GEOLOGIC MAP OF
WESTERN AND NORTHERN GALLATIN VALLEY
SOUTHWESTERN MONTANA

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2003

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Revised 11/04: *statement added regarding radiometric dates*

This report has been reviewed for conformity with Montana Bureau of Mines and Geology's technical and editorial standards.

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11/03/04: ^{40}Ar/^{39}Ar dates recently obtained from ash beds in the Madison bluffs have not been incorporated into this report. The dates indicate that the contact between the Dunbar Creek Member and the Madison Valley formation, the mid-Tertiary (Hemingfordian) unconformity, was accurately mapped. However, dates on two ashes in the Madison bluffs indicate that the upper Dunbar Creek is Arikareen, not Whitneyan as interpreted in this report. Therefore, the hiatus represented by the mid-Tertiary unconformity spans more time in the Menard area than in the Madison bluffs.

TERTIARY GEOLOGY AND CENOZOIC STRUCTURE IN WESTERN AND NORTHERN GALLATIN VALLEY

Introduction

The *Geologic Map of Western and Northern Gallatin Valley* (Fig. 1, 2, and 3) is the second of two geologic maps of the Gallatin Valley prepared under STATEMAP contracts with the U.S. Geological Survey. The first, *Preliminary Geologic Map of the Eastern Part of the Gallatin Valley* (Lonn and English, 2002), is at the same scale and joins this map on the east. Another STATEMAP product, *Preliminary Geologic Map of the Bozeman 30'x 60' quadrangle* (Vuke and others, 2002), at 1:100,000 scale, includes the entire Gallatin Valley.

Tertiary geology is the focus of this report. Rocks older than Tertiary were not emphasized, and Quaternary deposits received only cursory attention, with information primarily taken from previous work. The Montana Bureau of Mines and Geology Ground-water Characterization Program will be conducting a detailed ground-water study of the Gallatin Valley in the future, so ground water was not a focus of this report. References cited in the bibliography provide more information on ground water (including Lonn and English, 2002), and more detailed mapping and discussion of older rocks.

A geologic map of most of the map area was compiled at 1:100,000 scale (Vuke and others, 2002, Plate II) from previous mapping (Hackett and others, 1960; Hughes, 1980; Mifflin, 1963; Schneider, 1970), and initial field work for the preliminary geologic map of the Bozeman 30'x 60' quadrangle (Vuke, and others, 2002). Additional field work was done during September, 2002. The Madison Bluffs, western Camp Creek Hills, and Madison Plateau (Fig. 2) were mapped on foot. The rest of the Camp Creek Hills area was mapped from roads and trails, and therefore is not as comprehensive. Mapping in the Dry Creek area (Fig. 2) is preliminary, based on mapping from roads and aerial photos only. The *Geologic Map of Western and Northern Gallatin Valley* represents a revision of the map by Vuke and others (2002) and supersedes Plate II of that report.

TERTIARY STRATIGRAPHY

Two stratigraphic approaches have been used to map Tertiary deposits of southwestern Montana: lithostratigraphic and sequence stratigraphic. Robinson (1963) designated several lithostratigraphic units in the Tertiary rocks of the Three Forks area. Kuenzi and Fields (1971) carried some of these units farther west into the Whitehall area, with modifications and additions. The lithostratigraphic units of Kuenzi and Fields (1971) have been used in most of the other valleys of southwestern Montana and rely in part on the recognition of a mid-Tertiary unconformity.

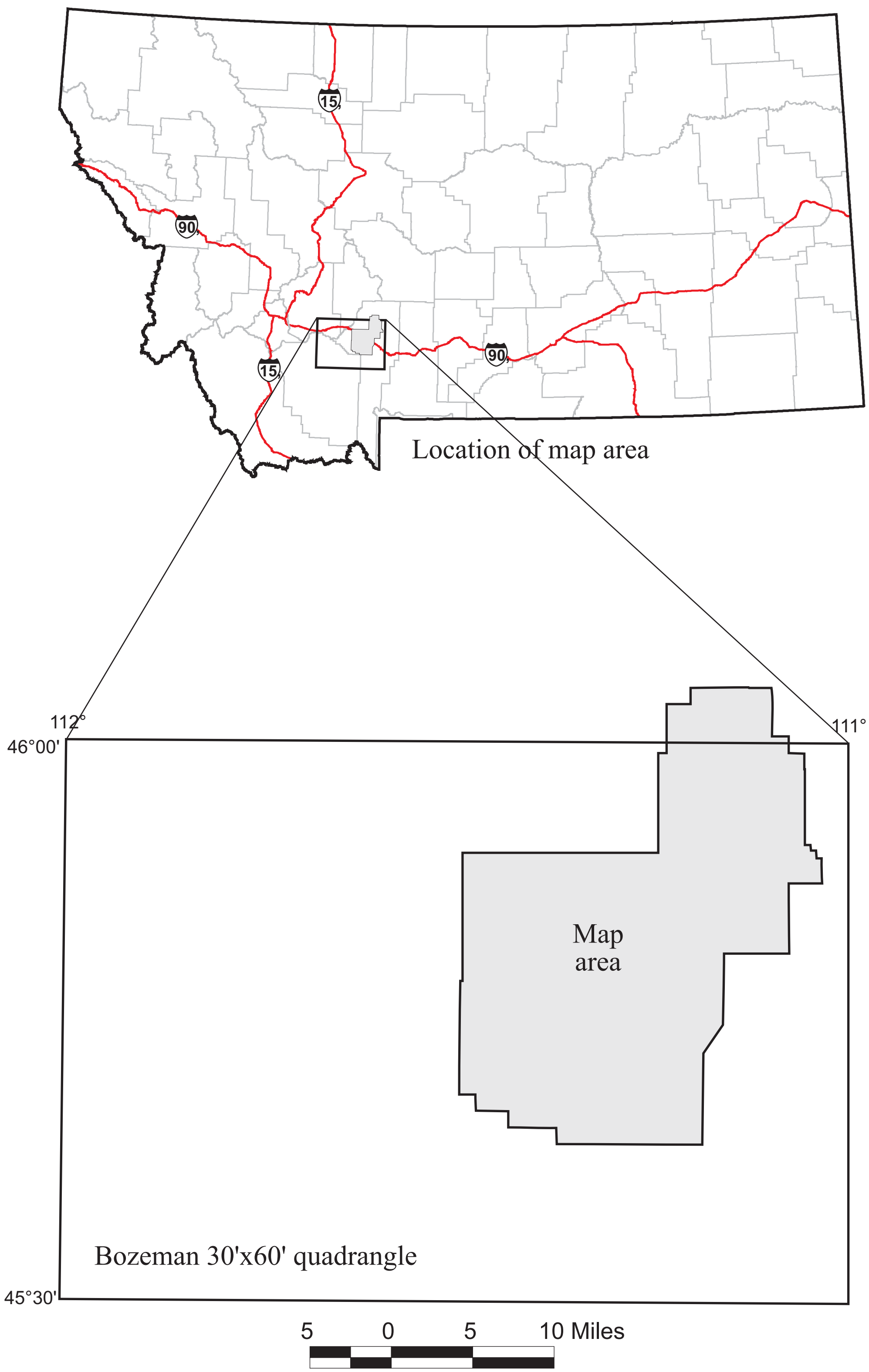


Figure 1. Location of map area relative to State of Montana and Bozeman 30'x60' quadrangle.

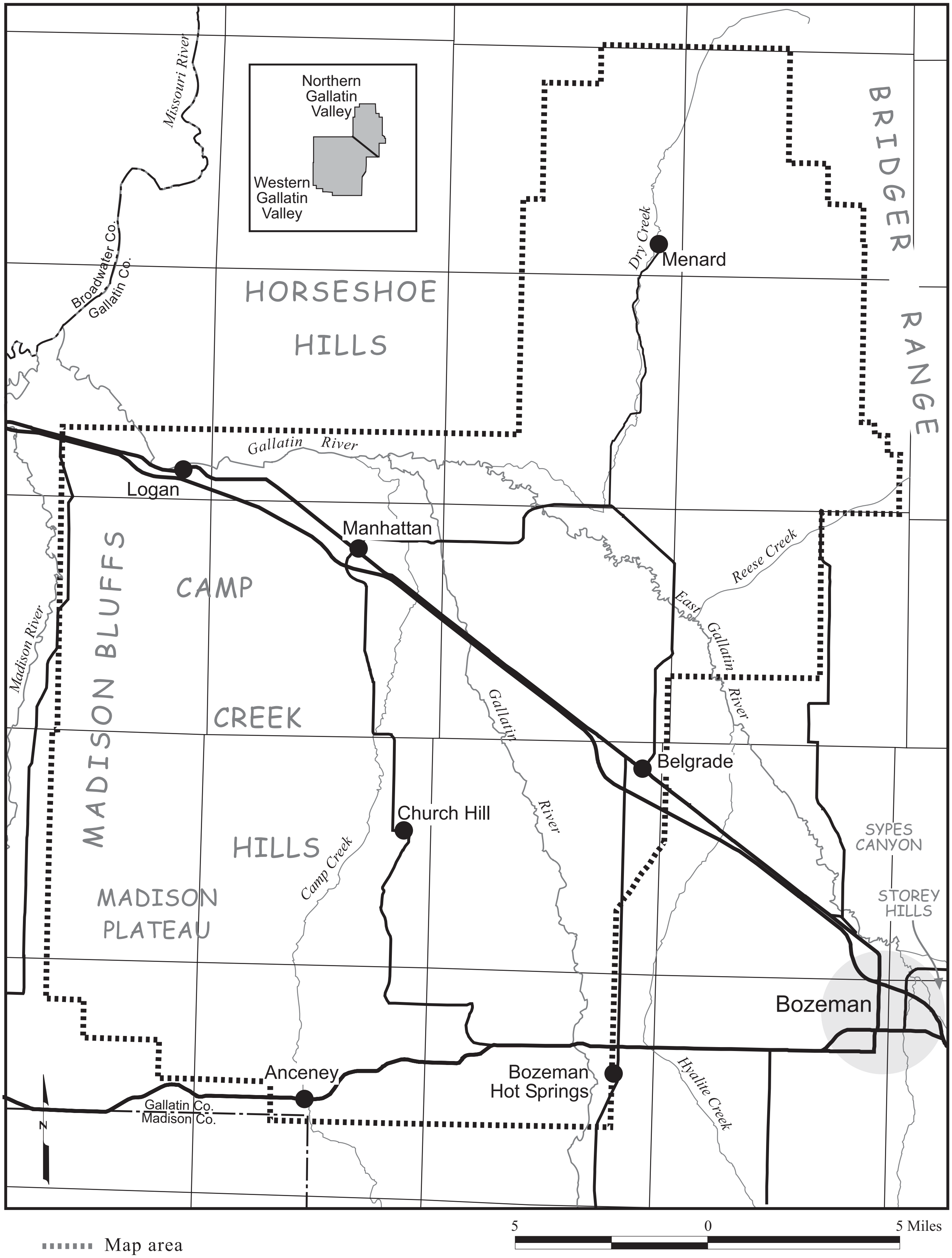


Figure 2. Geographic and cultural features referred to in text.

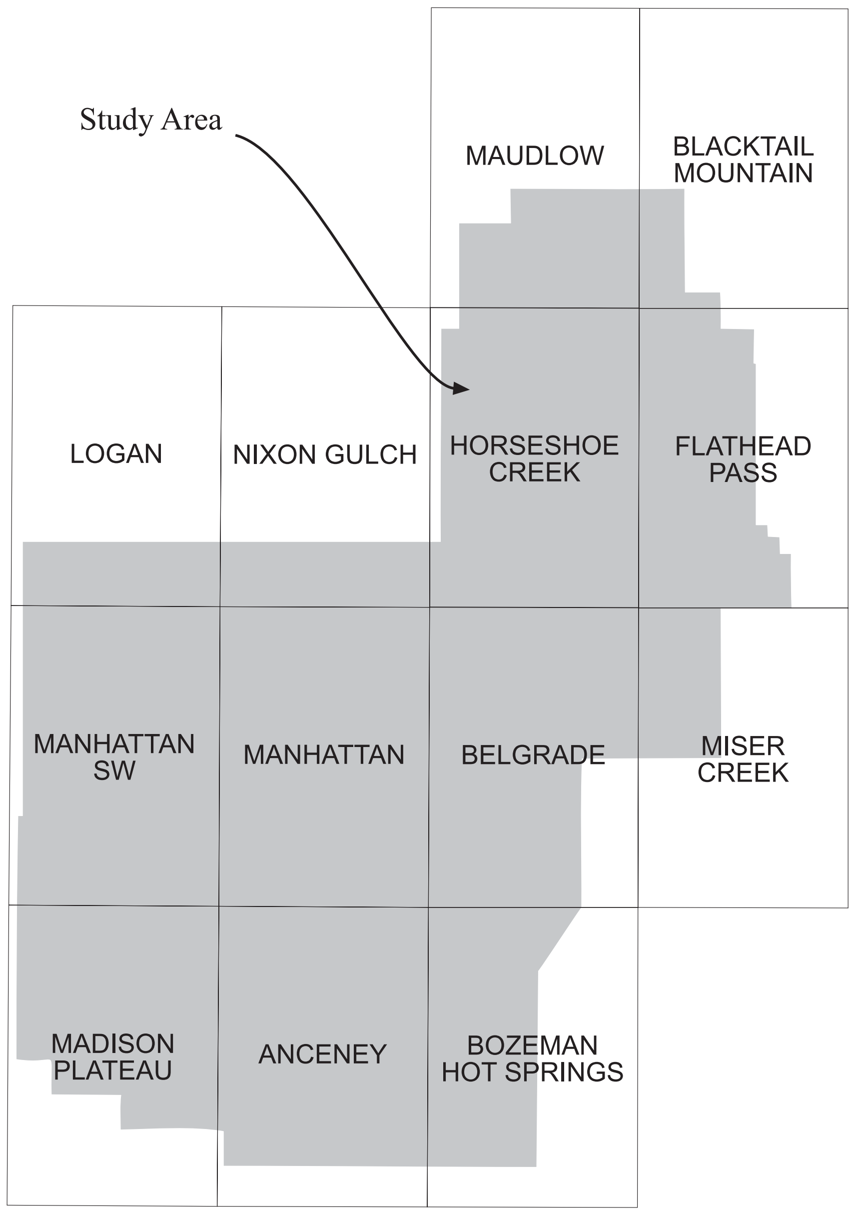


Figure 3. Index of 7.5' quadrangles.

Hanneman and Wideman (1991) discussed the problems of using lithostratigraphy for the Tertiary deposits of southwestern Montana, including abrupt facies changes and vertical repetition of lithologies. They proposed a sequence-stratigraphic approach, and recognized calcic paleosols at unconformities that can be followed on seismic lines as well as in outcrop.

The map of this report is adjacent to the Three Forks area where Robinson (1963) established some of the Tertiary lithostratigraphy, and the Madison Bluffs in the westernmost part of the map area provide miles of relatively good exposures. These advantages allowed tentative use of lithostratigraphic map units despite the abrupt facies changes and vertical repetition of lithologies encountered in this area.

Both the sequence-stratigraphic approach and the lithostratigraphic approach rely in part on accurate placement of a mid-Tertiary unconformity. Index fossils found in one of the units (Madison Valley formation, informal) indicate that the unit is younger than the unconformity. Two ash dates in the Dry Creek area span the unconformity (Hughes, 1980). Ash beds were sampled from three map units in the Madison Bluffs and submitted for dating. If the samples provide dates, they will serve as a check for the accuracy of the lithostratigraphic mapping relative to the mid-Tertiary unconformity. They may also allow extension of sequence-stratigraphic units into the Gallatin Valley from other parts of southwestern Montana.

Kuenzi and Fields (1971) divided the Tertiary of the Jefferson Valley into two redefined formations, the Sixmile Creek Formation (Robinson, 1967) and the Renova Formation (Robinson, 1963), separated by a mid-Tertiary unconformity that generally spans much of the Hemingfordian North American Mammal Age (NALMA), and may also span all or part of the Arikareean NALMA (Fig. 4). Kuenzi and Fields (1971) redefined the Sixmile Creek Formation as a coarse-grained unit *above* the unconformity, whereas Robinson's original type section (1967) included an Arikareean unit below the unconformity as well (Kuenzi and Fields, 1971; Fields, and others, 1985). Kuenzi and Fields (1971) redefined the members of the Renova Formation from what had been designated as formations by Robinson (1963) in the Three Forks area. Two of the members, Climbing Arrow and Dunbar Creek, are discussed in this report.

The map of this report is divided into two areas for the purpose of discussion, the northern Gallatin Valley, north of the Gallatin River, and the western Gallatin Valley, which is the remainder of the map (Fig. 2, inset). Although there are distinct similarities between the lithostratigraphic units in the northern Gallatin Valley and those in the western Gallatin Valley, there are also distinct differences. The four Tertiary units mapped in the northern Gallatin Valley resemble those in the western Gallatin Valley area in grain size, sedimentary structures, sand body shape, and morphology of coarse beds and lenses. The primary differences are clast composition in the coarser-grained units, and fossil abundance in one of the units. A thicker section of the uppermost unit is exposed in the Dry Creek area.

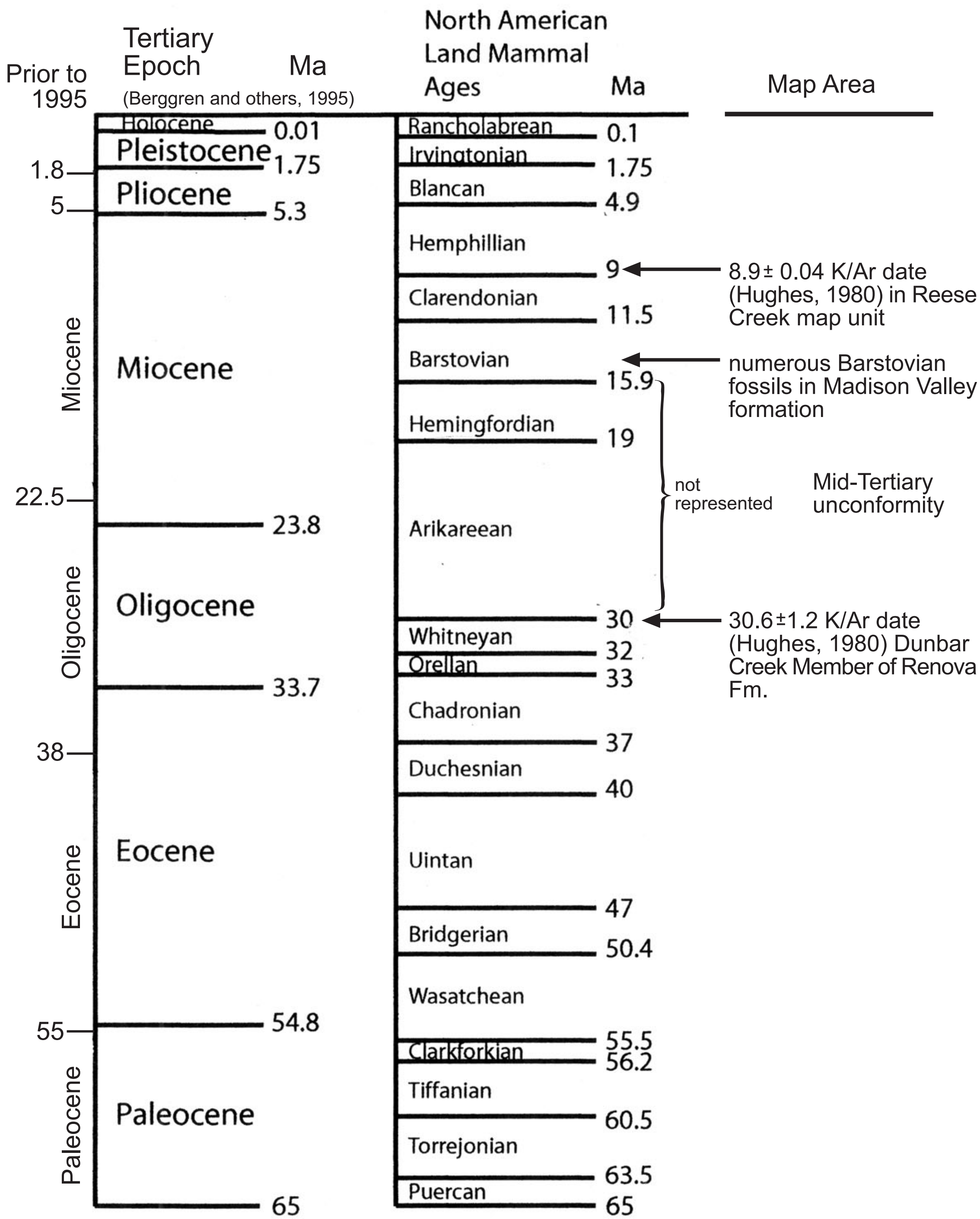


Figure 4. Tertiary dates in map area (two center columns from Hanneman and others, 2003).

Madison Plateau and Reese Creek map units

In both western and northern Gallatin Valley (Fig. 2, inset), a cobble or cobble and small boulder conglomerate, or gravel is present in the upper part of the section (Fig. 5). This unit is cemented by calcium carbonate where consolidated, or has clasts coated by calcium carbonate where it is unconsolidated. In both areas, the conglomerate is overlain by fine-grained, dominantly unconsolidated sediment.

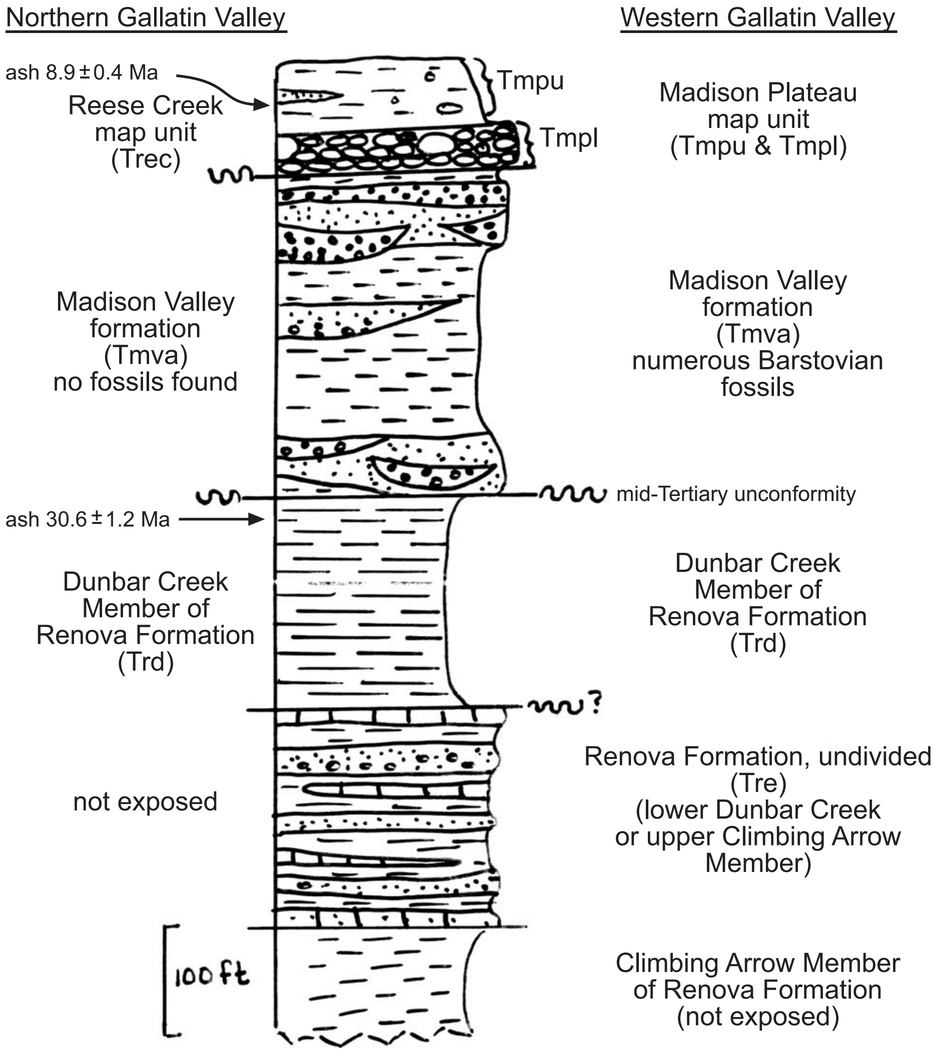
In other aspects the conglomerates differ between the two parts of the map area. In the western Gallatin Valley area, the contact between the Madison Plateau map unit and the underlying Madison Valley formation appears conformable. In the northern Gallatin Valley area, the conglomerate at this horizon (basal Reese Creek map unit, Fig. 5) rests with angular unconformity on the Madison Valley formation.

The clasts of the lower Madison Plateau map unit are dominantly Proterozoic Belt rocks from a western source and are well rounded. Clasts at the base may be reworked from the Madison Valley formation, but otherwise Archean metamorphic rocks and volcanic rocks are rare. Above the base of the unit, clasts are well rounded, moderately well sorted texturally and compositionally, and are dominantly cobble size. The conglomerate occurs as a sheet deposit on both sides of the Madison River. In contrast, the clasts in the basal Reese Creek map unit are composed of Proterozoic LaHood arkose, Paleozoic limestone, and volcanic and metamorphic rocks, and are subangular to subrounded, and locally poorly sorted texturally, but dominated by cobbles and small boulders. It was not determined if the conglomerate is distributed as a sheet deposit in this area.

In both areas, the conglomerates are overlain by poorly exposed fine-grained sediment. Some of this sediment is unmapped Quaternary loess, but a fine-grained Tertiary unit is recognized, too. In the Reese Creek area this unit was dated (K-Ar) as 8.9±0.4 (Hughes, 1980; Lange and others, 1980), late Clarendonian or early Hemphillian NALMA (Fig. 4).

The age of the fine-grained sediment of the Madison Plateau map unit in the western Gallatin Valley is not known, but the lower and upper parts of the map unit conform to the dip of the underlying Barstovian and Clarendonian? (Fig. 4) Madison Valley formation and overlie it with apparent conformity. For this reason, a late Clarendonian or early Hemphillian age also seems reasonable for the Madison Plateau map unit.

The conglomerate clasts in the lower Madison Plateau map unit came from a completely different source than those of the basal Reese Creek map unit. The Proterozoic Belt clasts in the Madison Plateau map unit (dominantly orthoquartzites) must have come from many miles to the west, whereas the clasts in the basal Reese Creek map unit were derived from the adjacent Bridger Range or Horseshoe Hills, and possibly also from the southeast (possible source of the volcanic and metamorphic rocks).



NOTES

- Ash dates from Hughes (1980).
- Climbing Arrow not exposed, but intercepted at Madison River level in a well just west of Madison Buffalo Jump State Park (Hackett and others, 1960).
- Placement of mid-Tertiary unconformity tentative pending $^{40}Ar/^{39}Ar$ dates on ash sampled in the Madison Bluffs.
- Correlation between Reese Creek map unit and Madison Plateau map unit is tentative.
- Schneider (1970) described three fining-upward sequences in the Madison Bluffs exposures, not recognized in this report.

KEY

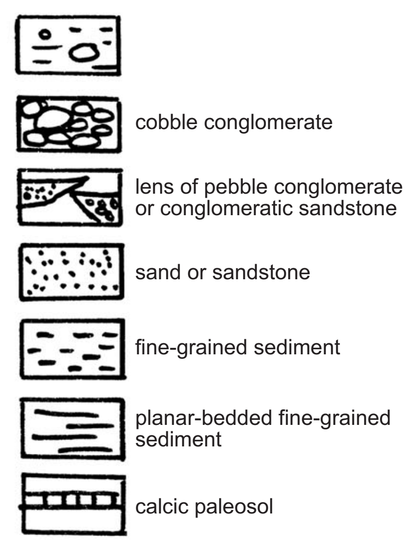


Figure 5. Generalized stratigraphic section of Tertiary deposits in the map area. See text for unit descriptions.

Madison Valley formation

The Madison Plateau and Reese Creek map units are underlain by tuffaceous siltstone and marl, interbedded with sheet deposits of cross-bedded sandstone that contain lenses of conglomeratic sandstone, pebble and granule conglomerate, and local cobble conglomerate (Fig. 5). This unit was mapped as the Sixmile Creek Formation by Hughes (1980) in the northern Gallatin Valley. He described the sandstones as blanket-like deposits with most clasts smaller than cobble size (Hughes, 1981). Hackett and others (1960) mapped this unit as the lower part of their unit 2 in both areas. Klemme (1949) correlated this unit (his unit B) near Menard with the "Madison Valley beds" south of Logan (Madison Bluffs area, Fig. 2). He recognized an unconformity at the contact between this unit and his underlying unit B (equivalent to the Renova Formation of Hughes (1980), and the Dunbar Creek Member of the Renova Formation of this report, discussed in the next section).

Color and clast composition of the Madison Valley formation vary between the western and northern parts of the Gallatin Valley. In western Gallatin Valley, the tuffaceous siltstones are pinkish tan, whereas in northern Gallatin Valley they are grayish orange. Silicified wood and fossil bone fragments are relatively abundant in the conglomerates of the western Gallatin Valley area , but were not found in the conglomerate of the northern area in this study or previous studies. Four *Merychippus* (horse) teeth (Bartstovian, Fig. 4) and a *Merychippus* jaw, were found at three different locations in the Madison Bluffs and Camp Creek Hills by the author (identified by Ralph Nichols, Museum of the Rockies, and by Alan Tabrum, Carnegie Museum of Natural History). Many other collections of Barstovian fossils in the Madison Valley formation of the Madison Bluffs and Camp Creek Hills have been made in the past (Tabrum and others, 2001; Douglass, 1899, 1901, 1903, 1907a, 1907b, 1908, 1909a, 1909b; Frick, 1937; Dorr, 1956; Sutton, 1977; Sutton and Korth, 1995, Evander, 1996).

Glassy ash beds are evident in the Madison Bluffs and south of the map area (Mifflin, 1963). They were not found in northern Gallatin Valley during field work for this report (perhaps because of the poor exposures, relative thinness of the unit in the area, and limited field work).

The pebbles and cobbles in the conglomerates of the Madison Valley formation in the western Gallatin Valley are dominantly Archean metamorphic rocks, and Mesozoic or Cenozoic volcanic rocks, including some scoria. Quartz and chert are much less abundant, and Paleozoic limestone and Proterozoic Belt orthoquartzites (from a western source) are generally rare, although south of Manhattan the amount of western-source Belt rocks is higher than elsewhere. The abundance of Archean metamorphic rock clasts suggests a southern, western, or eastern source. The composition of the Madison Valley formation clasts in northern Gallatin Valley varies with location. Near Menard, the clasts are dominantly Paleozoic limestone, Mesozoic sandstone, and volcanic rocks with sparse Archean metamorphic clasts. Hughes (1980) noted that the conglomerates in the Menard area lack Proterozoic LaHood clasts. He interpreted a northern source from the Maudlow basin and Horseshoe Hills with the volcanic rocks having come from the Livingston Formation exposed there. Closer to the Bridger Range, the Madison Valley formation conglomerate clasts are mostly Paleozoic limestone and Proterozoic LaHood arkose, the rocks exposed in the adjacent Bridger Range.

Outside the map area, Tertiary sediment in the lower Storey Hills north of Bozeman (Fig. 2) correlates lithostratigraphically (with the exception of conglomerate clast composition) and biostratigraphically (based on Barstovian fossils, Fig. 4) with the Madison Valley formation in the Madison Bluffs. The conglomerates contain clasts of mostly igneous rocks (basalt, andesite, porphyritic granodiorite, and porphyries of diorite, gabbro, granodiorite, and andesite) with minor Precambrian gneiss and rare Livingston Group sandstone, Paleozoic limestone, and other Paleozoic or Mesozoic rocks fragments (Glancy, 1964). Glancy (1964) interpreted an eastern and southeastern source. A granodiorite represented in the conglomerate clasts strongly resembles a granodiorite in the Crazy Mountains, that is apparently not found elsewhere (W. McMannis, personal communication in Glancy, 1964), suggesting an eastern source.

The conglomerate clasts are also composed of igneous rocks in the Sypes Canyon area north of the Storey Hills (J. Lonn, personal communication, 2003) even though the rocks exposed today in the east-adjacent Bridger Range are Archean metamorphic rocks. This clast composition suggests that the southern part of the Bridger Range was not exposed at the time of deposition (Barstovian and Clarendonian?).

In several local areas south of Manhattan, the Madison Valley formation conglomerates contain Proterozoic Belt orthoquartzite cobbles mixed with Archean metamorphic rocks and dark volcanic rocks. The Belt orthoquartzite clast composition suggests a contribution of sediment from the west.

The variety of clast compositions in the Madison Valley formation in different parts of the map area suggests either the presence of Miocene sub-basins, or drainage from multiple directions. A trunk drainage with a mixture of clasts from these different provenances was not found in the map area.

South of the map area, Mifflin (1963) described light-colored, fine-grained, tuffaceous sedimentary strata with beds of sandstone that contain granule to pebble conglomerate in cross-bedded channels. The conglomerate is composed of clasts of quartz, basic volcanic rock, metamorphic rock, chert, and silicified wood. This description closely resembles the lithology of the Madison Valley formation in the Madison Bluffs. Mifflin noted horse and camel fossils in this unit. Clast composition is similar in the Tertiary deposits east of Sourdough Creek near Bozeman that are lithologically similar to the Madison Valley formation of the western Gallatin Valley. Fix (1940) reported finding part of a fossil camel in this area.

The Madison Valley formation was mapped in both the western and northern Gallatin Valley for this report. It is in the stratigraphic position of the lower Sixmile Creek Formation of Kuenzi and Fields (1971) immediately overlying the mid-Tertiary unconformity. However, unlike the Sixmile Creek Formation, described by Kuenzi and Fields (1971) as predominantly coarse-grained, it is dominantly a fine-grained unit in much of the map area, although the presence of coarse-grained sand, and granule-, pebble-, or cobble-conglomerate lenses is characteristic. The informal name *Madison Valley formation*, applied to this unit by Douglass (1907) in the Madison Bluffs area, was used in this report to distinguish these deposits from dominantly coarse-grained Sixmile Creek Formation of other areas. Calcic paleosols are present at the base of the Madison Valley formation in the southern Madison Bluffs area. They were not seen anywhere else in the map area at this stratigraphic horizon.

At one location in the southeasternmost part of the map area, a breccia of dominantly Archean metamorphic clasts occurs within the Madison Valley formation. A similar breccia is present just south of Anceney. These breccias may reflect local sediment derivation from uplift of northwest-striking faults in the southern part of the map area and farther south that juxtapose Archean rocks against Tertiary strata.

<u>Dunbar Creek Member of Renova Formation</u>

In both western and northern Gallatin Valley, a planar-bedded, light-colored, tuffaceous, fine-grained unit that contains gastropods and ostracodes, underlies the Madison Valley formation (Fig. 5). This unit was mapped as Renova Formation by Hughes (1980) in the Dry Creek area, as unit 1 by Hackett and others (1960) in both areas, and as unit A by Klemme (1949) in the Dry Creek area. Hughes obtained a K-Ar date of 30.6±1.2 Ma (Whitneyan, Fig. 4) on an ash in his upper Renova Formation in the Dry Creek area which is consistent with the age of the Renova Formation in other areas (Hughes, 1981), and with its stratigraphic position below the mid-Tertiary unconformity. This unit was mapped as Dunbar Creek Member of the Renova Formation in both northern and western Gallatin Valley in this report. Its stratigraphic position in the Madison Bluffs is tentatively considered below the mid-Tertiary unconformity, pending the age analysis of an ash bed sampled from this unit that was submitted for $^{40}Ar/^{39}Ar$ dating.

<u>Renova Formation, undivided</u>

This map unit (Fig. 5) is exposed only in the Madison Bluffs area. It was mapped as *Renova Formation, undivided* because it was unclear whether the unit is upper Climbing Arrow Member or lower Dunbar Creek Member.

In the northern part of the Madison Bluffs, stacked calcic paleosols that underlie the unit mapped as Dunbar Creek Member (Fig. 5) are associated with what resembles upper Climbing Arrow conglomerate mapped by Robinson (1963) west of the Madison River. Farther south, in the Madison Buffalo Jump State Park area (Fig. 2), the calcic paleosols apparently occur in what Robinson (1963) mapped as Dunbar Creek Formation directly west of the Madison River. Robinson recognized that the upper Climbing Arrow and lower Dunbar Creek Formations (as he originally defined them) may interfinger, which may account for this discrepancy. Alternatively, a Tertiary fault where this interval is covered between the northern and central part of the bluffs may have juxtaposed Climbing Arrow and Dunbar Creek in this area.

The calcic paleosols near Madison Buffalo Jump State Park are similar to those recognized by Hanneman and others (1994) as located at unconformities in the Tertiary elsewhere (D. Hanneman, personal communication, 2002). Ash samples were collected from above and below the calcic paleosols near the park and submitted for $^{40}Ar/^{39}Ar$ dating. The calcareous beds have also been interpreted as travertine or hot springs deposits (Blake, 1953; Hackett and others, 1960; Schneider, 1970).

A Montana Power Company drill hole at river level just west of the middle part of the Madison Bluffs intercepted green and grayish-green bentonitic claystone, lignite, and other lithologies that Hackett and others (1960) correlated with Climbing Arrow west of the Madison River. The stratigraphic position of the drill hole is just below the Renova Formation, undivided, mapped in this report. Climbing Arrow lithologies at this stratigraphic position support the interpretation that the Renova Formation, undivided, is equivalent to the upper Climbing Arrow or lower Dunbar Creek as mapped by Robinson (1963) west of the Madison River.

CENOZOIC STRUCTURE

The Gallatin Valley lies at the eastern margin of basin-and-range extension in Montana, but does not fit the three general models of Tertiary extensional basins proposed for southwestern Montana: symmetrical horsts and grabens, differentially tilted hanging and footwall blocks, and rotated half-grabens, bounded on one side by a listric fault (Brodowy and others, 1991). Although gravity modeling suggests a rotated half-graben west of the Bridger Range along the Montana baseline (Lageson, 1989), other prominent structures have had a stronger influence on the Cenozoic deposits in other areas of the Gallatin Valley.

Tertiary strata were faulted, folded, and tilted in western and northern Gallatin Valley, dominantly along the trends of three major types of structures in the valley: northwest-striking basement faults (Schmidt and Garihan, 1983 and 1986), the Southwest Montana Transverse Zone (Schmidt and O'Neill, 1982), and the range-front faults of the Bridger Range (McMannis, 1955; Lageson, 1989). In addition, northeast-striking faults offset the Tertiary in two parts of the map area.

The Cenozoic structural influences in the western Gallatin Valley area were primarily reactivation of northwest-striking basement faults and movement on the Central Park Fault. The Cenozoic structural influences in the northern Gallatin Valley area were primarily movement on range-front faults of the Bridger Range and probable movement on the Willow Creek Fault.

Northwest-striking basement faults

In most of the western Gallatin Valley area, Tertiary strata dip to the northeast, perpendicular to northwest-striking faults and linear features. The northwest-striking faults are likely reactivated basement faults (Ruppel, 1982; Schmidt and Garihan, 1983 and 1986). Regionally, high-angle faults with this strike had a complex history of recurrent movement that changed direction in response to changed stress fields (O'Neill, and others, 1986; Ruppel, 1993). The faults were reactivated during the Laramide with left-reverse/oblique-slip movement (O'Neill, and others, 1986; Schmidt and Garihan, 1986) and during Tertiary extension with right-normal/oblique-slip movement (Schmidt and Garihan, 1986).

Northwest-striking faults offset the Tertiary and juxtapose Tertiary and Archean crystalline rocks in the southern part of the map area where Tertiary cover is thin over the Archean rocks. Faults that juxtapose Tertiary sediment and Archean crystalline rock are even more apparent south of the map area (Vuke and others, 2002). Farther north, where depth to basement rock increases, linear features with a northwest strike suggest that the basement faults continue into that area. Some of these linear features are indicated on the map. Others are more subtle, but can be traced on aerial photos in the Madison Plateau area and throughout the map area on shaded relief digital elevation models. These linear features also probably reflect the influence of basement faults. Cenozoic reversal of movement is apparent on other northwest-striking faults just west of the map area (Feichtinger, 1970).

Wells 9 and 10 (Table 1) were drilled through Tertiary sediment to Archean rocks at depths of 826 feet and 575 feet, respectively (Hackett and others, 1960). Hot water was intercepted in both wells, suggesting deep circulation of water along the basement faults (Hackett, and others, 1960).

Northeast-southwest-directed extension for this area was determined from fault plane solutions for hundreds of earthquakes recorded in southwestern Montana since 1982 (Stickney, 1999). This extension direction results in normal slip on NW-striking faults (Stickney, 1999). East-west-directed extension has been interpreted for the post-Laramide Tertiary resulting in right normal/oblique slip on the northwest-striking reactivated basement faults (Schmidt and Garihan, 1986).

Southwest Montana Transverse Zone

The Southwest Montana Transverse Zone is a significant Laramide structural boundary between tectonic features of the thrust belt on the north and structures related to basement-cored foreland uplifts on the south (Schmidt and O'Neill, 1982; Lageson, 1989). It is a reactivated basement structure that separates Proterozoic Belt Supergroup sedimentary rocks to the north from Archean crystalline rocks to the south (Harrison and others, 1974). Two major structures of this zone are interpreted in the Cenozoic deposits of the map area: the Central Park Fault and Willow Creek Fault.

Central Park Fault: The influence of the Central Park Fault is evident in the Tertiary deposits of the Madison Bluffs and Camp Creek Hills by the presence of a narrow zone of folds, including an anticline-syncline pair with a secondary monocline within the south-dipping limb of the anticline and syncline. The monocline suggests that more than one fault was involved. This narrow fold zone disrupts the regional northeast dip of the Tertiary beds.

Hackett and others (1960) located the position of the Central Park Fault beneath the Quaternary alluvial valley deposits based on a change in the thickness of Holocene and Pleistocene alluvium of the Gallatin River Valley. The following data are taken from their report. Thirty feet of alluvium overlie the Tertiary deposits at well 4 (Table 1) north of the fault, yet well 5 on the south side of the fault, was drilled through more than 300 feet of alluvium without intercepting the Tertiary deposits. North of the fault, well 3 penetrated 31 feet of alluvium, 104 feet of alluvium or Tertiary strata, and 72 feet of Tertiary strata. Well 6 was drilled through 215 feet of alluvium and 100 feet of Tertiary deposits. South of the interpreted location of the fault, Well 7 penetrated more than 400 feet of alluvium without reaching the Tertiary, and an oil test well, well 8 on the map, was drilled through more than 800 feet of alluvium without reaching the Tertiary.

Stermits and Boner, in Hackett and others (1960), noted that more ground water was discharged at the surface in the Central Park area during their study than in any other part of the Gallatin Valley. They concluded that because the alluvium north of the Central Park Fault cannot transmit all the water entering the area by underflow, some of the ground water is forced to the surface where it is discharged by spring flow and effluent seepage into streams and lost by evapotranspiration. The map of the present report shows a patterned area with seasonal high water tables less than 6 ft (U.S. Soil Conservation Service, 1992), and its possible relation to the Central Park Fault.

Fix (1940, Plate I) noted a broad swampy area just north of the fault in the Central Park area with numerous thermal springs. No other reference to thermal springs in this area was found during research for the present report. Information in the Montana Bureau of Mines and Geology Ground-water Information Center data base indicates that water in wells of the area is currently somewhat warmer than adjacent areas. The warmer temperatures could represent thermal water diluted by irrigation water (John Metesh, MBMG, personal communication, 2002). Alternatively, seismic activity in the area (e.g. Stickney and Lageson, 1999) may have changed the pattern of thermal ground-water movement. In either case, the presence of thermal water suggests a deep fault or fracture.

It is assumed that the Madison Plateau map unit (Fig. 5) was involved in the same folding as the underlying Madison Valley formation, even though it has presumably been eroded from the immediate area of folding. It appears to maintain a dip consistent with that of the underlying Madison Valley formation and maintains a consistent stratigraphic position in this area. If the Madison Plateau map unit and overlying sediment correlate with the Reese Creek map unit (dated as latest Clarendonian or earliest Hemphillian [Fig. 5] in the Reese Creek area), the fault movement responsible for folding the Tertiary beds must be younger than that. The influence of the fault on the thickness of the Pleistocene braid plain alluvium (Hackett and others, 1960) suggests that fault movement occurred before or during the Pleistocene, bracketing the age of movement between latest Miocene and latest Pleistocene.

Hackett and others (1960) projected the Central Park Fault eastward, toward an anomalous alluvial fan, the Springhill Fan, just outside the map area (Lonn and English, 2002), that they believed was controlled by the Central Park Fault. Davis and others (1965) interpreted a fault beneath the straight Reese Creek valley based on bouguer

Table 1. Data from selected wells and a test hole, summarized from Hackett and others (1960). Numbers correspond to numbers next to well symbols on map.

1.	22 ft of alluvium Greater than 4 ft of Paleozoic limestone
2.	69 ft of alluvium 245 ft of Tertiary sedimentary strata Greater than 150 ft of Proterozoic Belt rocks
3.	31 ft of alluvium 104 ft of Tertiary? sedimentary strata Greater than 72 ft of Tertiary sedimentarv strata
4.	30 ft of alluvium Greater than 45 ft of Tertiary sedimentary strata
5.	Greater than 301 ft of alluvium
6.	215 ft of alluvium Greater than 100 ft of Tertiary sedimentary strata
7.	Greater than 400 ft of alluvium
8.	Greater than 800 ft of alluvium
9.	826 ft of Tertiary sedimentary strata Greater than 23 ft of Archean metamorphic rock This well intercepted hot water.
10.	18 ft of loess?* 42 ft of terrace deposit?* 515 ft of Tertiary sedimentary strata Greater than 25 ft of Archean metamorphic rock This well intercepted hot water.

*The interpretation of the present study is that these units are Tertiary.

gravity and aeromagnetic data. Strike-slip or oblique slip movement may have occurred on the Central Park Fault (Brodowy and others, 1991). Left-lateral strike-slip along a vertical fault was interpreted from composite focal-plane solutions for the Central Park Fault zone (Zim and Lageson, 1985). If that is the case, the fault underlying Reese Creek (Davis and others, 1965) lies at an appropriate angle to the Central Park Fault to have been involved in second-order shear.

Willow Creek Fault: The Willow Creek Fault is well documented west of the map area where it offsets pre-Tertiary bedrock (e.g., Schmidt and O'Neill, 1982). Its position was inferred in western Gallatin Valley from the southern limit of Paleozoic and Proterozoic rock exposures. Well 2 on the map, which is north of the inferred position of the fault, intercepted Proterozoic Belt rocks beneath 245 ft of Tertiary strata (Hackett and others, 1960). Presumably, Archean rocks or Archean rocks overlain by Paleozoic rocks are south of the fault, as they are in outcrop to the west. The fault is interpreted to extend east of the Horseshoe Hills based on a syncline in the Tertiary deposits near the mouth of Reese Creek in northern Gallatin Valley.

The interpretation of a syncline in the southern Dry Creek area is based on two tentative assumptions: that the conglomerate at Reese Creek, south of the axial trace of the syncline shown on the map, is the same conglomerate north of the trace, and that the fine-grained sediment overlying the conglomerate is the same unit on both sides of the trace. Hackett and others (1960) interpreted all these deposits as their Tertiary unit 2. Hughes (1980), on the other hand, interpreted the upper part of these deposits as Quaternary and Pliocene alluvial fan deposits that overlie the fine-grained unit from which the ash date was obtained. The tentative interpretation of the present report is that the Reese Creek map unit from which the 8.9±0.4 ash date (Hughes, 1980; Lange and others, 1980) was obtained is the same as the Quaternary and Pliocene alluvial fan deposits of Hughes (1980) with the exception of a veneer of Quaternary gravel that mantles some of the deposits, and that the Reese Creek map unit (late Clarendonian or early Hemphillian, Fig. 4), was involved in the folding. In a published synopsis of his thesis, Hughes' interpretation changed from Quaternary or Tertiary alluvial fan deposits to Quaternary or Tertiary gravel (Hughes, 1981). In the present report, conglomerate was recognized at the base of the unit, but the sediment overlying it is fine grained.

The Holocene drainage pattern in this area follows the wider valleys of the Pleistocene braided-stream deposits. An abrupt change in the drainage pattern occurs in the area of the syncline, from westward toward Dry Creek, to southward, following the same pattern as the Tertiary strata, suggesting that the folding may have taken place during the Pleistocene.

The thickness of Pleistocene alluvium of the Gallatin Valley, across the inferred location of the Willow Creek Fault, does not suggest Pleistocene high-angle fault movement that influenced the Pleistocene valley fill as it does for the Central Park Fault, although the presence of a syncline along its strike may indicate a high-angle component of movement. The most recent movement on this fault may be strike-slip. A westward curve in the south-flowing tributaries on the north side of Reese Creek may indicate Pleistocene deflection by left-lateral strike-slip movement on the Willow Creek Fault. Laramide movement on the Willow Creek Fault was right-lateral (Schmidt and O'Neill, 1982), but reversal of previous fault movement during the Cenozoic is well documented on many faults in this area (e.g., Lageson, 1989; Feichtinger, 1970).

The eastern part of the map area is located within or near a transition zone between the mid-continent stress regime and basin-and-range extension (Stickney and Bartholomew, 1987). Fault-plane solutions for hundreds of earthquakes in southwest Montana suggest NE-SW-directed extension for most of southwestern Montana within the basin-and-range province (Stickney, 1999; Stickney and Bartholomew, 1987). This would result in right-lateral strike-slip movement on east-west-striking faults. However, the 1925 Clarkston Valley earthquake just west of the northern Gallatin Valley part of the map area reflects the NW-SE-directed extension of the mid-continent stress regime (Stickney and Bartholomew, 1987). This would result in left-lateral strike-slip movement on east-west-striking faults such as the Willow Creek fault.

An August 25, 1989, seismic event in the southernmost Horseshoe Hills showed nearly pure left-lateral strike-slip movement on a northeast-striking fault or right-lateral slip on a northwest-striking fault within a cluster of other nearby events compatible with (but not limited to) strike-slip movement (Stickney, 1997). This may suggest that slip is still occurring on second-order shear faults related to left-lateral movement on the Willow Creek fault.

The distance between pre-Tertiary rocks of the Horseshoe Hills and the Bridger Range widens southward in the Dry CreekValley, and the west margin of the valley fits the pattern of the range-front faults of the Bridger Range. The Dry Creek Valley may have opened by recurrent Cenozoic left-lateral strike-slip movement on the Willow Creek Fault. West-directed thrust faults in the Negro Hollow area (Schmidt and O'Neill, 1982) and in the southern Bull Mountains (Alexander, 1951; Coppinger, 1983) about 30 miles west of the Dry Creek Valley, may have accommodated the opening of the Dry Creek Valley. Glaman (1991, Plate 1) apparently shows Paleozoic rocks thrust over Tertiary debris-flow deposits in the southern Negro Hollow area, and Richard (1966, Plate 1) also apparently shows Paleozoic strata overlying Tertiary sediment in the same area. West-directed thrust faults were also mapped south of the Negro Hollow area on strike with those to the north (Vuke and others, 2002). A similar relation was seen in the Milligan Canyon area. In both cases, Mississippian Mission Canyon Limestone appears thrust to the west over the "Sphinx Conglomerate" of Robinson, the basal Tertiary unit in the area. More detailed mapping of Tertiary deposits in these areas should clarify whether Tertiary deposits were involved in the west-directed thrusting. Cenozoic left-lateral movement in the zone of the Willow Creek Fault (Southwest Montana Transverse Zone) may also have resulted in a much lower net translation distance for the Southwest Montana Transverse Zone compared to major Laramide thrust faults to the north, such as the Eldorado Thrust System north of Helena. This discrepancy is discussed in Burton and others (1987).

In the northernmost Madison Bluffs, near the stone ruins of an old cement plant (visible just south of Interstate 90 from the east-bound side), the Madison Valley formation dips more steeply than underlying beds and more steeply than the formation dips to the south. The base of the formation rests on successively lower parts of the underlying section toward the north. The hinge for this increased dip coincides with the inferred position of the Willow Creek Fault in this area.

Northeast-striking faults

Northeast-striking faults are inferred from geologic map patterns in the northernmost part of the Madison Bluffs and in the southeasternmost part of the map area. In addition, a fault or faults with this strike may be present in the subsurface in an area east of Anceney where the regional northeast dip of Tertiary strata is interrupted by a zone of dips to the northwest that continues south of the map area.

In the northernmost part of the Madison Bluffs, a facies change in the unit mapped as the Dunbar Creek Member of the Renova Formation may generally coincide with the zone of inferred northeast-southwest-striking faults. Just north of this zone, an August 3, 1996 seismic event occurred beneath the Gallatin River with a strike-slip mechanism consistent with left-lateral slip on a northeast-trending vertical fault (Stickney, 1997), suggesting possible reactivation of this fault zone.

Range-front faults of Bridger Range

An angular unconformity is tentatively interpreted in the northern Gallatin Valley between what was mapped as Madison Valley formation and the Reese Creek map unit (Fig. 5). This angular unconformity is apparently not present in western Gallatin Valley.

Exposures are poor, but east of Dry Creek, the Madison Valley formation appears to dip consistently to the east in the area north of the syncline. East-dipping attitude measurements were taken in several places near Dry Creek and closer to the Bridger Range by Hughes (1980), and at one location in the present study. In contrast, the overlying Reese Creek map unit dips to the southwest on the east side of Dry Creek and north of the syncline, based on map pattern. If correlations with datable units and attitude measurements are accurate, an unconformity must have developed during the late Barstovian or Clarendonian (Fig. 4), following downward movement of the valley and eastward rotation of the Madison Valley formation beds, resulting from down-to-the-west movement on a range-front fault of the Bridger Range as discussed by Lageson (1989). The contrasting dip of the overlying Reese Creek map unit, away from the Bridger Range, may reflect primary dip of sediment shed from the mountains during an episode of tectonic quiescence. Hughes' (1980) ash date in the Reese Creek area indicates a late Clarendonian or early Hemphillian age for this sediment. The possible movement on the Willow Creek Fault that caused subsequent synclinal folding of these beds was later than late Clarendonian, and likely occurred during the Pleistocene as discussed above.

Gravity modeling north of Bozeman and south of the Central Park Fault, along the Montana Baseline, indicates a westward-thinning wedge of Tertiary sediment, with Miocene deposits dipping from 2º to 35º toward the range-front fault, suggesting a listric normal fault geometry at depth (Lageson, 1989). The best-fit model is a half-graben with a maximum sediment thickness of 6560 ft, and with 7,200 ft of throw on the adjacent normal fault (Lageson, 1989). The gravity data further suggest that there is probably not a significant Paleozoic section beneath the Tertiary in this area (Lageson, 1989). A seismic event with an epicenter about 7 km northeast of Belgrade (Fig. 2) occurred on November 6, 1997 (Stickney and Lageson, 1999). The focal mechanism indicated dominantly normal slip with a dextral component on a N15ºW, 60°E fault, interpreted as an intra-valley normal fault that was antithetic to the range-front fault of the Bridger Range. The epicenter lies between the Willow Creek and Central Park Faults as interpreted in this report.

Barstovian fossils have been found extensively in the Madison Bluffs (Douglass, 1899, 1901, 1903, 1907a, 1907b, 1908, 1909a, 1909b), in the Anceney area (Dorr, 1956; Sutton, 1977; Sutton and Korth, 1995; Evander, 1996), south of Manhattan (this report), in the lower Storey Hills east of Bozeman (Glancy, 1964), and in the Tertiary hills southeast of Bozeman (Fix, 1940). Lithostratigraphy of the Madison Valley formation is consistent in these areas except for the change in clast composition in the Storey Hills (see Madison Valley formation discussion). The Madison Valley formation is bracketed by K/Ar ash dates in the Dry Creek area (Hughes, 1980). The Madison Valley formation is only about 200 ft thick in the Madison Bluffs, and 100 ft thick in the Menard area. Although the Barstovian Madison Valley formation is tilted eastward near the Bridger Range, probably as a result of movement on the Bridger range-front fault, the bulk of the 7,200 ft of throw on the fault (Lageson, 1989), must have occurred prior to the Barstovian for these deposits to extend across such a broad area. The base of the Madison Valley formation is exposed near Anceney. It is unlikely that the formation thickens dramatically between Anceney and Bozeman. Movement on northwest-striking basement faults seems to have had the most regional structural influence on the exposed Tertiary of the western Gallatin Valley, followed by subsequent movement on the Central Park Fault.

The Tertiary deposits in northern Gallatin Valley appear to thicken much more toward the Bridger Range than they do farther south. This difference may be related to the interplay between the Southwest Montana Transverse Zone and the possible pull-apart origin of the Dry Creek Valley, and to movement on the range-front faults of the Bridger Range. Cross-section A-A’ was not continued through this area because of the lack of subsurface data.

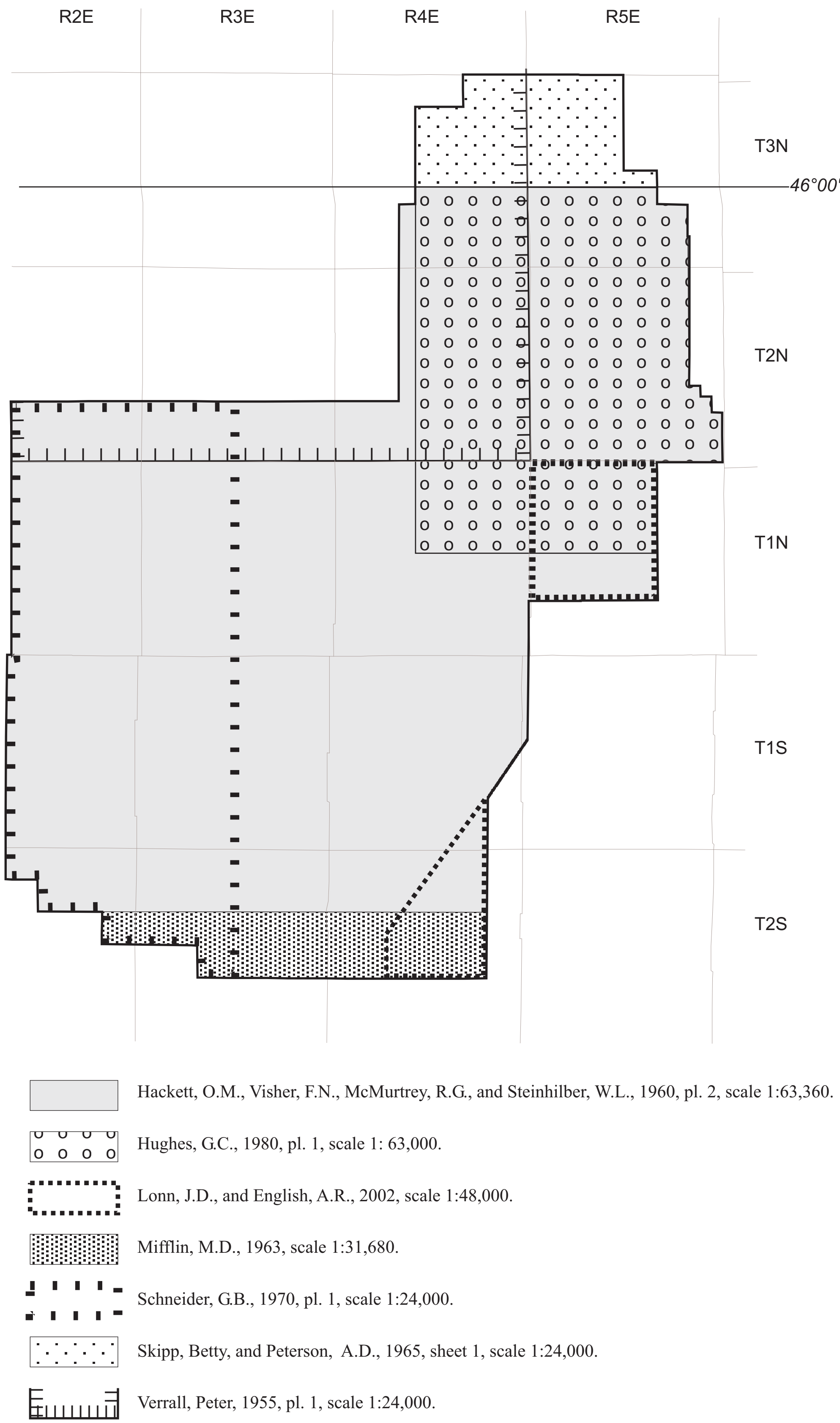


Figure 6. Previous geologic mapping.

CORRELATION DIAGRAM
Geologic Map of Western and Northern Gallatin Valley

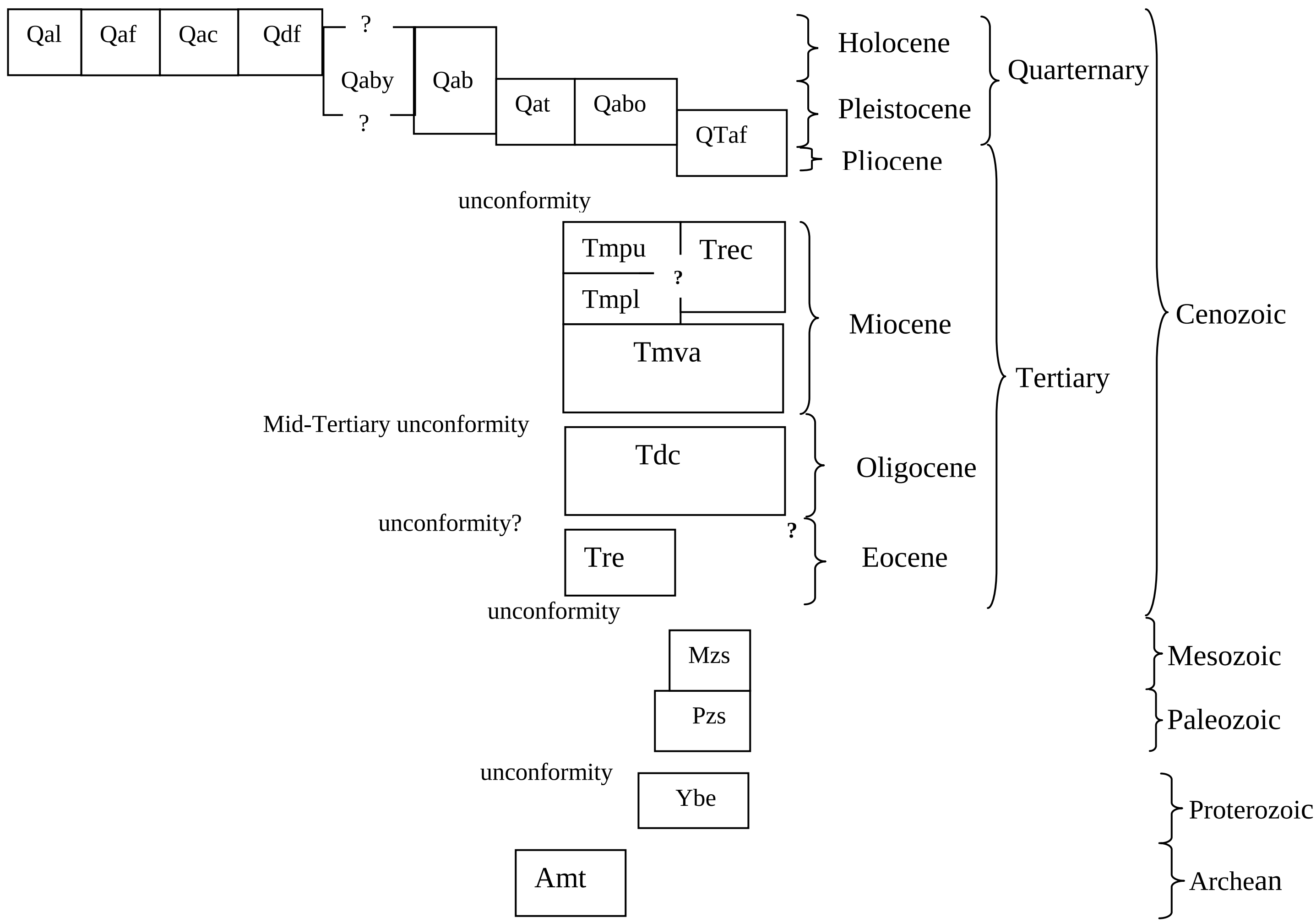


Figure 7. Correlation diagram.

DESCRIPTION OF MAP UNITS
Western and Northern Gallatin Valley

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

See Figure 2 for location of geographic and cultural features referred to in this section.

Qal **Alluvium (Holocene)—**<u>Gallatin and East Gallatin Rivers:</u> Rounded to well-rounded small boulders, cobbles, gravel, sand, silt, and clay, dominantly composed of Archean metamorphic rocks, and dark-colored volcanic rocks, with subordinate Paleozoic limestone, and Precambrian Belt rocks.
<u>Madison River:</u> Subrounded to rounded, gravel and sand with clasts rarely larger than cobble size (Robinson, 1963) dominantly composed of Archean metamorphic rocks, dark-colored igneous rocks, Paleozoic limestone, quartz, and chert.
<u>Tributaries of Gallatin and East Gallatin River:</u> Clast composition varies. Clasts of tributaries from the Tertiary of the Camp Creek Hills are derived primarily from the pebbles and cobbles of Tertiary fluvial deposits. Dry Creek and its tributaries contain clasts derived from the Maudlow Basin, Horseshoe Hills, Bridger Range, and local Tertiary and older Quaternary deposits. Estimated thickness of Holocene alluvium of Gallatin River is 50 to 80 ft based on thicknesses in well logs where Qal rests directly on bedrock.

Qaf **Alluvial fan deposit (Holocene)—**Heterogeneous mixture of subangular to moderately rounded coarse clasts as large as boulder size, and fine sediment (sand, silt, and clay) that is generally more concentrated near fan margins. Clasts composition dominantly Proterozoic LaHood Formation (Belt Supergroup). Estimated thickness is about 100 ft at thickest part.

Qac **Alluvium and colluvium, undivided (Holocene and Pleistocene)—** Locally derived sediment on slopes. Color reflects that of parent material. Ranges from clay and silt to gravel, depending on source. North of Menard composed of angular fragments of underlying bedrock and includes gravel of subangular to subrounded cobbles and boulders from an upstream source (Skipp and Peterson, 1965). Thickness generally less than 20 ft.

Qdf **Debris flow deposit (Holocene)—**Angular, subangular and subrounded clasts of compositionally well-sorted, texturally poorly sorted boulders and cobbles with subordinate finer sediment. Some fine sediment probably has been removed by erosion from around coarser clasts leaving them as lag. Clasts composed of Paleozoic limestone with some chert in northern deposit and Precambrian LaHood Formation arkose in other deposits. Thickness probably about 50 ft in thickest part.

Qaby **Younger braided-stream deposit of Gallatin River (Holocene? and Pleistocene?)—**Rounded to well-rounded, dominantly cobble gravel with clasts as large as boulder size, and sand, silt, and clay; mostly composed of Archean metamorphic rock fragments, and dark-colored volcanic rocks, with subordinate Paleozoic limestone and Proterozoic Belt rocks. Thickness not known because indistinguishable from Qal and Qago in well logs.

Qab **Braid-plain deposit of the Madison River Valley (Holocene and Pleistocene)—**Deposit that underlies the Madison River Valley and underlies and is adjacent to Qal of the valley. Deposit composed of subrounded to rounded, fairly well sorted gravel with few clasts larger than cobble size, and sand (Robinson, 1963). Deposit covered by organic material, silt, and mud in many swampy areas east of the Madison River. Thickness probably not more than 50 ft (Robinson, 1963).

Qat **Alluvial terrace deposit (Pleistocene)—**Remnant of older braided-stream deposit adjacent to and about 5 to 15 ft above modern stream or river. Estimated thickness about 20 ft.

Qabo **Older braided-stream or braid plain deposit (Pleistocene)—**Extensive deposit underlying and adjacent to Gallatin and East Gallatin Rivers and their tributaries and on slopes flanking the Bridger Range. Clast composition on the valley floor same as younger alluvium of Gallatin River, but also includes locally derived clasts. Clasts in deposits of tributary valleys and slopes flanking Bridger Range are locally derived. Thickness highly variable. More than 800 ft thick in Belgrade area (Hackett and others, 1960), but thins to 30 ft or less in at least one area north of the Central Park fault (Hackett and others, 1960).

QTaf **Alluvial fan deposit (Pleistocene? or Pliocene?)**—Remnants of old alluvial fans dissected by Pleistocene braided streams. Heterogeneous mixture of subangular to moderately rounded coarse clasts that range to boulder size, and fine sediment (sand, silt, and clay). Clasts composed of Paleozoic limestone and Proterozoic LaHood Formation arkose. Thickness about 50 ft.

Trec **Reese Creek map unit, informal (Miocene: Clarendonian or Hemphillian NALMA)—**Basal cobble or small boulder clast-supported conglomerate or gravel cemented by calcium carbonate, or unconsolidated with clasts coated by calcium carbonate, overlain by orangish-tan tuffaceous mudstone with lenses of fine-grained sandstone. Fine-grained upper part of unit best exposed near the mouth of Reese Creek. In most other areas, the poorly resistant, fine-grained part is poorly exposed. A vitric ash was sampled from near the mouth of Reese Creek and provided a K/Ar date of 8.9±0.4 Ma (youngest Clarendonian or oldest Hemphillian; Figure 4). The ash has an abrupt basal contact and climbing ripples at the top, and is 0.9 to 1.5 m thick (Hughes, 1980). The contact between this map unit and the underlying Madison Valley formation is an angular unconformity in the northern Gallatin Valley.

Tmpu **Upper Madison Plateau map unit (Miocene: Clarendonian? and/or Hemphillian? NALMA)—**Dark brown, clayey silt and fine-grained sand with sparsely distributed, matrix-supported pebbles and some cobbles, dominantly of Proterozoic Belt othoquartzite. Interpretation that this unit is Tertiary is based on the conformity of its distribution to the underlying Tertiary units and the presence of matrix-supported pebbles and cobbles. May correlate with the fine-grained part of the Reese Creek map unit in the northern Gallatin Valley from which an ash sample provided a K/Ar date of 8.9±0.4 (Hughes, 1980; Lange and others, 1980).

Tmpl **Lower Madison Plateau map unit, informal (Miocene?: Clarendonian? and/or Hemphillian? NALMA)**—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 of dominantly Belt orthoquartzites. Archean metamorphic clasts are found only at the base as pebble size or smaller. They were likely reworked from underlying Madison Valley formation pebble conglomerates with Archean clasts. May correlate with clast-supported cobble conglomerate in Reese Creek area at base of Reese Creek map unit, 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 (Fig. 4). West of the Madison River, unit appears to rest conformably on the Madison Valley Formation, but unconformably on the Dunbar Creek Formation of Robinson (1963) (Vuke, and others, 2002). East of the Madison River, unit appears to rest conformably on the Madison Valley formation and was involved in northeastward tilting and folding of underlying units with apparent conformity. Alternatively, unit may be younger and rest disconformably on the underlying Madison Valley formation, but regardless, was deposited prior to northeastward tilting and folding of Tertiary strata. Thickness 20-30 ft.

Tmva **Madison Valley formation (informal [Douglass, 1907]) (Miocene: Barstovian and Clarendonian? NALMA)—**

Madison Bluffs, Madison Plateau, and Camp Creek Hills area: Pinkish-tan or tan, tuffaceous silt or siltstone and marl 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 extrusive volcanic rocks, with subordinate Belt rocks, and occasional Paleozoic limestone clasts. Sandstone has large root casts locally, and marl 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 (Tabrum and others, 2001; Douglass, 1899, 1901, 1903, 1907a, 1907b, 1908, 1909a, 1909b; Frick, 1937; Dorr, 1956; Sutton, 1977; (Sutton and Korth, 1995; Evander, 1996), including the Anceney beds of Dorr (1956).

The contact between this unit and the underlying Dunbar Creek Member of the Renova Formation is sharp and locally appears unconformable as noted by Hackett and others (1960). In the northernmost part of the Madison Bluffs (Fig. 2) the contact appears to be an angular unconformity. A relatively resistant bed at the base of the Madison Valley formation cuts down to nearly the level of the conglomerate of the Renova Formation, undivided, as mapped in this report. In the southernmost part of the Madison Bluffs, calcic paleosols that closely resemble those described below in the Renova Formation, undivided map unit, occur at the contact between the Madison Valley formation and the underlying Dunbar Creek Member of the Renova Formation.

Thickness 200 ft throughout most of the Madison Bluffs area, but thickens to 300 ft in the southern bluffs.

Dry Creek area: Grayish-orange, cross-bedded sandstone and pebble conglomerate interbedded with brownish-orange tuffaceous siltstone and marl. Sandstone beds are crossbedded and contain large lenses of dominantly pebble conglomerate with occasional cobble-size clasts or local cobble conglomerate. Conglomerates vary from matrix supported to clast supported. Unlike the clast composition in the Madison Bluffs and Camp Creek Hills areas, the clasts in the Menard area are dominantly Paleozoic limestone and Mesozoic sandstone, with subordinate andesitic volcanic rock and minor metamorphic rocks. Hughes (1980) interpreted the volcanic rock source as the Maudlow Basin where Livingston Group rocks are exposed. Closer to the Bridger Range, the clasts are dominantly Proterozoic LaHood Formation arkose, Paleozoic limestone, and quartz. Thickness near Menard about 100 ft. It is not known if the Madison Valley formation thickens dramatically to the east, or if it has been downfaulted from the Bridger Range to Dry Creek. It is at a much higher elevation close to the Bridger Range in the northern Gallatin Valley area than at Dry Creek.

Some of the coarser-grained beds of the Madison Valley formation are shown on the map with a dotted pattern. In general, these are medium to coarse grained, fairly laterally persistent sandstone beds with numerous lenses of conglomerate and conglomeratic sandstone. Hughes (1981) describes these conglomeratic sandstones as "blanket-like" deposits in the Dry Creek area.

In local areas south of Manhattan and in the southeastern part of the map area, some of the conglomerate lenses contain dominantly cobble- rather than the more typical pebble-size clasts of other areas. These cobble conglomerates serve as caprocks with overlying fine-grained sediment stripped away. They have been interpreted as alluvial terrace deposits (Hackett and others, 1960) and pediment gravels (Mifflin, 1963), but were traced into the Madison Valley formation in several places. In this report, they are mapped as coarser-grained beds of the Madison Valley formation.

Gravel pits are numerous in the coarser-grained beds of the Madison Valley formation. Many of the gravel pits are shown on the map.

Trd **Dunbar Creek Member of Renova Formation (Oligocene: Whitneyan and Orellan? NALMA)—**

Madison Bluffs and Camp Creek Hills: White to very light gray and light-tan, tuffaceous planar-bedded siltstone and fine-grained sandstone with numerous tiny root casts, glassy ash beds, light-gray tuffaceous limestone beds, and an interval of white diatomite beds near the top that extends the length of the Madison Bluffs. Distinguished from Madison Valley formation by color, diatomite marker beds, and lack of significant conglomerate lenses. Tentatively correlated (pending $^{40}Ar/^{39}Ar$ date from ash sampled east of the Madison River) with Renova Formation near Menard in Dry Creek area from which an ash yielded a K/Ar date of 30.6±1.2 Ma (Whitneyan; Fig. 4) (Hughes, 1980; Lange and others, 1980).

Hackett and others (1960) also correlated this unit (their unit 1) in the Madison Bluffs and Camp Creek Hills with the Whitneyan unit near Menard. Ostracodes, gastropods, and fish have been reported from this unit in the Madison Bluffs (Blake, 1953; Dorr, 1956; Schneider, 1970).

An abrupt facies change occurs in this unit in the northeastern part of the Madison Bluffs from dominantly planar-bedded siltstone to the south, to gray, unconsolidated to poorly cemented, medium-grained immature sandstone overlain by the white diatomite marker beds described for the Dunbar Creek Member above. This facies change in the northern part of Madison Bluffs was walked out, but can also be viewed from a distance from the Madison Valley Road.

<u>Dry Creek area:</u> White to very light gray and light-tan, tuffaceous siltstone, fine-grained sandstone and mudstone, tuffaceous marl and limestone, and ash. Ostracodes and gastropods have been reported from this unit in the Dry Creek area (Hughes, 1980; Hackett and others, 1960; Verrall, 1955), and Klemme (1949) reported mammal fragments in this unit in the Dry Creek area.

Isolated patches of Tertiary sediment in the southern Horseshoe Hills are tentatively interpreted as this unit because of similar lithologies and the presence of gastropods similar to those found west of Menard (Verrall, 1955). Although gastropods are not good index fossils (R.W. Fields, personal communication in Hughes, 1980), poorly preserved gastropods are widespread in the Dunbar Creek Formation [Member] (Robinson, 1963). Gastropods have not been reported from the overlying Madison Valley formation in the map area.

Thickness of unit about 150 ft in central Madison Bluffs, but may be thicker in the southern part of the Madison Bluffs where it is obscured by slope alluvium and colluvium. In the northernmost bluffs it thins abruptly to about 50 ft.

Tre **Renova Formation, undivided, map unit (Oligocene or Eocene: Chadronian? NALMA)**—It is unclear whether this unit is lower Dunbar Creek or upper Climbing Arrow as mapped by Robinson (1963) west of the Madison River. In the northernmost part of the Madison Bluffs, conglomerates in this unit seem to correlate with similar conglomerates in the uppermost Climbing Arrow south of Three Forks (west of the Madison River). Farther south, near the buffalo jump, the unit seems to correlate with the lower part of the Dunbar Creek, directly across the river. Robinson (1963) states that the Climbing Arrow and Dunbar Creek may interfinger. The

Chadronian? age interpretation is based on a late Chadronian fauna (Tabrum and others, 2001) in the lower Dunbar Creek approximately 6 miles to the northwest.

In the exposures near Madison Buffalo Jump State Park, unit is dominantly light to medium gray, orange or tan, fine- to coarse-grained sandstone or conglomeratic sandstone with clasts as large as granule or small pebble size, interbedded with thinner gray siltstone and mudstone. Grain size is significantly coarser in the northern bluffs where unit is dominantly texturally and compositionally immature conglomerate with subangular to subrounded clasts ranging to small boulder size. In the northern part of the map area, the conglomerate has extensive orange zones from iron oxide staining and a sharp base where it rests on finer-grained beds.

Calcic paleosols as described by Hanneman and others (1994) occur near road level in the area of Madison Buffalo Jump State Park (D. Hanneman, personal communication, 2002). They also occur where this unit is exposed in the northernmost and southernmost parts of the bluffs. The maximum exposed thickness of this map unit is about 100 ft.

Units not emphasized in this report

Pzs **Paleozoic sedimentary rocks, undivided**

Mzs **Mesozoic sedimentary rocks, undivided**

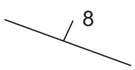
Ybe **Belt Supergroup rocks, undivided**

Amt **Archean metamorphic rocks, undivided**

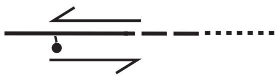
For more detailed mapping of these units, refer to Vuke and others (2002).

MAP SYMBOLS
GEOLOGIC MAP OF THE WESTERN AND NORTHERN GALLATIN VALLEY

Contact—Dashed where inferred, dotted where concealed.

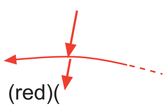


Strike and dip of bedding—Number indicates angle of dip in degrees.

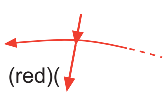


Fault, high-angle—Dashed where inferred, dotted where inferred and concealed. Ball and bar on downthrown side. Arrows indicate strike-slip movement. Some faults have undergone reversal of movement. Only last movement or net movement is shown.

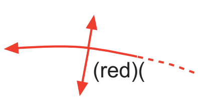
Syncline—Showing trace of axial plane and direction of plunge; dotted where concealed.



Anticlinal bend of monocline—Showing trace of axial plane and direction of plunge. Dashed where inferred; dotted where concealed; short arrow on more steeply dipping limb.

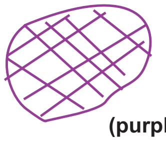


Synclinal bend of monocline—Showing trace of axial plane and direction of plunge. Dashed where inferred; dotted where concealed; short arrow on more steeply dipping limb.



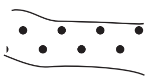
Anticline—Showing trace of axial plane and direction of plunge; dotted where concealed.

Linear feature—Straight, northwest-striking geologic map pattern. Strike is consistent with basement structural grain, so may be controlled by faults or fractures. Shaded relief images from digital elevation models reveal many more linear features in the region.



(purple)

Gravel pit in Madison Valley formation or basal Reese Creek map unit—Not all gravel pits shown. Several permits have been issued for more gravel pits in the Madison Valley formation in the area south of Logan (Montana Department of Environmental Quality, Industrial and Energy Mineral Bureau). Two Barstovian *Merychippus* (horse) teeth were found in a gravel pit south of Logan. Some of the Madison Valley formation gravel on valley floors south of the Gallatin River between Logan and Manhattan may have been very locally reworked during the Pleistocene.



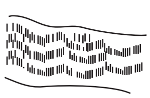
Coarser beds—

Madison Plateau map unit: Rounded caliche-coated cobble conglomerate or gravel with some pebbles and rare small boulders.

Reese Creek map unit: Basal bed of rounded cobble or small boulder conglomerate or gravel shown with dotted pattern on map. May be more extensive than shown. In part, traced on aerial photographs but not yet field-checked.

Madison Valley formation: Sand or sandstone with lenses of dominantly pebble conglomerate or gravel, but also with local lenses of cobble conglomerate or gravel. Not all such beds were mapped.

Renova Formation, undivided: Sandstone and poorly size-sorted conglomerate in northernmost part of Madison Bluffs with sharp basal contact; sandstone and locally conglomeratic sandstone or sandstone with thin stringers of conglomerate elsewhere. Many sandstone beds in Renova Formation, undivided, were not individually mapped.

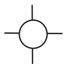


Anceney map unit (informal) in Madison Valley formation—Light-colored planar-bedded, tuffaceous siltstone and light-gray ash. Includes Anceney beds of Dorr (1956).

(blue),

Area with seasonal high water table less than 6 ft—Modified from *Seasonal high water tables, Bozeman area, Gallatin County, Montana*: U.S. Department of Agriculture, Soil Conservation Service, Bozeman, MT, 1992, approximate scale: 1:50,0000.

Limit of seasonal high-water table data.

 1,

Drill hole location—Numbers refer to data from Hackett and others (1960) in Table 1 of present report.

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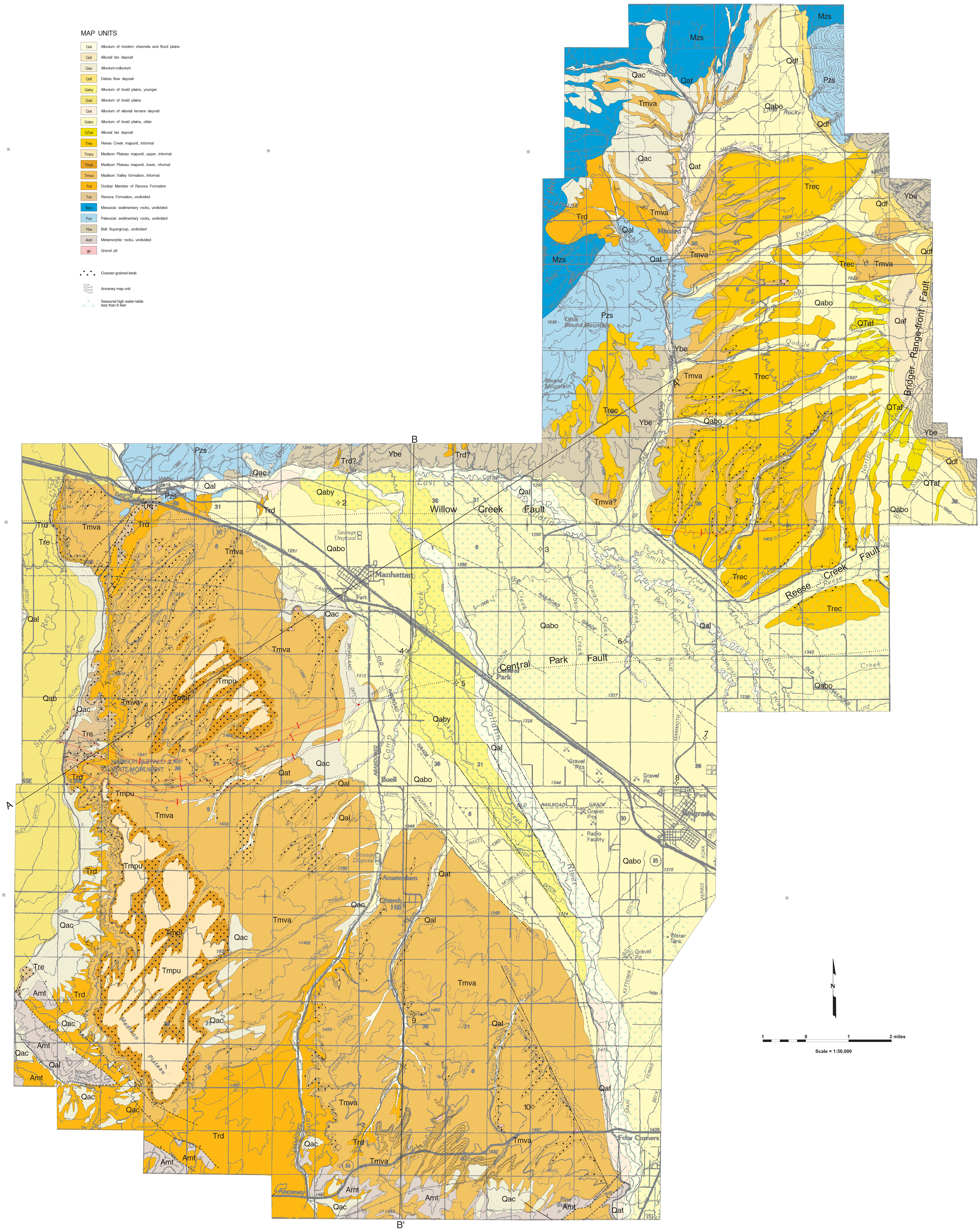
MAP UNITS

Qal	Alluvium of modern channels and flood plains
Qaf	Alluvial fan deposit
Qac	Alluvium-colluvium
Qdf	Debris flow deposit
Qaby	Alluvium of braid plains, younger
Qab	Alluvium of braid plains
Qat	Alluvium of alluvial terrace deposit
Qabo	Alluvium of braid plains, older
QTaf	Alluvial fan deposit
Trec	Reese Creek mapunit, informal
Tmpu	Madison Plateau mapunit, upper, informal
Tmpl	Madison Plateau mapunit, lower, nformal
Tmva	Madison Valley formation, informal
Trd	Dunbar Member of Renova Formation
Tre	Renova Formation, undivided
Mzs	Mesozoic sedimentary rocks, undivided
Pzs	Paleozoic sedimentary rocks, undivided
Ybe	Belt Supergroup, undivided
Amt	Metamorphic rocks, undivided
gp	Gravel pit

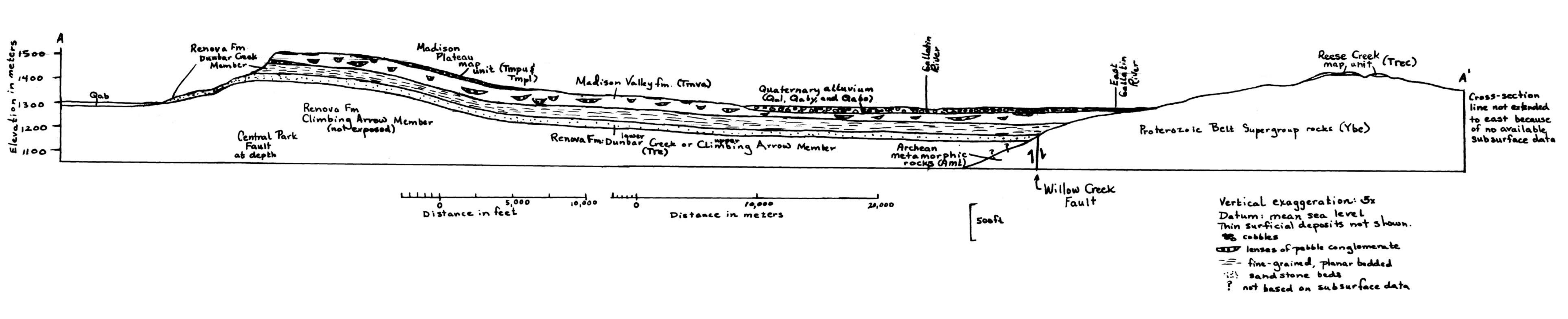
Coarser-grained beds

Anceney map unit

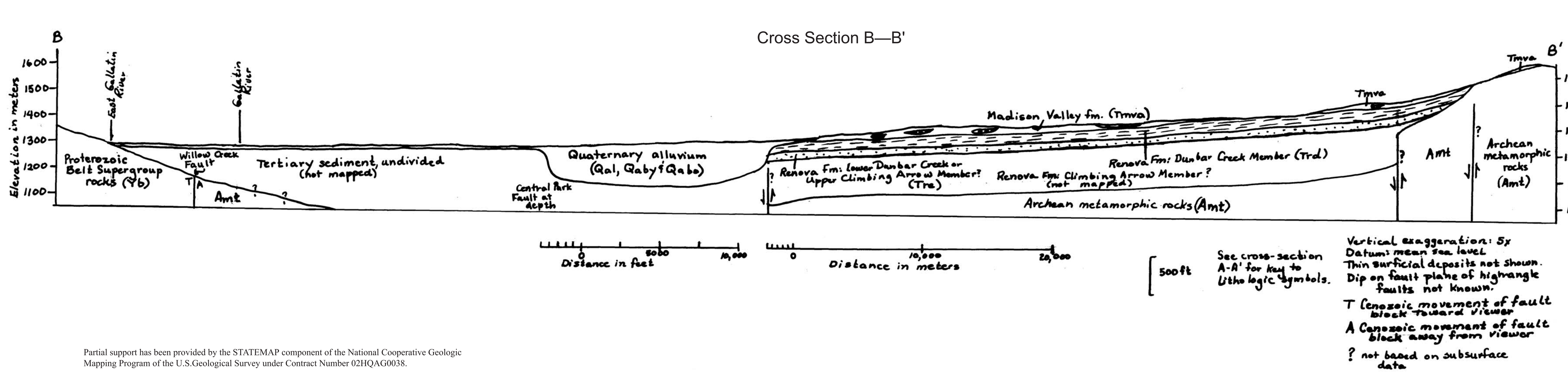
Seasonal high water-table less than 6 feet



Cross Section A—A'



Cross Section B—B'



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Montana Bureau of Mines and Geology
Open File No. 481

Geologic Map of Western and Northern Gallatin Valley Southwestern Montana

Susan M. Vuke

2003

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