Geologic Map of the southern Townsend basin Broadwater and Gallatin Counties, Montana

Montana Bureau of Mines and Geology Open File Report 586

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*Pre-Cenozoic geology largely compiled from Nelson (1963) and Robinson (1967).

Research supported by the U.S. Geological Survey National Cooperative Geologic Mapping Program under USGS award number 08HQAG0085. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

GEOLOGIC MAP OF THE SOUTHERN TOWNSEND BASIN
Description of Map Units

Colors for Cenozoic deposits from Rock Color Chart (Goddard and others, 1948).

Quaternary deposits

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

Qac **Alluvium and colluvium (Holocene)**—Argillaceous silt and sand with lenses of coarser sediment, generally pebble size or smaller.

Qp **Paludal deposit (Holocene)**—Argillaceous silt, sand, and organic matter deposited in swamp environment in the floodplain of the Missouri River.

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

Qdf **Debris-flow deposit (Holocene and Pleistocene?)**—Poorly size-sorted clasts derived from local highlands; may be as large as large boulders; originally matrix-supported within a dominantly silt/clay matrix. Matrix locally removed by erosion.

Qaf **Alluvial fan deposit (Holocene and Pleistocene)**—Gravel, sand, silt, and clay in deposits with fan-shaped morphology at break in slope along Missouri River valley. Moderately well sorted to poorly sorted with larger clasts both matrix- and clast-supported, and locally derived. Dominantly pebble-size clasts, with subordinate cobbles.

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 shows meander scars with subdued fluvial scarps primarily mapped from aerial photographs. Includes gravel, sand, silt, and clay on benches at elevations slightly above channels of Missouri River tributaries.

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

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

QTs **Sediment, undivided (Holocene, Pleistocene, and Pliocene?)**—Tuffaceous and argillaceous silt and sand with floating, angular and subangular, pebble- or small cobble-size clasts.

Tertiary deposits

Tscu **Upper Sixmile Creek Formation (Miocene: Hemphillian, Clarendonian, and Barstovian)**—Alternating lithologies that include:

1. Tuffaceous, grayish orange pink, fine-grained sandstone, siltstone and claystone with lenses of pebbles, granules and coarse sand. Weathered surfaces may be irregular from inconsistent, weak calcium-carbonate cementation. Locally contains abundant silicified wood. Rooted horizons common.
2. Lenses of rounded pebbles or cobbles of resistant lithologies. Clast composition and sedimentary structures resemble that of Tsct (described below). Locally contains blocky cobble- and boulder-size quartzite clasts. Unit generally unconsolidated, but locally calcium-carbonate cemented. Where unconsolidated fine matrix has been removed. Where cemented, conglomerate is associated with coarse, poorly sorted, crossbedded sandstone. Lenses may be very local or may extend for kilometers. One extensive lens is represented with a separate map pattern.
3. Lenses of flat clasts derived from rounded clasts of siltite that have broken along bedding planes. Clasts generally pebble and small cobble size. Unit appears pale reddish brown where clasts were dominantly derived from Spokane Formation. Amount of limestone clasts increases, lenses thicken, and size sorting decreases locally. Unit generally unconsolidated, but locally calcium-carbonate cemented.
4. Gray ash beds as much as 1.5 m (5 ft) thick of abundant unaltered glass shards. Beds may contain floating clasts and lenses of sand-, granule-, and pebble-size clasts. Locally reworked and crossbedded.

Exposed thickness of upper Sixmile Creek Formation at least 245 m (800 ft). Difficult to determine because of fault offsets.

Tsct **Sixmile Creek Formation, Toston member (Miocene: Barstovian)**—Fluvial gravel of dominantly rounded and subrounded cobbles of Belt Supergroup quartzite, well-cemented sandstone, volcanic rock and limestone, both clast-supported and matrix-supported with subordinate boulders and pebbles. Sparse metamorphic clasts include schist and gneiss. Notably devoid of granitic clasts. Limestone clasts rounded to the same degree as more resistant clasts. Interbedded with coarse, crossbedded sandstone with floating larger clasts and local rip-up clay clasts. Locally contains blocky cobble- and boulder-size quartzite clasts as large as large boulder size. Basal contact is significant unconformity on both Dunbar Creek Formation and Climbing Arrow Formation. Thickness 30-75 m (100-250 ft).

Tscl **Lower Sixmile Creek Formation (Oligocene and Miocene?: Arikareean)**—
Upper part: Conglomerate/gravel of poorly size-sorted, subangular to subrounded clasts that are dominantly limestone from local sources and include clasts as large as boulders. Coarse clasts are both matrix-supported and clast-supported.

Middle part: Alternating coarse- and fine-grained beds and lenses that range from 1 dm (4 inches) to 20 m (65 ft) thick. Coarse beds and lenses are matrix-supported or clast-supported and poorly size-sorted with clasts as large as boulders. Dominantly flat clasts of siltite, and blocky clasts of limestone. Limestone clasts increase upward in section. Fine-grained beds are grayish orange argillaceous siltstone and fine-grained sandstone, and grayish brown coarser-grained sandstone.

Lower part: Dominantly fine-grained with lenses of coarse-grained deposits. Coarse-grained lenses similar to those in middle part, but not as abundant. Fine-grained part grayish orange siltstone and fine-grained, locally micaceous sandstone, locally with 1 cm-wide (~1/2 in) calcite vugs, lenses of granule-size hash of flat green and red siltite clasts derived from Empire and Spokane Formations, and silicified horizons that may be silcrete. Root horizons are present in fine-grained beds of middle and lower parts.
Exposed thickness of lower Sixmile Creek Formation at least 275 m (900 ft).

Tdh **Dry Hollow map unit (Oligocene?: Early Arikareean and/or older)**. Alternating lithologies that include:

1. Grayish orange siltstone, and yellowish gray sandstone and conglomerate. Resembles Tscl. Conglomerate clasts are very poorly size sorted, and include clasts as large as boulders. Clast compositions indicate local source including abundant limestone. Clasts are subangular to subrounded. Fine-grained beds resemble Dunbar Creek Formation.
2. Red, silty mudstone (shown with hachure pattern). Moderate red, and reddish brown, somewhat bentonitic, generally unconsolidated, silty mudstone with conglomerate lenses that dominantly contain rounded clasts of Belt Supergroup siltite or flat clasts derived from rounded clasts of siltite that have broken along bedding planes. Clasts generally pebble size and smaller, but also cobble size. Unit can be traced to modern outcrops of Amsden Formation to the south which may have served as source of red color. Abundant Spokane Formation clasts may also impart red color. Locally, limestone clasts are mixed with siltite clasts. Locally contains interbeds of grayish orange, fine-grained sandstone and thin lenses of conglomerate that contain rounded clasts of quartzite and volcanic rock. Local root horizons with root casts as wide as 1 cm (~1/2 in). The middle Climbing Arrow Formation is also a reddish, silty mudstone, but does not alternate with lithologies as in unit 1. No limestone clasts were seen in the middle Climbing Arrow Formation, but they are locally present in the Tdh red mudstone.

Contact of Tdh with Tscl placed at the top of the highest persistent red mudstone.
Exposed thickness of Dry Hollow map unit about 60 m (200 ft).

Tdc **Dunbar Creek Formation (Oligocene)**—Grayish orange and yellowish gray, generally planar-bedded tuffaceous siltstone and mudstone and subordinate yellowish gray calcareous fine-grained sandstone. Local inconsistent cementation has created irregular weathered surfaces. Local calcium carbonate cemented spherical concretions. Weathers to powdery silt. Many Orellan vertebrate fossils have been identified from this unit in the map area. May be as young as Whitneyan (Fields and others, 1985). Thickness 45-60 m (150-200 ft).

Tca **Climbing Arrow Formation (Eocene: Chadronian)**

Tcau **Upper Climbing Arrow Formation**—Light gray, bentonitic mudstone and local small lenses of siltstone and sandstone, mostly devoid of modern vegetation other than lichens. Develops rounded, rilled slopes. Thickness approximately 60 m (200 ft).

Tcam **Middle Climbing Arrow Formation**—Reddish gray and reddish brown bentonitic mudstone with lenses of rounded resistant pebbles, and lenses of flat clasts derived from rounded clasts of siltite that have broken along bedding planes. Thickness approximately 120 m (400 ft).

Tcal **Lower Climbing Arrow Formation**—Alternating lithologies that include:

1. Relatively resistant, limonite-cemented, clast-supported conglomerate. Clasts are rounded and dominantly pebble size with sand/granule matrix. Conglomerate clasts dominantly Belt Supergroup quartzite, white quartz, and volcanics.
2. Bentonitic mudstone and siltstone. Various colors such as light greenish gray, pale red purple, moderate red, light bluish gray and very light gray.
3. Dark brown carbonaceous beds, dark gray paper shale, and thin coal beds. Plant impressions are abundant.
4. Gastropod coquina beds and bedding surfaces with gastropod impressions.

Secondary selenite crystals litter some surfaces. Vertebrate bones of indeterminate age found during field work include an astragalus bone of a small artiodactyl (A. Tabrum, written communication, 2008). An early Chadronian local fauna has been identified from this unit (Fields and others, 1985; Alan Tabrum, written communication, 2008). Thickness approximately 60 m (200 ft).

Mesozoic, Paleozoic, and Proterozoic rocks

Most of the bedrock geology shown on the map was taken directly from Nelson (1963) and Robinson (1967). Bedrock descriptions below are modified from Robinson (1967).

Kqm **Quartz monzonite**—Includes related medium- to coarse-grained calc-alkalic intrusive rocks. Thickness variable.

Kk **Kootenai Formation**—Orange siltstone, salt-and-pepper sandstone, varicolored mudstone and siltstone; coal and gastropod-rich limestone near top. Thickness 800-1000 ft.

Jme **Morrison Formation and Ellis Group, undivided**

Jm **Morrison Formation**—Red, yellow, and brown mudstone, siltstone, and sandstone; coal near top. Thickness 30-90 m (100-300 ft).

Je **Ellis Group**—Various lithologies that commonly include brown sandstone at top (Swift Formation), gray limestone (Rierdon Formation, and yellow siltstone (Sawtooth Formation); brown pebble conglomerate widespread at base. Thickness 0-30 m (0-100 ft).

Pp **Phosphoria Formation**—Various lithologies that commonly include brown chert, dark phosphatic sandstone, gray dolomitic limestone, and light-colored quartzitic sandstone. Thickness 0-60 m (0-200 ft).

IPq **Quadrant Formation**—Light-colored resistant quartzitic sandstone and subordinate limestone. Thickness 30-120 m (100-400 ft).

IPMabs **Amsden Formation and Big Snowy Group**

Amsden Formation—Red sandstone and mudstone that grade upward into pink and gray limestone and quartzitic sandstone. Thickness 60-120 m (200-400 ft).

Big Snowy Group—Varied lithology that commonly includes brown and gray siltstone, dark-gray limestone, dark gray and green shale, and red shaly sandstone near base. Thickness 0-120 m (0-400 ft).

Mm **Madison Group, undivided**

Mmc **Mission Canyon Formation**—Gray, thick-bedded resistant limestone. Thickness 240-460 m (800-1500 ft).

Ml **Lodgepole Formation**—Gray, thin-bedded limestone with minor amounts of intercalated calcareous shale. Thickness 90-215 m (300-700 ft).

MDt **Three Forks Formation**—Upper orange siltstone (Sappington Member), medial dark-gray and green shale, lower orange mudstone. Thickness 30-120 m (100-400 ft).

Dj **Jefferson Formation**—Brownish gray fetid dolomite and dolomitic limestone with subordinate black and gray dolomite and limestone. Thickness 120-215 m (400-700 ft).

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

Maywood Formation (Devonian)—Upper gray limestone grades downward into yellow to red calcareous siltstone. Thickness 50-200 ft.

Snowy Range Formation (Cambrian)—Various lithologies that include green shale, red limestone conglomerate, banded gray and orange dolomite, and orange siltstone. Thickness 1-100 ft.

€pi **Pilgrim Formation**—Gray, yellowish gray, and orange resistant dolomite and limestone. Thickness 120-150 m (400-500 ft).

€p **Park Shale**—Greenish-gray micaceous shale. Thickness 30-75 m (100-250 ft).

€m **Meagher Formation**—Gray and black orange-mottled resistant limestone. Thickness 75-150 m (250-500 ft).

€w **Wolsey Shale**—Olive and brown micaceous shale. Much glauconitic sandstone near base and limestone near top. Thickness 90-135 m (300-450 ft).

€wq **Quartzite bed**—Local bed in middle Wolsey Shale.

€f **Flathead Sandstone**—Pink feldspathic, quartzitic moderately resistant sandstone. Thickness 0-45 m (0-150 ft).

Zd **Diabase sill**—Thickness as much as 300 m (1,000 ft).

Ys **Spokane Formation**—Red and gray siltite. Thickness 0-760 m (0-2,500 ft).

Yg **Greyson Formation**—Greenish gray, dark gray and yellowish brown siltite and fine-grained brownish gray or light gray quartzite. Thickness 90-2440 m (300-8,000 ft).

Ygnu **Greyson Formation, upper**—Interbedded greenish gray siltite and subordinate light gray quartzite.

Ygnl **Greyson Formation, lower**—Interbedded dark gray siltite and brownish gray quartzite.

Yneu **Newland Limestone, upper**—Gray limestone and calcareous siltite, and subordinate light brown or yellowish brown medium-grained granitic sandstone.

Ynel **Newland Limestone, lower**—Gray calcareous siltite and argillite.
Thickness Newland Limestone more than 450 m (1500 feet), base not exposed.

GEOLOGIC MAP OF THE SOUTHERN TOWNSEND BASIN

Geologic Map Sources

Holker 7.5' quadrangle Nelson, 1963 Map scale 1:63,360 Wong and others, 1999 Map scale 1:100,000 (Toston fault)	**Lippert Gulch 7.5' quadrangle** Nelson, 1963 Map scale 1:63,350
Toston 7.5' quadrangle Robinson, 1967 Map scale 1:24,000 Wong and others, 1999 Map scale 1:100,000 (Toston fault)	**Deer Park 7.5' quadrangle** Robinson, 1967 Map scale 1:24,000

Cenozoic deposits and structure in the southern Townsend basin

The geologic map of the southern Townsend basin is the third in a series of recent valley maps that extend from Three Forks to Townsend, Montana. They include the Three Forks basin (Vuke, 2006), Toston-Radersburg basin (Vuke, 2007), and southern Townsend basin (current map) (Fig. 1). Cenozoic deposits and structure are the focus of the maps. A fourth map of the Canyon Ferry Lake area is underway, and extends the mapping to the north. The following are discussions of selected Cenozoic deposits and structure.

Sixmile Creek Formation Stratigraphy

Robinson (1967) named the Sixmile Creek Formation for exposures along Sixmile Creek which he designated as the type locality. He stated that similar deposits within the current map area along Dry Hollow Creek (Figure 1) and to the north are also Sixmile Creek Formation. Based on many collections of vertebrate fossils, Robinson (1967) indicated that the age of the Sixmile Creek Formation in the southern half of the map area (Toston and Deer Park 7.5' quadrangles, Figure 1) ranges from early Miocene to late Pliocene (late Oligocene to late Miocene based on subsequent revision of Tertiary time scale). Sixmile Creek Formation vertebrate fossils in the current map area, identified by scientific name (Robinson, 1967), range from early Arikareean to Hemphillian North American Land Mammal ages (Figure 2). Based on vertebrate fossils, the Sixmile Creek Formation at the type location is Arikareean (Oligocene, and possibly early Miocene), whereas the Sixmile Creek Formation along Dry Hollow Creek and to the north, ranges from Barstovian to Hemphillian (middle to late Miocene) (Robinson, 1967; Nelson, 1963; fossils collected during field work for current report).

The Sixmile Creek stratigraphy in the map area is complicated by syndepositional tectonic history. A north-south striking fault in the southern part of the map area, the Dry Hollow Fault, (Figure 3) appears to have been active during the Tertiary. West of the fault the Barstovian and younger Sixmile Creek Formation rests unconformably on Orellan or Whitneyan(?) Dunbar Creek Formation and Chadronian Climbing Arrow Formation; deposits equivalent to the Arikareean Sixmile Creek Formation at the type locality are apparently not present west of the fault. Arikareean Sixmile Creek Formation has only been recognized east of the Dry Hollow fault in the map area, suggesting that the western block was uplifted relative to the eastern block either during or after deposition of the Arikareean Sixmile Creek Formation. Consequently, it was either not deposited or was deposited but subsequently removed by erosion to the west but preserved to the east of the Dry Hollow fault.

No distinct Hemingfordian (Figure 2) fauna has been found in western Montana (Fields, and others, 1985), and a major unconformity has been recognized at that interval (Fields and others, 1985, Rasmussen, 1973; Robinson, 1960; Kuenzi and Richard, 1969). Hemingfordian fossils have likewise not been found in the southern Townsend valley. A significant unconformity with a Hemingfordian hiatus is recognized in the map area as elsewhere in western Montana, yet the deposits of the Arikareean lower Sixmile Creek Formation (late Oligocene, early Miocene?) below the unconformity lithologically resemble those of the

Barstovian to Hemphillian (mid to late Miocene) upper Sixmile Creek Formation above the unconformity, which led Robinson to place both units in the Sixmile Creek Formation. However, the lower Sixmile Creek Formation does not contain the thick, gray ash beds common in part of the Sixmile Creek Formation above the unconformity, nor the thick fluvial cobble conglomerate/gravel of the Toston member (Tsct) and upper Sixmile Creek Formation (Tscu). Robinson defined the Sixmile Creek Formation based on lithostratigraphy, whereas Fields and others (1985) redefined it as an allostratigraphic unit, restricted to Tertiary deposits younger than the Hemingfordian unconformity. Fields and others (1985) did not follow the guidelines of the North American Stratigraphic Code (1983) in making this revised designation, so Robinson's (1967) definition of the Sixmile Creek Formation should take precedence.

The Townsend basin is probably the only area where Sixmile Creek Formation (based on Robinson's original designation) occurs below the Hemingfordian unconformity as Arikareean deposits. Elsewhere Arikareean deposits do not lithologically resemble those of the type Sixmile Creek Formation. In many areas the Arikareean deposits have been included in the Renova Formation (Axelrod, 1984; Lofgren, 1985; Rasmussen, 1989). Therefore, the Sixmile Creek Formation as redefined by Fields and others (1985) is probably applicable everywhere else as shown on their Figure 4.

On the present geologic map, the Arikareean Sixmile Creek Formation is mapped as lower Sixmile Creek Formation (Tscl); the basal Barstovian rounded-cobble gravel/conglomerate deposit is mapped as Toston member of the upper Sixmile Creek Formation (Tsct); and younger Sixmile Creek Formation is mapped as upper Sixmile Creek Formation (Tscu). Previous mapping (Vuke, 2006; Vuke, 2004) has referred to Sixmile Creek and Renova synthems, informally acknowledging the allostratigraphic units designated by Fields and others (1985) despite the conflict with Robinson's (1967) formal lithostratigraphic designation of the Sixmile Creek Formation. Figure 2 shows this discrepancy.

Paleontology and age of Tertiary deposits (Refer to Figure 2.)

<u>Upper Sixmile Creek Formation</u>

During mapping for this project, tooth fragments were found at two locations in the basal part of the upper Sixmile Creek Formation (Tscu), immediately overlying the Toston member of the Sixmile Creek Formation (Tsct). At one location (N46 13.1535, W111 22.4736) the internal part of an upper molar or premolar of a hypsodont horse, probably *Merychippus*, was found. It is probably early Barstovian age and certainly no older than this. The second tooth fragment, in poor condition, was found in another area immediately overlying the Toston member (N46 12.4892 W111 24.3074). It appears to be from a lower tooth of a hypsodont horse and indicates a Barstovian or younger age if correctly identified. The identification is uncertain because of the poor condition of the specimen. (Identifications by Alan Tabrum, paleontologist, Carnegie Museum of Natural History, written communication).

Tooth fragments found at another location (N46 13.6067 W111 25.2865), higher in the upper Sixmile Creek section, represent one or more specimens of a hipparionine horse. Based

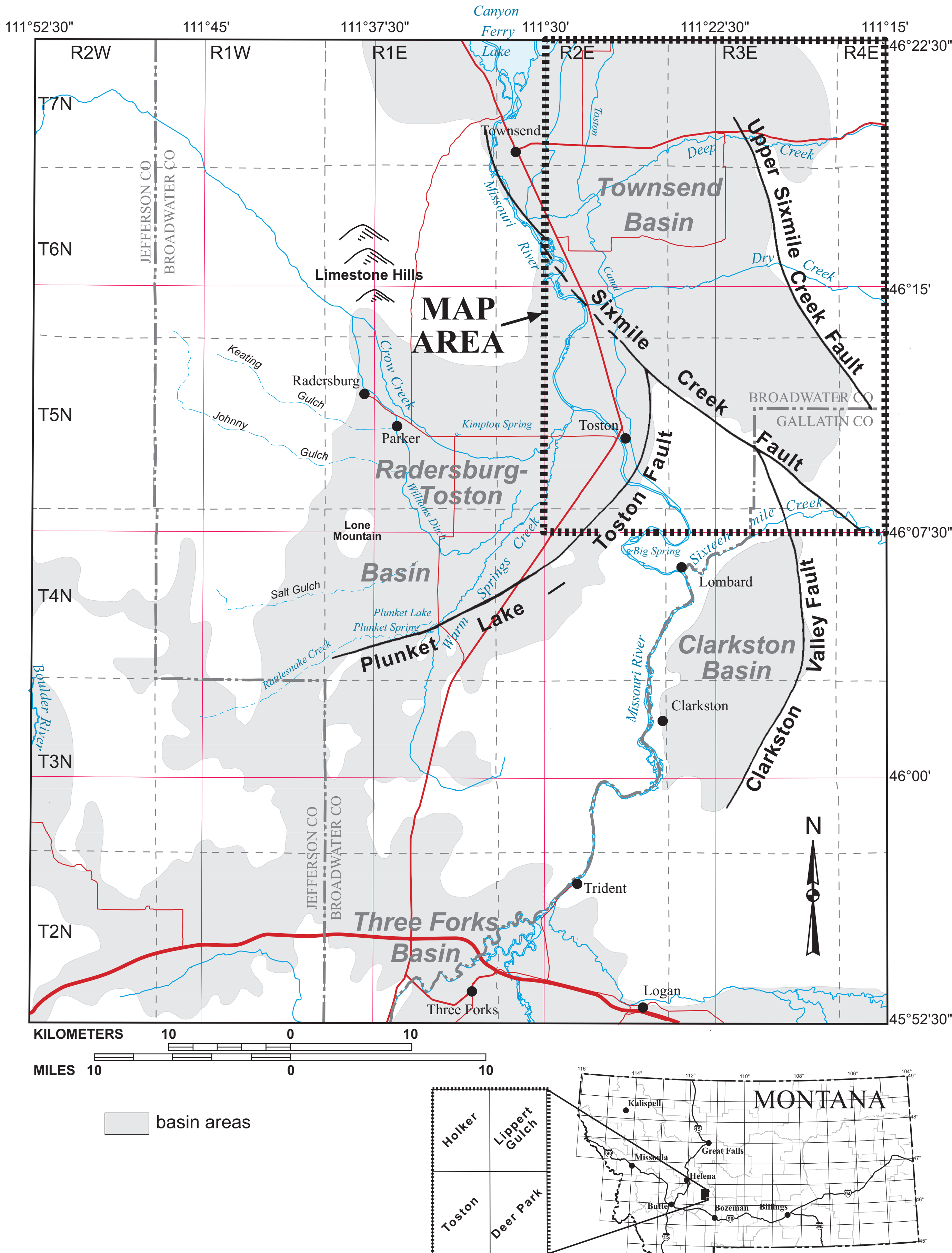

Figure 1. Location of map area showing adjacent basins.

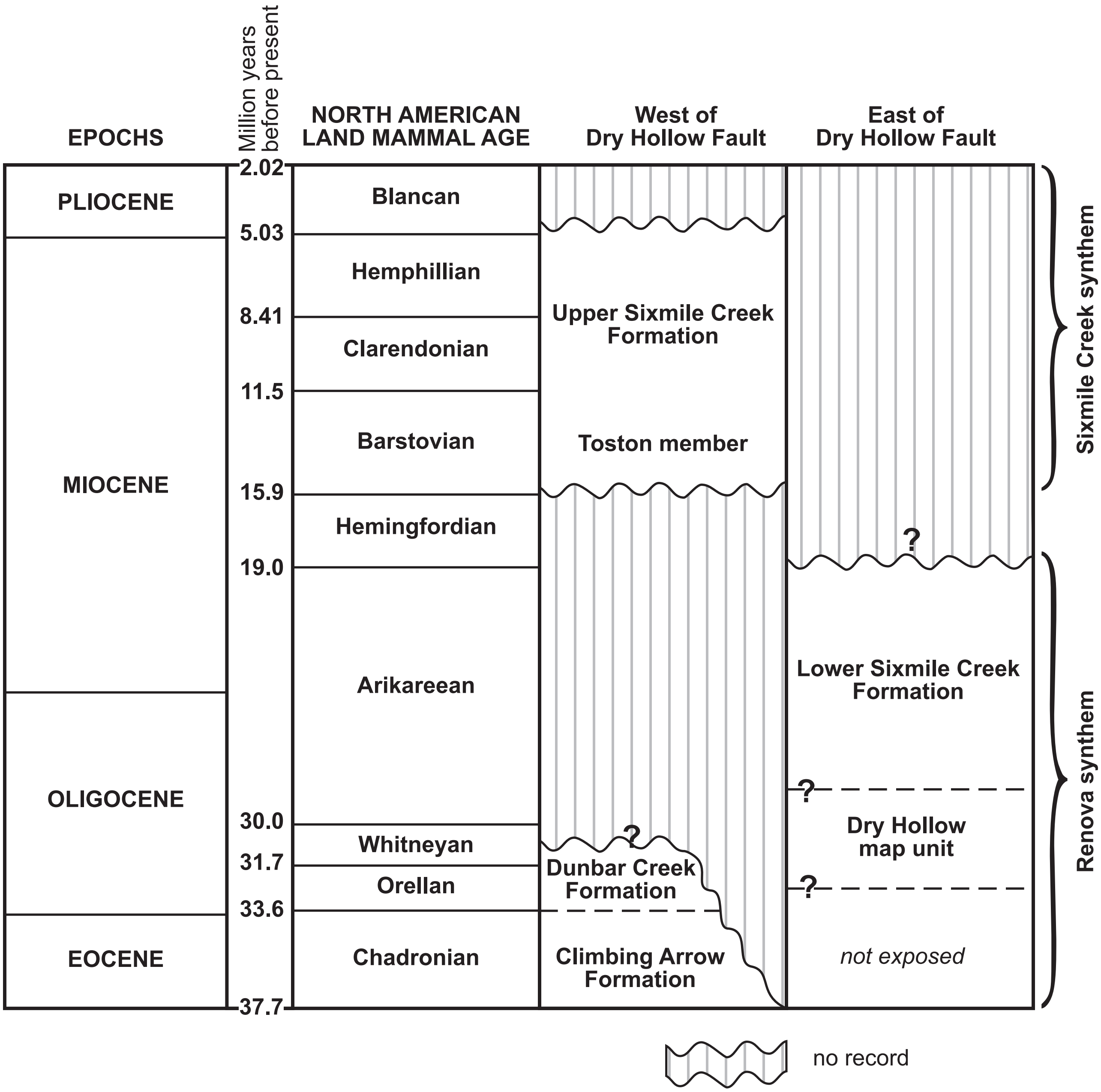

Figure 2. North American land mammal ages and correlation of Tertiary map units in map area.

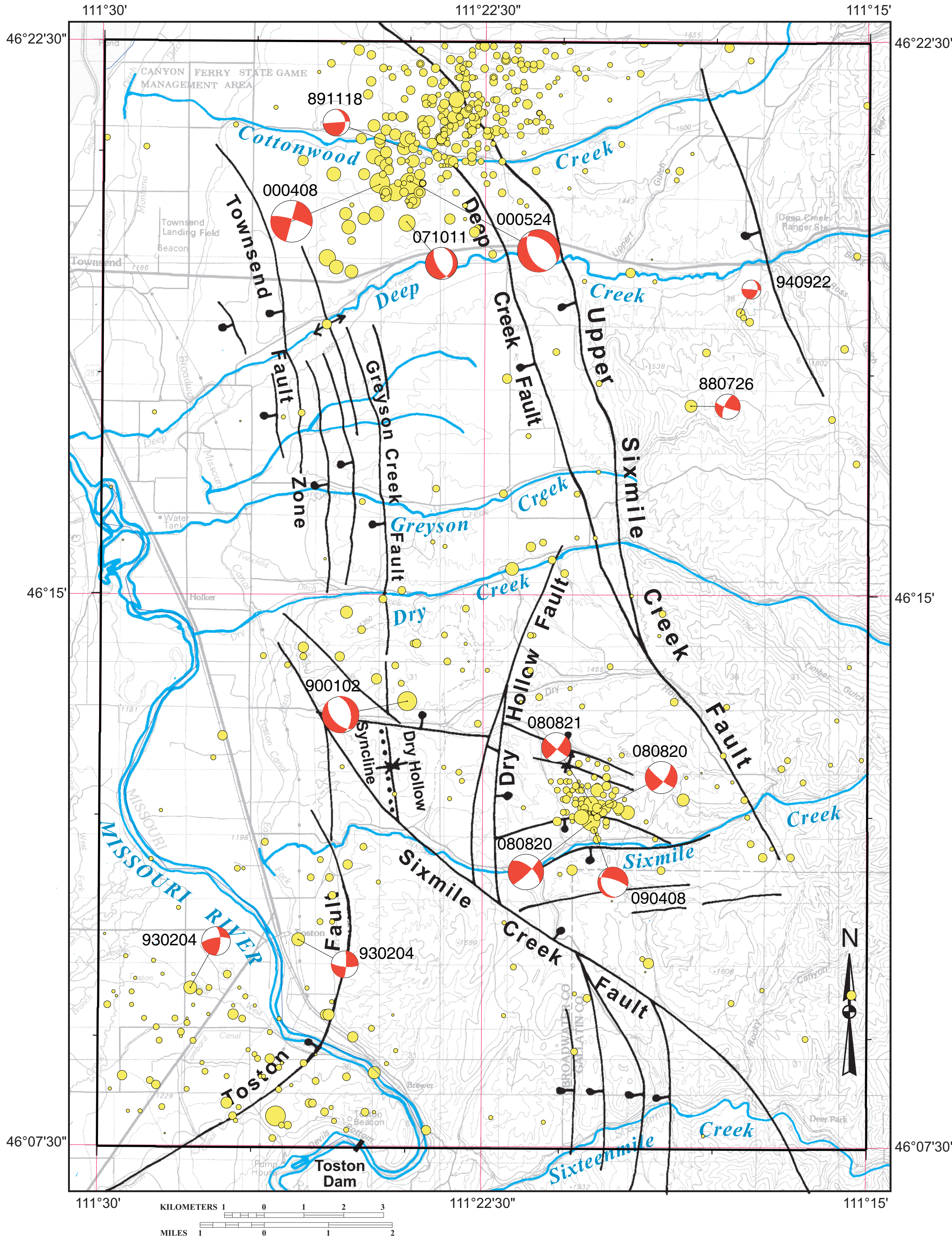

Figure 3. **Faults and folds in the map area.** Most of the faults shown are potentiallyactive. The *Dry Hollow fault* and concealed fault associated with the syncline north of Sixmile Creek (shown with dotted line) show evidence of Tertiary movement. Note that the *Toston fault* of Wong and others (1999) is here restricted to south of the *Sixmile Creek fault.*

on a combination of preserved pattern and inferred crown height, these are no older than late Barstovian and are more probably of Clarendonian or early Hemphillian age. Another location (N46 15.5739 W111 24.0364) yielded fragments of a hypsodont horse tooth that indicate a late Barstovian or later age. Single fragments of turtle and a medium-sized artiodactyl were also found at this location (identification by Alan Tabrum, written communication, 2008).

Robinson (1967) listed several vertebrate fossils found in the upper Sixmile Creek Formation (SW ¼ SW ¼ sec. 14 T. 5 N., R. 3 E.; NW ¼ NE ¼, and SE ¼ sec. 36 T. 6 N., R. 2 E.; center NE ¼ sec. 36 T. 6 N., R. 2 E.; and N ½ NW ¼ sec. 29 T. 4 N., R. 3 E.) The following statement from Fields and others (1985) applies to these fossils: "Fragmentary vertebrate remains from strata in which 'shard-rich sandstone is a major component,' and that were included in the Sixmile Creek Formation by Robinson (1967) are suggestive of a Clarendonian or Hemphillian age for this part of the formation."

Fossils listed by Nelson (1963) (2,500 ft east and 1,600 ft north of the SW corner sec. 25, T.8 N., R. 2 E.; 1,630 ft west of the east edge of sec. 34, T. 7 N., R. 2 E.; and 1,310 ft west of the NE corner sec. 35, T. 7 N., R. 3 E.) seem to be of late Hemingfordian or younger age (Alan Tabrum, written communication). Miocene horse fossils were first reported in the map area by Douglass (1902) from deposits in the Deep Creek valley.

Toston member, Sixmile Creek Formation

A Barstovian tooth fragment found in beds immediately overlying the Toston member (see above) and the pronounced unconformity at its base that places the Toston member on Whitneyan(?) (Fields and others, 1985), Orellan, and Chadronian units (Fields and others, 1985; Alan Tabrum, written communication, 2008) (Figure 2), suggest that this unit is Barstovian and/or possibly late Hemingfordian (unlikely given the paucity of Hemingfordian fossils in western Montana). It represents the basal Sixmile Creek Formation above the regional Hemingfordian unconformity.

Lower Sixmile Creek Formation

Robinson (1967) reported one specimen of the oreodont *Leptauchenia (Cyclopidius) simus* from the lower Sixmile Creek Formation. J. Leroy Kay, Carnegie Museum curator, collected specimens from two localities along Sixmile Creek in 1948, which included at least three specimens of *Leptauchenia* (originally identified as *Cyclopidius*, now considered to be a junior synonym of *Leptauchenia*) (A. Tabrum, written communication, 2008). The type specimen of the rodent *Gregorymys kayi* was collected from "Six Mile Creek 5 miles west [sic] of Toston, Montana" (Wood, 1950) (He clearly meant five miles east of Toston). The joint occurrence of *Gregorymys* and *Leptauchenia* is indicative of an early Arikareean age (A. Tabrum, written communication, 2008).

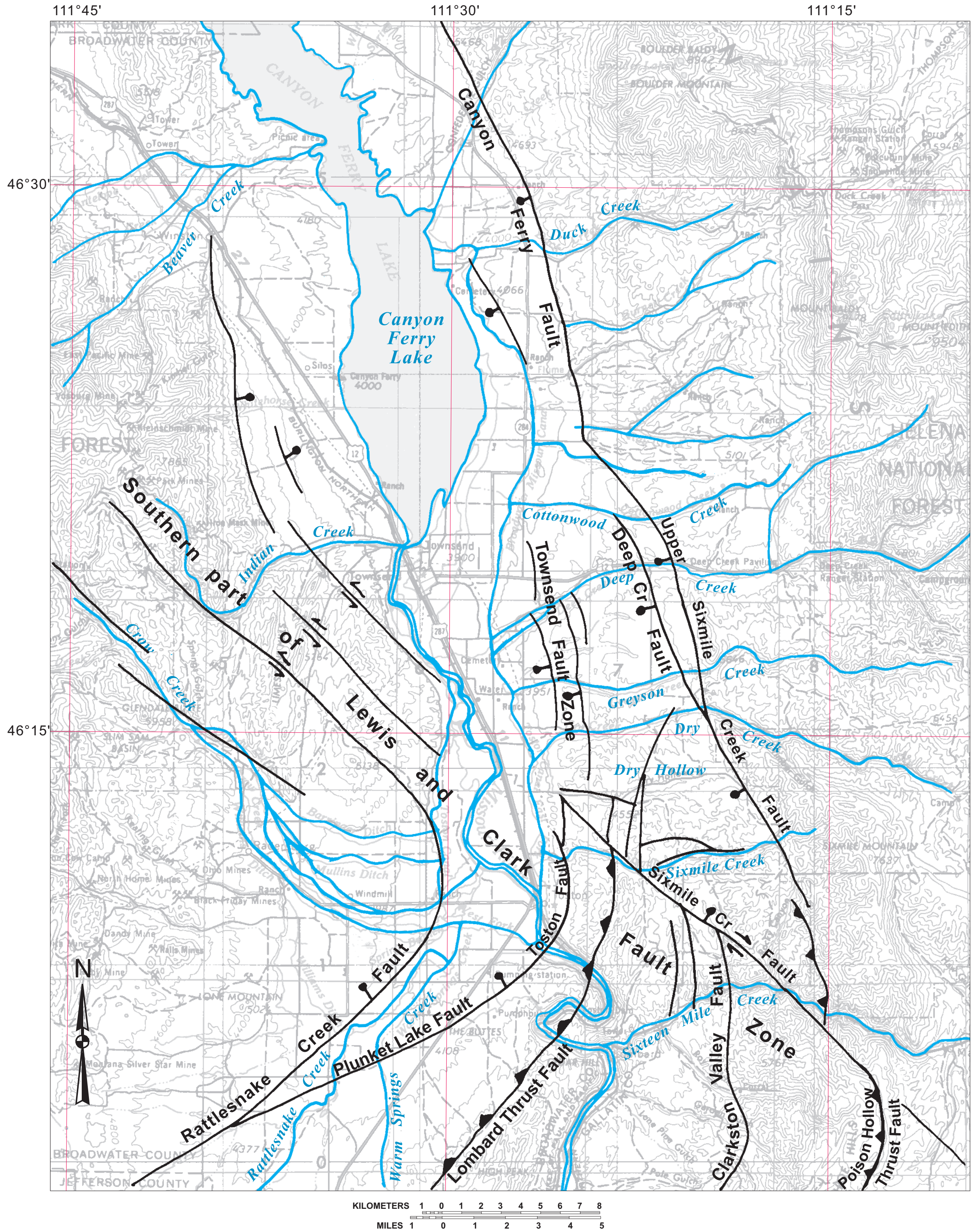

Figure 4. **Faults in the Toston-Townsend-Canyon Ferry Lake area.** Most normal faults in the area are potentially active. Thrust faulting and left-lateral strike-slip faulting predated Cenozoic extension. Sources of information in addition to current map: Anderson and LaForge (2003), Nelson (1963), Robinson (1967), Skipp and Peterson (1965), Vuke (2007), Wong and others (1999). Note that the *Toston fault* of Wong and others (1999) is here restricted to south of the *Sixmile Creek fault.*

Dry Hollow map unit

Fossils were not found and have not been reported from this unit. It contains beds that strongly resemble the overlying Arikareean lower Sixmile Creek Formation but that alternate with sections of red, silty mudstone of variable thickness, shown with a red hachure pattern on the map. The fossils found in the lower Sixmile Creek Formation are early Arikareean (Oligocene). The apparent association of the Dry Hollow map unit with the overlying Oligocene lower Sixmile Creek Formation suggests that the Dry Hollow map unit is likely also Oligocene, and probably younger than or age equivalent to the Dunbar Creek Formation west of the Dry Hollow fault.

Although Dunbar Creek and Climbing Arrow are considered members of the Renova Formation to the west (Kuenzi and Fields, 1971), they are distinct formations in the Three Forks basin (Robinson, 1960), Radersburg-Toston basin (Vuke, 2006), and in the Townsend basin (Figure 1).

Dunbar Creek Formation

The Dunbar Creek Formation in the map area is typical tuffaceous siltstone, but is younger than in the Radersburg area to the southwest where vertebrate fossils indicate that it is Chadronian (Vuke, 2007). It is also younger than the Dunbar Creek Formation in the Three Forks area where it is also Chadronian (Robinson, 1960; 1967). The Chadronian Dunbar Creek Formation is lithogically distinct from the Chadronian Climbing Arrow Formation in the Radersburg and Three Forks areas. The apparent lack of Chadronian Dunbar Creek Formation in the southern Townsend basin despite the proximity to the Radersburg area, may indicate an unconformity between the Dunbar Creek and Climbing Arrow Formations in the Townsend basin.

Climbing Arrow Formation

Fossils from beds mapped as lower Climbing Arrow Formation in the map area are early Chadronian (Fields and others, 1985), and the entire Climbing Arrow Formation in the map area may be early Chadronian (A. Tabrum, written communication, 2008). The Climbing Arrow Formation in the southern Townsend basin is typical of that in other areas in that it is very bentonitic.

Structure

The Cenozoic deposits of the southern Townsend valley are offset by many faults and deformed by several large folds. Deposits as young as Hemphillian (Figure 2), as indicated by fossil age, are folded with fold limb dips as much as 55°. Mantle deposits that overlie Pleistocene pediments are offset by faults.

Northwest-trending faults of the Lewis and Clark fault zone

Northwest-trending faults reflect the map area's location within the southern part of the prominent Lewis and Clark fault zone (Figure 4) which extends from Idaho across western

Montana. A northwest-striking fault, the **Sixmile Creek fault** (distinct from the Upper Sixmile Creek fault of Johns and others, 1982), bounds the southern part of the Townsend basin. It appears to be a significant fault that may be active.

<u>North-south and north-northwest-trending faults and folds</u>

The **Toston fault**, a down-to-the-west normal fault with visible scarps, was identified by Wong and others (1999) based on geomorphic, stratigraphic, structural, and geophysical evidence. Mapping for this report confirms the presence of this fault that extends between Toston and Townsend, becoming a zone of faults north of the Sixmile Creek fault, where it is renamed the Townsend fault zone on the current map. To the south, it joins the northeast-trending Plunket Lake fault (Vuke, 2007). Northward, the Townsend fault zone deflects from a north- to north-northwest trend, and projects toward the southern part of Canyon Ferry Reservoir. The Plunket Lake, Toston, and Townsend faults together form an arcuate pattern that mimics the pattern of older thrust faults in the Helena salient. The Toston fault displays evidence of recurrent movement during the last 500,000 years (Figure 4) (Wong and others, 1999). Slip rate on the Toston fault is estimated at 0.1 to 0.5 mm/year (Anderson and LaForge, 2003).

The Toston fault parallels part of the older Lombard thrust fault (Figure 4), a significant tectonic element of the Helena salient of the Montana fold and thrust belt. The Lombard thrust is only exposed south of the Sixmile Creek fault. It is not clear where it extends north of the Sixmile Creek fault because it is covered by Cenozoic deposits, and geophysical data suggest higher angle, down-to-the-east faults (Kinoshita and others, 1965) in that area. The Toston fault may sole in the basal décollement of the Lombard thrust.

The Toston fault scarp was interpreted to truncate fluvial terrace deposits of two different ages that are offset by 20-25 m (65-80 ft) (Wong and others, 1999). The upper fluvial deposit is the Toston member (informally named in this report) of the Sixmile Creek Formation, overlain by younger Sixmile Creek deposits and underlain by the Dunbar Creek and Climbing Arrow Formations. The interpretation of this report is that the lower fluvial deposit is also the Toston member underlain by Climbing Arrow Formation and down-dropped to the west along the Toston fault. A limonitic zone is present along the Toston fault where it juxtaposes Toston member and underlying Climbing Arrow Formation against Spokane Formation. The northern part of the original Toston fault (Wong and others, 1999), is named the Townsend fault zone in this report. The easternmost fault in this zone with perhaps the most offset is named the Greyson Creek fault (Figure 3). Mappable offset of Quaternary deposits occurs throughout the Toston fault zone. Benches 2 and 3 described by Pardee (1925) are here interpreted as an originally continuous pediment that was offset by down-to-the-west normal faulting in this fault zone. The Townsend fault zone appears to be a series of shallow, low-angle faults. Although they have the same trend as the Toston fault, they may not be directly associated.

Pediments in the area generally dip to the west, but west of the southern part of the **Upper Sixmile Creek fault** (Johns and others, 1982) along the east part of the basin (Figure 3), Quaternary pediments covered by mantle and eolian deposits dip to the northwest, parallel to the fault. The northwest dip of these surfaces does not reflect bedding-plane dip; underlying

Tertiary deposits generally dip to the east or northeast, because of rotation along the down-to-the-west Upper Sixmile Creek fault. The fault may have influenced the orientation of pediment-forming sheetwash drainage. North of Dry Creek, a western strand of the fault is named the Deep Creek fault (Figure 3). Johns and others (1982) indicated high confidence that the Upper Sixmile Creek fault has experienced late Cenozoic movement, and they estimated about 600 m (2,000 ft) of down-to-the-west displacement. Wong and others (1999) estimated displacement of 100-150 m (330-490 ft). Climbing Arrow Formation is present on the up-thrown footwall of the fault, whereas Tertiary deposits as young as upper Sixmile Creek Formation are present on the down-dropped hanging wall.

Anderson and LaForge (2003) interpreted the Upper Sixmile Creek fault to be an older southeast continuation of the Canyon Ferry fault (Fig. 3) which is considered active (Stickney and others, 2000). No surface-rupturing events have occurred for about 13,000 years on the Canyon Ferry fault, but segments of the fault have many Quaternary fault scarps (Anderson and LaForge, 2003).

The northwest-dipping and west-dipping pediments west of the Upper Sixmile Creek and Deep Creek faults are dissected by the valleys of the west-flowing Sixmile Creek, Dry Creek, Greyson Creek, and Deep Creek (Figure 3). Pediments are topographically higher on the north sides of the cross-cutting stream valleys than on the south sides. These differences are likely a result of hillslope modification from aspect-related microclimate influences, such as the effect of insolation differences on temperature, evapotranspiration, and moisture availability for weathering, similar to that measured and described by Burnett and others (2008). As a result of these aspect-related differences following stream dissection of the pediments, weathering may have exceeded erosion on the north-facing slopes, causing more surface water infiltration than run-off. Because of hillslope aspect differences, erosion may have exceeded weathering on the south-facing slopes, creating steeper topography on south-facing valley walls (Burnett, 2004).

Several faults with a north- or north-northwest trend show evidence of pre-Barstovian (Figure 2) movement. Arikareean deposits apparently only occur east of the **Dry Hollow Fault** (Figure 3). West of the fault, Barstovian deposits rest unconformably on Whitneyan(?) and older deposits suggesting down-to-the-east offset on the fault during the Arikareean, Hemingfordian, or early Barstovian, resulting in either non-deposition of the Arikareean or subsequent erosional removal of the Arikareean deposits to the west. The **Dry Hollow syncline** (Figure 3) west of the Dry Hollow fault appears to overlie an earlier fault that was truncated by the unconformity. The Toston member of the Sixmile Creek Formation overlies Whitneyan(?) and Orellan Dunbar Creek Formation on the east side of the syncline, and early Chadronian lower Climbing Arrow Formation on the west side, suggesting a down-to-the-east fault that was erosionally beveled prior to deposition of the Toston member of the Sixmile Creek Formation. The Dry Hollow fault and the fault that underlies the syncline may share the same mid-Tertiary history of movement. The down-to-the-east Dry Hollow fault and down-to-the-west Sixmile Creek fault formed a graben in which Arikareean deposits were preserved.

Faults indicated on cross section B-B' of Kinoshita and others (1965), are tentatively reinterpreted on cross section A-A' of the current map as pre-Hemingfordian, down-to-the-east faults. These faults may be truncated by the Hemingfordian unconformity similar to the fault that is interpreted to underlie the Dry Hollow syncline (Figure 3).

East-west-trending faults and linear features

A zone of east-west, and northeast-trending faults and lineaments occurs in the Sixmile Creek area west of Dry Hollow fault.

Seismicity

The northern part of the Intermountain seismic belt is the most seismically active zone in the intermountain U. S. Historically, the Clarkston Valley, just south of the map area, has been one of the most seismically active parts of the northern part of the belt (Qamar and Hawley, 1979). The second largest magnitude earthquake in Montana since 1900, the magnitude 6.6 Clarkston earthquake, occurred on June 28, 1925 within or just south of the map area, and severely shook the Townsend Valley. Springs that were the source of Sixmile Creek stopped flowing as a consequence of the earthquake, and sand spouts temporarily erupted in the Missouri River floodplain south of Lombard and near Townsend (Lorenz and McMurtrey, 1956). Pardee (1926) interpreted movement on the Clarkston Valley fault (Figure 4) as responsible for the 1925 earthquake. Wong and others (1999) estimated location uncertainties of 10 km (6 mi) and suggested that either the Clarkston Valley fault or the Toston fault could have produced the earthquake. Both faults connect to the Sixmile Creek fault (Figure 4).

Another high intensity earthquake severely shook the Townsend Valley in 1935, the magnitude 6.3 Helena earthquake. Two other large earthquakes, a magnitude 6.0 and magnitude 5.9 occurred in the same area during the same month. A magnitude 4.8 earthquake occurred in the southern Townsend valley in 1966, and a magnitude 4.8 earthquake occurred in the Clarkston valley in 1977 (Qamar and Hawley, 1979).

The map area has been seismically active since the Montana Bureau of Mines and Geology (MBMG) began monitoring and reporting local earthquakes in 1982. From 1982 through July 2009, the MBMG located a total of 629 earthquakes within the map area with magnitudes ranging from 0.3 to 4.0. Thirteen of these earthquakes had magnitudes of 3.0 or larger, and 26 earthquakes were reported as being felt by local residents. During the first 18 years of network recording, and average of 11 earthquakes per year occurred in the map area. An earthquake swarm occurred northeast of Townsend in the north-central part of the map area from April 1, 2000 through July 30, 2000 that included 169 earthquakes, eight of which had magnitudes from 3.0 to 4.0. Less energetic earthquake swarms occurred near the same location in October 2007 (19 events, maximum magnitude 3.2) and again August 20-27, 2008 (41 events, maximum magnitudes 3.2 and 3.5). The MBMG determined fault plane solutions from P-wave first motion patterns for 13 earthquakes with magnitudes ranging from magnitude 1.9 to 4.0. All fault plane solutions indicate strike-slip or normal faulting with a few mechanisms showing oblique-normal faulting. All fault plane solutions have axes of minimum compressive stress (sigma 3) oriented nearly horizontally with azimuths ranging from NE-SW to east-west. (M. Stickney, written communication, 2009).

During field mapping for this report, two earthquakes, felt locally, occurred on August 20, 2008: a magnitude 3.3, followed by a 3.5 about 3½ hours later. These events were followed by a swarm of 59 earthquakes, centered east of Toston that continued through the end of September, 2008 (Stickney, 2008), and into spring of 2009 (M. Stickney, personal communication). Figure 4 shows the relationship of the Sixmile Creek fault to the Clarkston Valley fault, a potentially active fault which is considered at least capable of generating a magnitude 6.75 earthquake (Wong and others, 1999).

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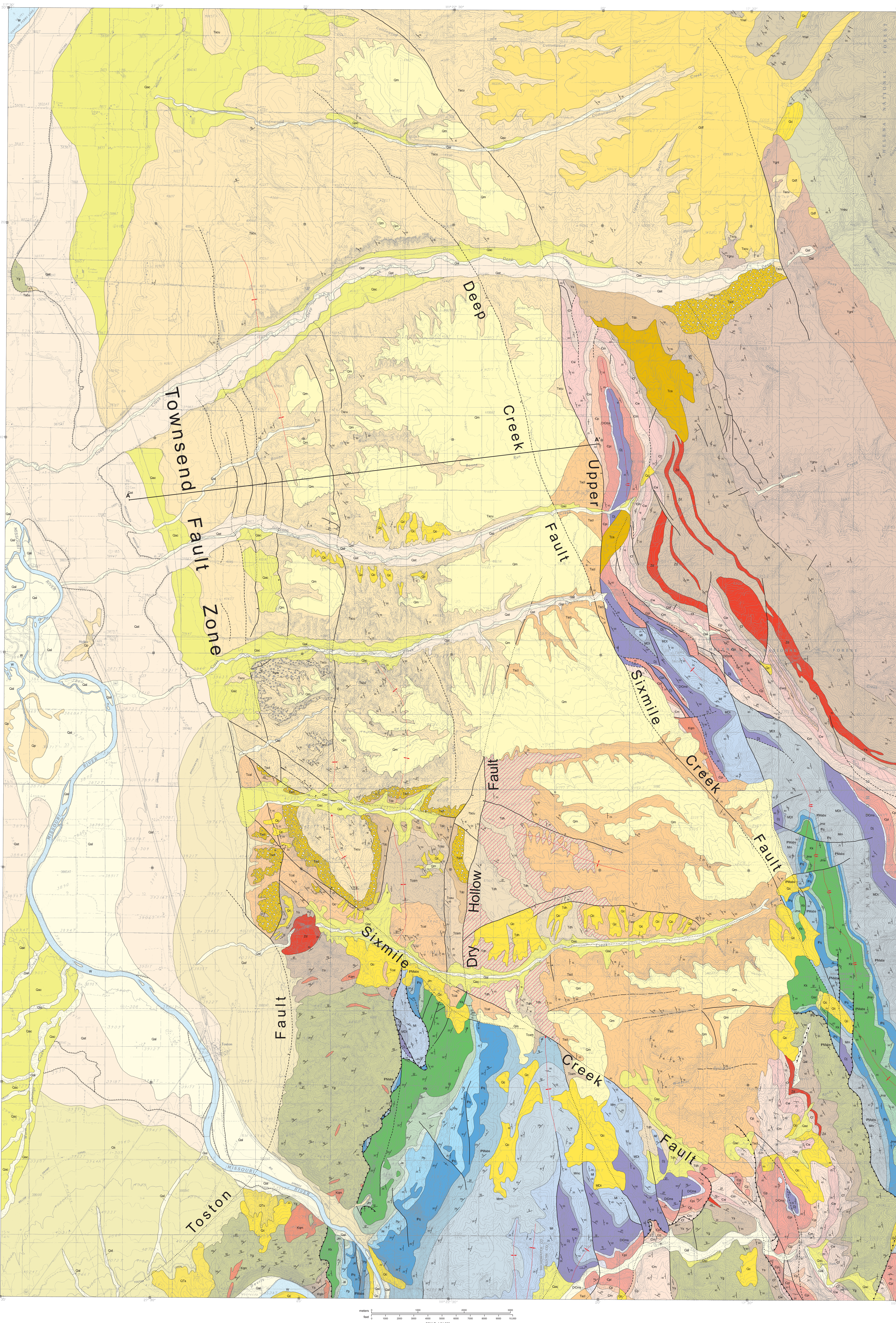


MAP UNITS

Qal	Alluvium of Holocene channels and flood plains
Qac	Alluvium and colluvium, undivided
Qp	Paludal deposit
Qs	Sediment, undivided
Qc	Colluvium
Qdf	Debris flow deposit
Qaf	Alluvial fan deposit
Qat	Alluvial terrace deposit
Qm	Mantle deposit
QTs	Sediment, undivided
Tscu	Sixmile Creek Formation, upper
Tsct	Sixmile Creek Fm., Toston member
Tscl	Sixmile Creek Formation, lower
Tdh	Dry Hollow map unit]
Tdc	Dunbar Creek Formation
Tca	Climbing Arrow Formation
Tcau	Climbing Arrow Formation, upper
Tcam	Climbing Arrow Formation, middle
Tcal	Climbing Arrow Formation, lower
Kqm	Quartz monzonite
Kk	Kootenai Formation
Jme	Morrison Formation and Ellis Group, undivided
Jm	Morrison Formation
Je	Ellis Group, undivided
Pp	Phosphoria Formation
IPq	Quadrant Formation
IPMabs	Amsden and Big Snowy Formations, undivided
Mm	Madison Group, undivided
Mmc	Mission Canyon Limestone
Ml	Lodgepole Limestone
MDt	Three Forks Formation
Dj	Jefferson Formation
D-Cms	Maywood and Snowy Range Fms.
-Cpi	Pilgrim Limestone
-Cp	Park Shale
-Cm	Meagher Limestone
-Cw	Wolsey Shale
-Cwq	Wolsey Formation, quartzite bed
-Cf	Flathead Formation
Zd	Diabase
Ys	Spokane Formation
Yg	Greyson Formation
Ygnu	Greyson Formation, upper
Ygnl	Greyson Formation, lower
Yneu	Newland Limestone, upper
Ynel	Newland Limestone, lower
W	Water

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

MAP SYMBOLS

Contact between geologic units

Fault, normal—Dashed where inferred, dotted where concealed fault is inferred. Ball and bar on downthrown side. Northwest-trending faults may have component of strike-slip movement

Fault, thrust—Dashed where inferred; dotted where concealed; teeth on upper plate

Lineament

Terrace scarp—Barbs on downcut side

Strike and dip of bedding—Number indicates angle of dip in degrees.

Strike and dip of overturned bedding—Number indicates angle of dip of overturned beds

Vertical bedding

Syncline—Showing axial plane trace

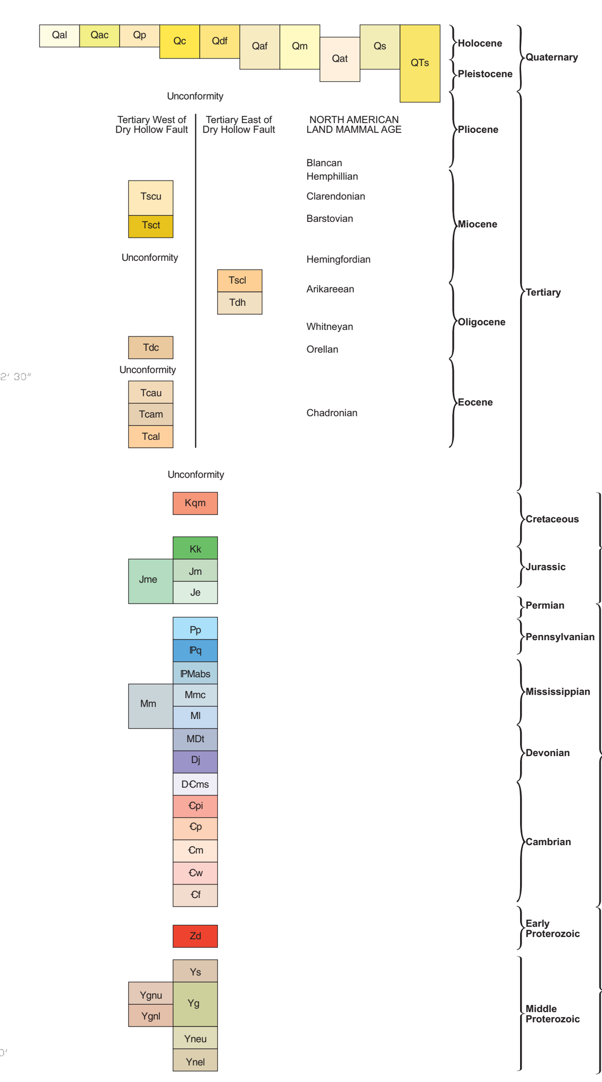
Anticline—Showing axial plane trace. Dotted where concealed

Monocline—Anticlinal bend. Short arrow on more steeply dipping limb

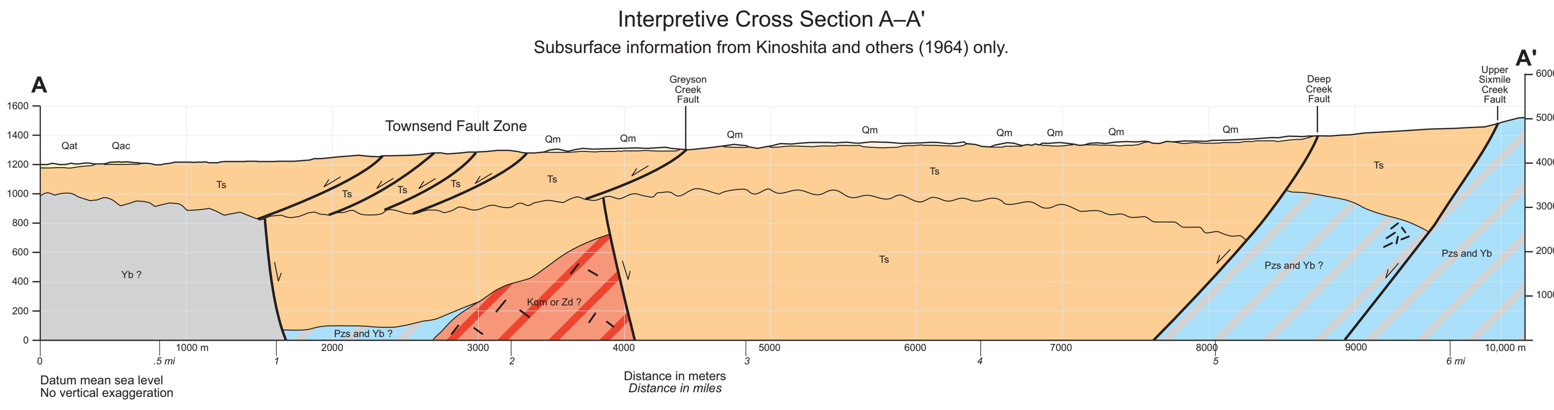
Tsct Tscu **Rounded cobble conglomerate/gravel**—Toston member of Sixmile Creek Formation (Tsct) and extensive bed in upper Sixmile Creek Formation (Tscu)

Tdh **Red mudstone facies of Dry Hollow map unit**

CORRELATION CHART



Interpretive Cross Section A–A'
Subsurface information from Kinoshita and others (1964) only.



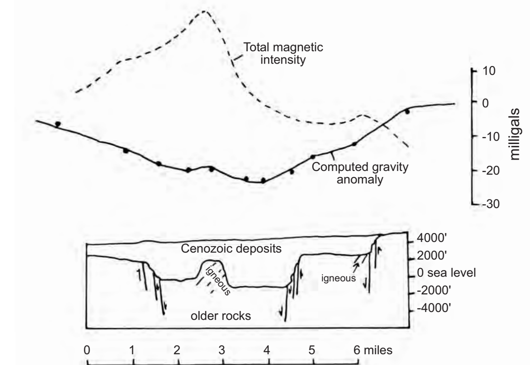
Cross section explanation

Qac	Alluvium and colluvium
Qat	Alluvial terrace deposit
Qm	Mantle
Ts	Tertiary deposits
Kqm	Quartz monzonite
Pzs	Paleozoic sedimentary rock
Zd	Diorite
Yb	Belt Supergroup

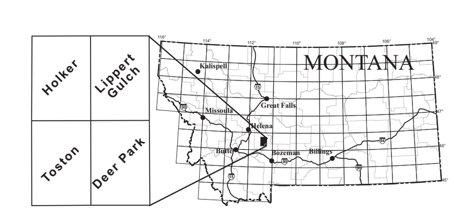
Igneous rock

unconformity

Fault showing relative sense of movement



Diagrammatic section near cross section A-A' interpreted from geophysical and geologic data. Modified from Kinoshita and others, 1964.



Holker
Base map produced by the United States Geological Survey
Control by: USGS, NOS/ NOAA, Bonneville Power Admin.
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° 30' East
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

Contour Interval: 20 feet

Toston
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: 20 feet; Supplemental Contour Interval 10 feet

Lippert 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

Deer Park
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

Maps may be obtained from: Publications Office
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Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number 08HQAG0085. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

GIS production: Ken Sandau and Paul Thale, MBMG. Map layout: Susan Smith, MBMG.

MBMG Open File 586

Geologic Map of the southern Townsend Basin, Broadwater and Gallatin Counties, Montana

Susan M. Vuke

2009