Self-Guided Field Trips Near Bozeman, Montana

Field Trip Guidebook, 2nd Edition (1995)

Guidebook for Field Trip Held in Conjunction with the 47th Annual Meeting of the Rocky Mountain Section of the Geological Society of America

by

Stephan G. Custer
Donald L. Smith
Molly Welker
and
1982 Geology Graduate Students

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Tobacco Root Geological Society

CONTENTS

PREFACE

This guidebook grew out of a local trip by Don Smith, Molly Welker, and the 1982 Geology Graduate Students titled "Geology of the Southeastern Gallatin Valley" presented at the 1982 Geological Society of America Rocky Mountain Section Meeting. The original trip route has been changed, and two new trips have been added. The three trips described here are self guided so that a meeting participant can become acquainted with the geology of the Bozeman area when convenient. One of the trips is a walking trip. The other two trips require a vehicle. The three trips address the general geology of the valley, a short trip to Bridger Canyon and into the western Crazy Mountains Basin, and a trip into Rocky Canyon to examine the local Mississippian through Cretaceous stratigraphy. The guidebook includes a Geologic Map of Montana and Yellowstone National Park (Taylor and others, 1986). This map has inset diagrams of mountain ranges in Montana, a tectonic map, a glacial map, and a physiographic map (Taylor and others, 1986). Because some figures are used by more than one trip, all figures are assembled at the end of this guidebook and are numbered sequentially. Relevant materials are repeated verbatim in different trips in the guidebook where appropriate to maintain the continuity of the trip at the expense of guidebook length.

A WALKING TOUR OF THE GEOLOGY OF THE SOUTHEASTERN GALLATIN VALLEY

by

Stephan G. Custer

Introduction:

This is a walking (or jogging) trip which focuses on panoramic views of the Gallatin Valley and surrounding mountains. You will see mountains, pediments, stream terraces, an alluvial fan, Tertiary sedimentary strata, evidence for listric-normal faulting and some ground-water and environmental geology. If you walk slowly, you should plan approximately 2.5 hours (more if you like to pause and take in the scenery). Runners will complete the trip more quickly.

General Setting:

The Gallatin Valley is the eastern-most of the four major valleys that compose the greater Three Forks Basin (Fig. 1). The basin is surrounded by mountains. To the southwest are the Tobacco Root Mountains, to the northwest the Elkhorn Mountains, to the north the Horseshoe Hills, to the east the Bridger Range, to the south the Madison and Gallatin Ranges. Basin elevations range from approximately 4,000 ft (1200 m) where the Missouri River cuts its way out of the basin near Three Forks to 6,000 ft (1800 m) where gently sloping basin uplands abut the steeper mountain fronts. The adjacent ranges tower above the basin floors at maximum elevations that range from slightly more than 7,000 ft (2100 m) in the Horseshoe Hills to the abrupt peaks of the Bridger, Gallatin, Madison, and Tobacco Root Mountains that are in excess of 9,500 ft (2900 m).

The Walk:

Because you are on foot, distances will not be marked by milages. Rather, land marks and street names and the topographic map of Bozeman (Fig. 2) will be used to guide you. The geologic setting for the valley will be developed at appropriate stops as you proceed.

1. Walk out the North Entrance of the Strand Union.

   You are facing Hamilton Hall to the north-northeast, Montana Hall to the north-northwest and Willson Hall to the north (somewhat behind Hamilton Hall). Hackett and others (1960) mapped this area as part of the Bozeman alluvial fan. This fan is

composed of unconsolidated Quaternary gravels, sands, and muds. Although the surficial map designation is correct, the Quaternary sediments are quite thin in this area (0-10m). Excavation for the Willson Hall foundation encountered Precambrian gneiss (Charles Bradley, personal Communication). Refraction seismic work by Brown and others (1983), showed a small area with seismic velocities greater than 5,700 m/s (20,000 ft/s) surrounded by material with velocities of 1600 m/s (5600 ft/s). Subsequent electrical and seismic work by Donohue (1989) and Nichols (1989) suggests that the material below the Quaternary sediment veneer and over the Precambrian Gneiss is best characterized as Tertiary-age sediment. This interpretation will be explored more fully at another stop. Oddly, the gneiss cannot be traced more than 300 m (1000 ft) from Willson Hall either geophysically, or in shallow foundation bore holes. Recent drilling for the Physical Sciences Complex under construction to the east of the Union did not encounter gneiss in 10 m (30 ft) deep drill holes.

2. When you reach the Centennial Mall (50 ft north) turn east (right).

3. Leave campus on Garfield Street (continue east).

4. Walk east across 6th, 5th, 4th, 3rd, Grand, Willson, and Tracy.

5. As you walk past Tracy begin watching for two posts with the words Linear Park written on them. When you see the posts turn left (north) and walk along the Gallagator Linear Trail (once the Milwaukee Road rail bed).

> As soon as you enter the park you will cross Figgins Creek. Several spring creeks arise south of here and flow approximately parallel to Bozeman Creek (Sourdough Creek; note that several streams and streets have two names in Bozeman, and are identified with a second name in parenthesis adjacent to the first). These spring creeks may be related to changes in transmissivity (thickness times hydraulic conductivity) in Bozeman Creek alluvium, to ground-water discharge from Quaternary-age alluvial fan gravels which thin to the north, or to discontinuities in channel gravels in Tertiary sediments which cause ground water to rise to the surface. These concepts will be developed further when you climb the bluff to your east where you can better see the geomorphology of the valley.
>
> You are traversing the flood plain of Bozeman Creek and Figgins Creek (Fig. 3). Zone A reflects areas inundated by the 100 year recurrence interval (0.01 probability) flood. The numbers after the A refer to areas where flood-insurance rate factors are determined. If there is no number, the flood insurance-rate factors have not been determined. Areas designated Zone B lie between the limits of the 100 and 500 year flood or are subject to 100 recurrence interval flooding estimated to be less than 1 foot deep. Zone C shows areas of minimal flooding. The flood plain areas have been used as open space here, but development pressures continue. This is also an area of high water table. Ground water permanently occupies the basements of some of the older homes near Ice Pond Road. The area with warehousing and manufacturing on your right, (near bench mark 4852) has

been proposed for additional development several times. Flood-plain zoning, concerns about traffic, and land-use history have been the focus of discussions regarding land-use changes in this area. Examination of the age of houses along the creek shows that early subdivision focused on the creeks in the area without regard to the flood hazard, a legacy that has intermittently left some with flooded homes and land here. The Mill Creek diversion (Fig. 3) is an engineered diversion constructed to reduce flooding in the down-town area where Bozeman Creek flows under main street and below the Bozeman Hotel.

6. Proceed northeast along the linear Park to Church Street. This is the first street you will encounter along the linear park.

7. If you would like to examine the Tertiary sediments that the bluff is composed of, walk south on the trail and sidewalk on the west side of Church Street for approximately 150 m (500 ft) to the outcrop just north of Bozeman Creek (Sourdough Creek) (Fig.2). Be very careful here as the road is narrow, traffic is heavy and sight distances are short. When you get to the outcrop you will be at 705 Church Street. If you are more interested in the panorama skip this digression and proceed up Peets Hill as indicated in the item 9.

The bluff immediately to the east is composed of massive buff to tan partly calcareous variously consolidated tuffaceous claystone, siltstone, sandstone, and channel conglomerate assigned to the Tertiary Bozeman Group (Hackett and others, 1960; Robinson, 1961). Some of the conglomerates are cemented with calcium carbonate and others are relatively unconsolidated. Those here are unconsolidated. Later on the walk you will have an opportunity to examine conglomerates that are lithified with calcite. Glancy (1964, p. 17) discusses clasts present in the conglomerates. Clasts in the area include Paleozoic limestone, sandstones, and quartz arenites, angular clasts of litharenite from the Livingston group. Igneous clasts are well represented and include basalt, andesite, porphyritic diorite, gabbro, granodiorite, monzonite and granite, and gneiss. The lithologies are not sufficiently distinctive to clearly indicate a specific source area (Glancy, 1964, p. 26). These sediments have not been formally assigned formation status in this area, but probably belong to the Six Mile Creek Formation based on a late Miocene Merychippus tooth and a Camelid tooth found four miles east away in similar material (Glancy, 1964), presence of cemented and uncemented discontinuous lenticular gravel and conglomerate fluvial channel deposits, and the presence of tuffaceous claystone and siltstone interpreted to be Oligocene Renova Formation approximately 700 feet below the surface in deep drill holes and approximately 30 km (20 mi west) (Hackett and others, 1960; Donohue, 1989; Custer, 1991). Both matrix supported and framework supported deposits are present. The cementation probably represents caliche developed in a semiarid environment (Hughes, 1980; Thompson and others, 1982). By analogy with similar sediments 30 km (20 mi) to the north, these deposits were probably formed in a complex of flood basin and alluvial fan environments (Hughes, 1980). Glancy (1964) used clast imbrication and composition to suggest transport from an area to the east of the modern Bridger Range, but other workers suggest more local sources

and different transport directions (Hughes, 1980). Hanneman and Wideman (1991) suggest a sequence stratigraphic approach to subdividing rocks in the intermontane valleys of Southwest Montana, but this approach has not been applied to sediments in the Gallatin Valley near Bozeman. Much more paleontologic, and stratigraphic work remains to be done with these sediments.

8. Return to the place where the Gallagator Linear Trail intersects Church Street (Item 7; Fig. 2).

9. As you cross Church Street, you will see Peets Hill which is part of Burke Park and is surrounded by a wooden pole fence. Take the foot trail that goes under the wooden fence on the north side of the Peet's Hill Area and walk up the bluff to the east. You are headed toward the bench you can see on the hill. Please stay on the trail. Do NOT follow the linear park to the northeast unless you plan to abandon this trip and go shopping in Dowtown Bozeman. To repeat, leave the linear park at Church Street and head up Peet's Hill to the main Burke Park Trail which passes the bench you can see on the hill.

10. Stop near the bench at the top of Peets Hill.

On a clear day you can see seven mountain ranges from this bluff. You can identify the mountain ranges by referring to Figure 1 and the map of mountain ranges on the Geologic Map of Montana in the Pocket (Taylor and others, 1986). To the north you can see the Bridger Range. On a clear day, the Big Belt mountains can be seen extending north of the Bridger Range toward Helena. To the north northwest are the Horseshoe Hills. On a clear day you can see the Elkhorn Mountains in the distance north north west of the Horseshoe Hills. To the west in the distance are the Tobacco Root Mountains. The Spanish Peaks (part of the Madison Range) can be seen on the sky line to the southwest. The Gallatin Range is to the south. The mountains to the southwest and west are part of the Bridger Range. Each mountain range has distinctive geology. To do true justice to each, many field trips are needed, but some of the general characteristics of each range can be gleaned from the Geologic Map of Montana. A few general comments are important for the mountains close by.

The crest of the **Bridger Range** is held up by erosion resistant Madison Group limestones (Lageson, 1989). The rib of limestone that forms the crest of the Bridger Range is the east limb of an asymmetric, overturned anticline. The west limb and axis of the anticline were dropped into the valley. North of Ross Pass (obscured by the mountains in the foreground to the north), Proterozoic Lahood Formation arkoses limestones and shales cover the Archean gneiss so that the older Precambrian rocks are not exposed. Ross Pass constitutes a fundamental geologic boundary between the Laramide Foreland style deformation to the south and Sevier fold and thrust deformation to the North (See the tectonic map on the Geologic Map of Montana in the pocket) (Lageson, 1989). The transverse zone separates the Sevier-style terrain to the north from

the Laramide-style terrain to the south. The west side of the Bridger Range is bounded by a normal fault which probably began moving in Miocene or younger time based on steeply dipping Miocene sediments in the fault zone in Dry Creek Valley 30 km north of here (Hughes, 1980) and involvement of Paleocene strata in Sevier-style deformation on the east side of the Bridgers.

Evidence for a listric geometry on the range-bounding fault can be seen if you look north-east at the foot hills just across form Interstate 90. Notice that the Tertiary-age gravels to the north-north east in the foot hills are tilted approximately six degrees into the mountain range. Gravity evidence suggests over 1800 m (6000ft) of Tertiary valley fill on the western flank of the Bridger Range (Davis and others, 1964). Since the valley floor at 1200 m (4000 ft) above sea level, and Bridgers rise to an elevation of 2900 m (9,500 ft) the total offset along the Basin-and-Range listric normal fault is approximately 3500 m (11,000 ft) (3500 m = 1800 m + (2900m-1200m)). A diagrammatic cross section through the Bridger Range is shown in Figure 4. Although the total offset on the range-bounding normal fault is large, no fault scarp has been recognized in the valley. The absence of a scarp has made fault zoning difficult to promote in the Valley.

Careful examination of the valley fill materials adjacent to the Bridger Range reveals a surface graded to the west to a level above the east Gallatin River. This surface is a pediment cut on Tertiary sediments. You are standing on or very near this erosional surface.

As the description above suggests, the Bridger Range overlaps the boundaries of four major tectonic provinces (Lageson, 1989): 1) Middle Proterozoic Belt Basin 2) the thin-skinned Sevier fold and thrust belt (which mimics the Belt Basin), 3) Laramide basement-involved foreland province, and 4) the Basin and Range Province. There are five episodes of deformation in the Bridger Range, each of which represents in part reactivation of old boundaries. The first deformation episode is Archean crustal assembly (D-1) which includes a 3.5 Ga accretion episode to produce a 20 km thick crust which was metamorphosed to upper amphibolite or perhaps granulite facies. Regionally these rocks include gneiss, amphibolite, marble, and quartzite. These rocks were isoclinally folded at about 2.8 Ga. The isoclinally folded rocks were refolded in a more open style shortly after the isoclinal event. This crustal assembly was followed by Proterozoic rifting and large-scale normal faults (D-2) from 1.45 to 0.85 Ga which formed the southern margin of the Belt Basin. This rifting is probably reflected in Ross-Pass fault which separates a northern terrain with Lahood rocks from a southern terrain without LaHood Rocks which is underlain by Archean quartzofeldspathic gneiss. This rift margin follows the Perry line approximately due west and extends across the north end of the Tobacco Root Mountains to the west. The third event was thin-skinned Sevier-style fold and thrust deformation (D-3). The southern margin of the Helena Salient roughly follows the ancient boundary between Archean uplands and the rifted

Belt Basin to the north. The Sevier deformation occurred in this area during the Paleocene extending past the time of Fort Union Formation deposition (Lageson, 1989). The fourth episode of deformation is basement-involved Laramide-style reverse faults (D-4). This episode occurred from latest Paleocene to early Eocene. This style of deformation is constrained to areas south of Ross Pass where Archean rather than thick sequences of Proterozoic sedimentary rocks are present. Basin and Range style deformation (D-5) is the fifth episode. This extensional period of deformation probably began in the Miocene. The listric faults may have exploited ramps in earlier Laramide and/or Sevier faults (Lageson, 1989). Thus young faults have exploited old weaknesses and fold styles are controlled by the thicknesses of sediments related to old faults. The historic weaknesses and depositional patterns are exploited by younger folding and faulting events.

The **Belt Mountains** have a geology similar to that in the Northern Bridger range with a full complex of Paleozoic and Mesozoic sediments folded and faulted in Sevier Style (see the Geologic Map of Montana in the Pocket).

The **Horseshoe Hills** to the north west contain a complete stratigraphic column which begins in the Proterozoic Lahood Formation and extends through Cretaceous mudstones of the Colorado Group. These rocks are at the southern margin of the Helena Salient (see the Tectonic Map of Montana which is part of the Geologic Map of Montana in the Pocket) so Archean rocks are not exposed in this area and Paleozoic and Mesozoic rocks are deformed in Sevier rather than Laramide structural style.

The **Elkhorn Mountains** are also part of the Helena Salient. This mountain range is composed of Cretaceous volcanic and intrusive rocks as well as Paleozoic and Mesozoic sediments (see the Geologic Map of Montana in the Pocket).

The **Tobacco Root Mountains** to the west are cored by Cretaceous granitic stocks and batholiths which intruded Archean metamorphic rocks and Paleozoic and Mesozoic sediments. There are several gold-mining districts in these mountains.

The **Madison and Gallatin Ranges** are similar geologically and are distinguished mainly on a physiographic basis. The mountains west of the Gallatin River are called the Madison Range and those east of the Gallatin River are called the Gallatin Range (3 GA; gneiss amphibolite and quartzite) (Mogk, 1990). The ranges are is composed of folded and faulted Archean metamorphic rocks which are overlain by Paleozoic and Mesozoic sediments deformed in basement-cored Laramide style. Overlying these rocks is the Eocene (ca. 49 ma) Gallatin Volcanic Field (Chadwick, 1969, 1970; Hiza, 1994). This complex consists of a sequence of intercalated andesitic lava flows, flow breccias, vocaniclastic debris flows and hyperconcentrated flow

deposits formed by pyroclastic flow and pyroclastic surges, phreatomagmatic explosions, debris avalanches, debris flows, hyperconcentrate flows and streams expected on stratovolcanoes. Figure 4 is an idealized schematic diagram of the Gallatin Range (Hiza, 1994). The volcanic and epiclastic rocks lie on a profound erosional surface and can be divided into the Golmeyer Creek Volcanics which were tilted before emplacement of the Hyalite Peak Volcanics. All these rocks are cut by Eocene intrusives of various ages. The Gallatin Range is bounded on the North by a large normal fault. Gravity evidence suggests approximately 2000 m (6000 ft) of sedimentary fill in the valley adjacent to the Gallatin Range (Davis and others, 1964). Since the Gallatin Range has peaks that exceed 3000 m (10,000 ft) and the valley floor is approximately 1400 m (4600 ft) above sea level, total throw on the fault is of the order of 3600 m (11,000 ft) (2000m + (3000m - 1400 m) = 3600 m). This offset is similar to that suggested for the Bridger range-front fault. Just as in the case of the Bridger range, no visible scarps have been identified. The Bridger range-front fault trends approximately north-south and the Gallatin range-front fault trends approximately east west. The two faults intersect to the south-southeast of here.

11. Follow the Burke Park Trail to the south (toward the blue water tower). Stop at the bench just west of the Hillcrest retirement community .

Look west from Hillcrest. Notice that Montana State University is on a knoll. Recall that Archean gneiss is present just below the surface here. Although throw on the both the Gallatin and Bridger range-front faults is large, offset must be higher at the range front than at some places in the valley such as the MSU campus if foundations observations and gravity evidence are correct. The presence of Precambrian gneiss near the surface below campus has interesting implications for ground-water flow to the north. A transmissivity decline is expected associated with the Precambrian rock near the surface. If the gneiss is an isolated body, flow is presumably diverted around the gneiss. If the gneiss is more extensive than suggested by limited shallow geophysical investigations, then transmissivity may be substantially smaller as ground water approaches the campus. The details of the distribution of bedrock below the Tertiary basin fill needs more work.

12. Continue south along the Burke Park Trail. When you reach the barbed wire fence just north of the blue water tower, stop and again look out over the valley to the west southwest.

Tertiary sediment has been eroded from the valley. The extent of the erosion can best be appreciated by examining a topographic cross section oriented S 80 W approximately 5 km (3 mi) south of here (Fig. 6). You are standing on Sourdough ridge. The Tertiary sediment has been eroded by Bozeman (Sourdough), Hyalite (Middle) , and Dry Creeks. Sourdough Ridge and Gooch's Hill are erosional remnants of material that once filled the valley 5400 feet (1645 m) or more above sea level. After the erosion of this sediment, a gravelly alluvial fan was deposited. Although one would expect this

alluvial fan to have been formed by the three main streams draining the Gallatin Range and flowing into this eroded area, the arcuate contours of the fan clearly emanate from Hyalite Creek (Fig. 7). Sourdough (Bozeman) Creek has a drainage area similar in size to that at Hyalite Creek, but does not appear to have contributed gravel to the fan and is incised into Tertiary sediments. The incision is clearly visible directly below you here.

Although Hackett and others (1960) mapped the entire eroded area as the Bozeman Fan, there is a decrease in gradient at Patterson Road (north edge of township 2 south Range 5 east section 35). This change in gradient coincides with a change in seismic velocity from values less than 1500 m/s (5200 ft/s) south of the 5040 ft (1540 m) contour to values higher than 1500 m/s (5200 ft/s) north of this contour (Fig. 8). The higher seismic velocities are similar to those found on Sourdough Ridge near the Peet's Hill area. A seismic cross section parallel to the fan axis suggests a wedge of lower-velocity material interpreted to be gravelly outwash material from Hyalite Creek. The edge of the gravel accumulation coincides with the beginning of the blue stream lines on the Bozeman 1:62,500 topographic quadrangle. This suggests that ground water recharges the fan and exits at the down stream edge of the gravel accumulation as the gravel thins to the north. This recharge-discharge relationship was tested by measuring discharge changes in Hyalite Creek as part of a graduate geomorphology class project by Guy Tanz in 1989 who found that discharge declined where seismic velocities were low and increased below the 5040 ft (1540 m) contour line. The absence of a gravel deposit at Bozeman (Sourdough) Creek is curious since both Bozeman Creek and Hyalite Creek drainages have been glaciated, and drainage areas of the two streams are similar. Locke (Earth Sciences, Montana State University, personal communication, 1989) has suggested that outwash gravels may have been stored in the mountains in the Bozeman Creek drainage but have been stored in on the fan in the Gallatin Valley at Hyalite Creek. This hypothesis remains to be tested with detailed geomorphic mapping in the Gallatin Range. These geomorphic and geophysical observations suggest that below the 5040 ft elevation the valley floor is really a pediment with a very thin gravel veneer, while north of this contour, there is a wedge of gravelly outwash? material. The upper fan is recharged near the Gallatin Range front and discharges water where the gravel thins (Donohue, 1989; Nichols, 1989; Custer, 1991). Sourdough (Bozeman) Creek is incised into the Tertiary sediment on the eastern side of the eroded valley area between Gooch's Ridge and Sourdough Ridge. Thus, Bozeman Fan is probably more appropriately named the Hyalite Fan, and the City of Bozeman is built on a Tertiary Pediment. We saw similar higher level pediment surfaces as we looked north toward the flanks of the Bridger Range. As you proceed from here you can also see high level pediment surfaces emanating south from the Gallatin Range front.

The topography associated with this erosion and deposition has implications for ground-water resources in the Valley. Wells drilled for homes on the ridges flanking the valley are commonly of the order of 300 ft (100 m) and encounter water at the valley level, while homes on the valley floor below the ridges encounter water at about 60 feet

on average. There is anecdotal evidence of larger fluctuations in water level for wells in the fan deposits at the south end of the valley than in the eroded Tertiary sediments south of the fan deposit, but further testing is needed. Springs and appear to be controlled, in part, by the position of the feather edge of the alluvial fan deposit.

Those who wish to see the morphologic expression of the deposit left by Hyalite Creek should drive south on Church Street (Sourdough Road) approximately 4 miles north of Kagy Street to Nash Road, turn east for about 0.5 mi. stop and look west.

13. At the barbed wire fence that bounds the south edge of Burke Park just north of the blue City Water Tower turn east and follow the gravel path toward Highland Boulevard.

You are walking on a dissected Tertiary erosion surface.

14. At Highland Boulevard, turn south (left). Walk along the foot path on the west side of the street to Kagy Street.

As you walk along look east and notice the dissected surface of the Tertiary sediments. Presumably this area was not as completely eroded because the streams exiting the Gallatin Range east of here are smaller and had less erosive power to remove sediment to the Gallatin River system and out of the valley. To the south you can see the Gallatin Range, and to the east south east the Bridger Range. The range-front faults for these two ranges intersect near Mount Ellis.

15. At Kagy Boulevard turn west back toward the University.

Look again at the incised Bozeman Creek, and the pediment surface cut into Tertiary sediments. Notice that the University is a high point in the Valley. One is tempted to explain the topographic elevation of the area MSU is built on by calling on the knob of Precambrian bedrock that lies just below the sedimentary veneer at Wilson Hall, but the origin of this low hill is not known.

As you walk down Kagy Boulevard toward Church Street, look at the sediment cut out for the road. (Please do not dig out this road cut as stabilization is an important priority for this area). Note that, unlike the digression at Peet's Hill, there are no gravelly channel deposits exposed in this hill side.

16. At Church Street IF you wish to see calcite cemented Tertiary gravels turn north. If you wish to head back to the University, continue along Kagy to the West across Church Street.

If you take the digression to the Tertiary gravels PLEASE BE VERY CAREFUL. Walk on the left side of the road. There are no sidewalks, the road is narrow, and traffic is fast.

Proceed approximately 425 m (1400 feet) to the cemented gravel outcrop of Six Mile Creek (?) Formation. This outcrop stands in contrast to that you visited at Peet's Hill which contained an uncemented gravel.

17. Retrace your steps walking south back to Kagy. Turn west on Kagy.

18. Proceed on Kagy down off Sourdough Ridge, across Sourdough Creek west toward the Montana State University Campus. You will cross Sourdough Creek. Notice the flood plain and the dissected stream cut below the general erosion surface to the west. You will pass the Valley View Golf Course, across a junction of three streets (Willson, South Third, and Kagy). The Museum of the Rockies is to the south (your left). Keep heading west on Kagy.

19. At 7th street, turn north toward campus. Approximately 0.3 miles north of the intersection of Kagy and 7th you will come to Grant Street. The Strand Union is immediately to the north. You are back where you started.

DRIVING TOUR OF THE GEOLOGY OF THE SOUTHEASTERN

GALLATIN VALLEY

BRIDGER RANGE

AND

WESTERN MARGIN OF THE CRAZY MOUNTAINS BASIN

by

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and
Geology Graduate Students
Department of Earth Sciences
Montana State University

1982

Revised
1995
by
Steve Custer

INTRODUCTION

The Gallatin Valley is the easternmost of the four major valleys that compose the greater Three Forks Basin (Fig. 1). This basin is surrounded by mountains, bordered on the southwest by the Tobacco Root Mountains, the northwest by the Elkhorn Mountains, on the north by the Horseshoe Hills, on the east by the Bridger Range, and on the south by the Madison and Gallatin Ranges. Basin elevations range from approximately 4,000 ft (1200m) where the Missouri River cuts its way out of the basin near Three Forks to 6,000 ft (1800 m) where gently sloping basin uplands abut the steeper mountain fronts. The adjacent ranges tower above the basin floors at maximum elevations that range from slightly more than 7,000 ft (2100 m) in the Horseshoe Hills to the abrupt peaks of the Gallatin, Madison, and Tobacco Root Mountains that are in excess of 10,000 ft (3000 m).

This short field trip provides a brief examination of the basin-to-mountain transition, from the Gallatin Valley just east of Bozeman, across the Bridger Creek Canyon cut in the extreme southern Bridger Range, and into the western margin of the Crazy Mountains Basin. This traverse illustrates stratigraphic, structural, and geomorphic relationships common to most other margins of the Three Forks Basin. The geologic map for the trip has been compiled from work by Roberts (1964 a and b) (Figure 10). The drive takes about 2.5 hours without long stops and as long as you wish if you get out of your car to look at the rocks.

ROAD LOG

Increment mileage	Cumulative mileage	
0.0	0.0	Leave the southeast side of the Strand Union parking lot on the campus of Montana State University. Reset your odometer at the southeastern most entrance to the parking lot at Grant street. Turn left (east) and immediately south on 7th Street. Travel south on 7th to Kagy. As you drive south you are looking at the Gallatin Range. Mount Blackmore and Hyalite Peak are the highest peaks on the sky line. The Spanish Peaks in the Madison Range can be seen to the southwest at about 2:00 o'clock. No field trip will be taken to the Gallatin Range because of snow on the road and accessibility.

The **Madison and Gallatin Ranges** are similar geologically and are distinguished mainly on a physiographic basis. The mountains west of the Gallatin River are called the Madison Range and those east of the Gallatin River are called the Gallatin

Increment mileage	Cumulative mileage	
		Range. The ranges are composed of folded and faulted Archean metamorphic rocks (gneiss, amphibolite, and quartzite) (Mogk, 1990) which are overlain by Paleozoic and Mesozoic sediments deformed in basement-cored Laramide style. Overlying these rocks is the Eocene (ca. 49 ma) Gallatin Volcanic Field (Chadwick, 1969, 1970; Hiza, 1994). This complex consists of a sequence of intercalated andesitic lava flows, flow breccias, vocaniclastic debris flows and hyper concentrated flow deposits formed by pyroclastic flow and pyroclastic surges, phreatomagmatic explosions, mass movement and streams expected on stratovolcanoes. Figure 4 is an idealized schematic diagram of the Gallatin Range (Hiza, 1994). The volcanic and epiclastic rocks lie on a profound erosional surface and can be divided into the Golmeyer Creek Volcanics which were tilted before emplacement of the Hyalite Peak Volcanics. All these rocks are cut by Eocene intrusives of various ages. The Gallatin Range is bounded on the North by a large normal fault. Gravity evidence suggests approximately 2000 m (6000 ft) of sedimentary fill in the valley adjacent to the Gallatin Range (Davis and others, 1964). Since the Galltin Range has peaks that exceed 3000 m (10,000 ft) and the valley floor is approximately 1400 m (4600 ft) above sea level, total throw on the fault is of the order of 3600 m (11,000 ft) (2000m + (3000 m - 1400 m) = 3600 m).
0.3	0.3	Turn east on Kagy (left). Drive across south Third on Kagy to Church Street.
1.1	1.4	Turn North (left) from Kagy onto Church.
0.3	1.7	Calcite cemented channel gravels in siltstone, claystone, and sandstone deposits of the Bozeman Group (Miocene Six Mile Creek Formation?). If you decide to stop, please be very careful. The road is narrow and the traffic is fast. Notice that the beds are tilted to the north approximately 6 degrees suggesting listric faulting along the Bridger Range. For more information refer to walking item 16 in the first guide in this guidebook.

Increment mileage	Cumulative mileage	
0.5	2.2	You are driving along the Bozeman Creek flood plain. This stream is also locally known as Sourdough Creek (Fig.3).
0.2	2.4	Cross Sourdough Creek. This area is often flooded in the spring.
0.1	2.5	A second outcrop of Bozeman Group sediments. The bluff is composed of massive buff to tan partly calcareous variously consolidated tuffaceous claystone, siltstone, sandstone, and channel conglomerate assigned to the Tertiary Bozeman Group (Hackett and others, 1960; Robinson, 1961). Some of the conglomerates are cemented with calcium carbonate and others are relatively unconsolidated. Those here are unconsolidated. Later on the walk you will have an opportunity to examine conglomerates that are fully lithified with calcite. These sediments have not been formally assigned formational status in this area, but probably belong to the Six Mile Creek Formation. This conclusion is based on upper Miocene or lower Pliocene fossils found four miles east in similar material (Glancy, 1964), presence of cemented and uncemented discontinuous lenticular gravel and conglomerate fluvial channel deposits, and the presence of tuffaceous claystone and siltstone interpreted to be Oligocene Renova Formation approximately 700 feet (200 m) below the surface in deep drill holes and approximately 30 km (20 mi west) (Hackett and others, 1960; Donohue, 1989; Custer, 1991). Both matrix and framework supported deposits are present. The cementation probably represents caliche developed in a semiarid environment (Hughes, 1980; Thompson and others, 1982). By analogy with similar sediments 30 km (20 mi) to the north, these deposits were probably formed in a complex of flood basin and alluvial fan environments (Hughes, 1980). Glancey (1964) used clast imbrication and composition to suggest transport from an area to the east of the modern Bridger Range, but other workers suggest more local sources and different transport directions (Hughes, 1980). Hanneman and Wideman (1991) suggest a sequence stratigraphic approach to subdividing rocks in the intermontane valleys of Southwest Montana, but this approach has not been applied to

Increment mileage	Cumulative mileage	
		sediments in the Gallatin Valley near Bozeman. Much more paleontologic, and stratigraphic work remains to be done on these sediments.
0.5	3.0	Proceed North across Babcok and across Main Street.
0.1	3.1	West (left) on Mendenhall
0.1	3.2	North (right) on Rouse
0.6	3.8	Stop light at Tamarack
0.3	4.1	Cross Railroad Tracks
0.4	4.5	Rouse merges into Bridger Canyon Road which bends eastward here (Zigs Building Supply is at the east end of the curve). You are now on Highway 86.
0.6	5.1	Story Mill Road. Look to the east. There is a grey house on the low hills at 12:00. This house is on a hill in the rumpled topography of a large paleolandslide which dominates the north slope of the Story Hills at this point (Griffith, 1982). This large landslide probably slid off the Story Hills highland to the south during the Pleistocene. This landslide has no known active scarps, but on top of the Story Hills, there are active scarps that offset roads to proposed subdivisions nearly annually. These slides are identified by their prominent headscarp, dip slope attitude, hummocky topography, and lobate terminus. The paleolandslide is in the Bozeman Group - upper part (Tb) to right at 3:00; the Bozeman Group is composed of poorly stratified, variously consolidated tuffaceous siltstone, claystone, sandstone and conglomerate here. Q1s (landslide deposits) at 2:00. Bridger Range trending north-south at left and straight ahead (10:00-12:00). Your are on Qya (younger alluvium) at Bridger Creek. The Story Hills to the south are composed of unconsolidated and semi-consolidated fluvial and eolian sediments of the Tertiary (Miocene-

Increment mileage	Cumulative mileage	
		Pliocene) Bozeman Group. These deposits dip gently eastward toward the basin margin, reflecting the post-depositional movement on the Bridger Range normal fault.
0.7	5.8	Grey house on paleolandslide at 12:00 o'clock

You are about to enter the area covered by the geologic map (fig. 10). The key for the map is on the back of the map.

0.2	6.0	Driving on approximate contact of Qac and Qya. Panoramic view of foreland Tobacco Root Mountains at 6:00 (behind vehicles). Watch to the north for several homes on or very near the Bridger range-front normal fault. No scarps are visible, but Archean quartzofeldspathic gneiss is in contact with Tertiary valley fill here. To the south in the Story Hills in the saddle east of the radio towers, Tertiary valley fill is in probable fault contact with Cretaceous Colorado Group shales. The range-front normal fault, is the easternmost Basin and Range normal fault in this part of Montana. (To the south, the easternmost fault is the Deep Creek Fault system in the Paradise Valley.) The offset in the location of the eastern-most Basin and Range Normal fault is at the Nye Bowler Lineament (see tectonic map on the Geologic map of Montana in the Pocket). The normal fault here probably exploits a ramp in an older thrust fault. The listric normal fault that was formed is responsible for the tilted Tertiary strata and the present Gallatin Valley.
1.1	7.1	Fish Hatchery road to the south (left). The exact position of the fault at the road is unknown but is probably about 0.2 mi behind you. The discussion at the previous rolling stop gave you time to watch for the fault location and think about earthquake-fault zoning problems.
0.2	7.3	"M" parking lot on the left. If you have time this is an excellent place for a hike. You may do what many do and walk straight up the hill

Increment mileage	Cumulative mileage	
		to the "M", but this causes erosion and bypasses an excellent sequence of Paleozoic strata beginning at the Cambrian-Precambrian contact with the Flathead Quartzite and proceeding through the Pilgrim Limestone which forms the face on which the "M" is written. Younger Paleozoic rocks and faults can be seen with hikes up hill, off trail. This traverse will require a little searching but can be facilitated by studying Figure 10.
0.1	7.4	The steel-roofed sheds cover a warm springs (26 °C) on the south (right) and a cold spring (8°C) on the left (north). The springs are probably fault controlled. The faulting is intricate in this area (more complex than can be depicted in Figure 10). More details regarding the fault-spring connection would be interesting, but have been hampered by the complexity of the deformation, the extraordinary detail needed on a map (large scale), and land access problems introduced by development plans for Drinking Horse Mountain on the south side of the road.
0.1	7.5	Drive straight ahead toward the barricade at the sharp bend in the road. Drive through the small gap in the barricade and proceed along the old road at the foot of the landslide. Remember that this is an active landslide and that boulders may roll down the hill and cause injury or damage. You accept this risk if you drive and stop here. If you decide not to drive on the old road, you should not stop because of the extreme traffic hazard on this narrow winding road. The difference in mileage on Montana 86 and the old highway is minimal. If you decide to disembark here to look at the rocks and faulting on the north side of the road, please watch for the traffic. Be very cautious so as to prevent rolling boulders onto the highway which might injure passers by.
		STOP 1: Narrows of Bridger Canyon (Figs. 2 and 3). Overturned and thrusted Mississippian Lodgepole Limestone to left and Bridger Canyon slide to the right. The lower half (the Paine Member) of the Lodgepole is a dark gray, thin-bedded, micritic limestone with silty

Increment mileage	Cumulative mileage	
		partings. The upper half of the formation (the Woodhurst Member) is interbedded with a light gray, medium-bedded, fossiliferous limestone containing bryozoans, crinoids, brachiopods and corals.
		In the late 1800's, a stone quarry was dug into the paleolandslide in order to remove the red stone for building purposes. At that time, the road was two-ruts which hugged the north bank of the stream. In 1962, the Montana State Highway Department, in an effort to reduce the sharp curve, constructed a new road on the south side, undermining the hillside. Sliding started almost immediately after the road was built. It moved rapidly for the first two months and then slowed down. Montagne and McMannis, in an unpublished report, anticipated two problems: 1) small slump blocks moving downslope, and 2) a larger movement caused by retrogressive extension failures. Montagne continued to monitor the movements in this area. In 1964, Montagne observed a crack 123 ft long and 43 ft deep about 70 ft upslope from the headwall of the initial slide. The fracture provided an avenue for water to reach the polished shear plane surfaces. On May 24, 1975, after an exceptionally wet Spring, debris rolled and slid downslope and covered the adjacent road. Shearing between the blocks can be observed on the hillside. Breakup of the slide blocks has been localized by the weakness developed along these shear planes.
		Proceed 0.1 mi east on the old highway.
0.1	7.6	**STOP 2.** Imbricate thrust fault (overturned?) at 9:00 with Mississippian Lodgepole in fault contact with gray, oolitic, basal part of Jurassic Rierdon Limestone. The Laramide structure in this part of the Bridger Range may be interpreted to represent "crowding" and thrusting on the overturned, east-verging limb of the Bridger Range anticlinorium (Fig. 4). Roberts (1964) mapped a total of six thrust faults from the "narrows" to the strike valley of the Upper Cretaceous Billman Creek Formation (Livingston Group), a distance of approximately 1.6 miles. As we drive east, we will pass upsection

Increment mileage	Cumulative mileage	
		through west-dipping (overturned) Jurassic and Cretaceous strata; the best exposures will be to the left (north).
0.1	7.7	You are about to rejoin highway 86. Turn right (east) **after** you have finished looking at the rocks. Orientations presented below assume your car is faced due north perpendicular to highway 86 as you prepare to join the traffic again. Outcrops on the mountain side at 12:00 are the Jurassic Ellis Group. The Rierdon and Swift are the resistant units. The Jurassic Morrison Formation forms the swale to the east of the Ellis Group, and the lower Kootenai Formation outcrops to the northeast at 2:00 o'clock. The section here is overturned with the beds dipping to the west. Younger beds are to the east. The thick, nonmarine, basal sandstone of the Lower Kootenai Formation forms the pinkish-tan outcrops on the west side of the roadcut. The gray to red-and-purple claystones and shales comprise the middle unit of the formation and grade into the thick-bedded quartzose sandstones and silty shales of the upper unit. Note the fault which visibly offsets the basal sandstone unit at the top of the roadcut.
0.2	7.9	The contact between the Kootenai and overlying Colorado Group is sharp here, marking a rapid change from non-marine sandstone to marine shale and silty sandstone deposition. Note the black shales and thin sandstone beds of the Lower Colorado Group just east of the Upper Kootenai Formation. The folds in these beds clearly demonstrates differing responses to Laramide compression with the shales exhibiting much more ductile behavior than the brittle sandstones.
0.4	8.3	Upper Cretaceous Eagle Sandstone at 9:00 in roadcut; road to an old gaging station and farm house at 3:00. The Eagle Sandstone consists of thin-to thick-bedded salt and pepper sandstone with intercalated shales. Shallow water deposition is indicated by pronounced ripple marks and cross-bedding near the west side of the roadcut and by thin coal seams on the east side. The Eagle Sandstone records the influx

Increment mileage	Cumulative mileage	
		of sediment from the Laramide highlands to the west. To the north, this unit contains coal which was mined at the turn of the century. The coal was converted to coke locally in coking ovens and shipped to furnaces in the Butte mining district for smelting. (Roberts, 1972)
0.3	8.6	Crossing the trace of inferred thrust fault in Upper Cretaceous Cokedale Formation (Livingston Group). Strata reverse dip direction from west-dipping (overturned) to east-dipping (upright) as the east limb of the Bridger Range anticlinorium "rolls out" into a syncline. The road crosses a small alluvial fan. Bridger Creek meanders in it's flood plain to the south of the road.
0.2	8.8	Crossing trace of inferred thrust between Upper Cretaceous Miner Creek and Billman Creek Formations (both in Livingston Group). Qya (younger alluvium) of Bridger Creek floodplain at 3:00.
0.3	9.1	Mile Post 6. To the east north east of the road is Green Mountain which is underlain by the Hoppers Formtion. Although the mountain has extensive landsliding on the west-facing slopes, recognition of these landslides is difficult from the car at this distance. The crest of the hills to the east and southeast contain the hingeline of the Kelly Canyon Syncline. The Livingston Group rocks in this area contain extensive broad open folds (Roberts, 1964 a and b; Figure 11).
0.6	9.7	Outcrops of sandstones and mudstones in the Billman Creek Formation.
0.2	9.9	Intersection with Kelly Canyon road; continue straight on Montana 86. Place Creek at 9:00 and Bridger Canyon Community Center (old Lower Bridger School) at 3:00. As the road turns NE, it follows the approximate contact of the Billman Creek Formation at 9:00 and Qya at 3:00. For the next several miles we follow a strike valley in the Billman Creek Formation (Kbc).
		At this point the course of Bridger Creek changes from a transverse

Increment mileage	Cumulative mileage	
		stream to a strike stream. At an earlier time, Bridger Creek may have flowed through Kelly Canyon or an adjacent pass, as a strike stream. A possible model for the development of the present drainage pattern in the area involves the headward erosion of an obsequent stream flowing west down the fault scarp on the west side of the Bridger Range. This stream may have exploited the east-west weaknesses related to a subsidiary fault system in the present Bridger Canyon. This obsequent stream may have eventually captured the strike stream to form the present Bridger Creek drainage.
1.3	11.2	Bridger Canyon Rural Fire Department on left.
0.1	11.3	**STOP 3.** Pull off just before the yellow caution signs for the small steel bridge on the right side of the road. You are across the road from 8131 Bridger Canyon Drive. Beasley Creek valley is at 9:00 with view of the southern Bridger Range crest at 10:00-11:00. The treed ridge in the foothills of the Bridger Range is underlain by the Miner Creek Formation. The Bridger Range rises in the background at an elevation 8,000-9,000 ft. The Mississippian Madison Group forms the range crest. This is a good example of the competency of a massive limestone in a semi-arid climate. Bridger Creek floodplain is at 3:00 with hills behind composed of east-dipping Upper Cretaceous Hoppers Formation (Livingston Group). The Hoppers Formation is composed of volcaniclastic siltstone, sandstone and shale. These hills are the eastward dipping margin of the Crazy Mountains Basin. At 1:00 o'clock is a flat ridge which is a pediment cut in the Billman Creek formation and left as a high remnant as Bridger Creek continued to cut into the incompetent mudstones and shales of the Billman Creek formation.
		Ground-water availability in this valley is controlled by the stratigraphy and geomorphology of this valley and provides a challenge to prospective home buyers. Homes built near Bridger Creek typically find adequate water at shallow depths. As homes are built higher on the hill sides away from the creek wells penetrate the

Increment mileage	Cumulative mileage	
		Billman Creek formation. Wells in this unit are often dry and if water is encountered tap water often smells of H_2S. Since the Billman Creek is tilted at approximately 9 degrees to the west here and is over 2000 feet thick, substantial drilling depths are required particularly on the east side of this valley if water is to be obtained (Moore, 1989). The Brown house next to the stream here has a 70 gpm well. The small log cabin to the east of this house has had considerable difficulty in finding water.
0.2	11.5	Outcrops of Billman Creek Formation on left.
0.5	12.0	Road crosses into Miner Creek Formation.
0.2	12.2	Road swings to right. Miner creek Formation in roadcut at 9:00.
0.5	12.7	Turn east (right) on Jackson Creek Road at 3:00 (connects with I-90). Continue north on Highway 86 along Kbc strike valley. Tree covered hills to left composed of Miner Creek Formation. The sag in the Jackson Creek divide to the right, may represent an ancient stream course of Bridger Creek. The creek may have flowed down dip (eastward) off the Bridger Range and possibly across the present divide to Rocky Creek and the East Gallatin River. At a later time, the strike portion of Bridger Creek captured the headwaters of this ancient creek forming the present stream course. Notice the pediment that forms the low ridge at about 2:00 o'clock. You will drive from here through open folds in the Fort Union Formation and the Livingston Group along Jackson Creek Road until you join the freeway. The Road is gravelled and passable. If you do not wish to travel a gravel road, you should turn back, retrace your path, and return to Montana State University. The roadloag proceeds from here along Jackson Creek Road to Interstate 90, through the core of the Bridger Range and on to the MSU Campus. Following along with Figure 10 may help you to see the geology. (The key is on the back of the figure.)

Increment mileage	Cumulative mileage	
0.3	13.0	Cross Bridger Creek. Outcrop on left is Billman Creek Formation. At 9:00 o'clock, there is a pediment cut on the Billman Creek which was discussed earlier.
0.3	13.3	Pass Teepee Ridge Road on the left.
0.5	13.8	The low ridges on the left are underlain by Hopper's Formation. The high ridges are supported by the conglomerates, sandstones, and siltstones of the Paleocene Fort Union Formation.
1.0	14.8	Bear left. Stay on Jackson Creek Road.
0.8	15.6	Cross Creek. Cross Aspen Meadows Road.
0.2	15.8	Sign to slow to 15 mph for curves.
0.1	15.9	Contact between Billman Creek and Hoppers formations. There are several small high angle faults in this area (Figure 10)
0.5	16.4	**Stop 4.** A vista from a local topographic divide on Billman Creek Formation. The moutain range at 11:00 o'clock is the Beartooth Range. (These snow-capped peaks may not be visible if the sky is overcast). The Beartooth Range (also known as the Absaroka by some) is underlain by Archean gneiss amphibolite, marbles and quartzites (Mogk, 1990). There are flank areas and some enclaves of paleozoic rocks. On the north flank of the Beartooth Range out of view are folded and reverse faulted Paleozoic and Mesozoic Strata. To the south (out of view) the Archean rocks are overlain by Eocene andesitic volcanic rocks. The western front of the Beartooth Range is bounded by the Deep Creek Fault System (Personius, 1982). You are looking across the Nye Bowler Lineament into the Eastern-most Basin and Range valley discussed earlier at milage 6.0.
0.1	16.5	Mile Post 4.0. Low ridges at 9:00 o'clock are underlain by thhe Hoppers Formation; ridges behind these hills are underlain by the

Increment mileage	Cumulative mileage	
		Fort Union Formation conglomerates and sandstones.
0.8	17.3	Howler's Inn Bed and Breakfast. Notice most of the development is on the Hoppers Formation. This is probably for a view, but may be fortunate since the Billman Creek Formation has little good-quality ground water in most areas.
1.2	18.5	Mile Post 5.0
0.2	18.7	Pass intersection with U.S. Forest Service Access Road. (A brief excursion up this road to Federal land will present opportunities to look at the Fort Union Formation. The trip continues on Jackson Creek Road toward the freeway in the interest of time.
0.2	18.9	The black top starts. You are at the approximate position of the Center Hill Anticline.
1.1	20.0	Malmborg School. At 12:00 o'clock, the ridge south of the freeway is the Miner Creek Formation. At 2:00 o'clock you can see another part of the Bridger Range. The Chestnut Mountain Anticline forms the core of the range here. Again the Madison Group forms the crest of the ridge. At 3:00 o'clock is a ridge underlain by the Fort Union Formation with Hoppers Formation producing the flanking low-lying ridges. The hinge line of the Kelly Canyon Syncline passes through the top of the ridge. This fold plunges to the west. The hinge line is offset by a fault near the intersection with the freeway. The hinge line is mapped as the Meadow Creek Syncline on the south side of the fault.
0.4	20.4	Turn West (right) onto the Interstate 90 on ramp. The Kelly Canyon Syncline crosses the road about here. Enter the Freeway.
0.7	21.1	Chain-removal area. Pull off if you want a moment to collect your thoughts and look at the core of the Bridger Range. At 1:00 o'clock is the Chestnut Mountain Anticline. This anticline is overturned.

Increment mileage	Cumulative mileage	
		Rocks on the east limb dip west at about 85 degrees. A down-plunge (west northwest at 35 degrees) projection with Figure 10 reveals a complex box-fold geometry with the crest of the range held up by erosion resistant Madison Group rocks. From here you will be driving down section.
0.2	21.3	Cross from the Billman Creek to the Miner Creek Formation.
0.5	21.8	Cross the contact with the Sulfur Flats Member of the Miner Creek Formation.
0.1	21.9	You are now in the Cokedale Formation.
0.1	22.0	Mile Post 318
0.7	22.7	Sign indicating 0.5 miles to Trail Creek Exit. Eagle Sandstone to the north (right).
0.4	23.1	Take Trail Creek Exit to catch your breath and prepare for the next mile or two of rapid lithological changes. Mile Post 317 Exit at Trail Creek. Pull over at the stop sign. The Eagle Sandstone is behind you. The low ridge at 1:00 o'clock is the Eldridge Creek Member of the Cody Shale. The valley to the east of the low ridge is the lower Cody Shale. The valley to the west of the ridge is the upper Cody Shale. The Frontier Formation is the low ridge in this valley. The brown mudstones and shales of the Cody Shale are visible in the road cut at about 12:00 o'clock. These brown rocks are followed by the grey sandstones in the Mowry Shale and the black shales in the Thermopolis Shale. As you enter Interstate 90 again you will see small landslides in the Mowry and Thermopolis which are actively changing the road cut on your right. Landslides are common in the Mowry and Thermopolis shales and account for much of the mass movement at the top of the Story Hills which was discussed but not examined earlier on this trip. From this stop sign you need to prepare for a rapid success of stratigraphic units. You will be driving

Increment mileage	Cumulative mileage	
		through the overturned Chestnut Mountain Anticline. If you would like to look at the rocks in more detail, pull off at the sign that indicates Bozeman is 6 miles away (approximately 1.2 miles from here) and join the next road log which describes Paleozoic and Mesozoic Stratigraphy of Rocky Canyon at Mile 12.0. As you drive through the canyon on Interstate 90, the beds are overturned. You will traverse down section through the Colorado Group, the Kootenai Formation (red), the Morrison Formation (swale), the Ellis Group (Swift Formation, Rierdon Formation (grey limestone), and the Piper Formation (a swale). Next will come the Quadrant Quartzite (really a dolostone and quartzite with a thin layer of Shedhorn sandstone above) and the red-purple-and-white Amsden Formation (mudstone and dolostones). Next you will see the karstified Mission Canyon Limestone of the Madison Group. As soon as you see the Karst limestone, look left (south) and you will see the axis of the fold as dips in the Mission Canyon change from east to west. The sequence will then repeat going up section through the Amsden (red-purple-and-white) and Quadrant Quartzite (white ridge former). The sequence will not be as obvious because Interstate 90 follows strike near the Amsden-Quadrant Contact. As the Interstate bends to the right you will see a quarry in the Quadrant sandstone. Then the stratigraphy will again be clear: Quadrant, Ellis Group (Piper (valley), Rierdon (grey limestone), Swift Sandstone), Morrison swale, Kootenai ridge and swale (red) and then the black shales of the Colorado Group. With this stratigraphy in hand, reenter Interstate 90 at the Trail Creek Entrance. Drive straight ahead. Keep your eyes north (right) except at mileage 24.3 where the fold axis is best seen on the left. IF YOU ARE DRIVING KEEP YOUR EYES STRAIGHT AHEAD AND DON'T HAVE AN ACCIDENT!
0.2	23.3	Reenter the Interstate.
0.3	23.6	Note landslide in Colorado Group. Brown Cody Shale
0.2	23.8	Kootenai Formation (red)

Increment mileage	Cumulative mileage	
0.1	23.9	Morrison Swale
0.1	24.0	Ellis Group (brown Swift Formation; Reirdon Formation (Grey Ridge)
0.1	24.1	Quadrant Quartzite
0.1	24.2	Amsden Formation (Purple and Red). Note landslide topography so common in this formation throughout the region.
0.1	24.3	Karstified Mission Canyon Limestone (Madison Group) (Roberts, 1966). Look left immediately and you will see the Mission Canyon beds "roll over" at the hinge line of the fold. Beds are now dipping to the west. You are at the Bozeman 6 miles sign that joins the next field trip if you want to look at the rocks more carefully, but you probably missed the turnout. If you wish to return, continue to the Bear Canyon interchange, retrace your steps to Trail Creek and pull out at the sign that says Bozeman 6 miles. Mileage from here does NOT assume you have retraced your steps.
0.1	24.4	West dipping Mission Canyon Formation. Note the karstification.
0.1	24.5	You are driving on strike with the Amsden and Quadrant beds. In a moment you will see the rock quarry in the Quadrant Quartzite (white rocks)
0.3	24.8	Quarry in Quadrant Quartzite.
0.4	25.2	Ellis Group (Rierdon, Swift, Piper), then the Morrison Formation Swale.
0.2	25.4	Kootenai Formation
0.1	26.5	Black Shales of the Colorado Group (Thermopolis?)

Increment mileage	Cumulative mileage	
0.4	27.1	Mile Post 313. You are traversing Cokedale Formation.
0.5	27.6	Look north (right). This is the approximate position of the Bridger range-front fault. The Tertiary age sediments (Miocene Six Mile Creek ?) are tilted gently (6 degrees) to the east suggesting a listric geometry for the fault. Watch for other beds more certainly dipping to the east as you proceed west.
0.6	28.2	Mile Post 312. Historic Fort Ellis to the right. (Also a Montana Agricultural Research Station. This is a sheep research facility.
0.4	28.6	Mile Post 311
0.6	28.2	Look north (right). Notice the tilted gravel beds of the Tertiary (Six Mile Creek? Formation) This is further evidence of tilting during listric faulting on the Bridger range-front Fault. Keep watching for tilted gravels.
0.2	30.0	More titled gravels to north
0.2	30.2	Take exit 309 to Bozeman. The exit requires 25 mph speeds and will bring you around until you are facing south.
0.5	30.7	Stop Sign at Main Street. Turn west (right).
0.6	31.1	Haggerty Lane. Don't turn, but **Do change to the left lane** NOW.
0.1	31.2	Continental Motor Inn. Turn left onto Highhland Boulevard. You are now driving south.
0.4	31.6	Turn right (west) onto Ellis Street to get out of the flow of traffic.
0.3	31.9	Turn south (left) at the dead end. You are now driving south.

Increment mileage	Cumulative mileage	
0.3	32.2	Stop sign at the driveway to the Hillcrest Retirement Community. STOP 5.

You may wish to get out of your car here to stretch, review where you have been, and consider other mountains not visited on this trip. You are looking north at the **Bridger Range**. The range crest is held up by erosion resistant Madison Group limestones (Lageson, 1989). The rib of limestone that forms the crest of the Bridger Range is the east limb of an asymmetric, overturned anticline. The west limb and axis of the anticline were dropped into the valley. North of Ross Pass (obscured by the mountains in the foreground), Proterozoic Lahood Formation arkoses limestones and shales cover the Archean gneisses so that the older Precambrian rocks are not exposed. Ross Pass constitutes a fundamental geologic boundary between the Laramide Foreland style deformation to the south and Sevier fold and thrust deformation to the North (See the tectonic map on the Geologic Map of Montana in the pocket) (Lageson, 1989). The transverse zone separates the Sevier-style terrain to the north from the Laramide-style terrain to the south. The west side of the Bridger Range is bounded by a normal fault which probably began moving in Miocene or younger time based on steeply dipping Miocene sediments in the fault zone in Dry Creek Valley 30 km north of here (Hughes, 1980) and involvement of Paleocene strata in Sevier-style deformation on the east side of the Bridgers.

Evidence for a listric geometry on the range-bounding fault can be seen if you look north-east at the foot hills just across from Interstate 90. Notice that the Tertiary-age gravels to the north-north east in the foot hills are tilted approximately six degrees into the mountain range. Gravity evidence suggests over 1800 m (6000 ft) of Tertiary valley fill on the western flank of the Bridger Range (Davis and others, 1964). Since the valley floor is at 1200 m (4000 ft) above sea level, and the Bridgers rise to an elevation of 2900 m (9,500 ft) the total offset along the Basin-and-Range listric normal fault is approximately 3500 m (11,000 ft) (3500 = 1800 m + (2900 m-1200

m)). A diagrammatic cross section through the Bridger Range is shown in Figure 4. Although the total offset on the range-bounding normal fault is large, no fault scarp has been recognized in the valley. The absence of a scarp has made fault zoning difficult to promote in the Valley.

Careful examination of the valley fill materials adjacent to the Bridger Range reveals a surface graded to the west to a level above the east Gallatin River. This surface is a pediment cut on Tertiary sediments. You are standing on or very near this erosional surface.

As the description above suggests, the Bridger Range overlaps the boundaries of four major tectonic provinces (Lageson, 1989): 1) Middle Proterozoic Belt Basin 2) the thin-skinned Sevier fold and thrust belt (which mimics the Belt Basin), 3) Laramide basement-involved foreland province, and 4) the Basin and Range Province. There are five episodes of deformation in the Bridger Range, each of which represents in part reactivation of old boundaries. The first deformation episode is Archean crustal assembly (D-1) which includes a 3.5 Ga accretion episode to produce a 20 km thick crust which was metamorphosed to upper amphibolite or perhaps granulite facies. These rocks were isoclinally folded at about 2.8 Ga. The isoclinally folded rocks were refolded in a more open style shortly after the isoclinal event. This crustal assembly was followed by Proterozoic rifting and large-scale normal faults (D-2) from 1.45 to 0.85 Ga which formed the southern margin of the Belt Basin. This rifting is probably reflected in Ross-Pass fault which separates a northern terrain with LaHood rocks from a southern terrain without LaHood Rocks which is underlain by Archean quartzofeldspathic gneiss. This rift margin follows the Perry line approximately due west and extends across the north end of the Tobacco Root Mountains to the west. The third event was thin-skinned Sevier-style fold and thrust deformation (D-3) . The southern margin of the Helena Salient roughly follows the ancient boundary between Archean uplands and the rifted Belt Basin to the north. The Sevier

deformation occurred in this area during the Paleocene extending past the time of Fort Union Formation deposition (Lageson, 1989). The fourth episode of deformation is basement-involved Laramide-style reverse faults (D-4). This episode occurred from latest Paleocene to early Eocene. This style of deformation is constrained to areas south of Ross Pass where Archean rather than thick sequences of Proterozoic sedimentary rocks are present. Basin and Range style deformation (D-5) is the fifth episode. This extensional period of deformation probably began in the Miocene. The listric faults may have exploited ramps in earlier Laramide and/or Sevier faults (Fig. 40 (Lageson, 1989). Thus young faults have exploited old weaknesses and fold styles are controlled by the thicknesses of sediments related to old faults. The historic weaknesses and depositional patterns are exploited by younger folding and faulting events.

The **Belt Mountains** can bee seen extending north of the Bridger Range in the distance. The Belt Mountains have a geology similar to that in the Northern Bridger range with a full complex of Paleozoic and Mesozoic sediments folded and faulted in Sevier Style (see the Geologic Map of Montana in the Pocket).

The **Horseshoe Hills** can be seen at 10:00 o'clock to the north west. These hills contain a complete stratigraphic column which begins in the Proterozoic Lad Formation and extends through Cretaceous mudstones of the Colorado Group. These rocks are at the southern margin of the Helena Salient (see the Tectonic Map of Montana which is part of the Geologic Map of Montana in the Pocket so Archean rocks are not exposed in this area and Paleozoic and Mesozoic rocks are deformed in Sevier rather than Laramide structural style.

The peaks of the **Gallatin Range** can be seen at 6:00 o'clock behind us. This mountain range was discussed as you left the parking

Increment mileage	Cumulative mileage	
		lot at the Strand Union. To the west (3:00 o'clock) you can see the south-most extension of the Bridger Range. Careful examination of the skyline shows a cut in the range made by Rocky Canyon. The stream is superposed. As the Bridger Range was uplifted, Rocky Creek maintained grade and cut through the Chestnut Mountain Anticline. The core of the anticline can be seen as unpside-down "u" in the trees on the south (left) side of the Rocky Canyon Stream Cut. The large scale east-dipping surface to the south of Rocky Canyon is the west limb of a syncline that parallels the Bear Canyon and Chestnut Mountain Anticlines (Figure 10). Although the Tectonic Map of Montana (on the Geologic Map of Montana in the pocket of this guidebook) does not extend the Nye-Bowler Lineament into the Gallatin Valley, Rocky Canyon does appear to form a boundary between two terrains. To the south of Rocky Canyon (and the Nye-Bowler Lineament), the last Basin and Range Style extensional valley is the Deep Creek Fault along the front of the Beartooth (Absaroka) Range. To the north of Rocky Canyon the last extensional fault is the listric fault along the front of the Bridger Range. The last volcanic deposits of the Gallatin volcanic pile also occur approximately 11 km (7 mi) north of Rocky Canyon, and suggests that an important boundary extends through this area. To the north, you can see the last Basin and Range Style extensional fault before the Great Plains. You can also see the western margin of the Crazy Mountains Basin. **Turn Left**
0.1	32.3	Turn right (South) on Highland.
0.5	32.8	Gallatin Range to the south.
0.1	32.9	Turn west (right) on Kagy. Spanish Peaks of the Madison Range at 11:00 o'clock; Tobacco Root Mountains at 12:00 o'clock. On north (right), notice fine-grained Tertiary sediments (Six Mile Creek?)

Increment mileage	Cumulative mileage	
0.3	33.2	Cross Church Street. Decend to Sourdough (Bozeman) Creek. Not incision of stream into Tertiary sediments.
0.8	34.0	Cross Third.
0.3	34.3	Right (north) on 7th Street.
0.3	34.6	You are back at the corner of Grant and 7th, back at MSU.

Paleozoic and Mesozoic Stratigraphy of the Bridger Range.

By

Stephan G. Custer

Introduction

This self-guided trip provides the interested geologist with an opportunity to examine the strata from the Mission Canyon Formation in the Mississippian Madison Group up section through the Mowry Shale of the Colorado Group. This trip focuses on stratigraphic familiarization. Those interested in more detail are referred to Roberts (1972). The field trip follows the same route as the trip above titled Geology of the Sotheastern Gallatin Valley which precedes this trip to Main Street and then follows Interstate 90 to the well exposed road cuts which are the focus of this self-guided excursion. The route is roughly the reverse of that for the previous trip, but turns around at Trail Creek Road and stops so the Mississippian through Cretaceous stratigraphic section can be examined on the ground rather than from a car. Many figures are reused. The route proceeds from the south side of the Strand Union at Montana State University, east up Sourdough Ridge, north to Interstate 90 and East to Rocky Canyon. The stratigraphy is exposed where Rocky Canyon cuts though the Chestnut Mountain Anticline.

Road Log

Increment Mileage	Cumulative Mileage	
0.0	0.0	Leave the southeast side of the Strand Union parking lot on the campus of Montana State University. Reset your odometer at the southeastern most entrance to the parking lot at Grant street. Turn left (east) and immediately south on 7th Street. Travel south on 7th to Kagy. As you drive south you are looking at the Gallatin Range. Mount Blackmore and Hyalite Peak are the highest peaks on the sky line. The Spanish Peaks in the Madison Range can be seen to the southwest at about 2:00 o'clock. No field trip will be taken to the Gallatin Range because of snow on the road and accessibility.

The **Madison and Gallatin Ranges** are similar geologically and are distinguished mainly on a physiographic basis. The mountains west of the Gallatin River are called the Madison Range and those east of the Gallatin River are called the Gallatin Range. The ranges are is composed of folded and faulted Archean metamorphic rocks (gneiss, amphibolite, and quartzite) (Mogk, 1990) which are overlain by Paleozoic and Mesozoic sediments deformed in basement-cored Laramide style. Overlying these rocks is the Eocene (ca. 49 ma) Gallatin Volcanic Field (Chadwick, 1969, 1970; Hiza, 1994). This complex consists of a sequence of intercalated andesitic lava flows, flow breccias, vocaniclastic debris flows and hyperconcentrated flow deposit formed by pyroclastic flow and pyroclastic surges, phreatomagmatic explosions, mass movement and streams expected on stratovolcanoes. Figure 5 is an idealized schematic diagram of the Gallatin Range (Hiza, 1994). The volcanic and epiclastic rocks lie on a profound erosional surface and can be divided into the Golmeyer Creek Volcanics which were tilted before emplacement of the Hyalite Peak Volcanics. All these rocks are cut by Eocene intrusives of various ages. The Gallatin Range is bounded on the North by a large normal fault. Gravity evidence suggests approximately 2000 m (6000 ft) of sedimentary fill in the valley adjacent to the Gallatin Range (Davis and others, 1964). Since the Galltin Range has peaks that exceed 3000 m (10,000 ft) and the valley floor is approximately 1400 m (4600 ft) above sea level, total

Increment mileage	Cumulative mileage	
		throw on the fault is of the order of 3600 m (11,000 ft) (2000 m + (3000 m - 1400 m) = 3600 m).
0.3	0.3	Turn east on Kagy (left).
0.3	0.6	Cross South Third
0.8	1.4	Cross Church Street. Proceed east. To your left notice the fine grained facies of the Tertiary (Six Mile Creek Formation?) discussed on the walking tour (position 16). Bozeman Creek (Sourdough Creek) and Hyalite Creek have cut through the Tertiary sediments leaving this dissected uplands as an erosional remnant above the modern alluvium and another pediment surface which forms the floor of the valley you just left.
0.3	1.7	Turn left (North) on Highland Boulevard. You are driving on a dissected Tertiary upland. Notice the amount of incision in this surface and compare it to that you have seen on the floor of the valley near Montana State University. The Bridger range stretches from 12:00 to 3:00 o'clock before you. This mountain range will be discussed further shortly.
0.7	2.4	Turn left (west) at the driveway to Hillcrest Retirement Community, and immediately right (north). Stop at the corner. This tum takes you out of the flow of traffic on Highland and provides an opportunity for a safe stop to view the mountains. You are looking north at the **Bridger Range**. The range crest is held up by erosion resistant Madison Group limestones (Lageson, 1989). The rib of limestone that forms the crest of the Bridger Range is the east limb of an asymmetric, overturned anticline. The west limb and axis of the anticline were dropped into the valley. North of Ross Pass, Proterozoic LaHood Formation arkoses, limestones, and shales cover the Archean gneisses so that the older Precambrian rocks are not exposed. South of the pass no LaHood is present. Ross Pass constitutes a fundamental geologic boundary between the Laramide Foreland style deformation to the south and Sevier fold and thrust deformation to the North (See the tectonic map on the Geologic Map of Montana in the pocket) (Lageson, 1989). The transverse zone

Increment mileage	Cumulative mileage

separates the Sevier-style terrain to the north from the Laramide-style terrain to the south. The west side of the Bridger Range is bounded by a normal fault which probably began moving in Miocene or younger time based on steeply dipping Miocene sediments in the fault zone in Dry Creek Valley 30 km north of here (Hughes, 1980) and involvement of Paleocene strata in Sevier-style deformation on the east side of the Bridgers.

Evidence for a listric geometry on the range-bounding fault can be seen if you look north-east at the foot hills just across form Interstate 90. Notice that the Tertiary-age gravels to the north-north east in the foot hills are tilted approximately six degrees into the mountain range. Gravity evidence suggests over 1800 m (6000 ft) of Tertiary valley fill on the western flank of the Bridger Range (Davis and others, 1964). Since the valley floor is at 1200 m (4000 ft) above sea level and the Bridgers rise to an elevation of 2900 m (9,500 ft) the total offset along the Basin-and-Range listric normal fault is approximately 3500 m (11,000 ft) (3500 m = 1800 m + (2900 m-1200 m)). A diagrammatic cross section through the Bridger Range is shown in Figure 4. Although the total offset on the range-bounding normal fault is large, no fault scarp has been recognized in the valley. The absence of a scarp has made fault zoning difficult to promote in the Valley.

Careful examination of the valley fill materials adjacent to the Bridger Range reveals a surface graded to the west to a level above the east Gallatin River. This surface is a pediment cut on Tertiary sediments. You are standing on or very near this erosional surface.

As the description above suggests, the Bridger Range overlaps he boundaries of four major tectonic provinces (Lageson, 1989): 1) Middle Proterozoic Belt Basin 2) the thin-skinned Sevier fold and thrust belt (which mimics the Belt Basin), 3) Laramide basement-involved foreland province, and 4) the Basin and Range Province. There are five episodes of deformation in the Bridger Range, each of which represents, in part, reactivation of old boundaries. The first deformation episode is Archean crustal assembly (D-1) which includes a 3.5 Ga accretion episode to produce a 20 km thick crust

which was metamorphosed to upper amphibolite or perhaps granulite facies. Regionally these rocks include gneiss, amphibolite, marble, and quartzite. These rocks were isoclinally folded at about 2.8 Ga. The isoclinally folded rocks were refolded in a more open style shortly after the isoclinal event. This crustal assembly was followed by Proterozoic rifting and large-scale normal faults (D-2) from 1.45 to 0.85 Ga which formed the southern margin of the Belt Basin. This rifting is probably reflected in Ross-Pass fault which separates a northern terrain with LaHood rocks from a southern terrain without LaHood Rocks which is underlain by Archean quartzofeldspathic gneiss. This rift margin follows the Perry line approximately due west and extends across the north end of the Tobacco Root Mountains to the west. The third event was thin-skinned Sevier-style fold and thrust deformation (D-3) . The southern margin of the Helena Salient roughly follows the ancient boundary between Archean uplands and the rifted Belt Basin to the north. The Sevier deformation occurred in this area during the Paleocene extending past the time of Fort Union Formation deposition (Lageson, 1989). The fourth episode of deformation is basement-involved Laramide-style reverse faults (D-4). This episode occurred from latest Paleocene to early Eocene. This style of deformation is constrained to areas south of Ross Pass where Archean rather than thick sequences of Proterozoic sedimentary rocks are present. Basin and Range style deformation (D-5) is the fifth episode. This extensional period of deformation probably began in the Miocene. The listric faults may have exploited ramps in earlier Laramide and/or Sevier faults (Fig. 4) (Lageson, 1989). Thus young faults have exploited old weaknesses and fold styles are controlled by the thicknesses of sediments related to old faults. The historic weaknesses and depositional patterns are exploited by younger folding and faulting events.

The **Belt Mountains** can bee seen extending north of the Bridger Range in the distance. The Belt Mountains have a geology similar to that in the Northern Bridger range with a full complex of Paleozoic and Mesozoic sediments folded and faulted in Sevier Style (see the Geologic Map of Montana in the Pocket).

Increment mileage	Cumulative mileage	

The **Horseshoe Hills** can be seen at 10:00 o'clock to the north west. These hills contain a complete stratigraphic column which begins in the Proterozoic LaHood Formation and extends through Cretaceous mudstones of the Colorado Group. These rocks are at the southern margin of the Helena Salient so Archean rocks are not exposed in this area and Paleozoic and Mesozoic rocks are deformed in Sevier rather than Laramide structural style. (See the Tectonic Map of Montana which is part of the Geologic Map of Montana in the Pocket)

The peaks of the Gallatin Range can be seen at 6:00 o'clock behind us. This mountain range was discussed as the you left the parking lot at the Strand Union. Recall that the Gallatin and Madison Ranges are cored by Archean rocks with a dissected Paleozoic to Mesozoic sedimentary veneer which is buried under Eocene andestic volcanic lava flows, flow breccias, and debris flow deposits.

To the west (3:00 o'clock) you can see the south-most extension of the Bridger Range. Careful examination of the skyline shows a cut in the range made by Rocky Canyon. The stream position may have been superposed during exhumation or may have maintained its position during uplift of the Mountains. The core of the anticline can be seen as upside-down "u" in the trees on the south (right) side of the Rocky Canyon Stream Cut. The large scale east-dipping surface to the south of Rocky Canyon is the west limb of a syncline that parallels the Bear Canyon and Chestnut Mountain Anticlines (Figure 11). Although the Tectonic Map of Montana (on the Geologic Map of Montana in the pocket of this guidebook) does not extend the Nye-Bowler Lineament into the Gallatin Valley, Rocky Canyon does appear to form a boundary between two terrains. To the south of Rocky Canyon (and the Nye-Bowler Lineament), the last Basin and Range Style extensional valley is the Deep Creek Fault along the front of the Beartooth (Absaroka) Range. To the north of Rocky Canyon the last extensional fault is the listric fault along the front of the Bridger Range. The last volcanic deposits of the Gallatin volcanic pile occur approximately 11 km (7 mi) north of Rocky Canyon, and suggests that an important boundary extends through this area. To the north, you can see the last Basin and Range Style

Increment mileage	Cumulative mileage	
		extensional fault before the Great Plains. You can also see the western margin of the Crazy Mountains Basin.
		Proceed north toward the Bridgers.
0.4	2.8	At the barricade turn east (right). (You are facing Chestnut Mountain Anticline exposed in Rocky Canyon on the sky line to the east.)
0.2	3.0	Turn north (left) on Highland Boulevard.
0.5	3.5	Turn east (right) on Main Street.
0.2	3.7	Bear right onto the on-ramp for I 90 to Livingston. Not the Frontage Road.
3.2	6.0	Mile-post 312. Approximate trace of the Bridger range-front fault. Notice the black Cokedale Formation muds in contact with Tertiary (Six Mile Creek?) sediments in the bluffs to the north (left).
0.4	8.2	Eagle Formation
0.3	8.5	Kootenai Formation (red) to north (left)
0.5	9.0	Ellis Group (Rierdon, Swift, Piper Formations to north (left)
0.1	9.1	Quarry on right in Quadrant Quartzite. From here we will drive on strike with the Quadrant Quartzite/Amsden contact for a short distance.
0.2	9.3	Red-colored Amsden
0.2	9.5	West-dipping Mission Canyon Formation of the Madison Group. Notice karstification. This rock is an excellent aquifer in the region and in some areas also bears hydrocarbons in the appropriate structural setting.

Increment mileage	Cumulative mileage	
0.4	9.9	Look right (south). Notice the dips in the Madison Group rocks switch to the east. You have just crossed the axis of the Chestnut Mountain Anticline. Karstified Mission Canyon Formation on the left (north).
0.1	10.0	Amsden Formation (red and purple siltstones and cream dolostones) on left (north). Notice landslide typical of Amsden Formation in the region.
0.1	10.1	Quadrant Quartzite forms ridge. (Quadrant is really composed of dolostone at the base and quartz arenite at the top here). At the very top is a very thin unit composed of quartz arenite with very angular chert fragments (brown, butterscotch, black and white) in a chert matrix which is probably the Shedhorn.
0.1	10.2	A swale (over-thickened Jurassic Piper Formation) followed by a grey limestone ridge (Rierdon) followed by a swale and a brown sandstone ridge (Swift Formation). The Swift formation here contains a storm sequence with hummocky cross stratified and graded beds. The Swift is glauconitic and contains oysters.
0.1	10.3	Morrison Formation Swale. Regionally this unit contains dinosaur remains. (Cooley, 1993)
0.1	10.4	Kootenai Formation. Basal chert-pebble conglomerate followed by interbedded red mudstone and chert litharenites. Top of unit contains a micrite with a few gastropods.
0.2	10.5	Black Thermopolis shale, grey sandstone beds of the Mowry, brown mudstones and shales of the Cody. Notice the mass movement in the Cody Shale in the road cut.
0.6	10.7	Turn off on the Trail Creek Exit (left) (Exit 316). We will make a "U" turn and reenter the freeway here. Turn left (north) at the frontage road. (Note: Some may wish to turn right to see the coke ovens on Trail Creek. In the spring, this road can be impassable. You are strongly discouraged from turning right.

Increment mileage	Cumulative mileage	
0.3	11.0	Turn left (west) back onto the freeway entrance. We are returning to the freeway to gain access to the outrcops on the north side of I-90.
0.3	11.3	Note mass movement in Colorado Group shales again.
0.7	12.0	**TURN OUT to the RIGHT** at the mileage sign that says Bozeman 6 miles, Butte 91 miles. You will be near the Mission Canyon Formation of the Madison Group. Park your car. Please leave room for others. The highway right of way is public, but the land to the North is private. We have permission to walk here, but please respect the fences and property. The best way to walk to the Amsden formation from here is to stay on the highway side of the fence. Follow the fence eastward up onto the benched road cut. **Please do not walk on the freeway. Please be careful not to roll rocks down onto the highway**. Figure 11 is a stratigraphic column which may help you to find the contacts.

The contact between the Amsden and Mission Canyon is obscured by a landslide.

The contact between the Amsden Formation and the Quadrant Quartzite is the last red mudstone. The base of the Quadrant here is a dolostone overlain by quartz arenite and dolostone interbeds. Quartz arenite dominates at the top. A thin layer of quartz arenite with black angular chert fragments sometimes surrounded by chert matrix is probably the Shedhorn.

Following the Quadrant ridge is a valley. As you approach the grey limestone ridge, you will need to cross over the fence to the north. You are now on private land. To the east of the valley is a grey oosparite/oomicrite. At the base of this overturned bed of Rierdon Formation is red siltstone and mudstone of the Piper Formation. To the east of the ridge is interbeded biomicrite and brown calcareous mudstone. As you proceed east you will encounter crossbeded oyster-bearing glauconitic chert litharenites of the Swift Formation. This unit has been interpreted as a storm sequence by Fox (1982). The Piper, Rierdon and Swift comprise the Ellis Group. The structure can be interpreted using down plunge projection (35

Increment mileage	Cumulative mileage	
		degrees to the north west) Figure 10.
		The swale after the Swift Formation is the Morrison. Good exposures of the Morrison including fine-grained quartz rich channel sands can be seen by walking up hill about 50 m (150 ft) to the telephone line and maintenance road for the line. Elsewhere in this region dinosaur fossils have been found in this unit. (Cooley, 1993). If you go to the line, you should return to the fence line near the highway when you encounter the chert pebble conglomerates of the Kootenai formation.
		The Kootenai formation consists of interbedded sandstones and red mudstones. The contact with the Kootenai and the Colorado Group rocks is near where the black shales appear. Careful examination of strata will reveal micrites and a quartz arenite at the contact. The quartz arenite is at the base of the Thermopolis Shale.
		Bioturbated chert sublitharenite and arkose of the Mowry are followed by the brown Cody shales. Turn back and follow the path you took from your vehicle to here. We do NOT have permission to walk on land past this point.
		When you pull out onto I 90 be very careful. This is not an approved exit and the traffic is moving very fast. Turn left (west) onto the freeway.
0.8	12.8	Quarry in Quadrant, watch for the Ellis Group Rocks, the Morrison Swale and the red Kootenai formation followed by the black Colorado Group Shales.
1.3	14.1	Bear Canyon Exit.
0.8	14.9	Mile Post 313. Note the strike valley on the east side of the Bridger Range underlain by the Billman Creek Formation of the Livingston Group in the background.
0.5	15.4	This is the approximate position of the Bridger Range Normal Fault. This contact extends to the north and can be found in the notch to the

Increment mileage	Cumulative mileage	
		right (east) of the radio tower at the top of the Story Hills to your left (north).
2.7	18.1	Pass exit 309. Continue to the second Bozeman exit.
1.2	19.3	You are passing the Idaho Pole superfund site. This site has a plume of diesel fuel, pentachlorophenol dibenzo-p-dioxins and polychlorinated dibenzofurans, which flows under the freeway at this location. Cleanup action requires steam cleaning of the contaminated soil below the freeway in addition to soil removal and pump and treat actions elsewhere on site. The contamination extends to Rocky Creek (Figure 12).
1.0	20.3	Exit at the north 7th exit. The Tobacco Roots are at 12:00 on a clear day. The Spanish Peaks are at 10:00. The Gallatin Range is at 9:00 o'clock.
0.2	20.5	Turn left (south) on north 7th. The Gallatin Range is visible at 12:00 o'clock.
1.2	21.7	Turn right (west on Mendenhall). This is a one-way street. Merge to the left lane for a left turn you will soon make.
0.3	22.0	Turn left (south) on llth street. (Mendenhall ends at the Bozeman Senior High.)
		Cross Main Street.
0.6	22.6	Cross College Street (4 way stop).
0.4	23.0	Turn left (east) on Grant Street (another 4 way stop).
0.3	23.3	You are back at the Strand Union.

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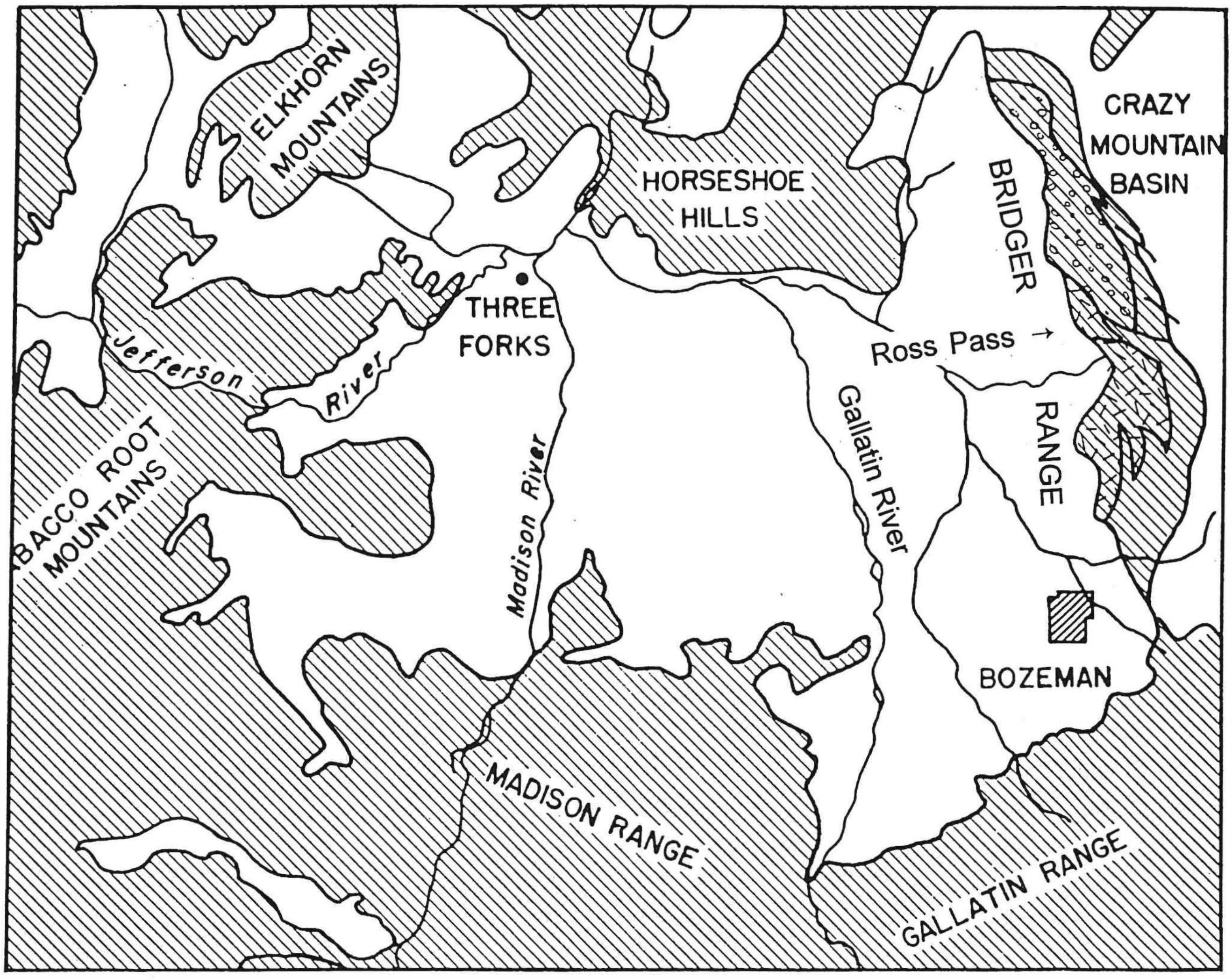


Figure 1. Generalized map of the Gallatin-Valley region. In the Bridger Range: Archean rocks stippled; LaHood open circles. Elsewhere diagonal lines indicate mountain areas.

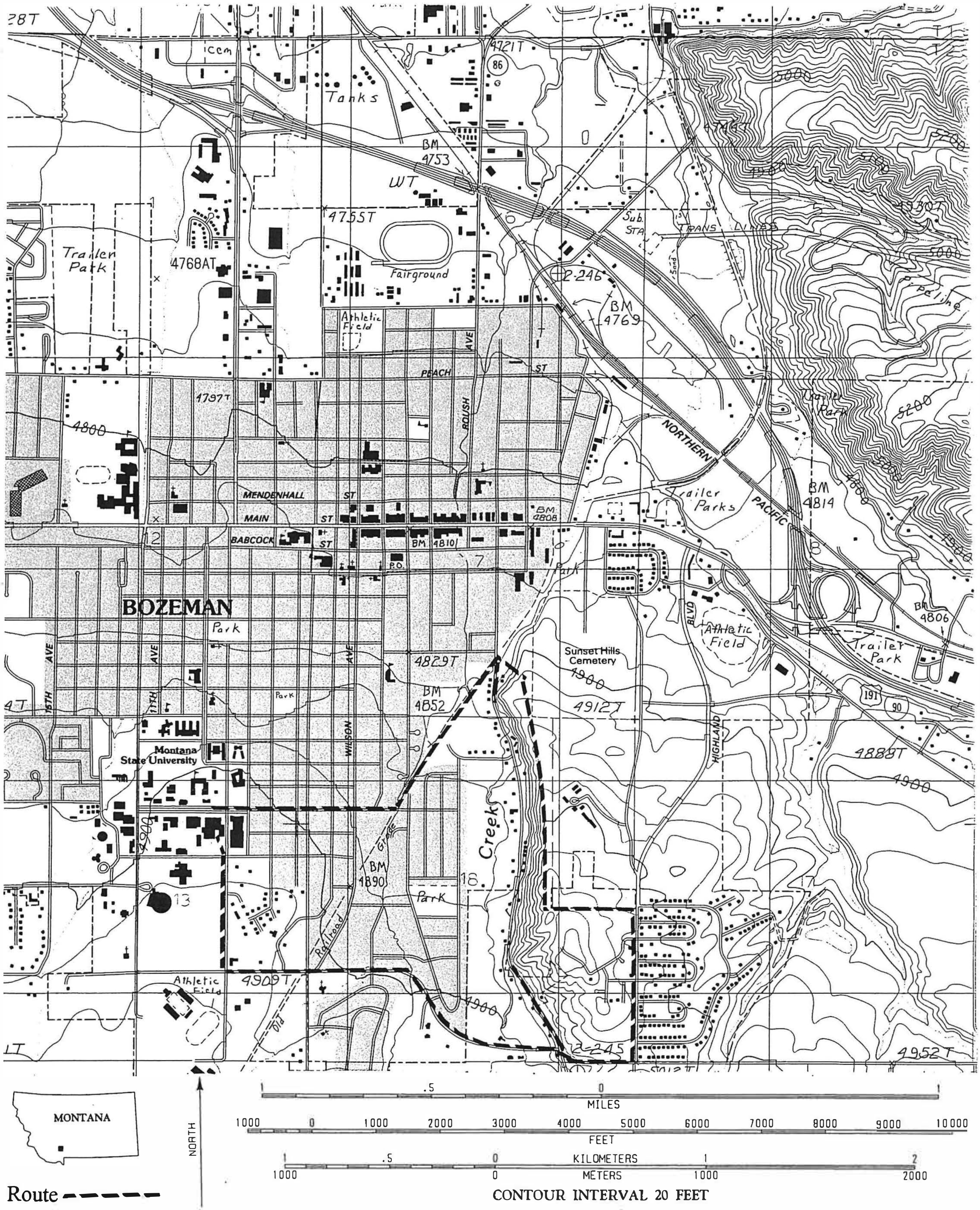


Figure 2. Topographic map of the Bozeman area showing principle streets and walking-trip route.

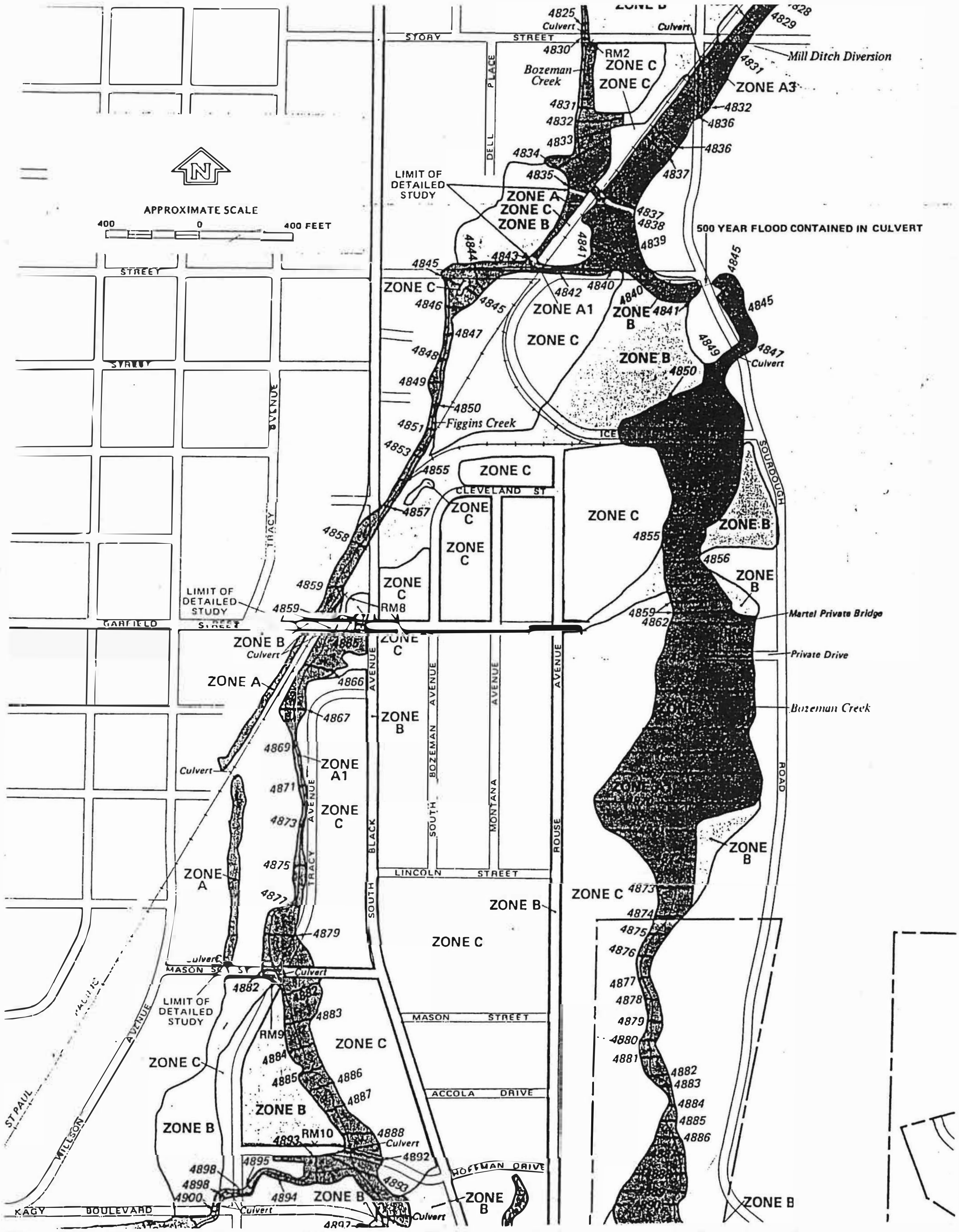


Figure 3. Flood map for part of Bozeman. The letters designate zone designations for flood-insurance purposes. The significance of letters A-C are defined in the text.

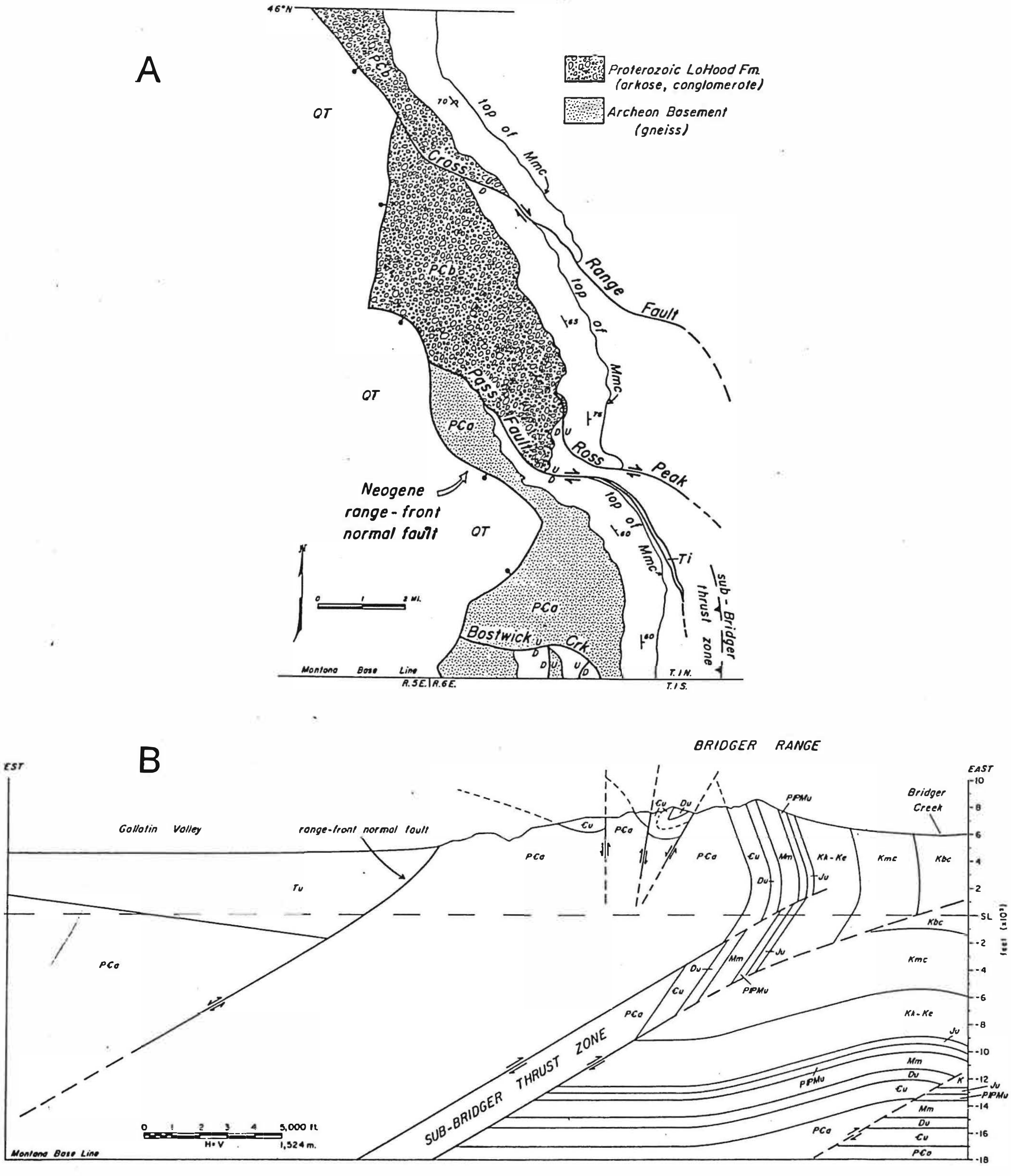


Figure 4. A. Generalized geologic map of the Bridger Range. B. Cross section through the Bridger Range along the Montana Baseline (from Lageson, 1989, Figs. 9 and 15).

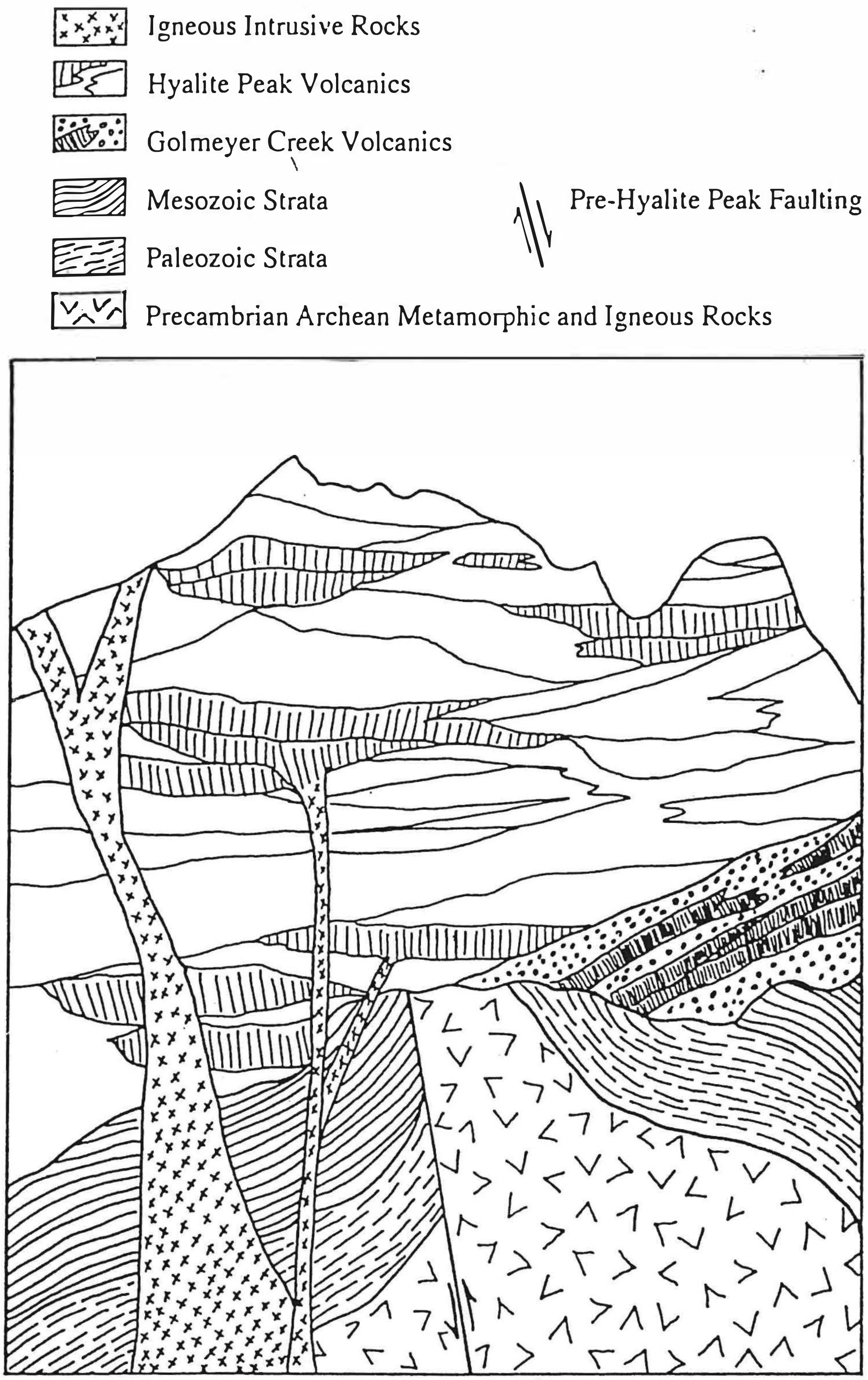


Figure 5. Schematic cross section through the Gallatin Range (From Hiza, 1994, p. 5)

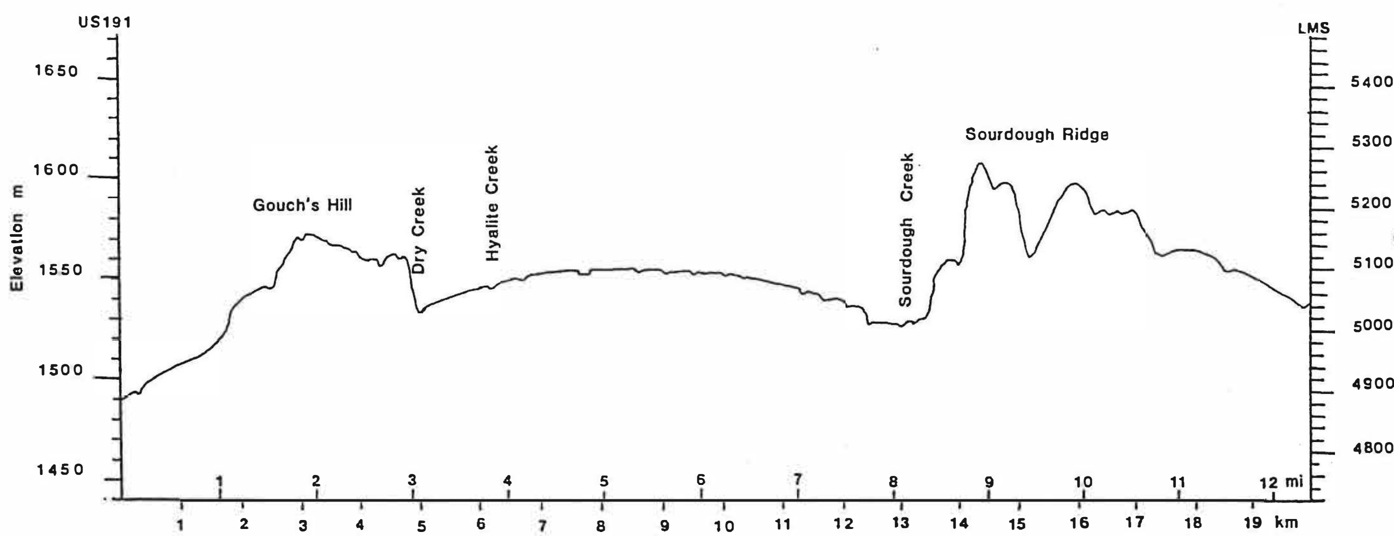


Figure 6. Topographic cross section across the southern part of Gallatin Valley approximately 5 km (3 mi) south of the Bozeman Water Tower on a N80E azimuth. Vertical exaggeration approximately 30 times (from Custer, 1991, p. 74)

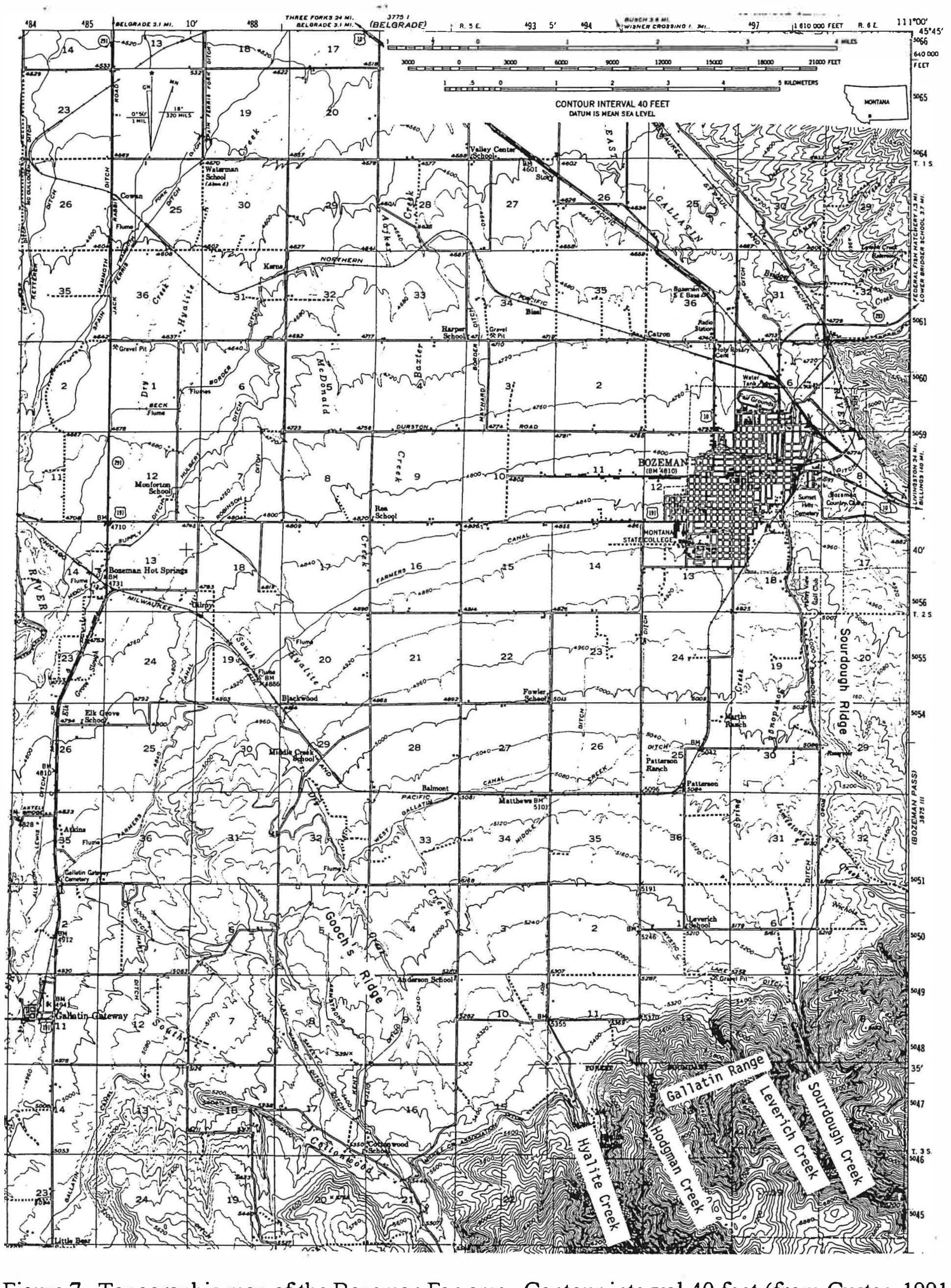


Figure 7. Topographic map of the Bozeman Fan area. Contour interval 40 feet (from Custer, 1991, p. 76).

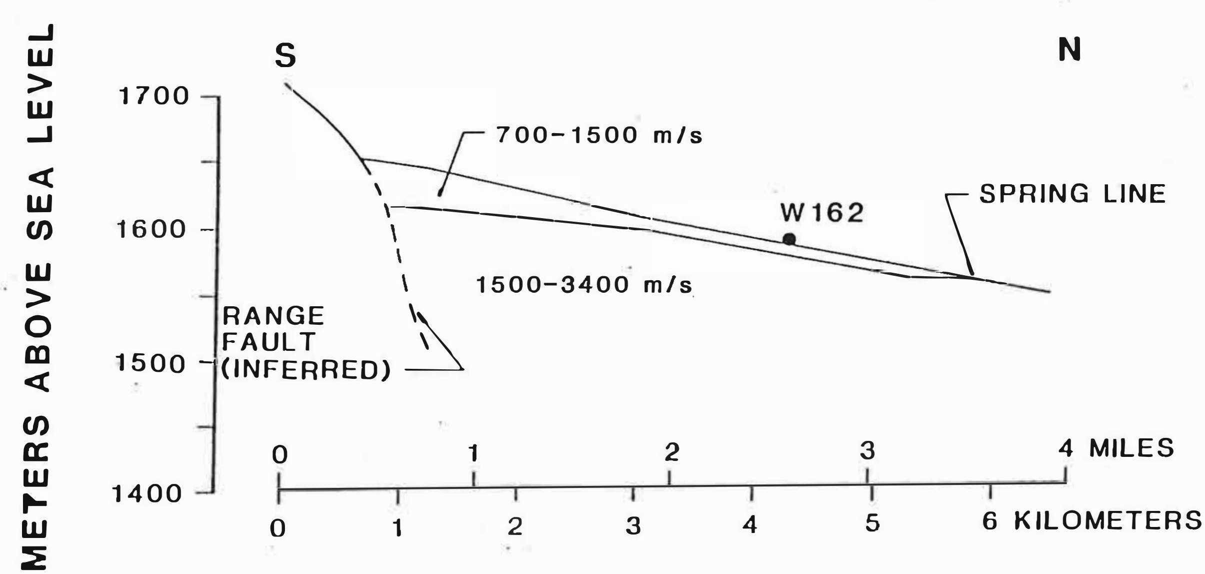


Figure 8. Seismic cross section parallel to the axis of "Bozeman" Fan (Nichols, 1989, Fig. 19).

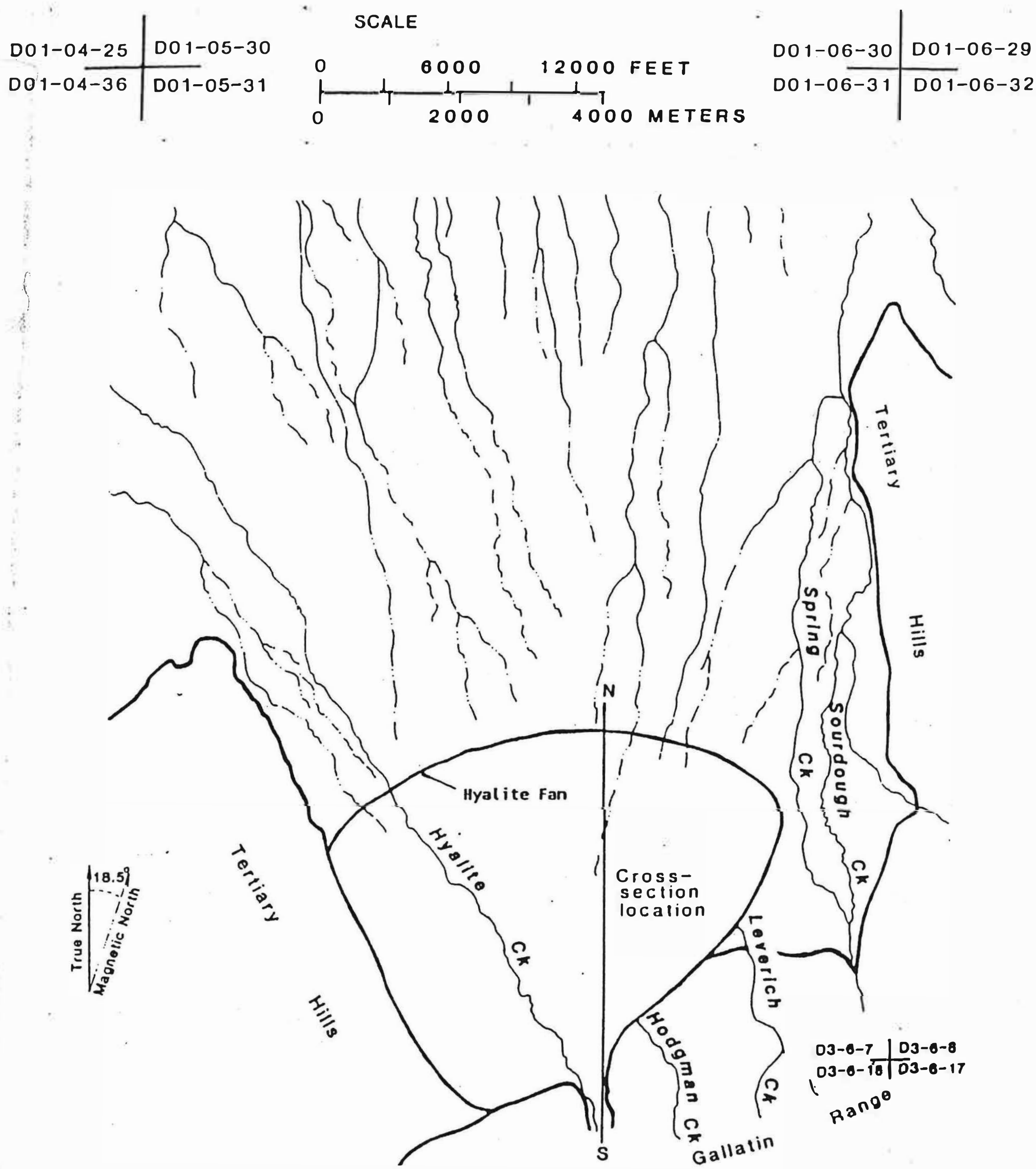


Figure 9. Generalized map showing where blue-line streams arise on the Bozeman Fan (from Custer, 1991, p. 112).

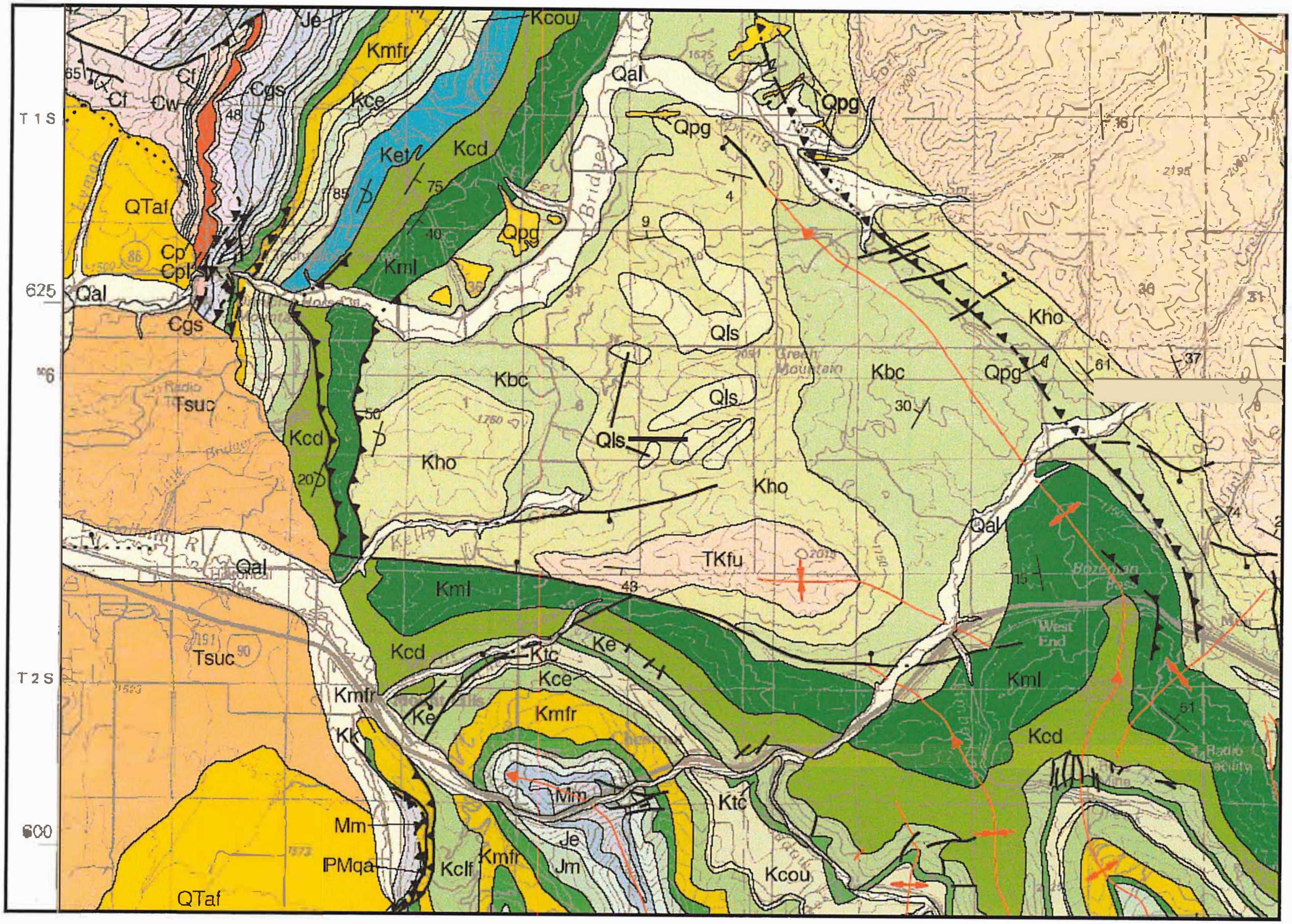
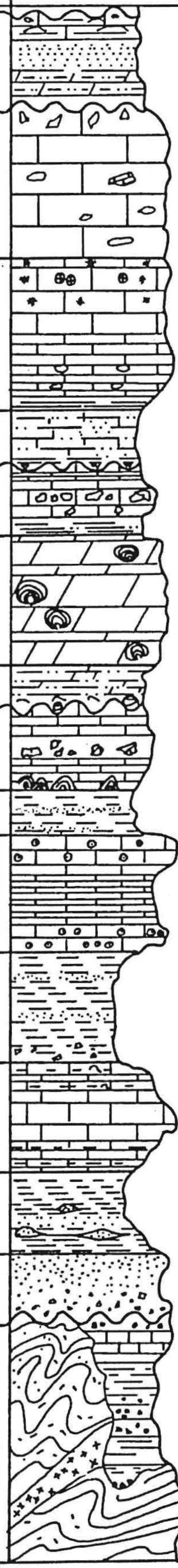


Figure 10. Geologic map of the driving field trip route (from Berg, R.B., Lopez, D.A., 2000, Geologic map of the Livingston 30' x 60' quadrangle, south-central Montana, Montana Bureau of Mines and Geology: Open File Report 406, 1 sheet(s), 1:100,000).

ERA	PERIOD	EPOCH	UNIT NAME	LITHOLOGY	DESCRIPTION
CENOZOIC		HOLOCENE	ALLUVIUM COLLUVIUM NEOGLACIATION		Immature silt, sand and gravel; chaotic debris, till in cirques (0-100').
		PLEISTOCENE	PINEDALE, BULL LAKE & PRE-BULL LAKE GLACIATION		Lacustrine silt; fresh, weathered, and deeply weathered till (0-200').
			HUCKLEBERRY RIDGE		Welded phenocryst-rich rhyolitic ash-flow tuff (2 my B.P.) (0-200').
		PLIOCENE	UNNAMED GRAVEL		Unconsolidated stream gravel (0-100').
		MIOCENE	BOZEMAN GROUP		Light-colored alternating biosparite, tuffaceous biomicrite, tuffaceous silty shale, vitric ash, and conglomerate, with cross-bedded sandstone in upper part (0-5,000').
		OLIGOCENE			
		EOCENE	GALLATIN ABSAROKA VOLCANICS		Light to dark grayish-brown andesite and basalt flows, breccia, agglomerate, and tuff (0-6,000').
			CONGLOMERATE & SILTSTONE		Conglomerate consisting of Precambrian and later boulders and cobbles (0-50').
		PALEOCENE	FORT UNION		Light brown to dark gray sandstone and basal conglomerate (0-600').
MESOZOIC	CRETACEOUS	UPPER	LIVINGSTON GROUP		Light and dark grayish-green andesitic or tuffaceous siltstone, sandstone, and conglomerate with some fresh-water limestone lenses in the lower part (0-7,000').
			EAGLE		Light gray, thin- to thick-bedded, locally cross-bedded, fine to medium grained, salt and pepper sandstone with some intercalated carbonaceous shale and thin coal beds (0-600').
			COLORADO GROUP: TELEGRAPH CREEK		Medium gray, thin-bedded siltstone containing calcareous concretions and some resistant sandstone beds (0-250').
			COLORADO GROUP: CODY SHALE		Medium to dark gray and brown thin-bedded shale with some beds of siltstone and sandstone, especially in middle part. Locally fossiliferous (50-600').
			COLORADO GROUP: FRONTIER		Buff to medium gray thin- to medium-bedded, fine- to coarse-grained arkosic sandstone, locally silty (50-200').
		LOWER	COLORADO GROUP: MOWRY		Grayish-brown and green shale and siltsone with some sandstone beds. Locally carbonaceous (25-400').
			COLORADO GROUP: THERMOPOLIS SHALE		Medium gray to black shale with numerous fine- to medium-grained gray sandstone beds. Locally arkosic, glauconitic, or carbonaceous. Lower resistant sandstone.
			KOOTENAI		Buff to light gray, medium- to thick-bedded shale and sandstone with cross-bedded basal conglomerate. Locally contains fresh-water limestone nodules and beds near top (100-490').
		DISCONF			
	JURASSIC		MORRISON		Variegated red and green, thin- to medium-bedded shale and siltstone with intercalated yellowish-brown calcareous siltstone and sandstone. Upper part locally contains carbonaceous shale (110-444').
			SWIFT		Yellowish-brown, medium-bedded, fine-grained, calcareous sandstone. Basal chert conglomerate (100').
			RIERDON-SAWTOOTH		Upper massive gray, resistant oolitic limestone. Lower variegated and mostly dark gray limestone with interbedded siltstone and shale. Chert pebbles in lower part (200').
		DISCONF			
PALEOZOIC	PERM		PHOSPHORIA		Pale yellowish-brown, calcareous sandstone with chert nodules & breccias (0-26').
	PENNSYLVANIAN		QUADRANT		White to pinkish-gray, medium- to thick-bedded (locally cross-bedded), subrounded, fine- to medium-grained orthoquartzite; dolomitic in lower part (135-250').
			AMSDEN		Pale yellow to reddish-brown, medium- to thick-bedded siltstone with some dolomite and impure fossiliferous limestone beds (11-189').
		DISCONF			

Figure 11. Stratigraphic column for the Bozeman region (two pages)

ERA	PERIOD	EPOCH	UNIT NAME	LITHOLOGY	DESCRIPTION
PALEOZOIC	MISSISSIPPIAN	DISCONF	BIG SNOWY GROUP		Upper dark-gray to black, cherty, fossiliferous shale and limestone. Middle, pink-buff, platy- to massive-bedded sandstone and siltstone. Lower pink- to buff dolomite and siltstone (0-263').
		DISCONF	MISSION CANYON		Light gray, massive or poorly bedded, resistant limestone with solution breccias at top. Locally contains chert nodules (430-950').
			LODGEPOLE		Dark gray thin- to medium-bedded fossiliferous, limestone. Lower medium to dark gray, thin-bedded, sparsely fossiliferous limestone with occasional chert nodules. Black shale at base (600-810').
	DEVONIAN		SAPPINGTON		Buff-brown, thin- to medium-bedded, fine-grained, calcareous siltstone and sandstone. Basal, black, conodont-bearing shale (46-100').
		DISCONF.	THREE FORKS		Upper gray, thin-bedded silty limestone. Middle buff, medium to thick bedded, brecciated limestone. Basal, red-orange limonite-nodule shale, and siltstone (100-150').
			JEFFERSON		Light and dark-brown, medium- to thick-bedded, fine- to medium-grained, dolomite and limestone. Often petroliferous and containing stromatoporoids. Intercalated yellow-pale pink, dolomitic siltstone beds (400-620').
			MAYWOOD		Yellow to brown, thin-bedded calcareous siltstone with some dolomite. Trilobite-brachiopod fossil hash in lower part (39-92').
	CAMBRIAN	DISCONF	SAGE PEBBLE		Yellow-brown to olive, thin- to medium-bedded, fine- to course-grained, commonly glauconitic and fossiliferous limestone and limestone-pebble conglomerate (121-204').
		UPPER	DRY CREEK SHALE		Gray-green shale with intercalated pale-orange to buff calcareous siltstone and sandstone (50-76').
			PILGRIM		Dark and light-gray mottled, medium-thick bedded, ledge-forming, oolitic limestone. Gray to yellow-brown, thin- to medium-bedded limestone with limestone-pebble conglomerate and interbedded green shale. Gray, massive oolitic, limestone (363-433').
		MIDDLE	PARK		Gray-green and maroon shale with interbedded brown, very fine-grained quartz sandstone, arkosic limestone, and arkosic conglomerate (100-200').
			MEAGHER		Light to dark-gray, thin-bedded, fine-grained, fossiliferous mottled limestone with some interbedded green shale. Dark-gray, massive, resistant limestone. Gray, thin-bedded, fine-grained limestone with interbedded green shale. Blue & gold mottled (350-450').
			WOLSEY		Green and maroon, micaceous shale with interbedded micaceous sandstone and siltstone. Locally contains glauconitic, arkosic limestone (152-210').
			FLATHEAD		White, buff, and orange, thin- to medium-bedded, fine-to coarse-grained quartz sandstone. Locally highly feldspatic, some glauconite and conglomerate (119-142').
PRECAMBRIAN		UNCONF	LAHOOD (BELT) AND CRYSTALLINE METAMORPHICS (PRE-BELT)		Dark grayish-green, coarse- to very coarse-grained, poorly bedded arkose and conglomeratic arkose. Interbedded dark-gray argillite and siliceous limestone beds in northern part of area. Thickens to north (0-10,000'). Gneiss, schist, metaquartzite, marble, injection gneiss, amphibolite, numerous pegmitite dikes and veins.

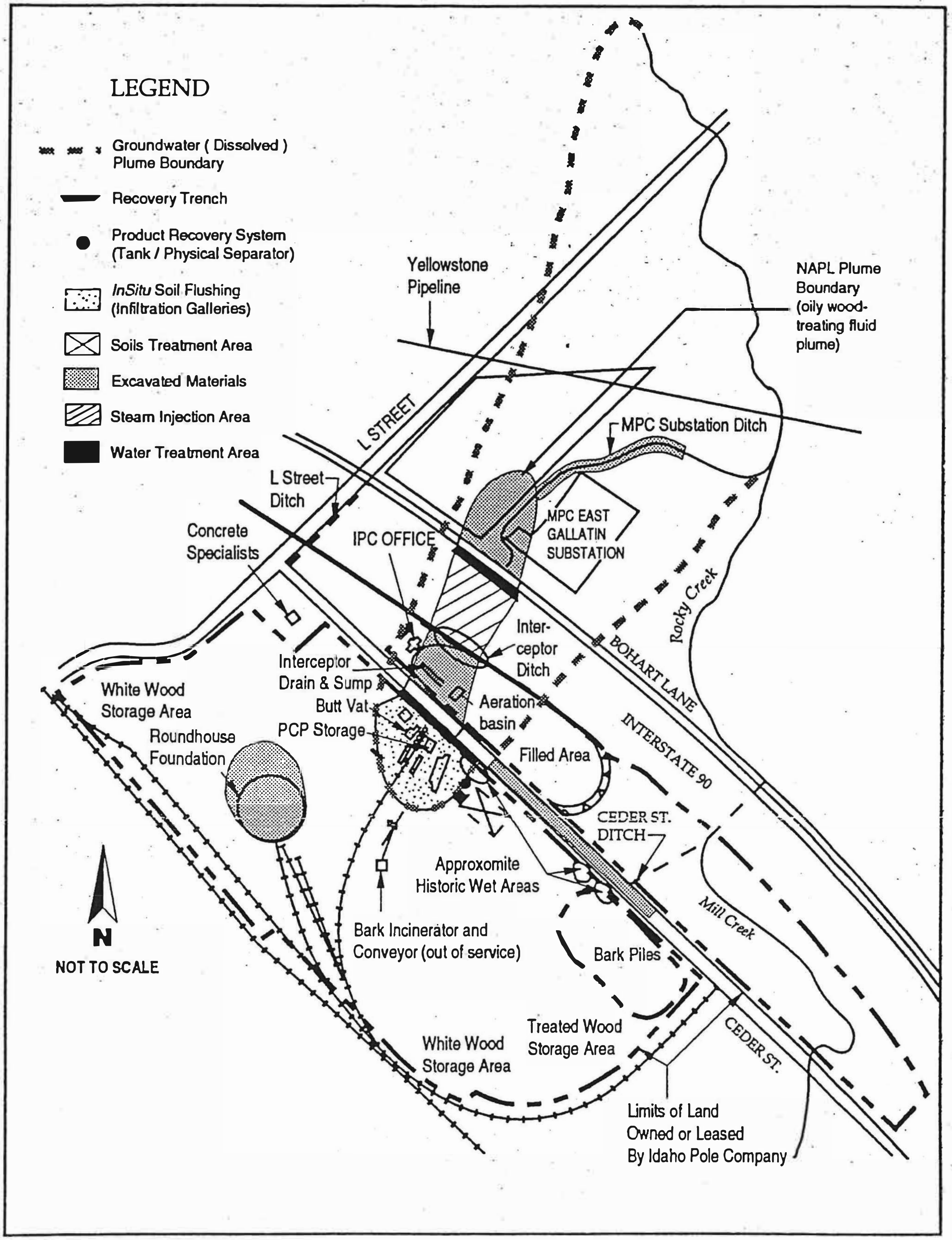


Figure 12. Idaho Pole superfund site (from U.S. Environmental Protection Agency, 1992, p 3)