary history of movement.

Date of compilation 06/02/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Dillon

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#757 Kuenzi, W.D., and Fields, R.W., 1971, Tertiary stratigraphy, structure, and geologic history, Jefferson basin, Montana: Geological Society of America Bulletin, v. 82, p. 3373-3393.

Bone Basin Creek fault B (Class C)

Structure Name Bone Basin Creek fault B

Comments: Source of name is Johns and others (1982 #259); fault is number 9 in their compilation. Based on the discussion in Kuenzi and Fields (1971 #757), the compiler believes that Kuenzi and Fields call this the Mayflower Gulch fault.

Reason for Class designation Kuenzi and Fields (1971 #757) indicated that faulting occurred since the middle Pliocene. However, Johns and others (1982 #259), who provide conflicting arguments favoring Quaternary movement, suggest the presence of a prominent scarp along the fault and also indicate a late Pleistocene pediment surface that extends across the trace of the fault. This fault is designated Class C herein because the original investigators did not indicate evidence of Quaternary movement.

Date of compilation 06/02/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Dillon

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#757 Kuenzi, W.D., and Fields, R.W., 1971, Tertiary stratigraphy, structure, and geologic history, Jefferson basin, Montana: Geological Society of America Bulletin, v. 82, p. 3373-3393.

Bone Basin Creek fault C (Class C)

Structure Name Bone Basin Creek fault C

Comments: Source of name is Johns and others (1982 #259); fault is number 8 in their compilation.

Reason for Class designation Johns and others (1982 #259) only reference for this fault is Kuenzi and Fields (1971 #757), who do not show or discuss a fault having the length, orientation, or location shown on map of Johns and others. Johns and others (1982 #259) suggest the presence of a prominent scarp along the fault. This feature is designated Class C herein because the original study provides no compelling evidence that a fault exists at this location or that it has a history of Quaternary movement.

Date of compilation 06/02/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Dillon

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#757 Kuenzi, W.D., and Fields, R.W., 1971, Tertiary stratigraphy, structure, and geologic history, Jefferson basin, Montana: Geological Society of America Bulletin, v. 82, p. 3373-3393.

Boulder Valley western border fault (Class C)

Structure Name Boulder Valley western border fault

Comments: This inferred fault bounds the western border of the Boulder River valley, west and northwest of Boulder, Montana, according to Johns and others (1982 #259); fault is number 29 in their compilation.

Reason for Class designation The only evidence that Johns and others (1982 #259) presented to support this fault is partially exhumed, truncated spurs. They suggest these spurs were originally of tectonic origin, and were exhumed by erosional processes in the Quaternary. We found no published information about Quaternary fault scarps or evidence of displacement of Quaternary deposits that would demonstrate Quaternary movement along the inferred fault, thus, the Class C designation.

Date of compilation 04/10/96

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet Butte

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

Cherry Creek fault (Class C)

Structure Name Cherry Creek fault

Comments: The name of Cherry Creek fault was used by Andretta and Alsup (1960 #419); earlier use of name unknown. Refers to number 81 (Cherry Creek fault) of Johns and others (1982 #259).

Reason for Class fault may be as old as Precambrian, but certainly was an active Laramide thrust fault (Andretta and Alsup, 1960 #419; Feichtinger, 1970 #456). During the Oligocene, the sense of movement on this fault reversed to normal, down-to-the-northeast slip (Andretta and Alsup, 1960 #419; Feichtinger, 1970 #456). Feichtinger (1970 #456) indicates that this most recent episode of faulting extended into the Holocene ("Recent"), by citing the existence of scarps along part of the fault. The location of these scarps is not specified but the scarps are likely confined to the Tertiary Dunbar Creek Formation. Much of the discussion of young movement is closely tied to faulting history of the Elk Creek fault [694], along which Quaternary movement is indicated. No data specific to the Cherry Creek fault suggests that it has a similar Quaternary history. Furthermore, Carl (1970 #689) indicated that the Cherry Creek fault is truncated and displaced by the Gallatin Range fault [692], along which there is no evidence of late Quaternary movement.

Date of compilation 03/22/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Bozeman

Physiographic Province Northern Rocky Mountains

References

#419 Andretta, D.B., and Alsup, S.A., 1960, Geology and Cenozoic history of the Norris-Elk Creek area, southwest Montana, *in* Campau, D.E., and Anisgard, H.W., eds., West Yellowstone—Earthquake area: Billings Geological Society, 11th Annual Field Conference, September 7-10, 1960, Guidebook, p. 185-190.

#689 Carl, J.D., 1970, Block faulting and development of drainage, northern Madison Mountains, Montana: Geological Society of America Bulletin, v. 81, p. 2287-2298.

#456 Feichtinger, S.H., 1970, Geology of a portion of the Norris quadrangle with emphasis on Tertiary sediments Madison and Gallatin Counties, Montana: Bozeman, Montana State University, unpublished M.S. thesis, 85 p., 2 pls.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

Clarkston fault (Class C)

Structure Name Clarkston fault

Comments: This inferred fault lies within the inner Clarkston valley, about 2 km east of Clarkston, Montana, as shown by Johns and others (1982 #259), fault number 108 in their compilation. Pardee (1927 #469) suggested that there is a probable fault about 6 km east of Clarkston; this may be the same fault shown by Johns and others (1982 #259).

Reason for Class designation According to Johns and others (1982 #259), about 15 m of Quaternary offset is associated with this apparently short (2.5-km-long) fault. Northwest-dipping strata (age unspecified) are sharply truncated along a straight, N.70°-80°W.-trending line (the Clarkston fault), the scarps are fresh appearing, and Quaternary alluvium has been downdropped. In addition, they state that this fault could be associated with the March 11, 1977 earthquake (Qamar and Hawley, 1979 #1071). However, bedrock mapping shows no displacement of Quaternary deposits in the vicinity of the Clarkston fault. We suspect that the dipping strata and movement on the fault are pre-Quaternary as supported by mapping by Pardee (1927 #469; 1950 #46) and Robinson (1967 #471), and that the scarps are the result of fluvial downcutting (terrace scarps) of the Missouri River.

Date of compilation 04/16/96

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Bozeman

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#469 Pardee, J.T., 1927, The Montana earthquake of June 27, 1925, *in* Shorter contributions to general geology 1926: U.S. Geological Survey Professional Paper 147, p. 7-23.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#1071 Qamar, A., and Hawley, B., 1979, Seismic activity near the Three Forks Basin, Montana: Bulletin of the Seismological Society of America, v. 69, p. 1917-1929.

#471 Robinson, G.D., 1967, Geologic map of the Toston quadrangle southwestern Montana: U.S. Geological Survey Geologic Investigations Map I-486, 2 sheets, scale 1:24,000.

Clarkston valley fault (Class C)

Structure Name Clarkston valley fault

Comments: This fault bounds the northeastern border of the Clarkston valley of the Missouri River between Trident and Lombard, Montana, and forms the northwestern margin of the Horseshoe Hills, according to Johns and others (1982 #259), and was included in their compilation as fault number 109.

Reason for Class designation Johns and others (1982 #259) included this fault in their compilation primarily on the basis of an association with the June 17, 1925 Clarkston earthquake. Pardee (1950 #46) reported ground cracks in the vicinity of the fault after the 1925 earthquake, but found no fault scarps indicating vertical or horizontal ground displacement. The ground cracks are the result of shaking, and may or may not have tectonic significance. Secondly, as support for movement on the Clarkston valley fault, Johns and others (1982 #259) cite the focal mechanism of Smith and Sbar (1974 #160), which showed right-lateral slip on a northeast-trending structure. Although these data are suggestive that the Clarkston valley fault may have been the structure on which the June 17, 1925 Clarkston earthquake occurred, it is not compelling evidence for Quaternary slip at the surface. There are no reports of demonstrable Quaternary scarps along the fault, although Johns and others (1982 #259) suggest about 100 m of late Cenozoic movement. We suspect that the dipping strata and movement on the fault are pre-Quaternary as supported by mapping by Pardee (1950 #46) and Robinson (1967 #471). Therefore, until further investigations show Quaternary displacement, we do not include the Clarkston valley fault as a Quaternary fault.

Date of compilation 04/15/96

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Bozeman, Butte

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#471 Robinson, G.D., 1967, Geologic map of the Toston quadrangle southwestern Montana: U.S. Geological Survey Geologic Investigations Map I-486, 2 sheets, scale 1:24,000.

#160 Smith, R.B., and Sbar, M.L., 1974, Contemporary tectonics and seismicity of the Western United States with emphasis on the Intermountain seismic belt: Geological Society of America Bulletin, v. 85, p. 1205-1218.

Cliff Lake-Elk Lake fault (Class C)

Structure Name Cliff Lake-Elk Lake fault

Comments: Name is from Johns and others (1982 #259); fault is number 40 in their compilation. Pardee (1950 #46) calls this the Cliff Lake fault.

Reason for Class designation Quaternary movement was inferred by Johns and others (1982 #259) based on as much as 70 m of offset on the Huckleberry Ridge Tuff (2 Ma) at northern end of the fault (Gary, 1980 #695). Demonstrable Quaternary (<1.6 Ma) movement is not known; thus, the Class C designation herein. No scarps have been reported; fault is indicated by alignment of deep valleys containing the West Fork and Madison Rivers (Pardee, 1950 #46). Pardee (1950 #46) suggests that faulting occurred during the middle or late Pleistocene because the valley would be filled with more detritus if activity on this fault was older.

Date of compilation 03/28/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison; Beaverhead

1° x 2° sheet Ashton

Physiographic Province Northern Rocky Mountains

References

#695 Gary, S.D., 1980, Quaternary geology and geophysics of the upper Madison Valley, Madison County, Montana: Missoula, University of Montana, unpublished M.S. thesis, 76 p., 2 plates.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

Culver Springs fault (Class C)

Structure Name Culver Springs fault

Comments: Fault may have first been named by Johns and others (1982 #259); fault is number 38 in their compilation.

Reason for Class designation Holocene movement was inferred by Johns and others (1982 #259) based on "moderately high seismicity" in this area shown by Smith and Lindh (1978 #694); much of the seismicity could be associated with this fault. Johns and others (1982 #259) suggest that the presence of a scarp on 2-Ma volcanics, but does not acknowledge scarps on younger deposits. Thus this fault is assigned a Class C designation herein because of the lack of geologic evidence to indicate Quaternary (<1.6 Ma) surface faulting.

Date of compilation 04/11/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Ashton

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#694 Smith, R.B., and Lindh, A.G., 1978, Fault-plane solutions of the Western United States—A compilation, *in* Smith, R.B., and Eaton, G.P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 107-109, 1 plate.

Dry Fork fault (Class C)

Structure Name Dry Fork fault

Comments: Source of name is Ostenaa and others (1990 #540). Mapped fault extends from about 1.5 km west of confluence of Mill and Bassoo Creeks southward to 2.4 km north of Garden Creek, but fault may extend a few kilometers farther to the south to include weak photolineament (Ostenaa and others, 1990 #540).

Reason for Class designation Fault was first documented by Ostenaa and others (1990 #540) based on photogeologic mapping and brief field reconnaissance. Origin of the scarps and lineaments was equivocal because of the level of detail study; Ostenaa and others (1990 #540) indicated that the fault could be Quaternary. Later, more extensive, field reconnaissance by Manley (1992 #1014) shows that the stratigraphic offset may be only a few hundred meters; the fault is not associated with a precipitous range front, and the expression of the fault may be entirely erosional. Several scenarios for faulting history were proposed by Manley (1992 #1014) and two of the three do not include Quaternary faulting. This fault is assigned Class C designation due to the lack of evidence for Quaternary surface faulting.

Date of compilation 02/26/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Sanders

1° x 2° sheet Wallace

Physiographic Province Northern Rocky Mountains

References

#1014 Manley, W.F., 1992, Seismotectonic studies on the Flathead Indian Reservation, Montana—Investigation of the Dry Fork fault: U.S. Bureau of Reclamation Seismotectonic Report 92-1, 57 p., 1 pl., scale 1:24,000.

#540 Ostenaa, D., Manley, W., Gilbert, J., LaForge, R., Wood, C., and Weisenberg, C.W., 1990, Flathead Reservation regional seismotectonic study—An evaluation for dam safety: U.S. Bureau of Reclamation Seismotectonic Report 90-8, 161 p., 7 pls.

English George Creek fault (Class C)

Structure Name English George Creek fault

Comments: Fault may have been named first by Johns and others (1982 #259); fault is number 54 in their compilation.

Reason for Class designation Johns and others (1982 #259) suggest Holocene movement, but they cite 60-70 m offset of Huckleberry Ridge Tuff (2 Ma) as the only evidence. No other evidence of Quaternary (<1.6 Ma) movement on the fault was documented. Scarps are not known, which is the basis that Stickney and Bartholomew (1987 #85; 1987 #242; written commun. 1992 #556) used to exclude this fault from their compilations. This fault is discussed in Shelden (1960 #478) as the northern (?) of the three Wall Canyon faults; the downthrown block has been buried by fluvial gravel that conceals any preexisting scarp. Shelden (1960 #478) does not show this fault extending as far to the northwest as Johns and others (1982 #259).

Date of compilation 04/11/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Bozeman

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#478 Shelden, A.W., 1960, Cenozoic faults and related geomorphic features in the Madison Valley, Montana, *in* Campau, D.E., and Anisgard, H.W., eds., West Yellowstone—Earthquake area: Billings Geological Society, 11th Annual Field Conference, September 7-10, 1960, p. 178-184.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

Gardiner fault (Class C)

Structure Name Gardiner fault

Comments: An early reference to this fault is Wilson (1934 #1054), who called it the Gardiner thrust fault, and named it for the nearby town of Gardiner, Montana. Later, this fault was described as a high-angle, northeast-dipping, reverse fault on the southwestern margin of the Beartooth uplift (Brown, 1961 #1056; Fraser and others, 1969 #467; Ruppel, 1972 #470); it may be continuous with the Spanish Peak fault zone to the northwest. Fault was included in compilation by Witkind (1975 #317) as fault number 28 (Gardiner fault) and in compilation by Johns and others (1982 #259) as fault number 61 (Gardiner fault).

Reason for Class designation This fault was included in the two earlier compilations of active faults in this part of the state (Witkind, 1975 #317; Johns and others, 1982 #259) based on the interpretations presented by Fraser and others (1969 #467), who reported scarps on Tertiary basalt and Pleistocene travertine near Gardiner, Montana. He further suggested that the Gardiner reverse fault was reactivated as a Quaternary normal fault. Pierce and others (1991 #1055) argue that apparent displacement of the two units can be explained by non-tectonic mechanisms. The basalt is actually two units of different age and that were emplaced at different topographic positions on either side of the fault; the scarps in travertine are the result of surficial slumping. In addition, Pierce and others (1991 #1055) point out that the argument of normal reactivation of a northeast-dipping thrust or reverse fault would result in northeast-facing scarps, not the southwest-facing scarps that exist in the travertine. Ruppel (1972 #470) states that the fault displaces Pleistocene glacial deposits down-to-the-north a few tens of feet near Grand Loop Road, at the southern end of the fault; however, this is not substantiated by recent work in the area. Recent investigation support early studies of this fault, which show that the Gardiner fault was buried at both ends by Tertiary volcanic rocks (Wilson, 1934 #1054) and the fault was probably last active during the Laramide orogeny (Pierce and others, 1991 #1055).

Date of compilation 03/14/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Park

1° x 2° sheet Bozeman

Physiographic Province Middle Rocky Mountains

References

#1056 Brown, C.W., 1961, Cenozoic stratigraphy and structural geology, northeast Yellowstone National Park, Wyoming and Montana: Geological Society of America Bulletin, v. 72, p. 1173-1194.

#467 Fraser, G.D., Waldrop, H.A., and Hyden, H.J., 1969, Geology of the Gardiner area, Park County, Montana: U.S. Geological Survey Bulletin 1277, 118 p., 1 pl., scale 1:24,000.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#1055 Pierce, K.L., Adams, K.D., and Sturchio, N.C., 1991, Geologic setting of the Corwin Springs Known Geothermal Resources Area-Mammoth Hot Springs Area in and adjacent to Yellowstone National Park, *in* Sorey, M.L., ed., Effects of potential geothermal development in the Corwin Springs Known Geothermal Resources Area, Montana, on the thermal features of Yellowstone National Park: U.S. Geological Survey Water-Resources Investigations Report 91-4052.

#470 Ruppel, E.T., 1972, Geology of pre-Tertiary rocks in the northern part of Yellowstone National Park, Wyoming: U.S. Geological Survey Professional Paper 729-A, 66 p., 1 pl., scale 1:62,500.

#1054 Wilson, C.W., 1934, Geology of the thrust fault near Gardiner, Montana: Journal of Geology, v. 42, p. 649-663.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

Hackett Creek fault (Class C)

Structure Name Hackett Creek fault

Comments: Fault may have been named first by Johns and others (1982 #259); fault is number 39 in their compilation.

Reason for Class designation Johns and others (1982 #259) infer Quaternary movement based on topographic differences between the southern part of the Gravelly Range and the Centennial Valley and inferred displacement of an unnamed upper Pliocene or lower Quaternary welded tuff. Quaternary (<1.6 Ma) movement has not been documented. No scarps are reported along the fault, and fault-controlled range-front morphology is poorly expressed. Schofield (1981 #314) shows a discontinuous fault in this area based on gravity data. Johns and others (1982 #259) indicate that some of their data comes from Witkind (1975 #296), but Witkind's map does not extend far enough north to include this fault. This fault is assigned Class C designation based on the absence of data supporting Quaternary surface faulting.

Date of compilation 04/11/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead

1° x 2° sheet Ashton

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#314 Schofield, J.D., 1981, Structure of the Centennial and Madison Valleys based on gravitational interpretation, *in* Tucker, T.E., ed. Guidebook to southwest Montana: Montana Geological Society, 1981 Field Conference and Symposium, p. 275-283.

#296 Witkind, I.J., 1975, Geology of a strip along the Centennial fault, southwestern Montana and adjacent Idaho: U.S. Geological Survey Miscellaneous Investigations Map I-890, 1 sheet, scale 1:62,500.

Hingeline Canal fault A (Class C)

Structure Name Hingeline Canal fault A

Comments: Source of name is Johns and others (1982 #259); fault is number 89 in their compilation.

Reason for Class designation Johns and others (1982 #259) indicate that scarps are absent and that the youngest faulted deposits are Miocene-Pliocene sedimentary rocks. They assign a Holocene age to this structure and the nearby Hingeline Canal faults B and C based on a M 4.4 earthquake south of Amsterdam. In the absence of any compelling evidence for Quaternary surface offset, we assign Class C designation to this feature.

Date of compilation 04/21/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Bozeman

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

Hingeline Canal fault B (Class C)

Structure Name Hingeline Canal fault B

Comments: Source of name is Johns and others (1982 #259); fault is number 90 in their compilation.

Reason for Class designation Johns and others (1982 #259) indicate that scarps are absent and that the youngest faulted deposits are Miocene-Pliocene sedimentary rocks. They assign a Holocene age to this structure and the nearby Hingeline Canal faults A and C based on a M 4.4 earthquake south of Amsterdam. In the absence of any compelling evidence for Quaternary surface offset, we assign Class C designation to this feature.

Date of compilation 04/21/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Bozeman

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

Hingeline Canal fault C (Class C)

Structure Name Hingeline Canal fault C

Comments: Source of name is Johns and others (1982 #259); fault is number 91 in their compilation.

Reason for Class designation Johns and others (1982 #259) indicate that scarps are absent and that the youngest faulted deposits are Miocene-Pliocene sedimentary rocks. They assign a Holocene age to this structure and the nearby Hingeline Canal faults A and B based on a M 4.4 earthquake south of Amsterdam. In the absence of any compelling evidence for Quaternary surface offset, we assign Class C designation to this feature.

Date of compilation 04/21/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Gallatin

1° x 2° sheet Bozeman

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

Horn Creek fault (Class C)

Structure Name Horn Creek fault

Comments: Fault may have first been named by Johns and others (1982 #259); refers to fault number 48 in their compilation.

Reason for Class designation Johns and others (1982 #259) infer Quaternary movement based on the presence of Huckleberry Ridge Tuff (2 Ma) at different elevations on either side of the fault. However, evidence presented does not support Quaternary (<1.6 Ma) movement. No scarps have been recognized, and fault is characterized only by a slight steepening of slopes.

Date of compilation 03/29/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Ashton

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

Horse Prairie fault zone (Class C)

Structure Name Horse Prairie fault zone

Comments: Possibly first described by Scholten (1981 #511; 1982 #531); shown by Ruppel (1982 #67) and Ostenaa and Wood (1990 #318). Faults traverse irregular topography from near Lemhi Pass in the Beaverhead Mountains eastward, along the southern side of Horse Prairie, and into the Red Rock Hills. Faults have not been shown in any previous compilation.

Reason for Class designation These subparallel east-striking faults are regarded herein as Class C features based on their omission from map of Pierce and Morgan (1992 #539). However, these faults were considered to be a potential seismic source (Ostenaa and Wood, 1990 #318), but they report there is no evidence for late Quaternary movement and indicate that west of Clark Canyon Reservoir the faults are buried by post-Beaverhead (lower Cenozoic) basin-fill deposits. In contrast, Scholten (1981 #511) reported that the faults are characterized by prominent scarps, abnormal drainage patterns, offset and tilting of pediments, gravel-filled pediment channels, and abrupt termination of spurs. However, there is no evidence presented in recent literature to support late Cenozoic and possibly Quaternary displacement suggested by Scholten (1981 #511) and Ruppel (1982 #67).

Date of compilation 04/16/97

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Beaverhead (Mont.); Lemhi (Id.)

1° x 2° sheet Dubois; Dillon

Physiographic Province Northern Rocky Mountains

References

#318 Ostenaa, D., and Wood, C., 1990, Seismotectonic study for Clark Canyon Dam, Pick-Sloan Missouri Basin Program, Montana: U.S. Bureau of Reclamation Seismotectonic Report 90-4, 78 p., 1 pl.

#539 Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1-53, 1 pl.

#67 Ruppel, E.T., 1982, Cenozoic block uplifts in east-central Idaho and southwest Montana: U.S. Geological Survey Professional Paper 1224, 24 p.

#511 Scholten, R., 1981, Horse Prairie fault in southwest Montana—Its role in sedimentation and tectogenesis: Geological Society of America Abstracts with Programs, v. 13, no. 4, p. 225.

#531 Scholten, R., 1982, Continental subduction in the northern U.S. Rockies—A model for back-arc thrusting in the western Cordillera, *in* Powers, R.B., ed., Geologic studies of the Cordilleran thrust belt, v. 1: Denver, Rocky Mountain Association of Geologists, p. 123-136.

Jordan Creek fault A (Class D)

Structure Name Jordan Creek fault A

Comments: Named and described in Johns and others (1982 #259); refers to fault number 58 in their compilation.

Reason for Class designation Johns and others (1982 #259) describe this fault, and the nearby Jordan Creek fault B, as offsetting alluvial-fan deposits and a late Pleistocene pediment. Thus, they infer the time of the most recent event as Holocene. A more recent structural study (Young, 1985 #690) and geologic mapping (1993 #565; Kellogg, 1993 #566) of this area do not indicate the presence of this fault. Thus, we assign Class D designation to this feature.

Date of compilation 03/24/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Bozeman

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#565 Kellogg, K.S., 1993, Geologic map of the Cherry Lake quadrangle, Madison County, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-1725, 1 sheet, scale 1:24,000.

#566 Kellogg, K.S., 1993, Geologic map of the Ennis Lake quadrangle, Madison County, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-1729, 1 sheet, scale 1:24,000.

#690 Young, S.L.-W., 1985, Structural history of the Jordan Creek area northern Madison Range, Madison County, Montana: Austin, University of Texas at Austin, unpublished M.S. thesis, 113 p., 2 pls.

Jordan Creek fault B (Class D)

Structure Name Jordan Creek fault B

Comments: Named and described in Johns and others (1982 #259); refers to fault number 59 in their compilation.

Reason for Class designation Johns and others (1982 #259) describe this fault, and the nearby Jordan Creek fault A, as offsetting alluvial-fan deposits and a late Pleistocene pediment. Thus, they infer the time of the most recent event as Holocene. A more recent structural study (Young, 1985 #690) and geologic mapping (1993 #565; Kellogg, 1993 #566) of this area do not indicate the presence of this fault. Thus, we assign Class D designation to this feature.

Date of compilation 03/24/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Bozeman

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#565 Kellogg, K.S., 1993, Geologic map of the Cherry Lake quadrangle, Madison County, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-1725, 1 sheet, scale 1:24,000.

#566 Kellogg, K.S., 1993, Geologic map of the Ennis Lake quadrangle, Madison County, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-1729, 1 sheet, scale 1:24,000.

#690 Young, S.L.-W., 1985, Structural history of the Jordan Creek area northern Madison Range, Madison County, Montana: Austin, University of Texas at Austin, unpublished M.S. thesis, 113 p., 2 pls.

Mammoth fault (Class C)

Structure Name Mammoth fault

Comments: Source of name may be Brown (1961 #1056), as Fraser and others (1969 #467) and Ruppel (1972 #470) attribute the name. But the location of the Mammoth fault on Brown's sketch map does not appear to coincide with that of later maps. Refers to fault number 29 (Mammoth fault) of Witkind (1975 #317; 1975 #819) and fault number 63 (Mammoth fault B) of Johns and others (1982 #259).

Reason for Class designation This fault was included in the earlier compilations of active faults (Witkind, 1975 #317; 1975 #819; Johns and others, 1982 #259). Inferred down-to-west (?) Holocene movement was based on displaced hot springs deposits (Ruppel, 1972 #470); Witkind (1975 #317; 1975 #819) shows the fault on his map as down-to-the-west but describes it as down to the northeast. Exposures are poor making definitive identification of the Mammoth fault difficult. Pierce and others (1991 #1055) state that the basal part of the Eocene volcanic sequence is not displaced between the northern part of the East Gallatin-Reese Creek fault system [746] and the northern extension of the Lava Creek reverse fault. From this relation they conclude that the Mammoth fault is older than Eocene or that it is east of the Eocene exposures. Because the Mammoth fault does not offset Quaternary deposits (Pierce and others, 1991 #1055), we assign Class C designation.

Date of compilation 03/27/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Park (Wyo.); Park (Mont.)

1° x 2° sheet Ashton; Bozeman

Physiographic Province Middle Rocky Mountains

References

#1056 Brown, C.W., 1961, Cenozoic stratigraphy and structural geology, northeast Yellowstone National Park, Wyoming and Montana: Geological Society of America Bulletin, v. 72, p. 1173-1194.

#467 Fraser, G.D., Waldrop, H.A., and Hyden, H.J., 1969, Geology of the Gardiner area, Park County, Montana: U.S. Geological Survey Bulletin 1277, 118 p., 1 pl., scale 1:24,000.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#1055 Pierce, K.L., Adams, K.D., and Sturchio, N.C., 1991, Geologic setting of the Corwin Springs Known Geothermal Resources Area-Mammoth Hot Springs Area in and adjacent to Yellowstone National Park, *in* Sorey, M.L., ed., Effects of potential geothermal development in the Corwin Springs Known Geothermal Resources Area, Montana, on the thermal features of Yellowstone National Park: U.S. Geological Survey Water-Resources Investigations Report 91-4052.

#470 Ruppel, E.T., 1972, Geology of pre-Tertiary rocks in the northern part of Yellowstone National Park, Wyoming: U.S. Geological Survey Professional Paper 729-A, 66 p., 1 pl., scale 1:62,500.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

#819 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in Wyoming: U.S. Geological Survey Open-File Report 75-279, 35 p. pamphlet, 1 sheet, scale 1:500,000.

Missouri Flats fault (Class D)

Structure Name Missouri Flats fault

Comments: Source of name is probably Johns and others (1982 #259); refers to fault number 50 in their compilation. Fault, as shown, is in Madison Valley, southwest of Earthquake Lake.

Reason for Class designation Although Johns and others (1982 #259) show this as a Holocene fault, more recent mapping with an emphasis on Quaternary faulting does not show a fault in this location (Lundstrom, 1986 #457). Thus the Missouri Flats fault is not included here and subsequently assigned Class D designation. Johns and others (1982 #259) indicate that fault may in fact be a fluvial terrace scarp.

Date of compilation 03/01/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Ashton

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#457 Lundstrom, S.C., 1986, Soil stratigraphy and scarp morphology studies applied to the Quaternary geology of the southern Madison Valley, Montana: Arcata, California, Humboldt State University, unpublished M.S. thesis, 53 p., 1 pl., scale 1:24,000.

Mol Heron Creek fault (Class C)

Structure Name Mol Heron Creek fault

Comments: Source of name may be Johns and others (1982 #259); refers to fault number 68 in their compilation. Ruppel (1972 #470) and Witkind (1975 #317; 1975 #819) refer to this structure as the West Gallatin fault (fault number 155 in his compilation). Fault bounds the western flank of the Gallatin Range.

Reason for Class designation The Mol Heron Creek fault is included in the compilation of Johns and others (1982 #259) as a Pleistocene structure even though documented movement occurred only between Eocene and late Pliocene time. No recent work indicates otherwise, we assign Class C designation in this compilation.

Date of compilation 03/28/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

State Wyoming; Montana

County and State (if other than Montana) Park (Wyo.); Park (Mont.)

1° x 2° sheet Ashton; Bozeman

Physiographic Province Middle Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#470 Ruppel, E.T., 1972, Geology of pre-Tertiary rocks in the northern part of Yellowstone National Park, Wyoming: U.S. Geological Survey Professional Paper 729-A, 66 p., 1 pl., scale 1:62,500.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

#819 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in Wyoming: U.S. Geological Survey Open-File Report 75-279, 35 p. pamphlet, 1 sheet, scale 1:500,000.

Moose Creek fault (Class C)

Structure Name Moose Creek fault

Comments: Fault may have first been named by Johns and others (1982 #259); refers to fault number 53 in their compilation.

Reason for Class designation Johns and others (1982 #259) inferred Holocene movement, but they cite 60-70 m offset of Huckleberry Ridge Tuff (2 Ma) as their only evidence. Because Quaternary (<1.6 Ma) movement is not documented, this feature is assigned Class C designation herein. Scarps are not known, which is the reason that Stickney and Bartholomew (1987 #85; 1987 #242; written commun. 1992 #556) excluded this fault from their compilations. This fault is discussed in Shelden (1960 #478) as the middle(?) of the three Wall Canyon faults; he mentions a veneer of gravel over the scarp on volcanic rocks but does not report that the gravels are faulted.

Date of compilation 04/11/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Ashton; Bozeman

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#478 Shelden, A.W., 1960, Cenozoic faults and related geomorphic features in the Madison Valley, Montana, *in* Campau, D.E., and Anisgard, H.W., eds., West Yellowstone—Earthquake area: Billings Geological Society, 11th Annual Field Conference, September 7-10, 1960, p. 178-184.

#85 Stickney, M.C., and Bartholomew, M.J., 1987, Seismicity and late Quaternary faulting of the northern Basin and Range province, Montana and Idaho: Bulletin of the Seismological Society of America, v. 77, p. 1602-1625.

#242 Stickney, M.C., and Bartholomew, M.J., 1987, Preliminary map of late Quaternary faults in western Montana: Montana Bureau of Mines and Geology Open-File Report 186, 1 pl., scale 1:500,000.

#556 Stickney, M.C., and Bartholomew, M.J., written commun. 1992, Preliminary map of late Quaternary faults in western Montana (digital data): Montana Bureau of Mines and Geology (digital unpublished version of MBMG Open-File Report 186), 1 pl., scale 1:500,000.

Muskrat Creek or Boulder Valley eastern border fault (Class C)

Structure Name Muskrat Creek or Boulder Valley eastern border fault

Comments: This inferred fault bounds the eastern border of the Boulder River valley, east and northeast of Boulder, Montana, according to Johns and others (1982 #259). They include this feature as fault number 30 in their compilation.

Reason for Class designation Johns and others (1982 #259) present no substantial evidence for Quaternary movement on this fault. We suspect that they included the fault in their compilation on the basis of structural considerations (eastern part of a valley-controlling graben) and as a northward extension of the Bull Mountain western border fault [690]. The Muskrat Creek fault is not shown on any other compilations of Quaternary faulting. Without evidence of demonstrable Quaternary movement, we assign Class C designation herein.

Date of compilation 04/10/96

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet Butte

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

North Meadow Creek fault (Class C)

Structure Name North Meadow Creek fault

Comments: This fault is part of the Spanish Peaks-Bismark fault system, thus various authors show preferential use of larger structure name. Various names used are Spanish Peaks fault (Schneider, 1985 #319; Bearzi, 1987 #455), Spanish Peaks/North Meadow Creek fault system (Locke and Schneider, 1990 #253), and Meadow Creek fault (Schneider, 1985 #319; 1990 #254). Refers to number 5 (Bismark-Spanish Peaks fault—North Meadow Creek segment) of Johns and others (1982 #259).

Reason for Class designation Montagne (1960 #688) and Schneider (1985 #319; 1990 #254), as well as others, speculate that down-to-south movement on this fault has deformed the long profile of and controlled the course of the Madison River. Faulting is inferred to be a possible causative agent in damming of Madison River north of Ennis Lake (Carl, 1970 #689), which was followed by spill over and the creation of the pervasive Cameron surface in Madison Valley (Schneider, 1985 #319; 1990 #254). The age of the Cameron surface is thought to be middle or late Pleistocene (Schneider, 1985 #319; 1990 #254). Bearzi (1987 #455) also speculates about Quaternary reactivation of this fault that may extend into the early Holocene and cites a nearby historical earthquake (M 4.5) as evidence to support young movement; however, he also notes that no fault scarps have been reported along this structure. Weinheimer (1979 #696) inferred 1000 m of movement on this fault since the deposition of the Huckleberry Ridge Tuff approximately 2 m.y. ago based on the dip of the unit. The only mapped feature that might be associated with this fault is shown by Young (1985 #690) and Garihan and others (1983 #686). Young (1985 #690) documents an exposure of the fault that defines the contact between Archean rocks and Cenozoic strata, but gives no evidence for Quaternary movement on the fault. This part of the fault is shown as dashed by Kellogg (1993 #566). There is no surficial evidence of faulting anywhere else along this fault, and in the absence of demonstrable Quaternary movement, this fault is assigned Class C designation herein.

Date of compilation 03/16/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Bozeman

Physiographic Province Northern Rocky Mountains

References

#455 Bearzi, J.P., 1987, Soil development, morphometry, and scarp morphology of fluvial terraces at Jack Creek, southwestern Montana: Bozeman, Montana State University, unpublished M.S. thesis, 131 p.

#689 Carl, J.D., 1970, Block faulting and development of drainage, northern Madison Mountains, Montana: Geological Society of America Bulletin, v. 81, p. 2287-2298.

#686 Garihan, J.M., Schmidt, C.J., Young, S.W., and Williams, M.A., 1983, Geology and recurrent movement history of the Bismark-Spanish Peaks-Gardiner fault system, southwest Montana, *in* Lowell, J.D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colorado, Rocky Mountain Association of Geologists, p. 295-314.

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#566 Kellogg, K.S., 1993, Geologic map of the Ennis Lake quadrangle, Madison County, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-1729, 1 sheet, scale 1:24,000.

#253 Locke, W.W., and Schneider, N.P., 1990, General geology and geomorphology of the Madison Range and Valley, southwest Montana, *in* Hall, R.D., ed. Quaternary geology of the western Madison Range, Madison Valley, Tobacco Root range, and Jefferson valley: Rocky Mountain Cell, Friends of the Pleistocene, August 15-19, 1990, Guidebook, p. 1-23.

#688 Montagne, J., 1960, Geomorphic problems in the Madison Valley, Madison County, Montana—An introduction and synthesis, *in* Campau, D.E., and Anisgard, H.W., eds., West Yellowstone—Earthquake area: Billings Geological Society, 11th Annual Field Conference, September 7-10, 1960, Guidebook, p. 165-169.
#319 Schneider, N.P., 1985, Morphology of the Madison Range fault scarp, southwest Montana—Implications for fault history and segmentation: Oxford, Ohio, Miami University, unpublished M.S. thesis, 131 p.
#254 Schneider, N.P., 1990, Terrace geomorphology of the central Madison Valley, *in* Hall, R.D., ed. Quaternary geology of the western Madison Range, Madison Valley, Tobacco Root range, and Jefferson valley: Rocky Mountain Cell, Friends of the Pleistocene, August 15-19, 1990, Guidebook, p. 24-57.
#696 Weinheimer, G.J., 1979, The geology and geothermal potential of the upper Madison Valley between Wolf Creek and the Missouri Flats, Madison County, Montana: Bozeman, Montana State University, unpublished M.S. thesis, 108 p., 1 plate.
#690 Young, S.L.-W., 1985, Structural history of the Jordan Creek area northern Madison Range, Madison County, Montana: Austin, University of Texas at Austin, unpublished M.S. thesis, 113 p., 2 pls.

Rainy Creek fault (Class D)

Structure Name Rainy Creek fault

Comments: Refers to fault number 192 (Rainy Creek fault) of Witkind (1975 #317).

Reason for Class designation The Rainy Creek fault is inferred to be a high-angle, down-to-the-northeast normal fault east of Libby, Montana. The fault's existence was based on interpreted surface faulting resulting from an earthquake on July 2, 1964 (Johns, 1970 #896); the fault as depicted by Johns (1970 #896) as being entirely in Precambrian bedrock. The U.S. Army Corps of Engineers (1978 #1028) later investigated the surface rupture and determined "the scarp did not originate from and earthquake, and was most probably related to impoundment of ground water in loosely compacted tailings and drift. Moreover, detailed mapping does not support the existence of the Rainy Creek fault." Thus, this feature is assigned a Class D designation herein.

Date of compilation 02/29/96

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Lincoln

1° x 2° sheet Kalispell

Physiographic Province Northern Rocky Mountains

References

#896 Johns, W.M., 1970, Geology and mineral deposits of Lincoln and Flathead Counties, Montana: Montana Bureau of Mines and Geology Bulletin 79, 182 p., 3 pls., scale approx. 1:125,000.

#1028 U.S. Army Corps of Engineers, 1978, Libby additional units and reregulating dam—Design memorandum 7: U.S. Army Corps of Engineers, Seattle District, v. 3.

#317 Witkind, I.J., 1975, Preliminary map showing known and suspected active faults in western Montana: U.S. Geological Survey Open-File Report 75-285, 36 p. pamphlet, 1 sheet, scale 1:500,000.

St. Joseph Gulch fault (Class C)

Structure Name St. Joseph Gulch fault

Comments: Fault may have first been named by Johns and others (1982 #259); refers to fault number 19 in their compilation.

Reason for Class designation Johns and others (1982 #259) infer Pleistocene movement based on inferred contemporaneous movement with the Bull Mountain western border fault [690]. Quaternary (<1.6 Ma) movement is not documented, and no scarps have been recognized. This feature is assigned Class C designation in this compilation based on the absence of compelling evidence.

Date of compilation 06/02/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet Dillon

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

State Capitol fault (Class C)

Structure Name State Capitol fault

Comments: This fault lies along the southern margin of the Helena valley, between Interstate Highway 15 and Fort Harrison as shown by Johns and others (1982 #259); refers to fault number 111 in their compilation.

Reason for Class designation The only evidence Johns and others (1982 #259) presented to support this fault is the presence of truncated spurs. These spurs may have originally been of tectonic origin, but their age is undocumented. Johns and others (1982 #259) indicate that middle Quaternary deposits are not displaced along the inferred trace of the fault, and conclude that the spurs may reflect early(?) Pleistocene movement. Although Johns and others (1982 #259) cite Stickney and Bingler (1981 #559) as a source, the fault is not shown on the later published map of Quaternary geology of the Helena valley, Montana (Stickney, 1987 #251) Thus, we conclude that Quaternary deposits are not demonstrably offset by the State Capitol fault and therefore the Class C designation herein.

Date of compilation 04/16/96

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet White Sulfur Springs, Butte

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#251 Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology Geologic Map 46, 1 pl., scale 1:50,000.

#559 Stickney, M.C., and Bingler, E.C., 1981, Earthquake-hazard evaluation of the Helena valley area, Montana: Montana Bureau of Mines and Geology Open-File Report 83, 30 p., 1 pl., scale 1:24,000.

Upper Sixmile Creek faults (Class C)

Structure Name Upper Sixmile Creek faults

Comments: This fault bounds the southwestern margin of the southern Big Belt Mountains from near Deep Creek on the north to Sixteenmile Creek on the south as shown by Johns and others (1982 #259), refers to fault number 112 in their compilation.

Reason for Class designation The Upper Sixmile Creek faults form resistant faceted spurs on Miocene fanglomerates. Pardee (1950 #46) estimated 150-300 m of post-Miocene offset from the height of the spurs and thickness of Miocene lacustrine deposits on the downthrown (western) side of the faults. Johns and others (1982 #259) suggested that all of this offset is of Quaternary age, and inferred that the fault was active in the late Pleistocene or Holocene on the basis of fresh-looking fault scarps on the northern part of the fault. However, there is no published information about actual offset of Quaternary deposits. Additionally, bedrock mapping by Robinson (1967 #471) does not indicate offset of post-Miocene deposits nor show continuous faulting along the east margin of the valley. Thus, until there is evidence of demonstrable Quaternary movement on the Upper Sixmile Creek faults, we assign Class C designation herein.

Date of compilation 04/16/96

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet White Sulfur Springs

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#46 Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.

#471 Robinson, G.D., 1967, Geologic map of the Toston quadrangle southwestern Montana: U.S. Geological Survey Geologic Investigations Map I-486, 2 sheets, scale 1:24,000.

Wade Lake Bench fault (Class C)

Structure Name Wade Lake Bench fault

Comments: Fault may have first been named by Johns and others (1982 #259); refers to fault number 49 in their compilation.

Reason for Class designation Johns and others (1982 #259) inferred Quaternary movement based on the presence of Huckleberry Ridge Tuff (2 Ma) at different elevations on either side of the fault. Quaternary (<1.6 Ma) movement is not documented; thus, Class C designation herein. No scarps are known and a uniform, gentle slope characterizes the east flank of Wade Lake Bench from its crest to the trace of the inferred fault.

Date of compilation 03/28/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Ashton

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

Wall Canyon fault (Class C)

Structure Name Wall Canyon fault

Comments: Fault may have first been named by Shelden (1960 #478), who shows the fault as extending from about 1 km south of Morgan Gulch southeastward, across the Madison River, to beyond Papoose Creek. Refers to number 52 (Wall Canyon fault) of Johns and others (1982 #259).

Reason for Class designation Johns and others (1982 #259) inferred Quaternary movement based on approximately 60m offset of Huckleberry Ridge Tuff (2 Ma). However, Quaternary (<1.6 Ma) movement is not documented; thus the Class C designation herein. The only recognized scarp is on rhyolite and welded tuff near the Madison River (Shelden, 1960 #478); the rest of the fault is characterized by an abrupt change in slope along the range front. Shelden (1960 #478) reports that the fault is exposed in Wall Canyon.

Date of compilation 03/29/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Madison

1° x 2° sheet Ashton; Bozeman

Physiographic Province Northern Rocky Mountains

References

#259 Johns, W.M., Straw, W.T., Bergantino, R.N., Dresser, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30' west longitude: Montana Bureau of Mines and Geology Open-File Report 91, 79 p., 2 sheets.

#478 Shelden, A.W., 1960, Cenozoic faults and related geomorphic features in the Madison Valley, Montana, *in* Campau, D.E., and Anisgard, H.W., eds., West Yellowstone—Earthquake area: Billings Geological Society, 11th Annual Field Conference, September 7-10, 1960, p. 178-184.

Whitetail Reservoir fault (Class D)

Structure Name Whitetail Reservoir fault

Comments: Source of name is Johns and others (1982 #259); refers to fault number 22 in their compilation.

Reason for Class designation Johns and others (1982 #259) speculate that the evidence of Quaternary movement is a series of aligned, small swampy parks. The only reference they cite is Smedes and others (1962 #763); however, they do not show a fault with similar length, orientation, and location as Johns and others. A more recent geologic map of Ruppel and others (1993 #646) likewise shows no fault at this location. Thus, we exclude this feature from our compilation. Due to lack of demonstrable evidence of the existence of this feature; we assign Class D designation herein.

Date of compilation 06/02/94

Compiler and affiliation Kathleen M. Haller, U.S. Geological Survey

County and State (if other than Montana) Jefferson

1° x 2° sheet Dillon; Butte

Physiographic Province Northern Rocky Mountains

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Winston South fault (Class D)

Structure Name Winston South fault

Comments: This inferred fault lies west of Canyon Ferry Lake and 3 km south of Winston, Montana, as shown by Johns and others (1982 #259); refers to fault number 116 in their compilation.

Reason for Class designation According to Johns and others (1982 #259), the Winston South fault is characterized by two lineaments that bound the southern margin of a topographic low. They mention that the feature may possibly have formed by lateral corrosion (erosion) of Beaver Creek, and that additional evidence is necessary to confirm the existence of the fault. For this reason, we assign Class D designation herein.

Date of compilation 04/16/96

Compiler and affiliation Michael N. Machette, U.S. Geological Survey

County and State (if other than Montana) Broadwater

1° x 2° sheet White Sulfur Springs

Physiographic Province Northern Rocky Mountains

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