GEOLOGIC MAP OF THE CENOZOIC DEPOSITS OF THE LOWER JEFFERSON VALLEY SOUTHWESTERN MONTANA

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LOWER JEFFERSON VALLEY
TERTIARY STRATIGRAPHY

Kuenzi and Fields (1971) established Tertiary lithostratigraphy for southwestern Montana partly as a modification of formal stratigraphy established in the Three Forks area (Robinson, 1963), and in the Toston area (Robinson, 1967). Modifications by Kuenzi and Fields (1971) included restricting the Sixmile Creek Formation of Robinson (1967) to Tertiary strata that overlie the mid-Tertiary (Hemingfordian) unconformity (Fig. 2), and defining a new stratigraphic unit, the Renova Formation, underlying the unconformity. Kuenzi and Fields (1971) described the Sixmile Creek Formation as typically coarse grained (defined as fine sand and coarser) and the underlying Renova Formation as fine grained (defined as greater than 70 percent terrigenous very fine sand and finer).

Kuenzi and Fields (1971) divided the Renova Formation into three members west of the map area. Two of the members, the Dunbar Creek and Climbing Arrow, were previously formally established as Tertiary formations by Robinson (1963) in the Three Forks area. Kuenzi and Fields (1971) changed the stratigraphic rank of these two formations to member status in the upper Jefferson Valley. Subsequently, an informal late Arikareean unit, the Negro Hollow map unit north of Red Hill, was described by Lofgren (1985) and considered the upper part of the Renova Formation.

Five sequences have been recognized in the Cenozoic deposits in the upper Jefferson Valley and other parts of southwestern Montana. These sequences are recognized principally from bounding unconformities rather than than lithology because of the lateral and vertical repetition of lithologies throughout the Tertiary section (Hanneman and Wideman, 1991). The sequence-bounding unconformities are recognized based on paleosols (primarily stacked calcic paleosols), erosion surfaces, and angular stratal relationships. Some paleosols have been traced from outcrop into the subsurface in the map area where they are recognized as seismic reflectors (Hanneman and others, 1994).

The lithostratigraphic and sequence stratigraphic approaches to dividing Cenozoic deposits have both been greatly augmented by fossil data, especially vertebrate fossils, and both approaches recognize unconformity-bounded units. The International Subcommission on Stratigraphic Classification prefers the name *synthem* (Chang, 1975) for unconformity-bounded stratigraphic units (Salvador, 1987). The latest (1983) North American Stratigraphic Code introduced the category of allostratigraphic units that are comparable to synthems (Salvador, 1987). A synthem mapping approach was informally used for the Tertiary deposits in this report on the upper Jefferson Valley. Rather than lump all of the Tertiary deposits that overlie the mid-Tertiary (Hemingfordian) unconformity into the Sixmile Creek Formation or Sequence 4, for example, separate facies were mapped as informal units that comprise the Sixmile Creek synthem in the map area of this report, and other reports (Vuke, 2004; Vuke and others, 2004; Vuke, 2003). This approach takes into account intrabasinal and interbasinal facies changes within the unconformity-bounded sedimentary packages and also helps in recognizing faults that may juxtapose a younger part of the synthem against an older part. Additionally, only one horizon of stacked calcic paleosols was recognized in the area, in the Fairview map unit south of Three Forks, the only place a paleosol horizon could be used for mapping. No stacked calcic paleosols were recognized at the mid-Miocene (Hemingfordian) unconformity (Fig. 2) anywhere in the map area.

In this report the Dunbar Creek and Climbing Arrow are treated as formations following their original designations by Robinson (1963) because the thick Climbing Arrow Formation is divided into many mappable units on the present map of the Lower Jefferson Valley.

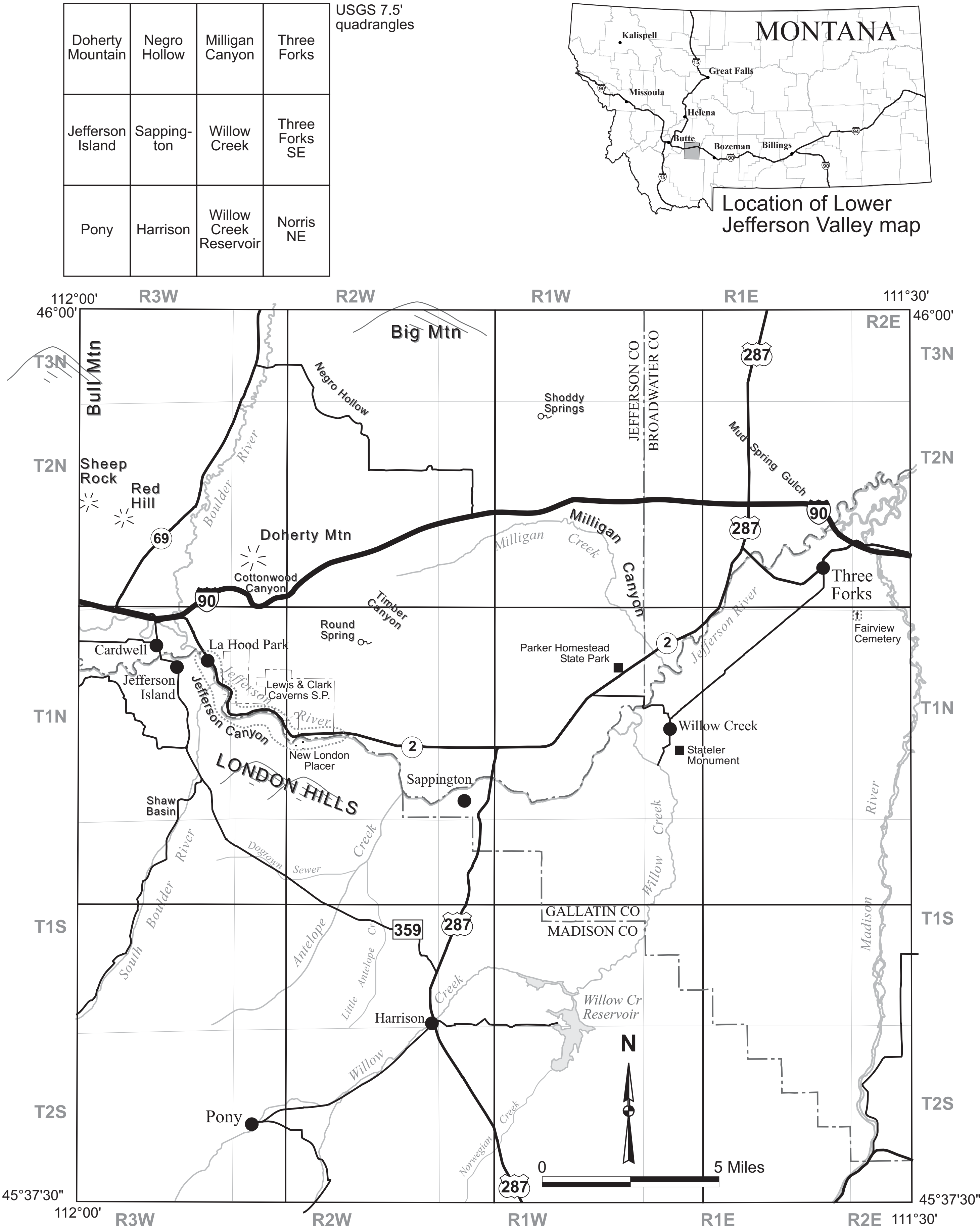


Figure 1. Location of the Lower Jefferson Valley map and index of 7.5' quadrangles.

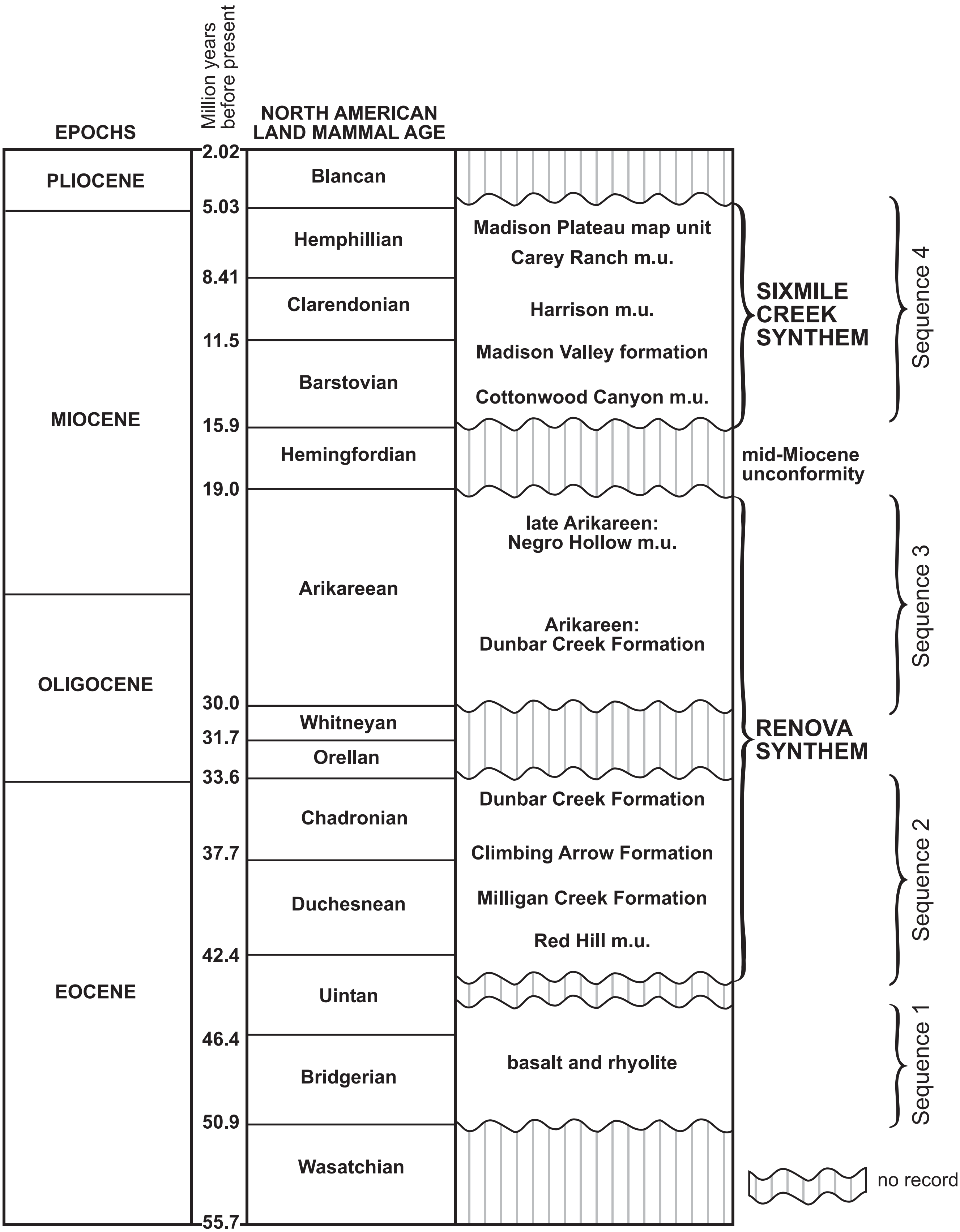


Figure 2. Lower Jefferson Valley correlation chart, modified from Rasmussen (2003), showing Tertiary sequences of Hanneman and Wideman (1991).

Southwest Montana Transverse Zone and Jefferson Canyon Fault

The east-striking Southwest Montana Transverse Zone is a significant tectonic feature that transects the map area along the Jefferson Canyon Fault (Schmidt and O'Neill, 1982; Schmidt and others, 1987). The Jefferson Canyon fault not only separates Proterozoic Belt Supergroup LaHood Formation to the north from Archean metamorphic rocks to the south, but also marks the southern margin of a major eastward bulge in the Montana part of the fold and thrust belt (Schmidt and O'Neill, 1982) (Fig. 3). The Archean crystalline rocks south of the fault have a pronounced northwest-striking structural grain (Schmidt and Garihan 1983). Many of the northwest-striking faults are associated with northwest-plunging hanging-wall anticlines cored with Archean metamorphic rocks (Schmidt and O'Neill, 1982). The Jefferson Canyon Fault and the northwest-striking faults to the south all experienced significant episodes of movement during the Proterozoic, Late Cretaceous, and late Cenozoic. Many studies have pieced together the geologic history of this area, especially during Late Cretaceous and early Paleocene compressional tectonics (Garihan and others, 1983; O'Neill and others, 1990; Schmidt, 1975; Schmidt, 1976; Schmidt, 1979; Schmidt and Garihan, 1983, Schmidt and Garihan, 1986a, Schmidt and Garihan, 1986b; Schmidt and Geiger, 1985; Schmidt, and others, 1989; Schmidt, and Hendrix, 1981; Schmidt, and O'Neill, 1982; Schmidt and others,1981; Schmidt and others, 1987; Schmidt, and others, 1988; Schmidt and others, 1990, Schmidt and others, 1991), but also during post-Laramide extensional tectonics (Schmidt and Garihan, 1986b; Schmidt and others, 1987).

Latest Cretaceous, Paleogene, and early Miocene

Near the end of the Cretaceous, about 70 million years ago, 10,000 or more feet of Elkhorn Mountains Volcanic rocks overlay older rocks in the area (Klepper and others, 1957). A tremendous volume of the volcanic rocks was eroded from the area during the late Maastrichtian and Paleocene and deposited to the east in the Upper Cretaceous Livingston Group (Lageson and others, 2001) and lower Paleocene Fort Union Formation.

Basalt and rhyolite on Bull Mountain and in the southeastern part of the map area, mark the start of Eocene extension. The Red Hill map unit may be the oldest preserved Tertiary sedimentary unit deposited during the Eocene in the map area. It is exposed in limited areas throughout the map area, always on bedrock and usually overlain by younger Tertiary units. The unit may represent colluvium, mass flow deposits, and alluvium associated with red, kaolinitic siltstone and mudstone that may have a pedogenic origin during a humid climate (Richard, 1966; Kuenzi, 1966). At Red Hill, Timber Canyon, and the east side of Doherty Mountain, the Red Hill map unit may be associated with Tertiary thrust faults, and may have a tectonic origin. If that is the case, the unit may be as young as Miocene. Various interpretations of the unit are discussed in Foster and others (1993), and Vuke and others (2004).

The Red Hill map unit is overlain by the Milligan Creek Formation at Milligan Canyon (Robinson, 1963); it is overlain by the Milligan Creek facies of the Climbing Arrow Formation east of Timber Canyon, and north of Negro Hollow; and it is overlain by the Antelope Creek map unit near Harrison. Each of the units overlying the Red Hill map unit is lithologically similar. The Shoddy Springs map unit has lithologies similar to those in the Milligan Canyon facies of the Climbing Arrow Formation. Both the Milligan Creek facies map unit (Climbing Arrow Formation) and the Shoddy Springs map unit (Climbing Arrow Formation) are overlain by the Doherty Mountain map unit (Climbing Arrow Formation). A vertebrate jaw found in the Milligan Creek facies map unit is late Duchesnean to early Chadronian (A. Tabrum, written communication, 2006). Fossils in the Shoddy Springs map unit are Uintan (Robinson, 1963) to Duchesnean (A. Tabrum, personal communication, 2005).

The Chadronian Doherty Mountain map unit (Climbing Arrow Formation) on the east side of Bull Mountain contains sinuous channels of immature sandstone, and granule and pebble conglomerate that have the appearance of weathered granitic rock that has undergone little transport. Biotite is relatively abundant. Lithic clasts are almost all granitic, and there are only minor, scattered clasts of Elkhorn

Mountains Volcanics. Despite the modern proximity to Bull Mountain, Doherty Mountain, and the Tobacco Root Mountains, there are only sparse lithic clasts other than granitic and volcanic rocks. Although the Boulder Batholith or Tobacco Root Batholith are obvious possibilities for the source of the granitic sediment, paleocurrent data suggest southwest paleoflow in the Climbing Arrow Formation east of Bull Mountain (Richard, 1966; Lofgren, 1985), making these batholiths and unlikely source. Huge boulders of granitic rock were found just south of Negro Hollow northeast of the exposures of Climbing Arrow east of Bull Mountain. Granitic rocks that are now buried in this area may have been exposed as sources for the Climbing Arrow granitic clasts. Some clasts of quartz and feldspar in the Climbing Arrow in this area are large enough to have been derived from pegmatites.

The granitic sandstone and conglomerate in the Climbing Arrow Formation near Bull Mountain contain biotite and subordinate muscovite (Streeter, 1983). Other two-mica sandstones in the Renova Formation of southwestern Montana are interpreted as derived from the Idaho Batholith to the west (Thomas, 1995). However, the immaturity of the Climbing Arrow sandstone and conglomerate in the Bull Mountain area suggests that they were not derived from a distal source. Granitic rocks of the exposed Boulder and Tobacco Root Batholiths contain only biotite (R. Berg, personal communication, 2004) and were not the source of the muscovite.

East of Timber Canyon, the Doherty Mountain map unit (Climbing Arrow Formation) is dominantly derived from a granitic source and commonly weathers to grus, but higher in the section the granitic clasts are replaced by fine-grained, dark volcanic and quartzite clasts probably indicating a western source. North of the Jefferson River granitic clasts were not found in the Climbing Arrow map units. South of the Jefferson River, Archean clasts are present in the Stateler map unit (Climbing Arrow Formation), indicating a southern source.

East of Bull Mountain, the late Arikareean (Early Miocene) Negro Hollow map unit unconformably overlies the Climbing Arrow Formation, and no deposits of Whitneyan or Orellan (Oligocene) age were found (Lofgren, 1985) (Fig. 2). Conglomerate in the Negro Hollow map unit is also primarily composed of granitic clasts (Lofgren, 1985), suggesting that the Elkhorn Mountains Volcanics on Bull Mountain were still not exposed or were only minimally exposed during the early Miocene. Arikareean fossils were also found in the lowest part of the Dunbar Creek Formation south of Three Forks (Douglas, 1901; Wood, 1938), mapped somewhat lower on the present map of the Lower Jefferson Valley than previously mapped (Robinson, 1963). Whitneyan and Orellan deposits are also apparently missing in the area south of Three Forks as in the area east of Bull Mountain. The Arikareean Dunbar Creek Formation disconformably overlies the Chadronian Climbing Arrow Formation south of Three Forks. The unconformity is marked by stacked calcic paleosols as described by Hanneman and Wideman (1991) in the Fairview map unit (top of the Climbing Arrow Formation). North of the Jefferson River, the Dunbar Creek Formation as mapped by Robinson (1963) has only yielded Chadronian fossils.

Deposits above the mid-Miocene unconformity

An episode of erosion or non-deposition occurred during the Hemingfordian. The oldest deposits following this episode are the Cottonwood Canyon map unit that contains early Barstovian (late Miocene) fossils (Lofgren, 1985) and the Madison Valley formation that also contains Barstovian fossils (Dorr, 1956). The Cottonwood Canyon map unit disconformably overlies the Negro Hollow map unit, the Climbing Arrrow map unit, or Paleozoic rocks and LaHood Formation. The Madison Valley formation disconformably overlies the Dunbar Creek Formation. The unconformity at both locations is the mid-Miocene unconformity or mid-Tertiary unconformity in older literature (Kuenzi and Richard, 1969; Rasmussen, 1973). East of Bull Mountain, west of Big Mountain, and south of Three Forks, Barstovian deposits overlie Arikareean deposits. The same relationship is true in the Madison bluffs just east of the map area (Vuke, 2003; revised 2004).

The Cottonwood Canyon map unit contains sporadic granitic boulders that are generally larger than the largest non-granitic clasts, both at Cottonwood Canyon and Negro Hollow. The Cottonwood Canyon map unit is laterally extensive and contains rounded and subrounded cobbles throughout most of its extent except near Cottonwood Canyon where it rests on Paleozoic rocks or LaHood Formation. In that area, the clasts range to boulder size. The Cottonwood Canyon map unit is likely a fluvial deposit.

The Harrison map unit also contains oversized granitic boulders. By contrast, it is a texturally poorly sorted, disorganized deposit with linear geometry, and contains abundant Archean clasts, totally lacking in the Cottonwood Canyon map unit. The Harrison map unit extends from southwest of Harrison to the Jefferson River at Sappington and may have been deposited as a debris flow that developed during uplift on the northeast side of the Elk Creek Fault (see fault section).

Clasts in the Barstovian deposits (mapped as Cottonwood Canyon map unit) on the west side of the Boulder River, just north of the map area, are almost exclusively composed of Elkhorn Mountains Volcanics (Lofgren, 1985), suggesting the exposure or uplift of Bull Mountain during the Miocene. Deposits of the Carey Ranch map unit on the east side of the Boulder River also overlie the Cottonwood Canyon map unit, but are dominantly composed of Paleozoic clasts, suggesting that Big Mountain was exposed. Red Hill, just east of Bull Mountain, was exposed during the Miocene or Pliocene.

Younger units in the map area also have a variety of sources. Distinguishing clast compositions such as units that have Archean metamorphic clasts, clasts of distally derived Belt Supergroup quartzite, clasts of LaHood Formation, clasts of Elkhorn Mountains Volcanics, or clasts of Paleozoic rocks, in conjunction with dating, will allow interpretation of the tectonic and paleogeographic geologic history of the area. The list below shows Cenozoic map units sorted by various criteria.

CENOZOIC DEPOSITS GROUPED BY VARIOUS CRITERIA

Units that contain boulders of granitic rock, generally larger than the average clast size of other compositions

- Harrison map unit (Tha)
- Cottonwood Canyon map unit (Tcc)
  Note that the Red Bluff Formation to the south of the map area also contains oversized boulders of granitic rock.

Te units that contain lenses of locally derived breccia

- Dunbar Creek Formation north of the Jefferson River (Tdc) (dominantly Pz limestone)
- Milligan Creek Formation (Tmc) (dominantly Pz limestone)
- Milligan Creek facies of Climbing Arrow Formation (Tdmca) (dominantly Pz limestone and intraformational limestone)
- Shoddy Springs map unit (Tcass) (dominantly Elkhorn Mountains Volcanics)
- Red Hill map unit (Treh) (dominantly Pz limestone, but also Archean clasts and one location and LaHood Formation clasts at another location)

QT units that contain lenses of unconsolidated angular locally derived clasts

- Eustis map unit (QTeu)
- Parker Homestead map unit (QTph) (Note that in a large area between the east side of Jefferson Canyon and the south end of Milligan Canyon, the Parker Homestead map unit rests on LaHood Formation and is not immediately adjacent to Paleozoic rocks, yet except at the base, all the clasts in the map unit are derived from Paleozoic rocks.
- Sappington Junction map unit (QTsj)

QT or Te units dominantly composed of angular locally derived clasts

- Silver Sage map unit (QTsi)
- Carey Ranch map unit (Tcar)

Te units that contain gravel or conglomerate with Archean clasts

- Jefferson Canyon map unit (QTjc)
- Harrison map unit (Tha)
- Shaw Basin map unit (Tsb)
- Madison Valley formation (Tmva)
- Antelope Creek map unit (Tanc)
- Stateler map unit (Tcas)

QT and Te units that contain clasts of LaHood Formation

- Jefferson Canyon map unit (only in Jefferson Canyon) (QTjc)
- Parker Homestead map unit (only at the very base) (QTph)
- Red Hill map unit (only at one location adjacent to the Jefferson Canyon Fault) (Treh)

Te units that contain gravel or conglomerate dominantly of Belt quartzite, volcanic, and plutonic rocks; no Archean clasts

- Madison Plateau map unit (some Archean clasts at base probably reworked from underlying Madison Valley formation) (Tmp)
- Cottonwood Canyon map unit (Tcc)
- Parrot Bench map unit (Tpb)
- Doherty Mountain map unit (higher in section only; lower in section granitic-derived clasts abundant) (Tcadm)
- Price farm map unit, Climbing Arrow Formation (Tcapf)

Units that are dominantly silt

- Eolian deposits (Qe)
- Parker Homestead map unit (QTph)
- Negro Hollow formation (informal) (Tnh) (in fine-grained part)
- Shoddy Springs map unit, Climbing Arrow Formation (Tcass) (in fine-grained part)

Units dominantly derived from granitic source rock

- Lower Doherty Mountain map unit (Tcadm)
- Negro Hollow map unit (Tnh) (coarser part)

Units that contain subordinate clasts derived from granitic source rock

- Antelope Creek map unit (Tanc)

Units with abundant redbeds

- Parker Farm map unit, Climbing Arrow Formation (Tcapf)
- Red Hill map unit (Treh)

Units in which silicified wood was found

- Madison Valley Formation (Tmva)
- Doherty Mountain map unit, Climbing Arrow Formation (Tcadm, Tcadml, Tcadmu)
- Fairview map unit, Climbing Arrow Formation (Tcaf)

Units in which limestone beds with gastropods and ostracods were found

- Dunbar Creek Formation (Tdc)
- Price Farm map unit, Climbing Arrow Formation (Tcapf)
- Milligan Creek Formation (Tmc)
- Milligan Creek facies, Climbing Arrow Formation (Tcamc)

CENOZOIC FAULTS

Cenozoic movement has occurred on a number of faults in the Lower Jefferson Valley. Selected faults are discussed below.

Elk Creek and Cherry Creek Faults

Faults in the southern part of the map area are dominantly northwest-striking. The most prominent are the Elk Creek and Cherry Creek Faults. Both faults have a geologic history of recurrent movement since the Precambrian, typical of the northwest-striking faults in Archean rocks south of the Jefferson Canyon Fault (Schmidt and Garihan, 1986). The Elk Creek Fault and to a lesser extent, the Cherry Creek Fault offset an extensive Pleistocene pediment, developed on the Tertiary Madison Plateau map unit, by as much as 200 ft (de la Montagne, 1960; Feichtinger, 1970). Parallel faults north of the Elk Creek Fault have also offset this pediment. The Miocene Madison Valley formation dips as much as 50° to the northeast on the northeast side of Cherry Creek Fault fault (Kellogg and Vuke, 1996), suggesting Neogene fault movement.

The Quaternary movement on the Elk Creek Fault that offset the Pleistocene pediment on the Late Miocene Madison Plateau map unit was down to the north. To the west where the fault cuts through Archean metamorphic rocks, the net relative sense of movement is down to the south suggesting reversal of movement on the fault (Feichtinger, 1970).

Paleocurrent data for the Antelope Creek map unit are to the northeast on both sides of the Cherry Creek and Elk Creek Faults, suggesting that the faults were not active at the time of deposition and did not serve as a barrier to paleoflow (Elliott, 1998; Elliott and others, 2003). By contrast, paleocurrent data for the Miocene Madison Valley formation show northeast flow south of the faults switching to southeast flow between the faults and parallel to them. This suggests that the Elk Creek Fault, or both Elk Creek and Cherry Creek Faults, influenced the drainage pattern during the Miocene. Younger sediment also shows this trend from northeast paleoflow south of the faults to southeast paleoflow along the south side of the Elk Creek Fault (Elliott, 1998; Elliott and others, 2003).

Geophysical studies across the Elk Creek and Cherry Creek Faults indicate that they bound a deep graben in the Harrison area (Kroeger, 1997; Hoh, 1977), also suggested by Bouguer gravity and paleomagnetic data (Davis and other, 1965). The graben is filled with Tertiary sediment.

The development of Jefferson Canyon by entrenchment of the Jefferson River has been attributed primarily to uplift on the Starrett's Ditch Fault (Aram, 1979)(see Starretts Ditch Fault below), but uplift on the Elk Creek Fault may have played a more significant role.

Milligan Canyon Fault

Several faults strike northwest through Milligan Canyon offsetting Paleozoic rocks. One of the faults is inferred to project into the Tertiary deposits of the western Three Forks Basin to the north. Offset of Tertiary units is inferred because of the change in lithology on either side of the inferred fault. The Doherty Mountain map unit on the west side of the fault, contains abundant silicified wood, only sparse reddish beds, and no limestone. On the east side of the inferred fault, the Price Farm map unit contains abundant redbeds, limestone and marlstone lenses, and no silicified wood was found. Both units contain lenses of pebble to cobble gravel or conglomerate, with grossly similar clast compositions. The movement on the Milligan Canyon Fault occurred after or during the Chadronian, the age of the units on either side of the fault.

Starretts Ditch Fault

The Starretts Ditch Fault was named by Aram (1979) for an old gold flume on the western flank of the London Hills. It marks an abrupt change in the Jefferson Valley from a wide valley with a broad flood plain on the western downthrown side of the fault to a narrow valley in the Jefferson Canyon to the east. The fault has juxtaposed Tertiary rock and sediment on the west against the Proterozoic LaHood Formation and Paleozoic rocks on the east side of the fault. Tertiary deposits dip as much as 45° to the east into the fault (Aram, 1979). Uplift on the Starretts Ditch Fault is partly responsible for the entrenchment of the Jefferson River in Jefferson Canyon (Schmidt and others, 1987).

The Jefferson Canyon map unit (QTjc) was deposited as old terrace deposits along the Jefferson River in the canyon and east of the canyon. Heavy calcium carbonate coating on clasts and the relation of the deposit to the Parker Homestead map unit (see explanation) suggest that the oldest Jefferson Canyon map unit terrace gravel in the canyon is Tertiary, possibly as old as Miocene. The Jefferson Canyon map unit is deep in the canyon generally about 80 to 250 ft above the modern Jefferson River, so probably reflects deposition late in the development of the canyon. The gravels contain Archean clasts implying a southern source. Miocene uplift on the Elk Creek Fault (discussed above) probably contributed significantly to the entrenchment of the Jefferson River in the canyon. The Starretts Ditch Fault may have moved concurrently with the Elk Creek Fault, or subsequently.

West-vergent thrust faults and associated grabens

Anomalous east-dipping thrust faults are present at the south end of Big Mountain just north of Negro Hollow. Kinematic indicators suggest that the east-dipping thrust faults are west-vergent (Schmidt, 1979). West-vergent thrust faults are unusual in southwestern Montana where west-dipping Laramide thrust faults that resulted from west to east compression (Schmidt and others, 1977) are prevalent. The west-vergent thrust faults extend only a short distance to the north, but are replaced by west-vergent folds on the east flank of the Devil's Fence Anticline just north of the map area that extend for 4 km (Schmidt and O'Neill, 1982; Klepper and others, 1957, Plate 3), possibly cored by west-vergent, blind thrust faults. Southwest-vergent thrust faults apparently occur on Bull Mountain and possibly Red Hill (Vuke and others, 2004). Other east-dipping thrust faults were interpreted east of Doherty Mountain and at Timber Canyon. Other possible east or northeast-dipping thrust faults are indicated on the map with gray fault lines, however the presence of some of these faults and the direction of movement on others is speculative. As on Red Hill (Vuke and others, 2004), the Red Hill map unit seems to be associated with several of these faults, but the relationship is unclear. Kinematic data, essential for more definitive interpretation, were not collected from these faults

East-vergent thrust faults in the map area are clearly Laramide, but the timing of movement on the west-vergent thrust faults may be younger. On the west side of southern Big Mountain, Paleozoic beds are locally overturned to the west reflecting Laramide movement, which may have preceded development of the west-vergent thrust faults.

To the north, reversal of movement occurred on the Lewis and Clark line, a major transform fault (Sears and Fritz, 1998) (Fig. 3). Dextral-slip movement on the Lewis and Clark Line represents a reversal of the Laramide sinistral strike-slip movement (Fig. 3 a and b). Westward extension of the block south of Lewis and Clark Line resulted in the development of pull-apart basins such as the Helena and Townsend grabens, and grabens to the south (Reynolds, 1977; 1979). The west-vergent thrust faults in the map area are associated with normal faults and what are interpreted as grabens at the southern part of Big Mountain in the Negro Hollow area, and Timber Canyon. The graben at the south end of Big Mountain is widest along the Negro Hollow Fault (see below) and terminates at an apparent pivot point to the north. By contrast, the graben west of Timber Canyon is widest to the north, and terminates at an apparent pivot point to the south.

The change from Laramide compressional tectonics to extensional may have promoted the change from east-vergent to west-vergent thrusting. Thrusting during extension may have developed because of buttressing against the Elkhorn Mountains Volcanics and the Boulder Batholith in the western part of the map area, with continued extension producing more typical normal faults and grabens. Extensional thrusting and normal faulting may have alternated in this area. Some of the normal faults in the southern Big Mountain area appear to follow the trace of the east-dipping thrust faults.

Negro Hollow Fault

The Negro Hollow Fault strikes northwest, also the strike of basement faults to the south and the strike of the Lewis and Clark Line, a transverse fault to the north and northwest (Fig. 3). The Negro Hollow Fault has been interpreted as a dextral tear fault (Dull, 1994). If it is a tear fault, it is more likely related to the west-vergent thrusting that may have possibly occurred during Tertiary extension as discussed above. The Miocene (Barstovian) Cottonwood Canyon map unit occurs on both sides of the fault, down-dropped to the south, so the last movement on the fault occurred during or after late Miocene.

North Boulder Valley basin-bounding fault

A locally well exposed, high-angle, down-to-the-west normal fault bounds the west side of southern Big Mountain and juxtaposes Tertiary sediment and rocks against the Mississippian Madison Group. The Miocene or Pliocene Carey Ranch map unit dips steeply to west along the fault. Offset on the fault may be as much as 500 ft (Aram, 1979), and it may be an extension of the Starretts Ditch Fault (Lofgren, 1083). In the upper Jefferson, Three Forks, Madison and other basins of southwestern Montana, the basin-bounding faults on the east side of valleys are listric-normal faults, often following older fault planes of Laramide thrust faults (Schmidt and others, 1984; Sheedlo, 1984; Kellogg and others, 1995). Tertiary valley fill typically dips eastward toward the basin-bounding listric fault. By contrast, the Tertiary deposits along the basin-bounding fault on the east side of the North Boulder Valley, dip to the west. The gravity profile of the fault is steep, about 84° (Dull, 1994) and does not appear to have followed a Laramide thrust plane. West-dipping Laramide thrust planes may have been broken up by subsequent east-dipping thrusts described above, prior to development of the basin-bounding fault, interfering with development of a typical listric-normal basin-bounding fault. A reverse fault model fits the 84° fault plane dip as well as a normal fault model (Dull, 1994). At the surface the fault plane dips at high angle to both the east and the west at different locations and locally the Madison Group limestone is overturned to the west along the fault. Gravity data suggest that the Boulder Valley is bounded by several faults that step down to the west (Dull, 1994), although the fault that bounds the Madison Group is the most prominent at the surface.

Inferred Arcuate Fault west of Madison River

An arcuate fault (T. 1 S., R. 1 E.) is inferred west of the Madison River based on map pattern. West of the fault, Archean rocks are extensively exposed, and there are only very limited exposures of Tertiary deposits. For several miles east of the fault, no Archean rocks are exposed, and the Tertiary section is estimated to be about 3000 ft thick (Davis and others, 1965). At some places along the fault, the Archean rocks on the west are at the same elevation as Tertiary deposits on the east side of the fault. Bouguer gravity data (Davis and others, 1965) show an arcuate pattern of relatively steep gravity contours coincident with the inferred fault. However, Tertiary deposits do not dip toward the fault, so if a fault is present, it must be a high-angle fault. This inferred fault may have moved simultaneously with movement on the Elk Creek Fault. To the west, the arcuate pattern of the London Hills Laramide basement-cored anticline associated with reverse-sinistral oblique slip movement on the associated basement fault (Schmidt and Hendrix, 1981; Schmidt and Garihan, 1983) is apparent. The fault-trace pattern of the inferred arcuate fault west of the Madison River may have been inherited from a Laramide foreland anticline that experienced reversal of movement during post-Laramide extension.

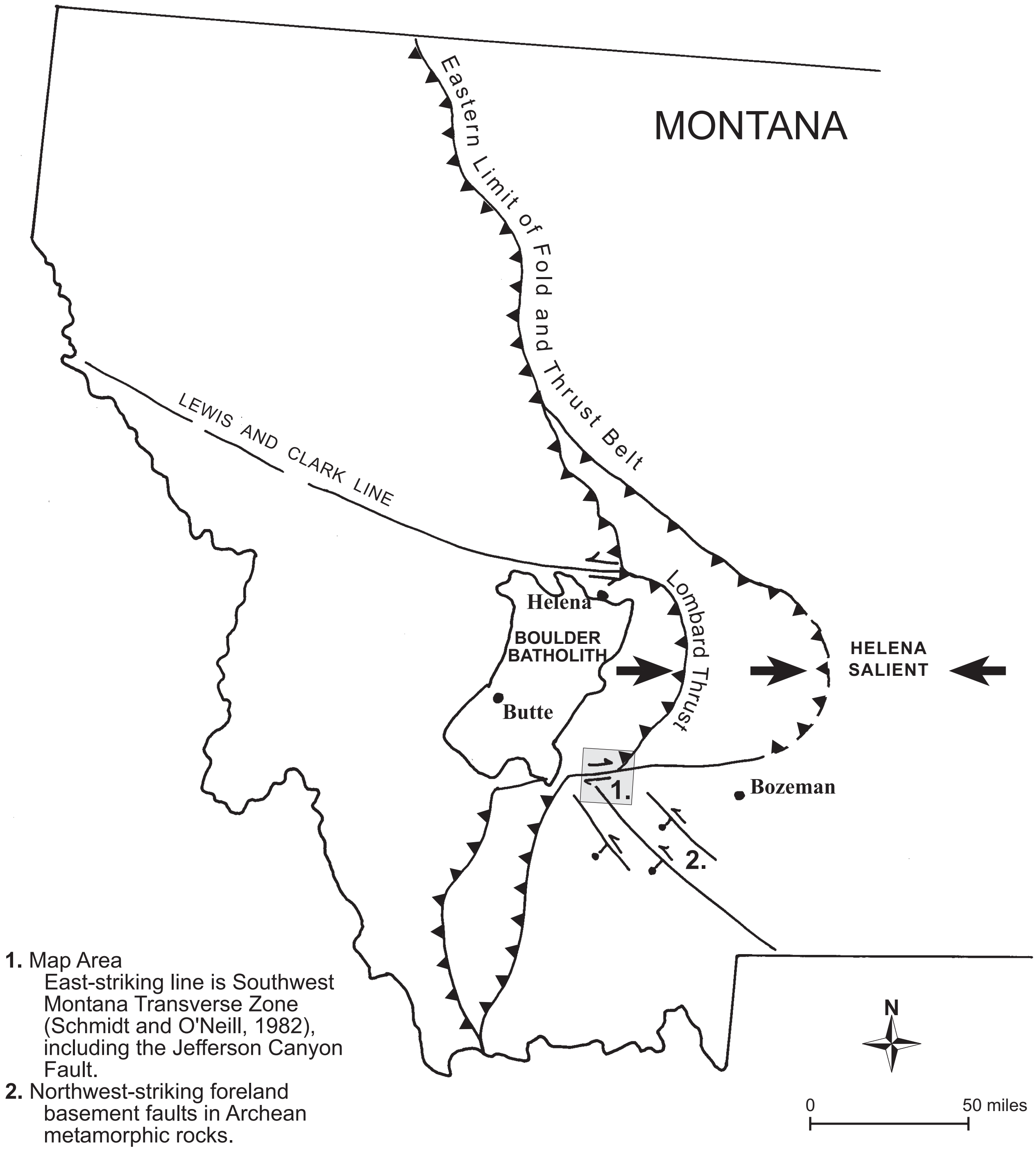


Figure 3A. Selected tectonic features in western Montana during Laramide compression. Arrows indicate direction of compression. Modified from Schmitt and others, 1995.

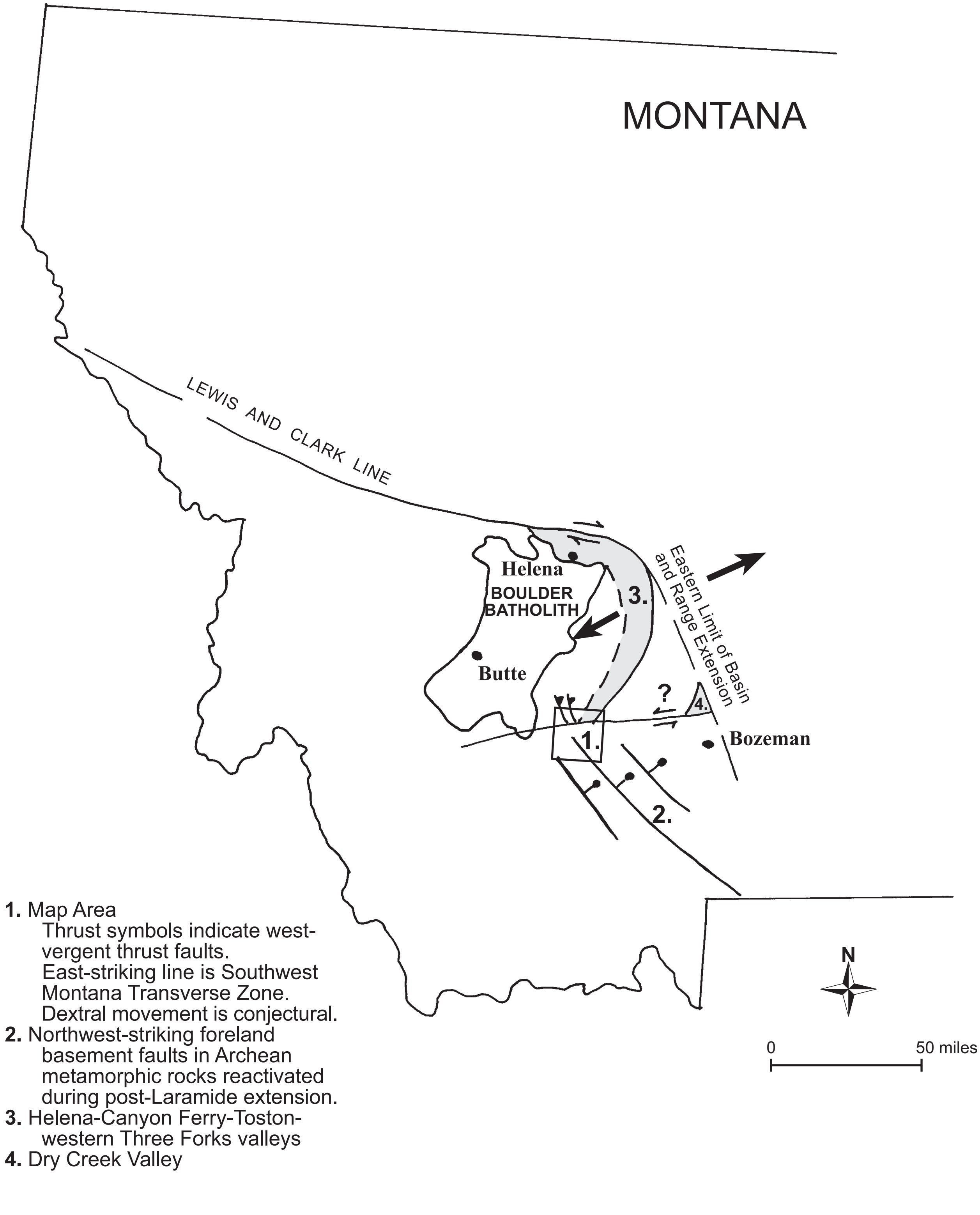


Figure 3B. Selected tectonic features in western Montana during post-Laramide extension. Arrows indicate direction of Recent extension (Stickney and Bartholomew, 1987).

ENVIRONMENTAL GEOLOGY

At the time the map of the Lower Jefferson Valley was prepared, several large housing developments were underway in the area, especially in the valley northwest of Three Forks and north of the Jefferson River (T. 2 N., R. 1 E.) (the western Three Forks Basin). Formerly, houses were primarily located at the valley margins where basin cover is relatively thin, and water could be obtained from bedrock beneath the Tertiary valley-fill sediment. Increasingly, houses are under construction within the central part of the valley where the basin fill may be as much as 2,500 ft thick (Robinson, 1963).

Most of the Tertiary section in the western Three Forks Basin north of the Jefferson River is the Climbing Arrow Formation, subdivided into five map units for this report: Shoddy Springs, Doherty Mountain, Price Farm, Mud Springs, and Broadwater map units. None of the units is likely to be a good aquifer capable of sustaining numerous dwellings. Sandstone and gravel in the map units occur either as linear channel deposits that pinch out laterally or as lenses. Based on surface exposures there are no sandstone, conglomerate or gravel deposits with a persistant sheet geometry that could be intercepted as an aquifer at a predictable stratigraphic horizon. Mudstone that separates the coarser lenses is typically bentonitic, and would serve as an impediment to groundwater flow. Siltstone in the Shoddy Springs map unit is argillaceous and tuffaceous, and likely has low porosity. Limestone beds occur in the Price Farm map unit, but they are thin and lenticular. Although water may be found in limited sand and gravel pockets in the western Three Forks Basin, the valley fill is not expected to contain predictable and reliable sources of quality groundwater.

At the Willow Creek Reservoir (Harrison Lake) area, the Elk Creek Fault (see fault section) has juxtaposed poorly resistant Tertiary deposits against resistant crystalline rock, providing a broad valley on the southwest side of the fault against a narrow gorge on the northeast side of the fault, a seemingly ideal place for the reservoir dam. The Willow Creek Reservoir overlies Tertiary sediment interpreted from Bouguer gravity data to be about 1,500 ft thick (Davis, and others, 1965) on the southwest side of the dam. However, the Elk Creek Fault is an active fault (Stickney, and others, 2000) with a probability of future movement, a consideration for dam safety.

LOWER JEFFERSON VALLEY
DESCRIPTION OF MAP UNITS

Note: Thicknesses are given in feet because original maps were on 7.5' quadrangles with contour intervals in feet. To convert feet to meters (the contour interval unit on this map), multiply feet x 0.3048.

*Map unit with age information from fossils.
**Map unit with age information based in part on stratigraphic relationship.

Qal **ALLUVIUM (Holocene)—**Gravel, sand, silt, and clay deposited in channels of modern rivers cut into Qalo, and channels of tributary streams. Jefferson and Madison River alluvium dominantly subrounded to rounded and fairly well sorted with clasts rarely larger than cobble size. Thickness probably less than 50 ft in most areas.

Qpa **PALUDAL DEPOSIT (Holocene)—**Sand, silt, and organic matter deposited in swamp environment. Taken from pattern on topographic base. Thickness probably less than 30 ft.

Qlk **LACUSTRINE DEPOSIT (Holocene)—**Sand, silt, and organic matter deposited during high water, and exposed around the margin of Willow Creek Reservoir (Harrison Lake) when water level is below maximum. Thickness probably less than 50 ft.

Qc **COLLUVIUM (Holocene)—**Deposit of unconsolidated, angular to subangular, locally derived clasts. Thickness variable; probably as much as 50 ft thick.

Qaf **ALLUVIAL FAN DEPOSIT** (**Holocene**)—Gravel, sand, silt, clay, and ash beds, poorly sorted with larger clasts both matrix-supported and clast-supported. Small deposits at mouths of minor tributaries along the Jefferson River that have retained at least some evidence of original alluvial fan morphology.

Qalo* **OLDER ALLUVIUM AND FLOOD PLAIN DEPOSIT** (**Holocene and Late Pleistocene**)—Gravel, sand, silt, clay, and organic matter deposited in broad, open older parts stream and river valleys. Late Pleistocene bison and Holocene animal bones have been found in these deposits (Robinson, 1963). Thickness about 450 ft (Robinson, 1963).

Qls **LANDSLIDE DEPOSIT** (**Holocene and late Pleistocene**)—Mass wasting deposit of rotated or chaotic beds that moved downslope. Landslide on east side of Golden Sunlight Mine in Doherty Mountain 7.5' quadrangle developed during 1994, caused by reactivation of an older landslide and initiated by weighting from mine waste dumps. A relatively competent part of the Tertiary section slid 2 to 4 ft on bentonitic mudstone of the Climbing Arrow Formation. Earlier natural downslope movement of the landslide was about 1,800 ft (Foster and Smith, 1995).

Qac **ALLUVIUM AND COLLUVIUM** (**Holocene and Pleistocene?)—**Dominantly sand, silt, clay, and subordinate gravel deposited on relatively gentle slopes primarily by sheetwash and gravity processes such as soil creep. Variable thickness, generally less than 30 ft thick.

Qat **ALLUVIAL TERRACE DEPOSIT** (**Holocene and Pleistocene?)—**Gravel, sand, silt, and clay underlying terraces along modern streams. Clasts subrounded and rounded and mostly pebble and cobble size. Thickness less than 30 ft.

Qe **EOLIAN DEPOSIT** (**Holocene and Pleistocene**)—(Description modified from Robinson, 1963) Yellowish-gray to very pale orange silt and clay-size sediment with scattered grains and streaks of rounded fine-grained sand. Dominantly volcanic glass, quartz, and clay minerals with minor amounts of mica, feldspar, and calcite. Some Quaternary eolian deposits are also included in the Parker Homestead map unit (QTph). Thickness highly variable. Locally as much as 100 ft. thick.

Qde **DEBRIS DEPOSIT (Holocene and Pleistocene)**—Surficial deposit of loose, angular rock fragments mechanically detached from bedrock. Thickness highly variable. Locally as much as 150 ft.

Qgr **GRAVEL DEPOSIT (Pleistocene)—** Flanks of Bull Mountain: Gravel, sand, silt, clay, and ash on the flanks of Bull Mountain that underlie pediment surface. Composed of locally derived rock, mostly of Elkhorn Mountains Volcanics with subordinate Paleozoic rocks. Southeast of Sheep Rock, deposit overlain by occasional blocky boulders of Cambrian Flathead Sandstone that may have undergone very little transport. Lower part brown and moderately cemented; upper part unconsolidated (Foster and others, 1993). Overlain by Holocene and Pleistocene loess that contains calcareous paleosols (Foster and others, 1993). Thickness as much as 40 ft. Negro Hollow area: Gravel, sand, silt, and clay that underlies pediment surface. Clasts subrounded and locally derived. Thickness about 20 ft. Along Negro Hollow Fault: Veneer of clasts reworked from Cottonwood Canyon map unit (Tcc). Clasts dominantly cobble size coated with calcium carbonate with some pebbles, sand, and silt. Thickness less than one foot.

Qgt **GLACIAL TILL (Pleistocene)—**Poorly sorted, angular to rounded, unconsolidated clasts of dominantly cobbles and boulders, but also pebbles, sand, silt, and clay. Larger clasts dominantly composed of Archean metamorphic rocks, and igneous rocks of the Tobacco Root Batholith. Includes some stratified outwash. Thickness less than 150 ft.

QTgr **GRAVEL (Pleistocene and/or Pliocene?)—**South of Three Forks: Well-rounded, well-sorted, clast-supported cobble gravel and calcium carbonate-cemented conglomerate. Clast composition: Belt Supergroup quartzite, Archean metamorphic rocks, and white quartz. Maximum thickness about 30 ft. Timber Canyon area: Unconsolidated poorly organized deposit of texturally poorly sorted, subangular to subrounded clasts of locally derived rock. Reddish soil associated with deposit locally. Clasts range to boulder size and boulders are abundant. Water well logs (Montana Bureau of Mines and Geology Groundwater Information Center database) south of Round Spring suggest thickness of 35 ft at that location and very thin at Round Spring itself.

QTph **PARKER HOMESTEAD Informal map unit (Holocene, Pleistocene, and Pliocene)—**Yellowish-gray to very pale orange, angular silt and clay-size sediment with lenses of angular and subangular locally-derived rock ranging to very large boulder size but commonly cobble size and smaller. Much less abundant lenses of rounded and subrounded pebbles and cobbles also present. In some areas, granules and pebbles float in the silty matrix. Locally cemented; clasts may be coated with calcium carbonate, especially near the base. May represent eolian deposits reworked by debris flows, small streams, and continual eolian redistribution and localized debris flows of angular locally derived rock. Thick calcium carbonate coating on clasts, local moderately well-cemented zones, and clast composition suggest the oldest part of the unit may be Pliocene or possibly older. Thickness variable. Maximum thickness may be as much as 200 ft.

Note: In a large area between the mouth of Milligan Canyon and the east end of Jefferson Canyon, the Parker Homestead map unit rests on the LaHood Formation, but the clasts in the map unit are Paleozoic limestone and other Paleozoic lithologies with LaHood clasts only locally at the base of the unit. This is true even where miles of LaHood Formation separate the map unit and the Paleozoic section.

Informal unit name derived from Parker Homestead State Park in the Willow Creek 7.5' quadrangle.

QTeu **EUSTIS Informal map unit (Pleistocene and/or Pliocene?)—**Light brown, gray, and locally reddish-gray, angular and subangular locally derived gravel in a coarse sand and granule matrix. Clast size ranges from pebble to small boulder. Maximum thickness probably about 150 ft.

Informal unit name derived from the community of Eustis in the Logan 7.5' quadrangle (west-adjacent to the Three Forks 7.5-minute quadrangle).

QTsj **SAPPINGTON JUNCTION Informal map unit** (Younger than Harrison map unit; probably **Pleistocene or Pliocene**)—Several rubble deposits of disorganized subangular clasts, dominantly boulder size, of very limited lateral extent near Sappington; some boulders extremely large. Clast composition locally derived Paleozoic limestone and orthoquartzite. Maximum thickness probably about 40 ft.

Note: The clasts in the map unit are derived from Paleozoic rocks even where the map unit rests on Archean rocks.

Informal unit name derived from local name for junction between Montana State Highways 2 and 287 near Sappington.

QTjc **JEFFERSON CANYON Informal map unit** (Younger than Milligan Canyon Formation; probably mostly **Pliocene or possibly Miocene**, but unconsolidated deposits in Jefferson Canyon west of Lewis and Clark Caverns may be **Pleistocene)**—Remnants of a terrace deposit with linear distribution along the Jefferson River between Milligan Canyon and LaHood Park; along South Boulder River; and near the mouth of the Boulder River. Gravel composed of subrounded clasts that range to boulder size along the Jefferson River and to cobble size along the South Boulder River and near the mouth of the Boulder River. Between Milligan Canyon and Lewis and Clark Caverns State Park most clasts are cobble size and the dominant clast compositions are Archean metamorphic rock and Belt Supergroup quartzite; unit is locally well cemented, although generally unconsolidated. At the New London placer (Fig. 1) most clasts are boulder size; clast composition includes Archean metamorphic rocks and Belt Supergroup quartzite as in the other deposits, and also subangular and subrounded clasts of LaHood Formation, quartzite from the LaHood Formation, and Paleozoic limestone, not present farther east. Clasts are dominantly LaHood Formation boulders and cobbles at two locations southeast of the mouth of the South Boulder River. The isolated deposits in this map unit may not all be contemporaneous. Thickness of Jefferson Canyon map unit along Jefferson River generally less than 20 ft, but thicker at the former New London location and other locations in Jefferson Canyon where clasts are boulders. Thickness less than 1 ft along the South Boulder River and near the mouth of the Boulder River.

Note: At two locations near Milligan Canyon, deposit is overlain by colluvium, but everywhere else it is overlain by the Parker Homestead map unit. In Jefferson Canyon, the overlying Parker Homestead map unit is limited to the width of the Jefferson Canyon map unit exposure. The interface between the two units was the focus of placer operations (R. McCulloch, personal communication, 2005), and this horizon was also apparently prospected about one mile west of the entrance to Lewis and Clark Caverns State Park. A similar relationship occurs south southwest of LaHood Park just northwest of the mouth of the South Boulder River where a cobble gravel and conglomerate are overlain by the Parker Homestead map unit. At this location the gravel is locally well cemented, and the clasts are mostly cobbles. By contrast to the otherwise similar deposits in the Jefferson Canyon map unit, clast composition resembles that of the Cottonwood Canyon map unit, with no Archean metamorphic clasts, no LaHood clasts, and no clasts of Paleozoic limestone. Because of the lack of Archean clasts, the conglomerate at this location was mapped as Cottonwood Canyon informal map unit (Tcc). However, it is similar to the Jefferson Canyon map unit in its geographic position along the Jefferson River, the presence of overlying Parker Homestead map unit, and evidence that the interface between the units has been prospected, presumably for gold as at the New London placer operation.

Informal unit name derived from Jefferson Canyon in the Sappington and Jefferson Island 7.5’ quadrangles.

QTsi **SILVER SAGE Informal map unit (Miocene or younger)—**Angular clasts of Elkhorn Mountains Volcanics associated with a pebble gravel in a very limited linear distribution on the tops of low hills east of Shoddy Springs. A Miocene (Barstovian) fossil was found in this unit (Robinson, 1963). Thickness about 10 ft.

Informal unit name derived from Silver Sage Ranch, an older name for the ranch at Shoddy Springs in the Milligan Canyon 7.5’ quadrangle.

SIXMILE CREEK SYNTHEM

Tha **HARRISON Informal map unit (Miocene and/or Pliocene?)** Grayish-brown matrix-suppported conglomerate or gravel with subrounded texturally poorly sorted and disorganized clasts, ranging from pebble to large boulder size in iron oxide-stained matrix of granule and smaller size clasts. Clast composition dominantly Archean metamorphic rocks (mostly gneiss and schist) with subordinate quartzite, granitic rock including pegmatite, and Paleozoic limestone. Locally well-cemented, but generally unconsolidated. Linear distribution of unit extends along Antelope and Little Antelope Creeks to Sappington. Appears cut into older Tertiary units and in places rests on Archean and Paleozoic rocks. Maximum thickness as much as 200 ft.

Note: Linear geometry and presence of granitic boulders are similar to the Red Bluff Formation near Norris, Montana, about ten miles to the southeast, south of the map area (Kellogg, 1994 and 1995).

Informal unit name derived from town of Harrison in the Harrison 7.5' quadrangle.

Tcar** **CAREY RANCH Informal map unit** (**Miocene and/or Pliocene**)—Light gray unconsolidated, angular to subangular, and subordinate subrounded gravel, and well cemented breccia, especially at the base. Basal breccia matrix is reddish-brown in most places and patches of reddish-brown matrix also occur locally higher in the unit. Clasts are almost exclusively locally derived Paleozoic limestone but also include locally derived chert and Quadrant Sandstone. Includes slightly bentonitic, pinkish-gray and very light gray, tuffaceous sandstone west of the southern part of Big Mountain. Unit overlies Cottonwood Canyon map unit (Tcc), dated as Barstovian (Lofgren, 1985), therefore, Carey Ranch map unit is Barstovian or younger. Considered Tertiary because of well-cemented basal part of unit. Maximum thickness may be as much as 200 ft.

Note: This unit occurs on the east side of the North Boulder River on the southern flanks of Big Mountain, the source of the Paleozoic clasts. It is not present on the west side of the North Boulder River where Bull Mountain is dominantly Elkhorn Mountains Volcanics.

Informal unit name derived from Carey Ranch in the Doherty Mountain and Negro Hollow 7.5'quadrangles, and quadrangles to the north of the map area.

Tmap** **MADISON PLATEAU Informal map unit (Miocene?:** Clarendonian? or Hemphillian?)—Sheet deposit of moderately well-sorted and well-rounded clast-supported cobble conglomerate or gravel; color reflects maroon, gray, and brown calcium-carbonate-coated cobbles dominantly of Belt Supergroup quartzite. Archean metamorphic clasts are found only at the base as pebble size or smaller and were likely reworked from underlying Madison Valley formation pebble conglomerates that contain Archean clasts. May correlate with clast-supported cobble conglomerate in Reese Creek area north of Bozeman at base of Reese Creek map unit (Vuke, 2003), from which an ash bed yielded a K/Ar date of 8.9 ±0.4 Ma (Hughes, 1980; Lange and others, 1980). If so, the Madison Plateau map unit is likely youngest Clarendonian or oldest Hemphillian. Thickness 20-30 ft.

Informal unit name applied by Vuke (2003) for Madison Plateau in the Madison Plateau and Manhattan SW 7.5’ quadrangles, east of the map area.

Tcc* **COTTONWOOD CANYON Informal map unit** (**Late Miocene**: Barstovian)**—**Brown conglomerate or gravel dominantly of rounded cobbles of Elkhorn Mountains Volcanics and Belt Supergroup quartzite, although almost exclusively derived from Elkhorn Mountains Volcanics west of the Boulder River. Conglomerate/gravel clast size includes pebbles and small boulders in matrix of granules and coarse sand. Clasts are commonly stained with iron oxide. Conglomerate and gravel are in sheets and lenses interbedded with subordinate light gray, coarse-grained sandstone with conglomeratic stringers and floating granules, greenish-brown or reddish-brown, slightly bentonitic mudstone, and tan siltstone and micaceous, silty mudstone. Other than immediately west of the Negro Hollow uplift and east of Bull Mountain, unit contains abundant to occasional subrounded boulders of granitic rock with weathering rinds as much as 1/4 inch thick. At one location south of the Negro Hollow uplift, extremely large boulders of granitic rock and Elkhorn Mountains Volcanics are present. Barstovian fossils were found in the finer-grained component of the unit between the Boulder River and the Negro Hollow uplift (Lofgren, 1985). Maximum exposed thickness as much as 350 ft.

Note: Near Cottonwood Canyon this unit was called Ballard gravel by Aram (1979). Gravel in what is interpreted as the Doherty Mountain map unit in this report, on the tops of linear ridges east of Cottonwood Canyon and south of Doherty Mountain, was also called Ballard gravel by Aram.

Near Cottonwood Canyon there appear to be two levels of deposits both mapped as Cottonwood Canyon map unit. The higher deposit overlies a syncline in Cambrian units. It contains more clasts of intrusive rocks than the lower deposit, but similar to the lower deposit, does not contain Archean clasts. In the Cottonwood Canyon area unit rests on LaHood Formation and Paleozoic rocks but does not contain clasts of either.

Informal unit name derived from Cottonwood Canyon in Doherty Mountain 7.5’ quadrangle.

Tpb* **PARROT BENCH Informal map unit (Cottonwood Canyon facies) (Middle Miocene**: Barstovian)**—**Brown conglomerate and gravel dominantly of subrounded to rounded cobbles of Elkhorn Mountains Volcanics and Belt Supergroup quartzite. Conglomerate/gravel clast size ranges from pebbles to small boulders in matrix of granules and coarse sand. Clasts are commonly stained with iron oxide. Resembles Cottonwood Canyon informal map unit which is also Barstovian and proximal, but mapped as part of the Parrot Bench map unit to the west (Vuke, and others, 2004). Middle to Late Miocene, Barstovian and Hemphillian fossils found in the Parrot Bench map unit immediately to the west on Parrot Bench (Kuenzi, 1966), but only the lower, probably Barstovian, part of the map unit is exposed in the Lower Jefferson map area.

Informal unit name applied by Kuenzi (1966). Name derived from Parrot Bench in the Whitehall 7.5' quadrangle (west-adjacent to the Jefferson Island 7.5' quadrangle.)

Tmva* **MADISON VALLEY FORMATION (informal)** (**Late Miocene**: Barstovian and Clarendonian?)— Pinkish-tan, tan, yellowish-white, and very light gray, unconsolidated to indurated, tuffaceous silt or siltstone and marlstone interbedded with cross-bedded, texturally immature, coarse sandstone that contains lenses of pebble conglomerate or local cobble conglomerate that ranges from matrix- to clast-supported, and from cemented to unconsolidated. Conglomerate clasts are dominantly Archean gneiss and quartzite and extrusive volcanic rocks, with subordinate Proterozoic Belt Supergroup quartzite and siltite, and occasional Paleozoic limestone clasts. Sandstone has large root casts locally, and marlstone beds are typically full of small root casts. Several vitric ash beds are present throughout the unit. Opalized wood fragments are abundant in many of the conglomerate lenses. Conglomerate also contains relatively abundant disarticulated bones and bone fragments and occasional teeth. Numerous articulated Barstovian fossils have been collected and studied from the fine-grained parts of this unit in the Madison bluffs area on the east side of the lower Madison River (Tabrum and others, 2001; Douglass, 1899, 1901, 1903, 1907a, 1907b, 1908, 1909a, 1909b; Frick, 1937; Dorr, 1956; Sutton, 1977; Sutton and Korth, 1995).

Thickness as much as 300 ft in the southeastern part of the map area. Thins and pinches out to north in the map area. Informal unit name applied by Douglass (1907b). Name derived from the Madison River valley.

Tshb **SHAW BASIN Informal map unit (Miocene?)—**Several deposits along the South Boulder River that may not be contemporaneous, all of which contain Archean metamorphic clasts. <u>Shaw Basin area:</u> Sand and silt matrix with floating pebbles and cobbles; unconsolidated. A well lithified unidentifiable bone was found in this deposit suggesting that it is Tertiary. Deposit may be as much as 100 ft thick. <u>West of London Hills:</u> Conglomerate with dominantly rounded and subrounded cobble-size clasts; about 40 ft thick.

Informal unit name derived from Shaw Basin in the Jefferson Island 7.5' quadrangle.

<u>RENOVA SYNTHEM</u>

Tnh* **NEGRO HOLLOW Informal map unit** (**Early Miocene**: Arikareean) (Mount Doherty and Negro Hollow 7.5' quadrangles)—<u>West of North Boulder River</u>: (Description modified from Lofgren, 1985) Dominantly poorly sorted, unconsolidated to moderately well cemented matrix-supported pebble conglomerate with granitic clasts dominant, and subordinate clasts of Elkhorn Mountains Volcanics, in a tuffaceous silt matrix. Conglomerate locally crossbedded. Lenses of clast-supported conglomerate generally at top of beds. Matrix-supported conglomerate grades laterally into, or is interbedded with, tabular beds of thinly laminated vitric silt and ash. Late Arikareean age determined from fossils (Lofgren, 1985). East of North Boulder River tuffaceous silt is dominant, and conglomerate is subordinate. Thickness about 900 ft.

Informal unit name derived from Negro Hollow in the Negro Hollow 7.5' quadrangle.

Tdc* **DUNBAR CREEK FORMATION** (South of Jefferson River--**Early Miocene and Oligocene**: Arikareean; North of Jefferson River--**Late Eocene:** Late Chadonian—Very light gray to grayish-yellow, thick-bedded, tuffaceous silt and siltstone with subordinate sand, sandstone, conglomerate and rare bentonitic clay and very light gray limestone. North of the Jefferson River, unit includes many tongues of poorly sorted, poorly rounded carbonate-rich gravel not present south of the Jefferson River. The tuffaceous rocks and sediment are dominantly composed of fine volcanic ash. Base of formation south of Jefferson River mapped at top of stacked calcic or siliceous paleosols (pedocomplex) and associated moderately well-cemented to well-cemented sandstone or conglomerate of the Fairview map unit (Tcaf). This placement of the contact differs from Robinson's (1963) higher placement of the contact between the Climbing Arrow and Dunbar Creek Formations in this area. An Arikareean (Early Miocene) fossil, *Diceratherium armatum* Marsh, was found in a sandstone four miles south of Three Forks (Wood, 1938) in the lower Dunbar Creek Formation as mapped in this report. Also, an Arikareean beaver was described from the bluffs on the west side of the Madison River "about nine or ten miles south of Three Forks" (Douglass, 1901) in the Dunbar Creek Formation. On the east side of the Madison River, just east of the map area, Arikareean radiometric dates were obtained from two ashes collected from locations 5 miles apart in this unit (Vuke, 2003). By contrast north of the Jefferson River the Dunbar Creek Formation contains Chadronian (Eocene) fossils (Tabrum and others, 2001). North of the Jefferson River the contact between the Climbing Arrow and Dunbar Creek Formations is conformable, and south of the Jefferson River, the contact is disconformable. If the Dunbar Creek Formation south of the Jefferson River is Arikareean, the Dunbar Creek Formation is as old as Chadronian and as young as Arikareean as originally mapped by Robinson (1963).

Named by Robinson (1963). Name derived from Dunbar Creek, a tributary of Mud Creek north of the eastern part of the map area. Thickness as much as 300 ft in the southeastern part of the map area.

Note: Immediately west of the map area, Dunbar Creek rank was formally designated as a member of the Renova Formation (Kuenzi and Fields 1971). Unit is treated as a formation on present map because of its thickness, and the thickness and mappable units in the underlying Climbing Arrow Formation (see below).

Age summary: The Dunbar Creek Formation is apparently as young as Arikareean south of the Jefferson River where it unconformably overlies the Climbing Arrow Formation. North of the Jefferson River it is conformable on the Climbing Arrow Formation and is Chadronian.

Tnc **NORWEGIAN CREEK INFORMAL MAP UNIT (Oligocene? or Eocene?)—** Interbedded white, light-gray, and light-tan very fine-grained locally vuggy limestone and sandy limestone, white to light-brown tuffaceous, micaceous, calcareous siltstone and sandstone, and massive white ash. Contains silicified stems one cm in diameter with visible internal structure, and tubular root casts. Exposed thickness about 200 ft. Informal map unit named by Feichtinger (1970). Name derived from Norwegian Creek in the Willow Creek Reservoir 7.5' quadrangle.

Note: The Norwegian Creek map unit lies geographically between exposures of Dunbar Creek Formation and Antelope Creek informal map unit (Tac). It was not determined which of those two units it correlates with. Kellogg and Vuke (1996) interpreted that it correlates with the Dunbar Creek Formation, but although it lacks prominent channel conglomerate found in the Antelope Creek map unit to the northwest, it could also correlate with that unit. The Antelope Creek map unit may correlate with the Dunbar Creek Formation (Vuke, and others 2002; Elliott, 1998 a), however stratigraphic relations and the presence of prominent conglomerate channels suggest that it may correlate with the Milligan Creek Formation instead.

Tca* **CLIMBING ARROW FORMATION, undivided** (**Eocene**)—Small areas of exposure that were not assigned to one of the informal Climbing Arrow map units listed below but contain typical Climbing Arrow greenish-gray, bentonitic mudstone.

Note: Immediately west of the map area, Climbing Arrow rank was formally designated as a member of the Renova Formation. The Climbing Arrow is shown as a formation throughout the area of the current map to maintain continuity and because the Climbing Arrow can be divided into numerous mappable and mostly relatively thick map units, that would more appropriately be considered informal members than beds.

Named by Robinson (1963). Name derived from the Climbing Arrow Ranch in the Three Forks SE 7.5' quadrangle.

The informal units mapped within the Climbing Arrow Formation are listed below.

<u>Climbing Arrow Formation North of Jefferson River and east of inferred Milligan Canyon Fault</u>

Tcabr** **Broadwater informal map unit** (**Eocene:** Chadronian)**,** (Milligan Creek and Three Forks 7.5' quadrangles)—Light brown tuffaceous siltstone interbedded with gray bentonitic mudstone and fine-grained sandstone. Thickness approximately 60 ft.

Note: Unit is between Mud Spring map unit and Dunbar Creek Formation, both of which contain Chadronian fossils in this area. Therefore, the Broadwater map unit is Chadronian.

Informal unit name derived from Broadwater County line in the Milligan Canyon 7.5' quadrangle.

Tcams* **Mud Spring informal map unit** (**Eocene:** Early Chadronian)**,** (Milligan Creek 7.5' quadrangle)—<u>Upper part</u>: Dark gray and grayish brown bentonitic mudstone

and gray sandstone. Robinson (1963) reported three Chadronian fossils from this part of the unit.
<u>Lower part:</u> Very light gray and yellowish gray bentonitic, mudstone and tuffaceous siltstone that weather powdery, and lenses of gray, medium- to coarse-grained sandstone and pebble conglomerate. Contains Early Chadronian mammal fossils (Tabrum and others, 2001). Thickness approximately 150 ft.

Informal unit name derived from Mud Spring in the Milligan Canyon and Three Forks 7.5' quadrangles.

Tcapf* **Price Farm informal map unit** (**Eocene:** Chadronian) (Milligan Canyon and Three Forks 7.5'quadrangles)—Variety of interbedded lithologies including reddish-brown, brown, and gray conglomerate with mostly pebble size subrounded to subangular clasts, but ranging to large cobbles; reddish-brown and gray, coarse, locally cross-bedded sandstone and conglomeratic sandstone; reddish-brown, greenish-gray, and gray, bentonitic mudstone, limestone lenses locally with gastropods; lenses and pods of white to very light gray marlstone, locally with root casts; tan siltstone; and rare carbonaceous dark gray shale. Conglomerate clasts dominantly composed of Elkhorn Mountains Volcanics and quartzite. Clast size increases to the north where green and purple Belt Supergroup quartzite and siltite clasts are in greater abundance than to the south. This is the only Climbing Arrow map unit that contains an abundance of red-colored lithologies, especially mudstone. Silicified wood, relatively abundant in the Doherty Mountain informal map unit, was not found in the Price farm map unit. Thickness as much as 250 ft.

Note:
1. A lot of what is shown as Qos (subrounded Quaternary gravel) by Robinson (1963) is considered part of the Tertiary Price farm map unit in this report for the following reasons: Lithologies are the same as the part of the Price farm map unit shown as Tc (Tertiary Climbing Arrow Formation) on Robinson's map; the Qos unit is locally well-cemented, suggesting Tertiary rather than Quaternary age; and a Chadronian rhinoceros skull was found in the Qos unit.

2. The rhinoceros skull found in the Price Farm map unit was identified as a juvenile *Metamynodon* (R. Nichols, written communication, 2005), and is a new species for Montana (A. Tabrum, written communication, 2006).

Informal map unit name derived from Price Farm in the Milligan Canyon 7.5' quadrangle.

<u>Climbing Arrow Formation South of Jefferson River</u>

Tcaf **Fairview informal map unit (Eocene**) (Three Forks SE and Willow Creek 7.5' quadrangles)—Light gray to dark brown calcareous to non-calcareous, locally siliceous, feldspathic and biotitic granule/pebble conglomerate with many clear, glassy quartz grains; and gray to pinkish-gray, coarse- to fine-grained sandstone with coarser grains floating in matrix; associated silicified wood and occasional reddish-brown scoria clasts. Overlain by white, stacked calcic or silicic paleosol beds (pedocomplex) with floating clear glassy quartz grains and abundant burrows or root casts, and associated gray ash bed. This may correlate with prominent pedocomplex (Hanneman and Wideman, 2006) of stacked calcic and silicic paleosols at the base of the Dunbar Creek on the east side of the Madison River. Thickness 40 to 60 ft.

Informal map unit name derived from Fairview Cemetery in the Three Forks SE 7.5’ quadrangle.

Tcabu* **Buttleman informal map unit** (**Eocene:** Chadronian) (Three Forks SE and Willow Creek 7.5’quadrangles—Greenish-gray, greenish-brown, and minor grayish-red, bentonitic mudstone with subordinate yellowish-gray to grayish-green sandstone and pebble conglomerate. Sandstone is mostly coarse-grained and composed of quartz with subordinate feldspar, flakes and books of biotite, and dark, fine-grained volcanic rocks (Robinson, 1963). The Buttleman map unit has the greatest volume of bentonite of any of the Cenozoic units in the map area. The bentonite is capable of appreciable swelling, as much as doubling original volume (Robinson, 1963). An Early Oligocene (now considered Late Eocene and therefore Chadronian) fossil (A. Tabrum, written communication, 2006) was identified from this unit (Robinson, 1963). Base not exposed. Exposed thickness approximately 200 ft.

Informal map unit name derived from Buttleman Ranch in the Three Forks SE 7.5’ quadrangle.

Tcas **Stateler informal map unit (Eocene**) (Three Forks SE and Willow Creek 7.5’ quadrangles)—Yellowish-orange to brownish-orange, pebbly, cross-bedded sand or sandstone and gravel or conglomerate with subrounded clasts locally rimmed with calcium carbonate. Clasts dominantly pebble size to the east and dominantly cobble size to the west. Interbedded with greenish-gray bentonitic mudstone and poorly resistant sandstone with pebbles floating in matrix. Clast composition includes Archean metamorphic rocks, quartz, quartzite, feldspar, biotite, and dark igneous rocks. Abundant iron-oxide staining near town of Willow Creek. Ranges from 40 to 100 ft thick.

Informal map unit name derived from Stateler Monument in the Willow Creek 7.5’ quadrangle.

<u>Climbing Arrow Formation North of Jefferson River and west of Milligan Canyon Fault</u>

Tcadm* **Doherty Mountain informal map unit, undivided** (**Eocene:** Chadronian) (Doherty Mountain, Negro Hollow, Jefferson Island, and Milligan Canyon 7.5’ quadrangles)—Entire unit contains scattered silicified wood including occasional stumps and logs. In the lower part sandstone and granule/pebble conglomerate composed almost entirely of clasts derived from a granitic source are common in shoestring bodies that weather to grus. Iron oxide staining is abundant. Higher in section, map unit contains many lenses of sand or sandstone, and granule/pebble conglomerate or gravel with fewer granitic clasts and more subrounded dark volcanic clasts and clasts of Belt Supergroup quartzite. Lacks granitic clasts in the uppermost part of the map unit. The sandstone and conglomerate occur as lenses and bodies within bentonitic mudstone of a variety of colors that commonly include greenish and brownish-black, olive-gray, dark greenish-gray, pale olive, pale yellowish-brown, and reddish-brown. Throughout the unit there are local small zones of cobble-size clasts, but unlike the Cottonwood Canyon informal map unit that has clasts of similar composition, the cobble distribution is not extensive or thick. Light brown, pale yellowish-brown and pale reddish-brown silty mudstone that is slightly bentonitic occurs locally and weathers to powder. Ash beds occur throughout the unit. Units shown as upper and lower Doherty Mountain informal map unit were arbitrarily divided at prominent ash bed easily traceable on aerial photos. Westernmost thickness approximately 500 ft, thins eastward.

Note: Pebble and granule gravel at the top of the Doherty Mountain map unit were called Ballard gravel by Aram (1979) and considered to be an early Quaternary deposit. Large blocks of shale were found in the gravel with over fifty leaf fossils that are similar to leaves from a collection from the Dunbar Creek Member of the Renova Formation in the Ruby Valley (Aram, 1979). Eight genera were identified. Two of the genera became extinct in North America before the Pliocene (Miller, 1978, written communication in Aram, 1979). *In situ* beds of light gray shale and mudstone are present between gravel lenses in the Doherty Mountain map unit near where the leaves were found. The block of fossiliferous shale was likely from the Doherty Mountain map unit, and the gravel at that location is likely Eocene rather than Quaternary.

Informal unit name derived from Doherty Mountain in the Doherty Mountain 7.5' quadrangle.

Tcadmu **Doherty Mountain informal map unit, upper** (**Eocene:** Chadronian) (Negro Hollow and Milligan Canyon 7.5' quadrangles). Doherty Mountain map unit above a prominent ash bed traceable on aerial photos. Top eroded. Exposed thickness approximately 60 ft.

Tcadml **Doherty Mountain informal map unit, lower** (**Eocene:** Chadronian) (Negro Hollow and Milligan Canyon 7.5' quadrangles.) Doherty Mountain map unit below a prominent ash bed traceable on aerial photos. A prominent sandstone/conglomerate bed occurs at the base of the unit west of Milligan Canyon. Thickness approximately 120 ft.

Tcamc* **Milligan Creek facies informal map unit** (**Eocene:** Chadronian and Duschesnean?) (Milligan Canyon, Doherty Mountain, and Negro Hollow 7.5' quadrangles)—Gray and very light gray limestone beds, locally fossiliferous, white and very light gray tuffaceous limestone and siltstone, discontinuous beds of breccia derived from both within the unit and from Paleozoic limestone, and ash beds, interbedded with pale olive bentonitic mudstone. Overlies Red Hill map unit at Negro Hollow and east of Timber Canyon.

Limestone beds locally contain abundant well preserved gastropods some of which resemble genera previously collected and identified from the Milligan Creek and Climbing Arrow Formations (B. Roth, written communication, 2006; Roth, 1986, species *a* fig. 5 and figs. 31 and 32). Identification by B. Roth of gastropods collected from west of Timber Canyon include*:* *Gastrocopta*,sp., *Polygyrella* (?) sp., Helminthoglyptidae (?), Planorbidae (?), Lymnaeidae (?) and *Physa* sp. Identification by B. Roth of gastropods in the Negro Hollow area include: *Holospira* sp., Pupillidae, and *Gastrocopta* sp. Lenses of breccia that contain limestone clasts with Milligan Creek facies gastropods cemented into the limestone were found at Negro Hollow and east of Timber Canyon, indicating that those breccias are from within the unit.

The lower jaw of an insectivore, *Aptemodus*, was found east of Timber Canyon by D. Hanneman. It probably belongs to the late Duchesnean to early Chadronian *Aptemodus baladontus* rather than the middle to late Chadronian *Aptemodus mediaevus*, but certainly pertains to one of these two endemic Montana species (A. Tabrum, written communication, 2005). Maximum thickness approximately 200 ft.

Note: A probable new species of *Holospira* was found in this unit in the Negro Hollow area. *Gastrocopta* sp. was found in both the Negro Hollow area and east of Timber Canyon in this unit. All of the gastropod taxa identified are terrestrial except for *Physa*, Lymnaeidae, and Planorbidae, which are freshwater snails (B. Roth, written communication, 2006).

Informal unit name derived from Milligan Creek Formation. The Milligan Creek facies of the Climbing Arrow Formation is considered a facies of the Milligan Creek Formation.

Tcass* **Shoddy Springs informal map unit** (**Eocene:** Late Uintan and Early Duschesnean?)**—**White, very light gray, yellowish-gray and tan, tuffaceous to very tuffaceous, generally calcareous siltstone and silty limestone. Siltstone weakly to moderately cemented with abundant pods and spherules more strongly cemented by calcium carbonate. Weathers tan and powdery or very light gray, breaking into small chips. Locally pale green to reddish-brown and slightly to moderately bentonitic. Contains lenses of breccia and uncemented angular gravel derived from the Elkhorn Mountains Volcanics. Where the angular gravel serves as caprock it is easily mistaken for colluvium. Also contains pods and lenses of coarse sandstone and granule conglomerate that weather to grus. Fossils at Shoddy Springs dated as Uintan (Robinson, 1963), but may be early Duchensnean (A. Tabrum, personal communication, 2006). Thickness approximately 150-200 ft.

Informal unit name derived from Shoddy Springs in the Milligan Canyon 7.5’ quadrangle.

Tmc **MILLIGAN CREEK FORMATION** (**Eocene)** (Milligan Canyon 7.5’ quadrangle)—Gray, sucrosic, tuffaceous, locally silicified and locally vuggy limestone; gray, platy limestone beds with gastropods and charophytes; very light gray marlstone beds locally with floating sandstone grains; white tuffaceous limestone and siltstone beds; and tan and reddish mudstone and siltstone that weathers to powdery silt and clay-size particles. Within these lithologies are well-cemented coarse sandstone to granule conglomerate beds with matrix-supported angular and subangular pebbles. Clast composition includes quartz, quartzite, granitic rocks, and dark volcanic rocks. Overlies Red Hill map unit with a gradational contact. Lenses of breccia similar to those in the Red Hill map unit occur sporadically in the lower part of the formation. Most lack red color of the Red Hill map unit, but some lenses have red color similar to that of the Red Hill map unit. Gastropods collected from unit were identified by B. Roth (written communication, 2006) as *Physa* (?), Lymnaeidae, and *Gastrocopta* (?), all of which are also found in the Milligan Canyon facies of the Climbing Arrow Formation. Maximum exposed thickness 300 ft.

Named by Robinson (1963). Name derived from Milligan Creek in the Milligan Creek and Willow Creek 7.5' quadrangles.

Tanc **ANTELOPE CREEK INFORMAL MAP UNIT (Eocene?)**—White to very light yellow, tuffaceous, fine-grained sandstone, siltstone, mudstone, and limestone; pebbly, locally crossbedded, coarse sandstone and granule conglomerate; and clast-supported conglomerate with subrounded to rounded clasts composed of quartz, quartzite, granitic rock, and Archean metamorphic rock. Overlies Red Hill map unit. Previously mapped as Dunbar Creek Formation (Vuke and others, 2002; Elliott, 1998a), but more likely a facies of the Milligan Creek Formation (Tmc) and/or the Milligan Creek facies of the Climbing Arrow Formation (Tcamc) based on stratigraphic position and thick channel conglomerate typical of Milligan Creek Formation. Basal part of map unit resembles that of the Milligan Creek facies of the Climbing Arrow Formation described above and is in the same stratigraphic position overlying the Red Hill map unit. Exposed thickness about 200 ft.

Informal map unit name derived from Antelope Creek in the Harrison and Sappington 7.5' quadrangles.

Treh **RED HILL INFORMAL MAP UNIT** (**Eocene**)—

Red Hill area: Reddish-brown, texturally poorly sorted, locally silicified breccia and conglomerate in sandy matrix generally cemented by calcium carbonate. Clasts in breccia as large as boulder size. Clast composition that of adjacent Paleozoic rocks (dominantly limestone, dolomite, shale, and chert) with subordinate clasts of Elkhorn Mountains Volcanics. Clasts are angular to subrounded. Overlain by kaolinitic red tuffaceous siltstone that is locally brecciated, and locally apparently overlain by beds of red or brown, immature coarse-grained sandstone or granule conglomerate derived almost exclusively from granitic rock with locally abundant biotite with no Paleozoic clasts. Abundant slickensides and local silicification. Some red-stained Climbing Arrow Formation sandstone and granule and pebble conglomerate is included in this map unit at Red Hill. Thickness 80–150 ft.

Milligan Canyon area: (Description from Robinson, 1963, who called this unit Sphinx Conglomerate). Reddish-orange conglomerate and breccia composed of subangular pebbles and cobbles of dark, fine-grained Paleozoic limestone. Larger clasts rare, but locally includes boulders as much as three feet long.

Doherty Mountain area: Resembles unit at Red Hill described above, but lacks slickensides and has numerous calcite veins; locally well cemented; boulder-size clasts more abundant lower in section. Thickness about 200 ft.

Timber Canyon area: Recognized by red soil that contains abundant angular to subangular Paleozoic limestone clasts. Unconsolidated in this area. Thickness 60–100 ft.

Antelope and Little Antelope Creek area: Light brown to reddish-brown, texturally poorly sorted breccia and subordinate conglomerate with clasts of Paleozoic limestone, dolomite, and chert, cemented by calcium carbonate or silica. In several places clasts are coated with dogtooth spar with crystals as much as 1 inch long. Red mudstone and soil are associated with the breccia or conglomerate, that ranges from unconsolidated to well cemented. Clasts range from angular to subrounded. Larger clasts in a matrix of granules and sand are mostly pebble and cobble size, but range to small boulder size. Occurs as patches that either rest disconformably on Paleozoic rock or are within 1/8 mile of Paleozoic or Archean rock along the length of Antelope and Little Antelope Creeks to Sappington.

Note: Near the mouth of Dogtown Sewer along Antelope Creek, unit is adjacent to Archean rock, but no Archean clasts are present--clasts are Paleozoic rock.

Willow Creek area (atypical clast composition): Breccia similar to that described above, but with different clast composition. Near the Willow Creek fault, unit rests on Cretaceous Elkhorn Mountains Volcanics but clasts are wholly derived from the LaHood Formation. West of Willow Creek on the south side of the Jefferson River unit contains abundant clasts of gneiss and schist in addition to Paleozoic rocks (Robinson, 1963).

Note: Some of the Red Hill map unit deposits may be partly tectonic in origin and may be Miocene (see text).

Informal map unit name derived from Red Hill in the Doherty Mountain 7.5' quadrangle.

Tba **BASALT**

Tr **RHYOLITE**

TKi **INTRUSIVE ROCK**

TKg **GRANITE**

Ks **CRETACEOUS SEDIMENTARY ROCKS, UNDIVIDED**—Includes Thermopolis Shale, and Kootenai Formation.

Ki **INTRUSIVE ROCK**

Kan **ANDESITE**

Kdi **DIORITE**

Kit **INTRUSIVE ROCK OF TOBACCO ROOT BATHOLITH**

Kem **ELKHORN MOUNTAINS VOLCANICS**

KJs **CRETACEOUS AND JURASSIC SEDIMENTARY ROCKS, UNDIVIDED**—Includes Thermopolis Shale, Kootenai Formation, Morrison Formation, and Ellis Group.

Js **JURASSIC SEDIMENTARY ROCKS, UNDIVIDED**—Includes Morrison, Swift, Rierdon, and Sawtooth Formations.

JTRs **JURASSIC AND TRIASSIC SEDIMENTARY ROCKS, UNDIVIDED**—Includes Morrison, Swift, Rierdon, Sawtooth, and Dinwoody Formations.

Ps **PERMIAN ROCKS, UNDIVIDED—**Includes Phosphoria Formation.

IPMs **PENNSYLVANIAN AND MISSISSIPPIAN SEDIMENTARY ROCKS, UNDIVIDED—**Includes Quadrant and Amsden Formations.

PIPMs **PERMIAN, PENNSYLVANIAN, AND MISSISSIPPIAN SEDIMENTARY ROCKS, UNDIVIDED**—Includes Phosphoria, Quadrant, and Amsden Formations.

Ms **MISSISSIPPIAN SEDIMENTARY ROCKS, UNDIVIDED**—Includes Mission Canyon and Lodgepole Formations.

MDs **MISSISSIPPIAN AND DEVONIAN SEDIMENTARY ROCKS, UNDIVIDED**—Includes Three Forks, Jefferson, and Maywood Formations

€s **CAMBRIAN SEDIMENTARY ROCKS, UNDIVIDED**— Includes Pilgrim, Park, Meagher, Wolsey and Flathead Formations.

Yla **LAHOOD FORMATION (BELT SUPERGROUP)**

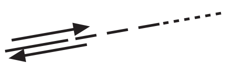
Amt **ARCHEAN METAMORPHIC ROCKS, UNDIVIDED**

MAP SYMBOLS

Contact between geologic units—Dashed where approximately located; dotted where concealed.

Linear Feature—Possibly controlled by fracture or fault.

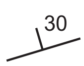
Fault, normal or reverse—Dashed where inferred, dotted where inferred fault is concealed. Ball and bar on downthrown side where relative displacement known.



Fault, strike-slip or oblique slip—Dashed where inferred, dotted where concealed. Arrows indicate relative lateral movement. Most faults with this symbol are oblique slip with both dextral and reverse movement (Schmidt, 1971).

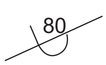
Fault, thrust—Dashed where inferred; dotted where concealed; teeth on upper plate.

Fault, thrust—Speculative west-vergent thrust fault, unconfirmed.



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

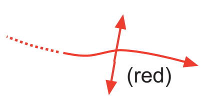
Vertical beds.



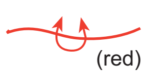
Overturned beds—Number indicates angle of dip in degrees.

Horizontal beds.

Syncline—Showing trace of axial plane and direction of plunge; dotted where concealed. Plunge arrow omitted where not plunging or plunge direction unknown.

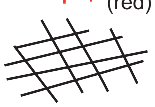


Anticline—Showing trace of axial plane and direction of plunge; dotted where concealed. Plunge arrow omitted where not plunging or plunge direction unknown.



Overturned anticline

Overturned syncline



Rubble—Has maintained integrity of mappable units; interpreted as broken thrust plate.

Golden Sunlight Mine, Inc., mine dump

LOWER JEFFERSON VALLEY
SOURCES OF GEOLOGIC MAPPING AND
INDEX OF 7.5' QUADRANGLES

112°

46°

Doherty Mountain 1, 3, 7, 10, 11, 12, 13, 16, 17	Negro Hollow 1, 6, 10, 13	Milligan Canyon 14	Three Forks 14
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Pony 15	Harrison 4, 8, 15	Willow Creek Reservoir 5, 9	Norris NE 5, 9

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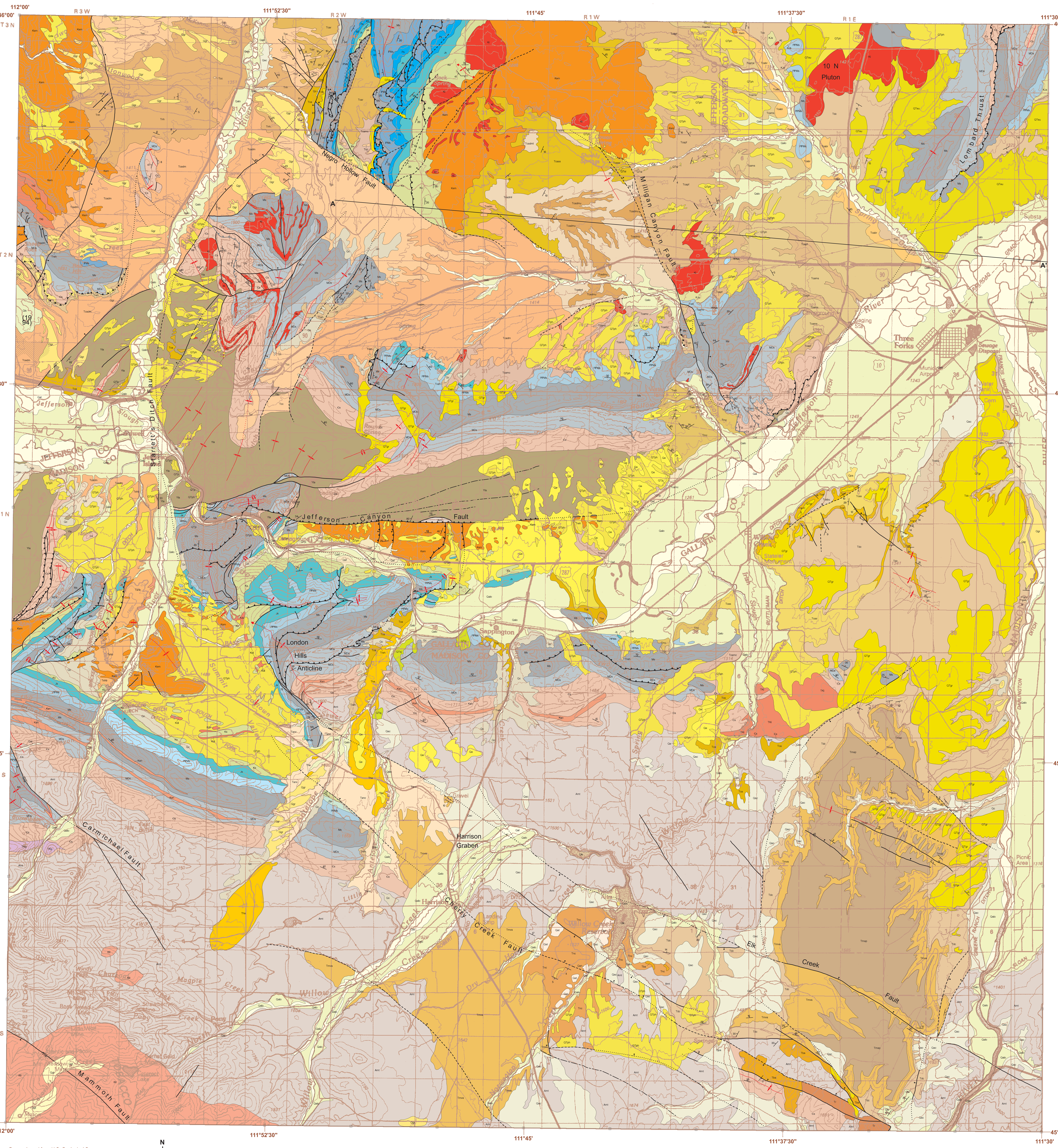


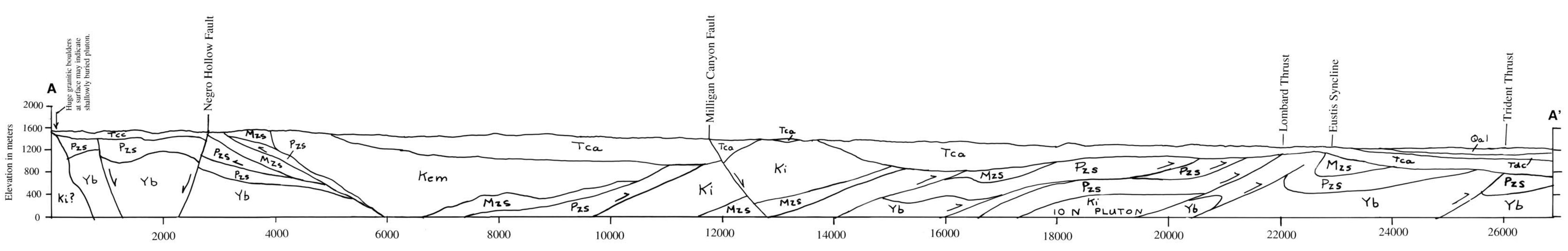
Base enlarged from U.S. Geological Survey:
Bozeman 30'x60' topographic quadrangle
Map date: 1989
Projection: UTM zone 12; 1927 NAD

SCALE: 1:50,000

MAP UNITS

Qal	Alluvium of modern channels and flood plains
Qpa	Paludal deposit
Qlk	Lake deposit
Qc	Colluvium
Qaf	Alluvial fan deposit
Qalo	Older alluvium and floodplain deposit
Qls	Landslide deposit
Qac	Alluvium and colluvium, undivided
Qat	Alluvium of alluvial terrace
Qe	Eolian deposit
Qde	Debris deposit
Qgr	Gravel
Qgt	Glacial till
QTph	Parker Homestead map unit, informal
QTgr	Gravel
QTeu	Eustis map unit, informal
QTsj	Sappington Junction map unit, informal
QTjc	Jefferson Canyon map unit, informal
QTsi	Silver Sage map unit, informal
Tha	Harrison map unit, informal
Tcar	Carey Ranch map unit, informal
Tmap	Madison Plateau map unit, informal
Tcc	Cottonwood Canyon map unit, informal
Tpb	Parrot Bench map unit, informal
Tmva	Madison Valley map unit, informal
Tshb	Shaw Basin map unit, informal
Tnh	Negro Hollow map unit, informal
Tdc	Dunbar Creek Formation
Tnc	Norwegian Creek map unit, informal
Tca	Climbing Arrow Formation
Tcabr	Broadwater map unit, Climbing Arrow Formation, informal
Tcams	Mud Spring map unit, Climbing Arrow Formation, informal
Tcapf	Price Farm map unit, Climbing Arrow Formation, informal
Tcaf	Fairview map unit, Climbing Arrow Formation, informal
Tcabu	Buttleman map unit, Climbing Arrow Formation, informal
Tcas	Stateler map unit, Climbing Arrow Formation, informal
Tcadm	Doherty Mountain map unit, Climbing Arrow Formation, informal
Tcadmu	Dougherty Mountain map unit, upper part, Climbing Arrow Formation, informal
Tcadml	Dougherty Mountain map unit, lower part, Climbing Arrow Formation, informal
Tcamc	Milligan Creek map unit, Climbing Arrow Formation, informal
Tcass	Shoddy Springs map unit, Climbing Arrow Formation, informal
Tmc	Milligan Creek Formation
Tanc	Antelope Creek map unit, informal
Treh	Red Hill map unit, informal
Tba	Basalt
Tr	Rhyolite
TKi	Intrusive rocks, undivided
TKg	Granite
Ks	Sedimentary rocks, undivided
Ki	Intrusive rocks, undivided
Kem	Elkhorn Mountains Volcanics
Kit	Intrusive rock of Tobacco Root Batholith, undivided
Kdi	Diorite
Kan	Andesite
KJs	Sedimentary rocks, undivided
Js	Sedimentary rocks, undivided
JTRs	Sedimentary rocks, undivided
Ps	Sedimentary rocks, undivided
IPMs	Sedimentary rocks, undivided
IPPMs	Sedimentary rocks, undivided
PIPMs	Sedimentary rocks, undivided
Ms	Sedimentary rocks, undivided
MDs	Sedimentary rocks, undivided
Cs	Sedimentary rocks, undivided
Yla	Lahood Formation
Amt	Metamorphic rocks, undivided

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



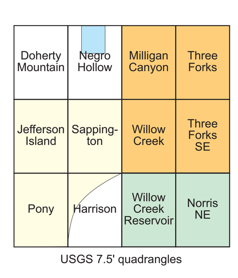
Cross section is not based on subsurface data except general depth of valley fill from Robinson (1963), Davis and others (1965), and Richard (1966), and thrusted geometry of the 10N Pluton from Zietz (1960).

EXPLANATION
Datum: Mean sea level
No vertical exaggeration
Thin surficial deposits not shown.

Qal	Alluvium
QTeu	Eustis map unit
Tcc	Cottonwood Canyon map unit
Tdc	Dunbar Creek Formation
Tca	Climbing Arrow Formation
Kem	Elkhorn Mountains Volcanics
Ki	Intrusive rock
Mzs	Mesozoic sedimentary rocks, undivided
Pzs	Paleozoic sedimentary rocks, undivided
Yb	Belt Supergroup rocks, undivided

Fault--Arrow shows sense of relative movement.

Major sources of pre-Cenozoic geology
For other sources of geologic map information see text.



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MBMG Open File 537

Geologic Map of Cenozoic Deposits of the Lower Jefferson Valley, Southwestern Montana

Susan M. Vuke

2006