Geologic Map of the Clarkston Valley
Broadwater and Gallatin Counties
West-Central Montana

Compiled and mapped by Susan M. Vuke
with a section on seismicity by Michael C. Stickney

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DESCRIPTION OF MAP UNITS

Qal **Alluvium (Holocene)**—Gravel, sand, silt, and clay in modern stream valleys and the Missouri River Valley. Clasts generally cobble size and smaller, but Missouri River alluvium contains boulders.

Qls **Landslide deposit (Holocene)**—Small mass-wasting deposit north of the mouth of Pole Gulch that consists of Tertiary deposits that have moved downslope.

Qac **Alluvium and colluvium (Holocene)**—Argillaceous silt and sand with lenses of coarser-grained sediment, generally pebble size or smaller. Thickness generally less than 3 m (10 ft).

Qc **Colluvium (Holocene and Pleistocene?)**—Angular to subrounded clasts, boulder size and smaller, derived from adjacent rock. Includes talus, and sheetwash deposits.

Qaf **Alluvial-fan deposit (Holocene and Pleistocene?)**—Gravel, sand, silt, and clay in deposits with fan-shaped morphology along Missouri River Valley and some streams in the Missouri River drainage.

Qs **Sediment, undivided (Holocene and Pleistocene)**—Tuffaceous and argillaceous silt and fine-grained sand with coarser sand in shallow drainages.

Qm **Mantle (Holocene and Pleistocene)**—Deposits on pediments which include regolith and lag deposits as large as boulder size derived from underlying Tertiary deposits, and subordinate water-transported deposits and colluvium. Unit includes extensive eolian deposits that overlie coarser-grained deposits. Thickness generally less than 6 m (30 ft), including eolian deposits.

Qat **Alluvial terrace deposit (Holocene and Pleistocene)**—Gravel, sand, silt, and clay on benches above the Missouri River. Clasts generally rounded to subrounded, cobble size and smaller. Barbed line symbol indicates subdued fluvial scarps primarily mapped from satellite imagery.

Qalo **Alluvium, older (Pleistocene?)**—Alluvium of the Missouri River at elevations higher than that of the modern Missouri River. Mapped primarily from satellite imagery where meander scars are higher than the modern Missouri River floodplain.

Qafo **Alluvial-fan deposit, older (Pleistocene?)**— Gravel, sand, silt, and clay in deposits with fan-shaped morphology that have been truncated by fluvial erosion along Missouri River Valley.

Ts **Sediment and sedimentary rock, undivided (Tertiary)**—Deposits not identified as Sixmile Creek, Dunbar Creek, or Climbing Arrow Formations.

Tba **Basalt (Tertiary)**—Peperitic olivine basalt in two small exposures along Big Davis Creek and east of Lombard.

Tsc **Sixmile Creek Formation (Miocene)**

Alluvial fan facies. Brownish gray and brownish yellow breccia or unconsolidated deposit with clast-supported or matrix-supported fine to coarse, angular clasts that include dominantly Greyson, Newland, and Spokane Formation clasts, and Paleozoic quartzite and limestone. Paleozoic clasts as large as boulder size. Coarse- and fine-grained beds locally alternate. Cementation is variable, producing irregular surfaces.

Fluvial facies. May represent trunk drainage system of ancestral Missouri River, and tributary drainage of ancestral Sixteenmile Creek. Clast-supported and matrix-supported rounded cobble or pebble gravel or conglomerate, and gray sandy, matrix. See explanation for patterns that represent the fluvial facies.

Exposed thickness of Sixmile Creek Formation more than 305 m (1,000 ft).

Trdc **Dunbar Creek Member of Renova Formation (Eocene? and Oligocene)**—Very light gray, grayish orange, reddish tan, and yellowish gray tuffaceous, locally slightly bentonitic siltstone and mudstone and subordinate yellowish gray, calcareous fine-grained sandstone with colors lighter to the south. Locally contains angular, floating clasts of tuffaceous siltstone. Gray limestone in upper part of member in Roy Gulch (previously mapped as Devonian Jefferson Formation; Robinson, 1967) contains burrows or root casts. Angular unconformity apparent between the Dunbar Creek Member and overlying Sixmile Creek Formation in Roy Gulch near Clarkston Valley Fault. Exposed thickness about 90 m (300 ft).

Tca **Climbing Arrow Member of Renova Formation (Eocene)**—Greenish gray, bentonitic mudstone with coarse-grained, irregularly cemented brown sandstone and conglomerate. Brown organic-rich shale in lower part and red or reddish orange mudstone in upper part. Secondary selenite abundant on some surfaces. Exposed in northeast part of valley south of Sixteen Mile Creek. Exposed thickness about 60 m (200 ft).

Kdia **Diabase (Late Cretaceous)**—Highly altered, porphyritic augite diabase sills intruded into Cretaceous sedimentary rocks (Sayers, 1962).

Kqm **Quartz monzonite (Late Cretaceous**)—Includes related medium- to coarse-grained calc-alkalic intrusive rocks. Exposed thickness 50 m (160 ft).

Kcot **Cody through Thermopolis Formations, undivided (Upper and Lower Cretaceous)**—May include Cody, Frontier, Mowry, Muddy, and Thermopolis Formations, but poor exposures did not allow formations to be mapped separately. A conglomerate 0.3-2 m (1-7 ft) thick of extremely well rounded chert pebbles in a matrix of coarse-grained quartz-feldspar sandstone serves as a marker bed in the middle of the unit. A sequence of poorly exposed shale, siltstone, and sandstone with minor interbeds of granule/pebble conglomerate overlies the conglomerate marker bed. An abundantly fossiliferous shale zone, about 30 feet thick, occurs approximately 23 m (75 feet) above the conglomerate.

The conglomerate marker bed is underlain by a sequence of gray to olive gray, limonite-stained, blocky to fissile, micaceous shale and claystone, interbedded with a few thin, dense, dark gray, argillaceous limestone beds and many laminated to thick-bedded, greenish gray siltstones and sandstones. Most sandstones in the lower part contain black chert and lithic grains and may be crossbedded, glauconitic, and bioturbated. Bentonitic mudstone beds increase in abundance upward. Basal sandstone is tan to medium gray, fine- to medium-grained and quartzose, with thin interbeds of siltstone. Trace fossils abundant on bedding surfaces of basal sandstone. (Verrall, 1955; Dyman and others, 1995). Thickness about 915 m (3000 ft).

Kk **Kootenai Formation (Lower Cretaceous**)—Coal and gastropod limestone near top, underlain by variegated mudstone and shale, orange siltstone, and quartz- and chert-rich sandstone beds. Basal light brown to yellowish gray quartz- and chert-rich, crossbedded, conglomeratic sandstone or conglomerate. Thickness 244-304 m (800-1000 ft).

KJme **Morrison Formation and Ellis Group (Jurassic)**

KJm **Morrison Formation (Jurassic)**—Dark gray or black coal or lignitic shale at top, underlain by red, yellow, green, and brown mudstone, and yellowish brown to grayish orange siltstone, very fine grained sandstone, and thin gray limestone beds. Thickness 30-90 m (100-300 ft).

Je **Ellis Group (Jurassic)**

Swift Formation—Grayish orange to brown coarse-grained, calcareous, limonitic or glauconitic, crossbedded, quartz sandstone which is locally conglomeratic and fossiliferous.

Rierdon Formation—Light gray, oölitic, fossiliferous limestone, and calcareous shale.

Sawtooth Formation—Yellowish brown siltstone, fossiliferous mudstone, and subordinate thin-bedded, gray fossiliferous limestone. Basal gray to dark brown conglomerate or conglomeratic quartz- and chert-rich sandstone.

Thickness of Ellis Group 0-30 m (0-100 ft).

Pp **Phosphoria Formation (Permian)**—Various lithologies that commonly include brown, light gray, or pinkish gray, laminated chert, dark gray, medium- to coarse-grained oölitic, phosphatic sandstone, gray dolomitic limestone, and light-colored quartzitic sandstone.

IPq **Quadrant Formation (Pennsylvanian)**—Light gray, pinkish gray, and yellowish gray medium- to thick-bedded, medium- to fine-grained, well-sorted quartz sandstone with rounded clasts, cemented by quartz overgrowths. Very light gray limestone in lowermost and uppermost parts, interbedded with quartz sandstone. Thickness 30-120 m (100-400 ft).

PMsr **Snowcrest Range Group (Pennsylvanian and Mississippian)**—Includes Conover Ranch, Lombard, and Kibbey Formations.

PMcr **Conover Ranch Formation (Pennsylvanian and Mississippian)**—Red sandstone and mudstone that grade upward into pink and gray limestone and quartzitic sandstone. Equivalent to the Amsden Formation. Thickness 60-120 m (200-400 ft).

Mlk **Lombard and Kibbey Formations (Mississippian)**

Lombard Formation—Dark gray limestone, brown and gray siltstone, and dark gray or grayish green shale. Originally designated Lombard facies of Big Snowy Group after Lombard station in the northern part of the map area (Blake, 1959). Thickness 100 m (325 ft).

Kibbey Formation—Clean, light gray sandstone interbedded with red shale. Thickness 53 m (175 ft).

Mmc **Mission Canyon Formation (Mississippian)**—Gray, thick-bedded, resistant, locally fossiliferous limestone with abundant black or pale yellowish brown chert nodules. Thickness 230-460 m (800-1,500 ft).

Ml **Lodgepole Formation (Mississippian)**—Dark gray, thin-bedded, microcrystalline limestone with yellowish brown and grayish orange, thin partings and interbeds of calcareous mudstone. Thickness 90-215 m (300-700 ft).

MDt **Three Forks Formation (Mississippian and Devonian)**

Sappington Member—Yellowish orange and yellowish gray, thin- to thick-bedded, flaggy siltstone and fine-grained sandstone.

Trident Member—Greenish gray, light olive gray, and yellowish gray calcareous to slightly calcareous, fossiliferous clay shale.

Lower member—Orange calcareous mudstone and yellowish gray argillaceous limestone. Thickness of formation 30-120 m (100-400 ft).

Dj **Jefferson Formation (Devonian)**

Birdbear Member—Brownish gray to medium gray, very finely crystalline to microcrystalline, sucrosic dolomite.

Lower member—Medium dark gray, finely crystalline, fetid dolomite and limestone. Thickness 120-215 m (400-700 ft).

D€s **Maywood and Snowy Range Formations**

Maywood Formation (Mississippian and Devonian)—Upper gray limestone that grades downward into yellow to red calcareous siltstone. Thickness 15-60 m (50-200 ft).

Snowy Range Formation (Cambrian)—Green shale, red limestone conglomerate, banded gray and orange dolomite, orange siltstone. Thickness 15 m (50 ft).

Ꞓpi **Pilgrim Formation (Cambrian)**—Light gray or bluish gray limestone and dolomite, typically with yellowish orange mottles. May be sandy or sucrosic; may contain intraformational flat-pebble conglomerate or lenses of dark gray limestone or dolomite that are glauconitic, oölitic, and/or fossiliferous; weathers hackly. Thickness 120-150 m (400-500 ft).

Ꞓp **Park Formation (Cambrian)**—Grayish green fissile, micaceous shale and silty shale. Thickness 30-75 m (300-450 ft).

Ꞓm **Meagher Formation (Cambrian)**—Gray limestone with yellowish orange mottles, weathers hackly. Dominantly thick-bedded. Thickness 75-150 m (200-500 ft).

Ꞓw **Wolsey Formation (Cambrian)**—Grayish green, olive, and brown micaceous shale with trace fossils, interbedded with glauconitic sandstone near base, and limestone near top. Thickness 90-135 m (300-450 ft).

Ꞓf **Flathead Formation (Cambrian)**—Pinkish gray or light brownish gray feldspathic, quartzose sandstone. Thickness 0-45 m (0-150 ft).

Zgb **Gabbro (Neoproterozoic)**—Gabbro and diabase of Robinson (1967). Olive gray to olive black sills as much as 300 m (1,000 ft) thick in the Spokane Formation.

Ys **Spokane Formation (Mesoproterozoic)**—Reddish brown, grayish red, and dusky red, thinly bedded siltite and subordinate greenish gray argillite. Many surfaces display ripple marks. Exposed thickness about 150 m (500 ft).

Yg **Greyson Formation (Mesoproterozoic)**—Greenish gray and yellowish brown siltite and fine-grained quartzite. Subordinate gray, thick-bedded limestone. Coarse-grained brown arkose south of Garden Gulch (LaHood tongues from south). Thickness 245 m (8,000 ft).

Yn **Newland Formation (Mesoproterozoic)**—Gray limestone, yellowish brown calcareous siltite, and subordinate light brown, coarse-grained arkose (LaHood tongues from south). Exposed thickness 460 m (1,500 ft).

DISCUSSION

The Clarkston Valley was selected for geologic mapping because of its on-going, anomalously high background seismicity and the occurrence of Montana's second largest historic earthquake (Clarkston Earthquake, magnitude 6.6) which occurred on June 27, 1925 (Figure 1). The map area spans the upper Missouri River and includes the small community of Clarkston on the east side of the river (Figure 2). The Lombard, Roy Gulch, and northern parts of the Logan and Nixon Gulch 7.5' quadrangles in Broadwater and Gallatin Counties comprise the map area (Figure 3). Most of the bedrock geology in the Lombard and Roy Gulch quadrangles was compiled directly from Robinson (1967) but includes some stratigraphic nomenclature updates. Sayers (1962) and Verrall (1955) were sources of geologic map information for the northern Logan and Nixon Gulch 7.5' quadrangles.

Seismicity

by Michael C. Stickney

The 1925 Clarkston Earthquake was the first instrumentally recorded earthquake in western Montana (Hill and Bartholomew, 1999). The earthquake caused considerable damage within an area of 1,554 square kilometers (600 square miles) (Pardee, 1926). Fatalities were probably avoided because it occurred when office and public buildings, heavily damaged by the earthquake, were unoccupied (Pardee, 1926).

Pardee visited the epicentral area for 30 days in the summer of 1925, immediately following the Clarkston Earthquake, to investigate the earthquake's effects. He noted many seismic shaking effects in the map area, such as extensive rockfall and swells in the railroad tracks at Lombard (Figures 4 and 5); a large rock slide at Deer Park immediately northeast of the map area involving 30,580 cubic meters (40,000 cubic yards) of rock that blocked Sixteenmile Creek and caused a lake to form; cracked and shattered ground with overturned clods along Roy Gulch (Figure 6); and cracks in the alluvium along the Missouri River near Clarkston through which sand and water spouted for several hours. He also noted changes in many springs and wells in the area. However, he did not find evidence of a new fault scarp and concluded that "*no new fault displacement is manifest at the surface*" (Pardee, 1926, p. 22). Field work for the current map also did not reveal an historic or Holocene fault scarp or abundant young landslide deposits that could be attributed to the 1925 Clarkston Earthquake.

The epicenter location of the June 28, 1925 earthquake has been a matter of some discussion in seismological literature. This earthquake was felt over an area of 802,900 km^2 (310,000 mi^2) and produced maximum shaking of 9+ on the Rossi-Forel Intensity Scale (equivalent to intensity VIII on the Modified Mercalli Intensity Scale). Based on the distribution of shaking intensities, Pardee (1926) concluded that the earthquake was centered in the northern Clarkston Valley (46.08˚N, 111.33˚W) at unspecified depth ("*moderately deep, perhaps several miles*") along the Clarkston Fault. Byerly (1926) used P-wave arrival times from stations located at Victoria, British Columbia; Berkeley, California; and Pasadena, California, with epicentral distances ranging from 935 to 1479 km (935-919 mi) to calculate an epicenter at 46.40˚N, 111.24˚W (±0.8˚ latitude, ±0.10˚ longitude). This location places the epicenter over 30 km NNE of the Clarkston Valley, well north of the area of maximum shaking intensity.

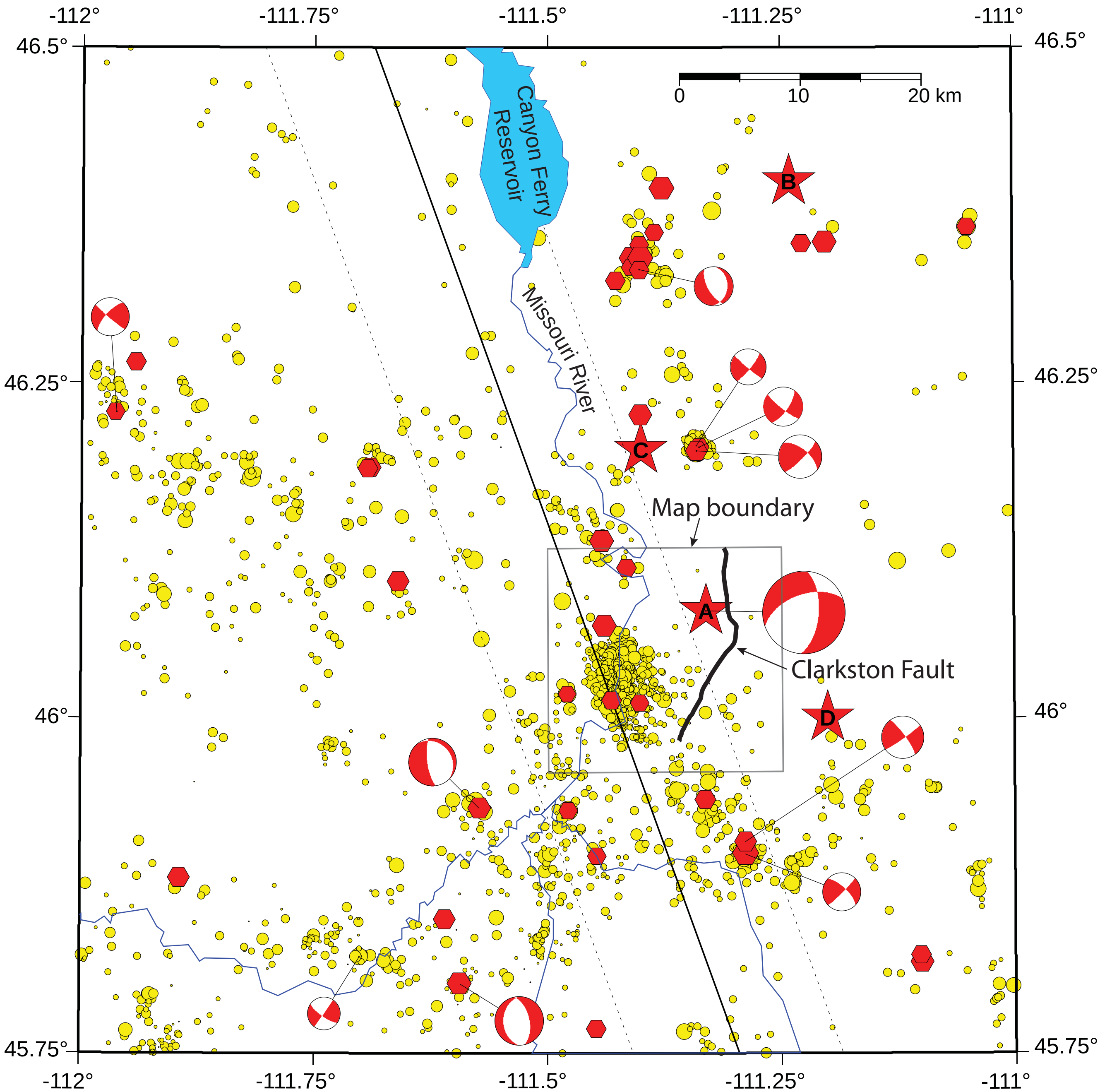


Figure 1. Clarkston Valley seismicity and focal mechanisms.
Labeled stars show: (A) 1925 Clarkston Valley epicenter locations reported by Pardee (1926) and focal mechanism from Doser (1989); (B) Byerlee (1926); (C) Dewey and others (1973); and (D) Coffman and others (1982). The NNW-SSE-trending solid line shows the loci of possible epicenters along with the uncertainty resulting from +/-0.5 second timing errors (dashed lines) reported by Qamar and Hawley (1979). Selected Montana regional seismograph network earthquake locations from August 1983 through June 2013 include 1,785 well-determined earthquake epicenters with magnitudes ranging from 0.0 to 2.9 and horizontal uncertainties less than 1 km (yellow circles), and 38 earthquakes with magnitudes ranging from 3.0 to 4.3 (red hexagons). Well-determined fault planes solutions ("beach balls") are shown for 11 earthquakes with magnitude ranging from 2.7 to 3.9 that occurred from 1986 to 2008. Source: Montana Bureau of Mines and Geology Earthquake Studies Office.

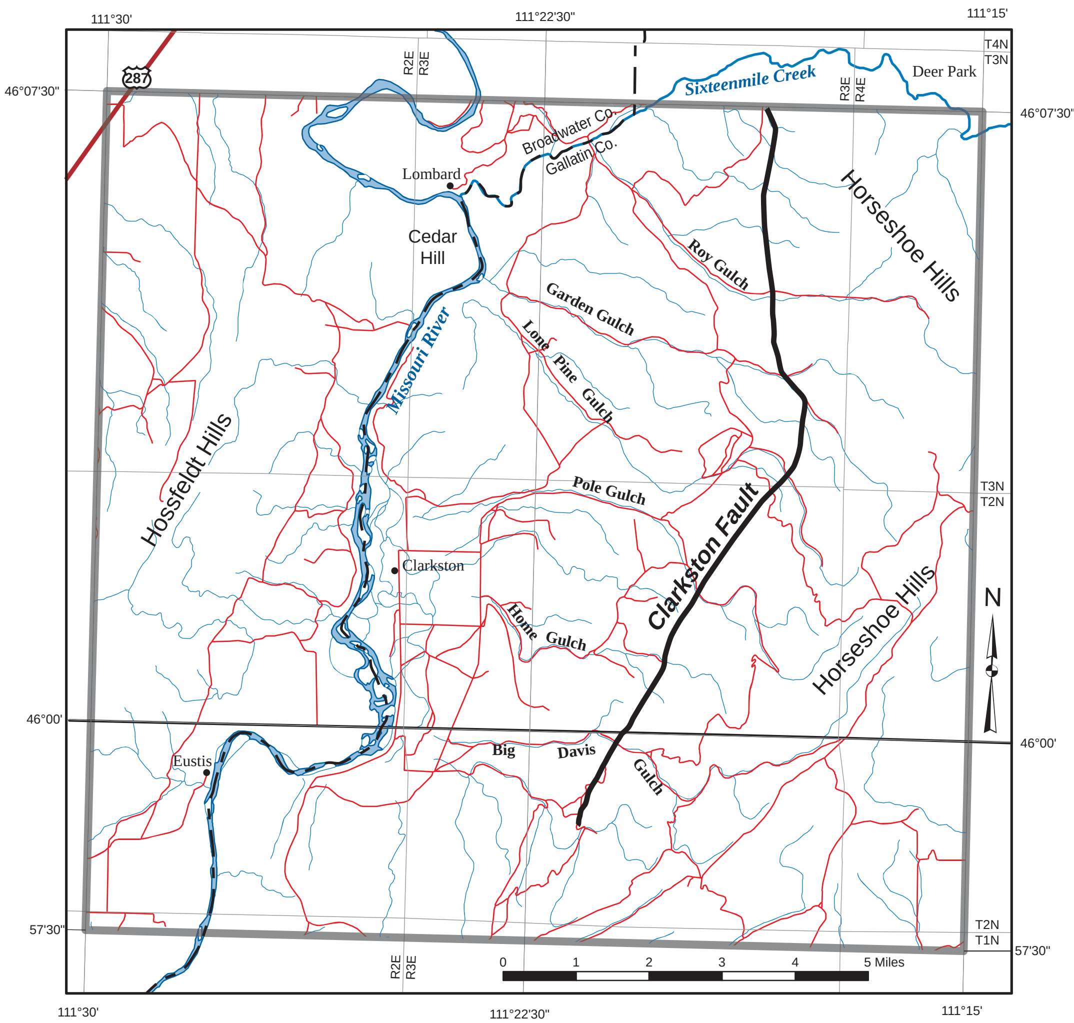
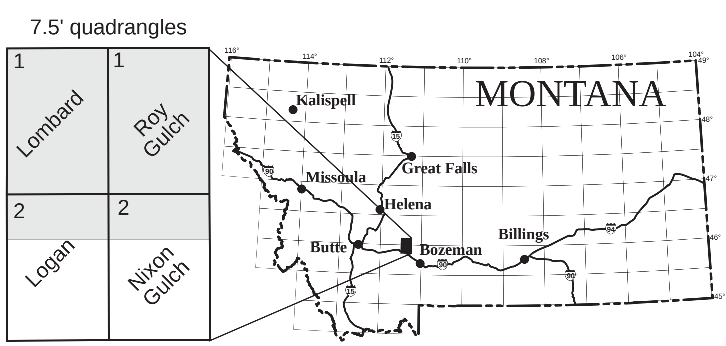


Figure 2. Clarkston Valley location map.



1. Most bedrock geology in Lombard and Roy Gulch 7.5' quadrangles compiled directly from Robinson (1967) with some stratigraphic nomenclature changes
2. Sources for northern Logan and Nixon Gulch 7.5' quadrangles: Sayers (1962) and Verrall (1955)

Figure 3. Index of 7.5' quadrangles and sources of geologic mapping.

Clarkston earthquake of June 27, 1925
Magnitude 6.6
Montana's second largest historic earthquake

Figure 4. Rocks on railroad track near Lombard, Montana. Photo by J.P. Swarts. Broadwater County, Montana. 1925.
Published in U.S. Geological Survey Professional Paper 147, Plate 8-B. 1927. USGS Library Image file: /htmlorg/lpb566/land/pjt01616.jpg

Figure 5. Broken railroad track near Lombard. Note rebound of the broken rail. Photo by J.P. Swarts. Broadwater County, Montana. 1925.
Published in U.S. Geological Survey Professional Paper 147, Plate 8-A. 1927. USGS Library Image file: /htmlorg/lpb566/land/pjt01615.jpg

Figure 6. Shattered ground and overturned clods, Roy Gulch; the upturned clods show white because of a deposit of caliche just beneath the soil. Gallatin County, Montana. Photo taken by J.T. Pardee, September 3, 1925. Approximate geographic coordinates determined in the field, 2011: N46.6.0055 W111.20.5109.
Plate 12-A in U.S. Geological Survey. Professional paper 147. 1927. USGS Library Image file: /htmlorg/lpb273/land/pjt00976.jpg

Subsequently, Dewey and others (1973) used Byerly's P-wave arrival times along with Herrin and others (1968) P-wave travel times to compute an epicenter at 46.2˚N, 111.4˚W, approximately 15 km (9 mi) north of the Clarkston Valley. In addition, Dewey and others (1973) used P-wave first motions and S-wave polarization angles recorded at teleseismic distances to determine a strike-slip focal mechanism with a SSE-oriented T axis. Smith and Sbar (1974) reinterpreted Byerly's (1926) P-wave first motion data and inferred that the 1925 earthquake resulted from right-lateral slip on a northeast-trending fault on the east side of the Clarkston Valley. Coffman and others (1982) reported an epicenter at 46.0˚N, 111.2˚W, about 12 km (7 mi) east of the Clarkston Valley. Qamar and Hawley (1979) used Pg-Pn travel time differences recorded at Spokane, Washington (Δ=490 km) and Saskatoon, Saskatchewan (Δ=720 km) to determine a hyperbolic distribution of points along which the epicenter must lie. This locus of possible epicenter locations touches the southern end of the Clarkston Valley and the uncertainty zone that allows for ±0.5 second seismogram timing errors encloses most of the Clarkston Valley, in agreement with Pardee's (1926) epicenter. The curve also closely approaches the epicenter of Dewey and others (1973). Doser (1989) used teleseismic waveform modeling and P-wave first motion analysis to determine source parameters for the 1925 earthquake. She determined a moment magnitude (M_w) of 6.6 but apparently held the epicenter to Pardee's (1926) coordinates. Doser's (1989) focal mechanism indicates either oblique normal faulting on a north-trending, east-dipping fault or on a northeast-striking, northwest-dipping fault with a southeast directed, nearly horizontal T axis.

The Clarkston Valley has been a persistent source of seismicity for the past 40 years (Stickney and Bartholomew, 1987; Stickney, 1997; Stickney, personal communication, 2013). Following a magnitude 4.8 earthquake in the Clarkston Valley on March 11, 1977, Qamar and Hawley (1979) installed a 5-station portable seismograph network in the Clarkston Valley area to record aftershocks. The resulting aftershock epicenters lie in the western Clarkston Valley on either side of the Missouri River, about 5-10 km (5-6 mi) southwest of Lombard in the vicinity of Clarkston (Qamar and Hawley, 1979). Focal mechanisms for the aftershocks indicate normal slip on north- or northwest–trending normal faults, in agreement with the solution for the 1977 main shock, a northerly trending normal fault. Since establishment of the Montana regional seismograph network in 1982, the Montana Bureau of Mines and Geology has determined hypocenter locations for more than 1200 earthquakes with magnitudes ranging from 0.0 to 3.8 in the Clarkston Valley (taken as 45.975°N to 46.095°N and 111.450°W to 111.325°W). Most of this recent seismicity occurs in the southern half of the Clarkston Valley east and west of the Missouri River. Scattered seismicity, which includes two magnitude 3.0 earthquakes, occurs in the northern part of the Clarkston Valley. Most hypocenter depths in the Clarkston Valley range from 5 to 14 km below the surface with an average depth of 8.7 km (Stickney 1997). However seismograph station configuration is such that hypocenter depths are in general not well resolved and the faults at depth along which this seismicity occurs is not revealed by hypocenter distributions. Three focal mechanisms—two located west of the Missouri River and one to the east—all indicate oblique normal faulting (Stickney 1997). All three mechanisms have a north-trending, west-dipping nodal plane. Focal mechanisms in the Clarkston Valley and immediately surrounding region indicate normal, strike-slip, or oblique-normal faulting. Extension directions inferred from these mechanisms range from NE to ESE with an average orientation of approximately N80°E (Stickney 1997).

Interpreted paleolandslides

Paleolandslides are tentatively interpreted along Roy, Garden, Pole, and Big Davis Gulches. Most appear to be rotational with subdued topographic expression of headwall scarps, and landslide masses with beds rotated toward the valley walls regardless of the dip of adjacent undisturbed beds. For the most part, landslide masses appear to have rotated coherently. Translational landslides are also interpreted on a dipslope of the Spokane Formation on the south side of Garden Gulch.

In addition, larger paleolandslide deposits are tentatively interpreted along the western edge of the Tertiary deposits, east of the Missouri River. North of the mouth of Big Davis Creek, and north of Clarkston, a distinctive arcuate topography has developed in Tertiary deposits. This topography contrasts with that developed in Tertiary deposits to the east. The arcuate topography may reflect the outline of several alternating headwall scarps and large landslide masses. Similar to most of the interpreted paleolandslide deposits along the gulches, beds in the upper parts of the interpreted paleolandslide deposits east of the Missouri River Valley dip toward their likely source in much of the area, and appear to have rotated as coherent masses. North of Clarkston, the dip of bedrock that underlies the Tertiary deposits does not appear to be affected, suggesting that the rupture surface of paleolandslide deposits was higher than the bedrock. The traces of the interpreted paleolandslide rupture surfaces are shown with blue lines on the map. They are probably Pleistocene or older based on topographic expression.

Ancestral Missouri River drainage

A Tertiary trunk fluvial system (rounded sand and gravel member of Robinson, 1967) is evident in the Sixmile Creek Formation east of and roughly parallel to the modern Missouri River in the Clarkston Valley. The presence of well-rounded cobbles of crystalline metamorphic rock suggests northward paleoflow that transported the clasts from the Archean or Paleoproterozoic metamorphic rocks in southwestern or south-central Montana, analogous to the present-day Missouri River. Subparallel proximity to the Missouri River suggests that this Tertiary fluvial system was a Missouri River precursor. To the north in the Toston and Townsend areas, two fluvial systems were recognized in the Sixmile Creek Formation, both of which also contain crystalline metamorphic clasts (Vuke, 2009; Vuke, 2011). The lower fluvial system is overlain by possible Hemingfordian, but probable Barstovian (middle Miocene) Tertiary deposits based on vertebrate fossils (Vuke, 2009; 2011). The younger fluvial system is likely Hemphillian (younger Miocene) based on associated vertebrate fossils (Vuke, 2009). Farther north in the Canyon Ferry Lake area, only the older fluvial deposits are exposed. The age of the system represented by the trunk fluvial deposits in the Clarkston Valley could not be determined. Although a mastodonoid fossil of questionable Pliocene age was found in the area of the fluvial deposits (Robinson, 1967), it likely came from overlying surficial deposits. Placement of the Pleistocene-Pliocene boundary has changed (Gibbard and others, 2009), making the fossil likely Pleistocene.

Other fluvial deposits extend in a discrete northeast-southwest band from northeast of the lower part of Roy Gulch to north of the mouth of Garden Gulch. They are interpreted as deposits of a tributary system to the main trunk system, perhaps a precursor to the present-day Sixteenmile Creek (Fig. 1). Unlike those of the trunk fluvial system, the tributary deposits do not contain crystalline metamorphic and other rocks from distant sources, but rather, clasts are locally derived from rocks in the Big Belt Mountains. Pebbles dominate the coarse fraction in tributary deposits whereas cobbles dominate the coarse fraction in the trunk fluvial deposits. Both fluvial deposits are shown with patterns on the map (see map explanation).

Cenozoic faults

The Clarkston Valley Fault (Fig. 1) is a significant down-to-the-west normal fault along the eastern margin of the Clarkston Valley that juxtaposes Sixmile Creek Formation and Proterozoic Belt rocks along much of its extent. This fault may have produced the 1925 Clarkston Earthquake as suggested by Pardee (1926), but no apparent Quaternary scarps were observed that would support this interpretation. The fault offsets Miocene deposits, but the youngest movement is not known.

Other Cenozoic faults occur in the Clarkston Valley west of the Clarkston Valley Fault. A fault was previously mapped (Robinson, 1967; Reynolds and Brandt, 2006) from Home Gulch to north of Pole Gulch along an island of Belt Supergroup and Paleozoic rocks that is surrounded by Tertiary deposits. The fault is inferred on the current map to extend northward continuing along the contact between Tertiary deposits and bedrock on the west side of the bedrock island.

A down-to-the-west fault is not likely along the west side of the Tertiary deposits east of the Missouri River. Well logs (Montana Bureau of Mines and Geology Groundwater Information Center database) indicate that bedrock is close to the surface west of the Tertiary deposits.

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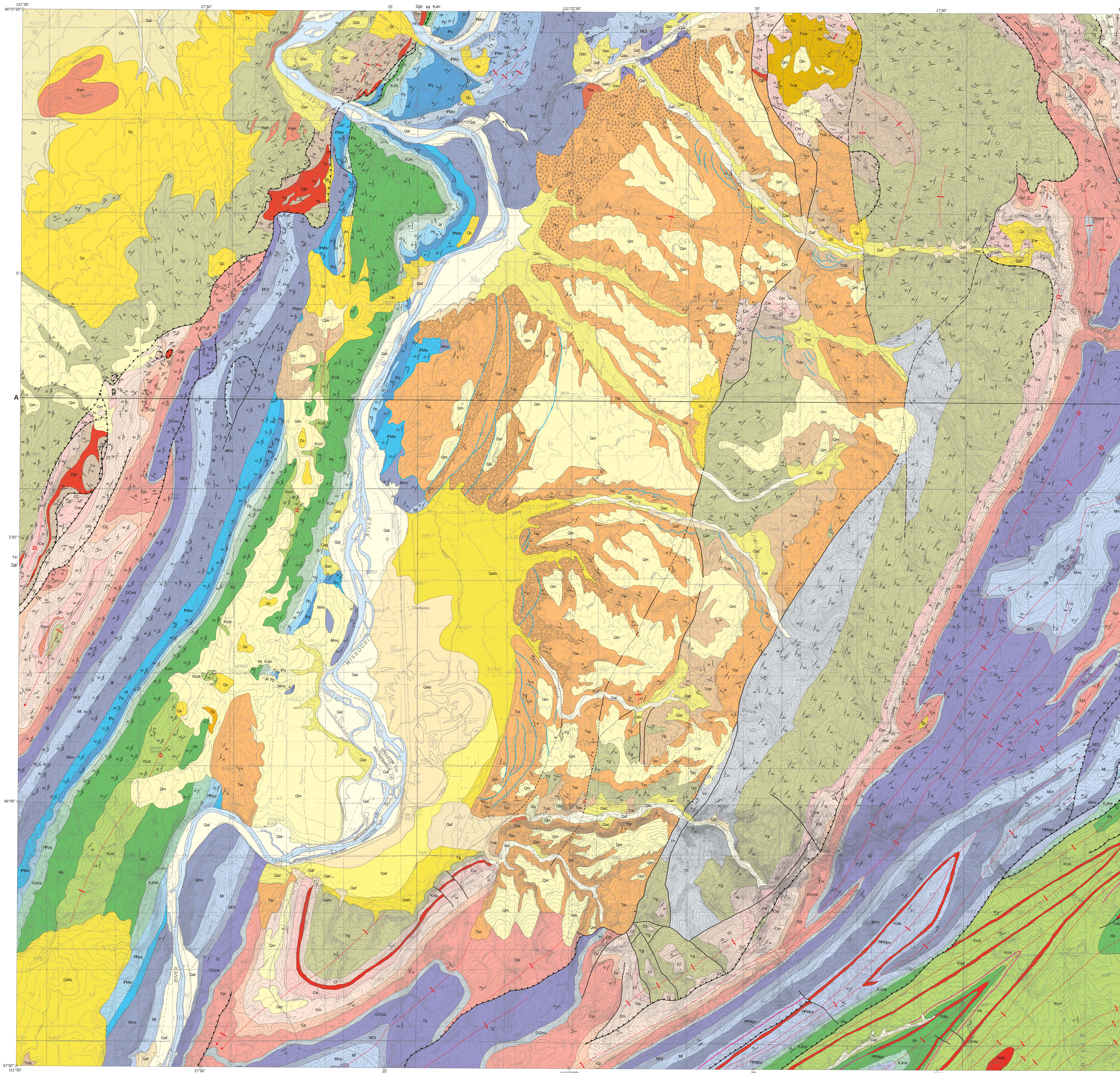
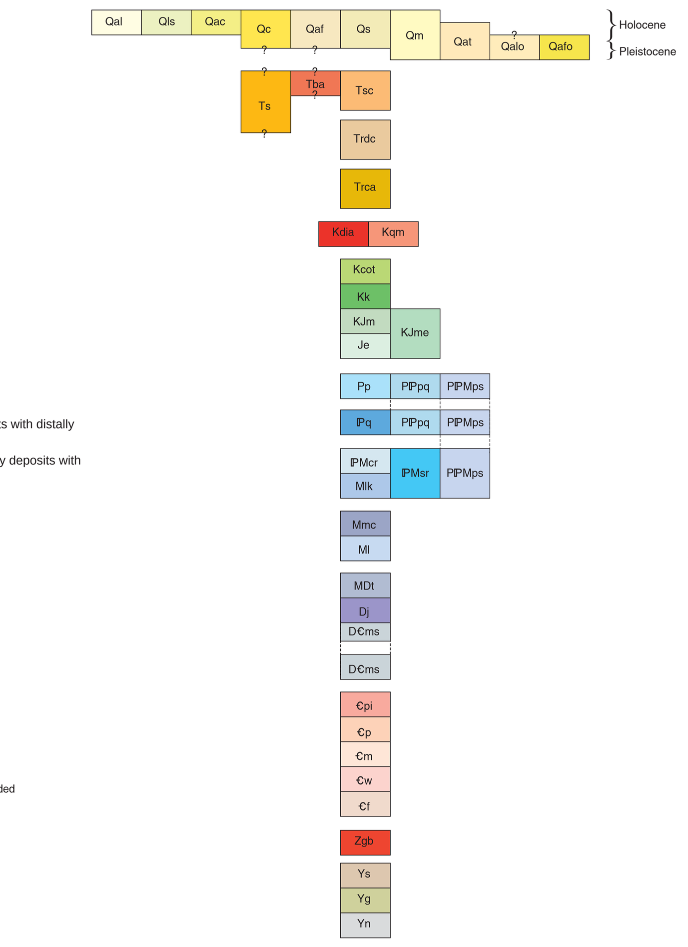


Map Units

Qal	Alluvium of modern channels and flood plains
Qls	Landslide deposit
Qac	Alluvium and colluvium, undivided
Qc	Colluvium
Qaf	Alluvial fan deposit
Qs	Sediment, undivided
Qm	Mantle deposit
Qat	Alluvium of alluvial terrace
Qalo	Alluvium, older than Qal
Qafo	Alluvial fan deposit, older than Qaf
Ts	Sediment or sedimentary rocks, undivided
Tba	Basalt
Tsc	Sixmile Creek Formation
	Interpreted ancestral Missouri River deposits with distally derived clasts from the south (see text)
	Interpreted ancestral Missouri River tributary deposits with locally derived clasts (see text)
Trdc	Dunbar Creek Member of Renova Formation
Trca	Climbing Arrow Member of Renova Formation
Kdia	Diabase
Kqm	Quartz monzonite
Kcot	Cody through Thermopolis Fms., undivided
Kk	Kootenai Formation
KJme	Morrison Formation and Ellis Group, undivided
KJm	Morrison Formation
Je	Ellis Group, undivided
PIPMps	Phosphoria Fm. through Snowcrest Range Group, undivided
PIPpq	Phosphoria and Quadrant Formations, undivided
Pp	Phosphoria Formation
IPq	Quadrant Formation
IPMsr	Snowcrest Range Group
IPMcr	Conover Ranch Formation
Mlk	Lombard and Kibbey Fms., undivided
Mmc	Mission Canyon Limestone
Ml	Lodgepole Limestone
MDt	Three Forks Formation
Dj	Jefferson Formation
D€ms	Maywood and Snowy Range Fms., undivided
€pi	Pilgrim Limestone
€p	Park Shale
€m	Meagher Limestone
€w	Wolsey Shale
€f	Flathead Formation
Zgb	Gabbro and diabase
Ys	Spokane Formation
Yg	Greyson Formation
Yn	Newland Formation
W	Water

For a more detailed description of the map units please refer to the text accompanying this map.

Correlation Chart



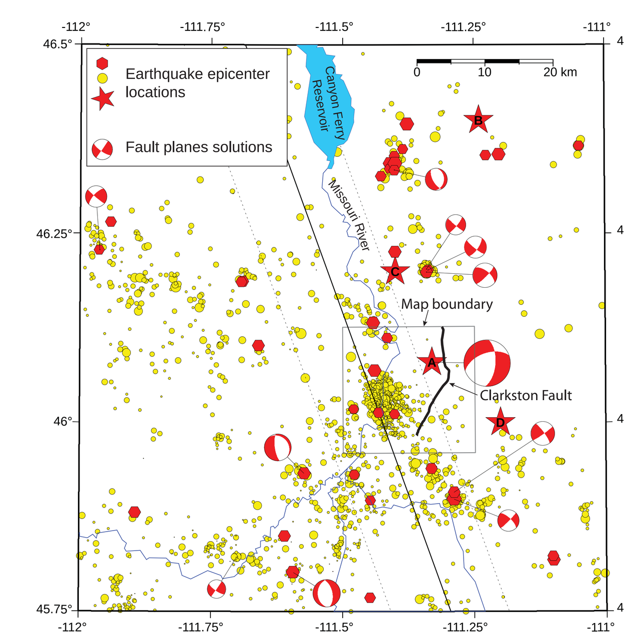


Figure 1. Seismicity and focal mechanisms in the Clarkston Valley region. Please see text pamphlet (p. 7) for a more detailed explanation

Map Symbols

Contact

Normal fault: dashed where inferred; dotted where concealed, bar and ball on downthrown side

Thrust fault: teeth on upthrown block; dashed where approximately located; dotted where concealed

Syncline: showing trace of axial plane and plunge direction where known; dotted where concealed

Anticline: showing trace of axial plane and plunge direction where known; dotted where concealed

Overturned syncline: Showing trace of axial plane and direction of dip of bedding

Overturned anticline: showing trace of axial plane and direction of dip of bedding

Strike and dip of inclined beds

Strike and dip of overturned bedding

Traces of interpreted paleolandslide rupture surfaces (see text)

Sill

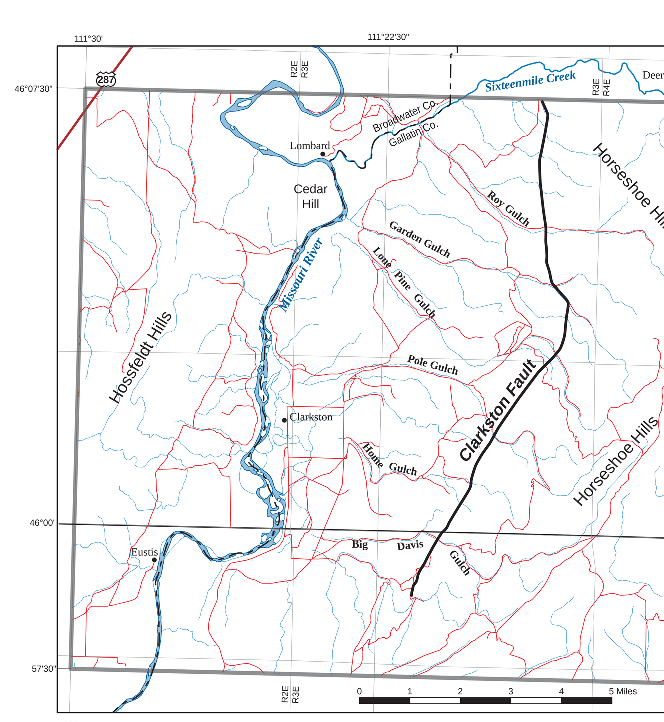


Figure 2. Clarkston Valley location map.

Lombard
Base map produced by the United States Geological Survey
Control by: USGS, NOS/NOAA
Compiled from aerial photographs taken: 1980
Field checked: 1982
Map edited: 1986
Projection: Lambert Conformal Conic
Grid:1000 meter Universal Transverse Mercator Zone 12
UTM grid declination: 0°19' West
1986 Magnetic NorthDeclination: 16° East
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

Contour Interval: 40 feet

Roy Gulch
Base map produced by the United States Geological Survey
Control by: USGS, NOS/NOAA
Compiled from aerial photographs taken: 1980
Field checked: 1982
Map edited: 1986
Projection: Lambert Conformal Conic
Grid:1000 meter Universal Transverse Mercator Zone 12
UTM grid declination: 0°14' West
1986 Magnetic NorthDeclination: 16° East
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

Contour Interval: 40 feet

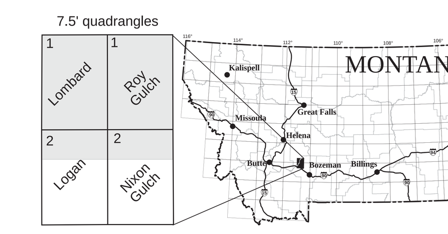
Logan
Base map produced by the United States Geological Survey
Control by: USGS, NOS/NOAA
Compiled from aerial photographs taken: 1981
Field checked: 1984
Map edited: 1987
Projection: Lambert Conformal Conic
Grid:1000 meter Universal Transverse Mercator Zone 12
UTM grid declination: 0°19' West
1987 Magnetic NorthDeclination: 16° East
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

Contour Interval: 20 feet

Nixon Gulch
Base map produced by the United States Geological Survey
Control by: USGS, NOS/NOAA
Compiled from aerial photographs taken: 1981
Field checked: 1984
Map edited: 1987
Projection: Lambert Conformal Conic
Grid:1000 meter Universal Transverse Mercator Zone 12
UTM grid declination: 0°13' West
1987 Magnetic NorthDeclination: 16° East
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

Contour Interval: 20 feet

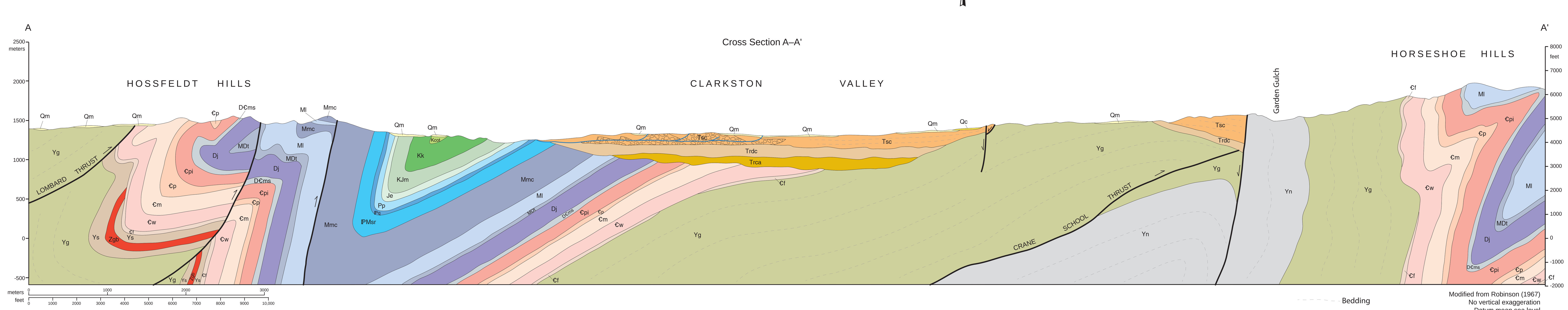
7.5' quadrangles



1. Most bedrock geology in Lombard and Roy Gulch 7.5' quadrangles compiled directly from Robinson (1967) with some stratigraphic nomenclature changes

2. Sources for northern Logan and Nixon Gulch 7.5' quadrangles: Sayers (1962) and Verrall (1955)

Figure 3. Index of 7.5' quadrangles and sources of geologic mapping.



Modified from Robinson (1967)
No vertical exaggeration
Datum mean sea level

Clarkston earthquake of June 27, 1925
Magnitude 6.6
Montana's second largest historic earthquake.

Figure 4. Rocks on railroad track near Lombard, Montana. Photo by J.P. Swarts. Broadwater County, Montana. 1925.
Published in U.S. Geological Survey Professional Paper 147, Plate 8-B. 1927. USGS Library Image file: /htmlorg/lpb566/land/pjt01616.jpg

Figure 5. Broken railroad track near Lombard. Note rebound of the broken rail. Photo by J.P. Swarts. Broadwater County, Montana. 1925.
Published in U.S. Geological Survey Professional Paper 147, Plate 8-A. 1927. USGS Library Image file: /htmlorg/lpb566/land/pjt01615.jpg

Figure 6. Shattered ground and overturned clods, Roy Gulch; the upturned clods show white because of a deposit of caliche just beneath the soil. Gallatin County, Montana. Photo taken by J.T. Pardee, September 3, 1925. Approximate geographic coordinates determined in the field, 2011: N46.6.0055 W111.20.5109.
Plate 12-A in U.S. Geological Survey. Professional paper 147. 1927. USGS Library Image file: /htmlorg/lpb273/land/pjt00976.jpg

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Map layout: Susan Smith, MBMG.

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Butte, Montana 59701-8997
Phone: (406) 496-4167
Fax: (406) 496-4451
http://www.mbmg.mtech.edu

MBMG Open-File Report 642

Geologic Map of the Clarkston Valley Broadwater and Gallatin Counties West-Central Montana

Compiled and mapped by Susan M. Vuke
with a section on seismicity by Michael C. Stickney

2013