Guidebook
of the
Seventh Annual
Tobacco Root Geological Society
Field Conference

THE OVERTHRUST PROVINCE IN THE VICINITY OF DILLON, MONTANA, AND HOW THIS STRUCTURAL FRAMEWORK HAS INFLUENCED MINERAL AND ENERGY RESOURCES ACCUMULATION

Patricia Beaver, Chief Editor

1982

Published by:

The Tobacco Root Geological Society, Inc.
P. O. Box 2734
Missoula, Montana 59806

http://trgs.org

Reprinted:
November 1984
April 2004

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ROAD LOG FOR FIELD TRIP IN THE EASTERN PIONEER MOUNTAINS, MONTANA

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with a section on

"GEOLOGY AND MINERALIZATION OF THE CANNIVAN GULCH DEPOSIT, BEAVERHEAD COUNTY, MONTANA"

by

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Amoco Minerals Company
Denver, Colorado

INTRODUCTION

(This road log was prepared from maps and memory without benefit of odometer readings. Mileages were measured from quadrangle maps, which show most of the roads traveled. Although "cumulative miles" may have cumulative error, it is hoped that these figures are as accurate as most odometers, and the "incremental miles" are probably accurate to within 0.1 mi [0.2 km]).

DESCRIPTIVE ROAD LOG

Cumulative Mileage mi (km)	Increment Mileage mi (km)

0.0 (0.0) 0.0 (0.0)

Start at southwest corner of Western Montana College on Atlantic Street, Dillon. Drive south on U.S. Highway 91. For the first 10 mi (16 km) or so, the route traverses Quaternary gravels along the Beaverhead River and two of its tributaries--Blacktail Deer Creek and Rattlesnake Creek.

1.3 (2.1) 1.3 (2.1)

Cross Blacktail Deer Creek, which flows from the broad valley to the southeast between the Ruby Range to the east and the Blacktail Range, rising steeply to the south. The Ruby Range is composed of Archean crystalline rocks. The Blacktail Range is composed of folded and faulted Paleozoic and Mesozoic sedimentary rocks and, at the west end, Tertiary volcanic rocks. The steep mountain front of the Blacktail Range results from Cenozoic movement on a northwest-trending fault at the base.

3.4 (5.6) 2.1 (3.4)

Cross Beaverhead River. The Beaverhead flows through a narrow gap visible about 4 mi (6.4 km) to the southwest. The gap, called "Rattlesnake Clifts" by Lewis and Clark when they passed this way in 1805, is composed of Eocene lavas.

3.6 (5.8) 0.2 (0.3)

Turn right onto Montana Highway 278. Hills to north and south of Highway 278 are volcanic and sedimentary rocks of probable Tertiary age capped locally by pediment gravels.

8.1 (13.0) 4.5 (7.2)

Argenta Road to right.

<u>Argenta mining district</u> The Argenta district (Fig. 1), about 6 mi (10 km) northwest of this intersection, is located in the Rattlesnake Creek valley (Fig. 2). Mines along French Gulch, 4 mi (6.4 km) northwest of the town, and in the Ermont area, 2.5 mi (4.0 km) southwest of the town, are also generally included in the district. The lodes were discovered in 1865 after gold was found in gravels along Rattlesnake Creek (Shenon, 1931). The placers proved to be unimportant compared to the lodes. Estimates by Shenon (1931) and Geach (1972) suggest that the Argenta district has produced about $7 million worth of metals, mainly silver, lead, and gold.

The rocks of the Argenta district are mainly sedimentary strata of Proterozoic Y and Paleozoic age that have been complexly folded and faulted. Myriad high-angle faults have broken the sedimentary rocks in

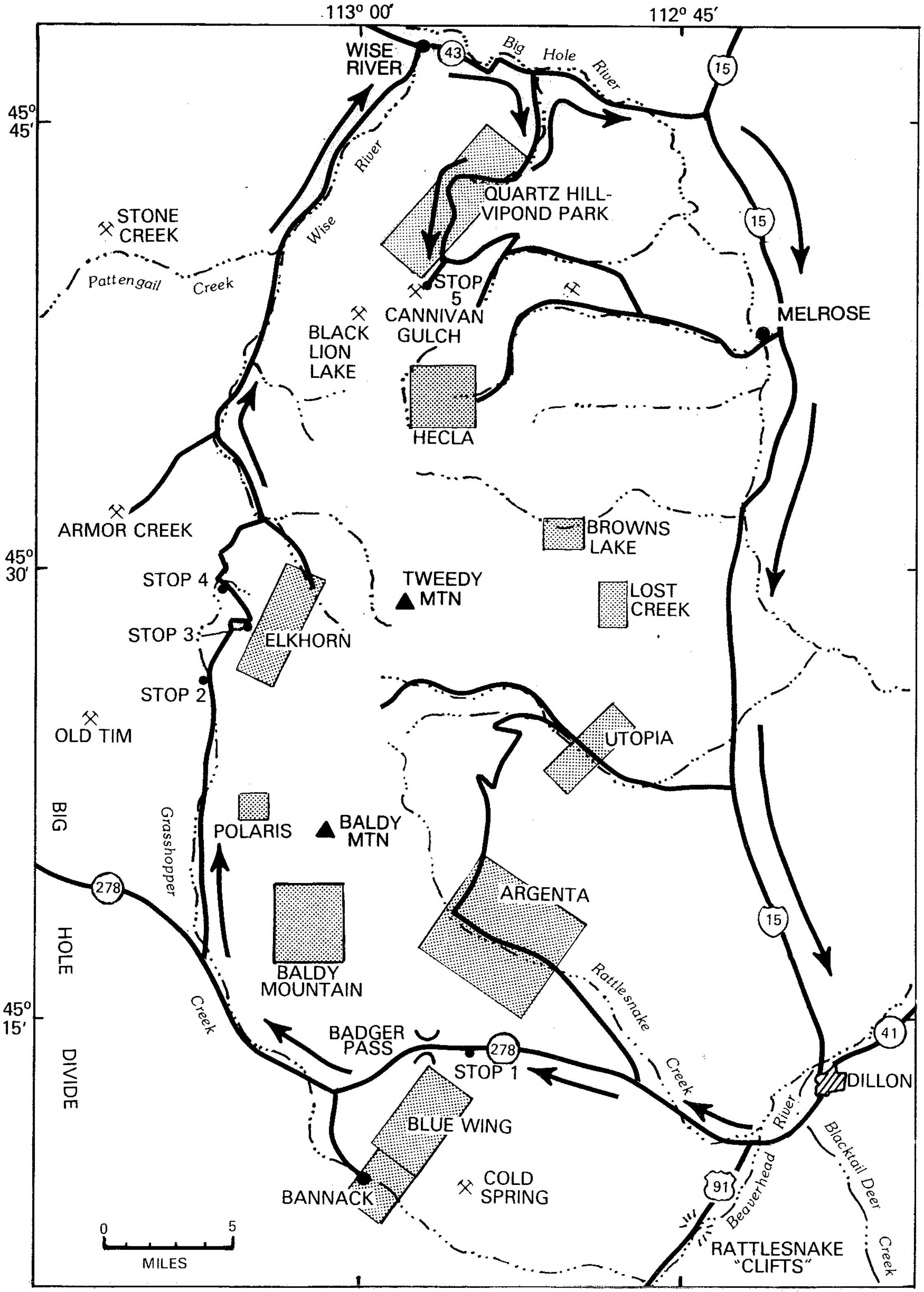


Figure 1. Route of field trip and location of mining districts (stippled) and some major prospects (⚒), Pioneer Mountains.

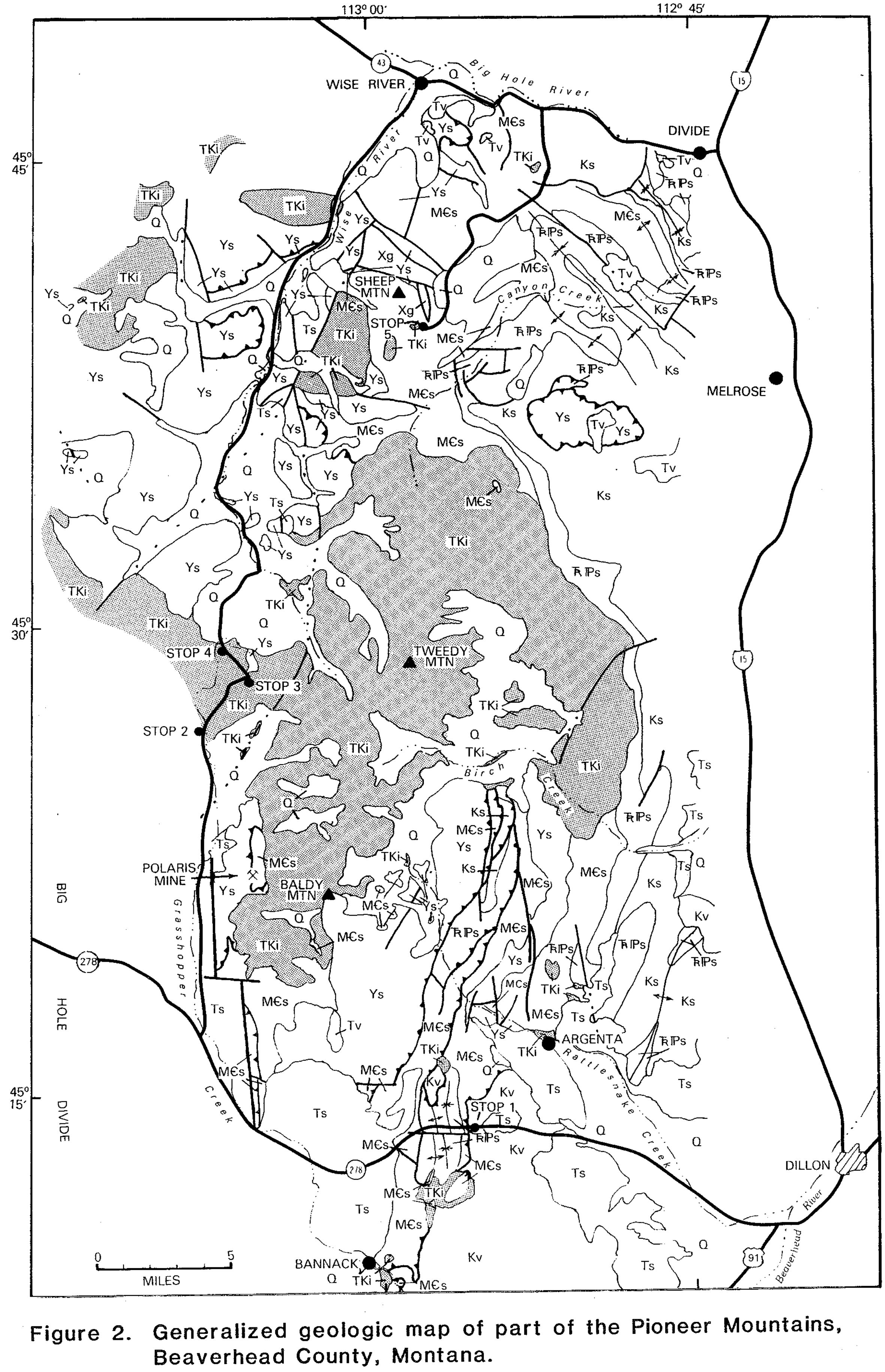


Figure 2. Generalized geologic map of part of the Pioneer Mountains, Beaverhead County, Montana.

Figure 2. EXPLANATION

Q	QUATERNARY DEPOSITS -- Includes alluvial, glacial, landslide, and debris-slide deposits.
Ts	TERTIARY SEDIMENTARY ROCKS -- Weakly consolidated gravelly, sandy, and clayey rocks, commonly tuffaceous, forming basin-fill deposits. Age poorly known but most are probably mid-to late-Tertiary.
Tv	TERTIARY VOLCANIC ROCKS -- Basaltic, intermediate, and silicic lavas and breccias. Some, at least, are of Eocene age.
TKi	TERTIARY(?) AND CRETACEOUS INTRUSIVE ROCKS -- Chiefly the Pioneer batholith and satellitic plutons that range from hornblende gabbro, through hornblende-biotite granodiorite, to biotite granite. Ages range from 65 to 80 m.y.
Kv	CRETACEOUS VOLCANIC ROCKS -- Light-colored felsic tuff and dark-colored intermediate breccias and lava flows. K-Ar age determinations by Snee and Sutter (1979) are 67 to 71 m.y.
Ks	CRETACEOUS COLORADO GROUP AND KOOTENAI FORMATION.
T Ps	TRIASSIC TO MISSISSIPPIAN DINWOODY, PHOSPHORIA, QUADRANT, AND AMSDEN FORMATIONS -- May include Big Snowy Formation locally.
MꞒs	MISSISSIPPIAN TO CAMBRIAN MISSION CANYON, LODGEPOLE, THREE FORKS, JEFFERSON, RED LION, HASMARK, SILVER HILL, AND FLATHEAD FORMATION.
Ys	PROTEROZOIC Y MISSOULA GROUP -- Locally in northern part of area, includes pebble conglomerate and quartzite that may be Proterozoic Y, Proterozoic Z, or Cambrian.
Xg	PROTEROZOIC X GRANITIC GNEISS

Geology modified from: Fraser and Waldrop (1972); Lowell (1965); Myers (1952); and from U.S. Geological Survey unpublished maps by R. C. Pearson (1978-80), E. T. Ruppel, J. M. O'Neill, and D. Lopez (1982), L. W. Snee (1975-81), E. Zen (1970-80), D. R. Zimbelman (1979-81).

the central part of the district, and an imbricated thrust zone bounds the district on the west (Fig. 2) (Myers, 1952). These deformed strata were intruded by stocks, dikes, and sills that are considered to be satellitic to the Cretaceous Pioneer batholith to the northwest. The largest intrusive body is a monzogranite stock bisected by Rattlesnake Creek and exposed over about 1 mi^2 (2.6 km^2); it gives and ^{40}Ar/^{39}Ar cooling age on biotite of 71.5 ± 0.6 Ma (Snee, 1982). Bifurcated sills in the Ermont area are very fine-grained hornblende granodiorite. Tertiary and Quaternary deposits cover bedrock over several square miles to the south and east. Ore deposits include replacements and veins in carbonate rock, veins in siliceous sedimentary rocks, and disseminations in carbonate and intrusive rocks. The principal deposits, mainly lead and silver, are replacements of and veins in carbonate rocks adjacent to the Argenta stock. Veins in Proterozoic and Cambrian siliceous sedimentary rocks contained appreciable gold as well as lead and silver. Gold was the most valuable commodity in the Ermont mines, where it was disseminated with quartz and iron hydroxides (oxidized pyrite?) in Jefferson Dolomite and in granodiorite. Gold was also the most important metal in the French Creek area.

11.0 (17.7)   2.9 (4.7)

Ermont Gulch. Ermont road to right.

After crossing Ermont Gulch, the highway climbs steeply onto volcanic rocks. Volcanic breccias and lavas of intermediate composition are exposed in several roadcuts. These may be equivalent to lavas a couple miles (couple km) to the north dated by K-Ar techniques as 67 to 71 m.y. (Snee and Sutter, 1979).

15.5 (24.9)   4.5 (7.2)

STOP 1. Road-metal quarry in silicic tuff that underlies the intermediate volcanics to the east. Pull off road on left for discussion of rocks, structure, and mineralization in the Bannack, Blue Wing, and Argenta districts.

The timbered ridge to west, sometimes called Badger Ridge, has been interpreted by some to be an allochthonous plate of Paleozoic and Mesozoic strata separated from the silicic tuff at Stop 1 by the Ermont thrust shown on Figure 2 just west of Stop 1 (Lowell, 1965; Myers, 1952; Thomas, 1981); others have interpreted the tuff as being in depositional contact with the Paleozoic rocks (Ruppel, O'Neill, and Lopez, written commun., 1982). E-an Zen and L. W. Snee (oral commun., 1982) believe the contact is a high-angle fault.

The timbered hill 2 mi (3.2 km) south of Stop 1 is a slab of Mission Canyon Limestone (Mississippian) that lies on igneous rocks which were interpreted by Lowell (1965) as volcanic and by Thomas (1981) as intrusive. The dumps visible on the lower east side of the hill are at the New Departure Mine, the largest mine in the Blue Wing district.

Through the Badger Pass area, the rocks exposed in hogbacks near the highway are folded Quadrant Quartzite. Talus of Quadrant covers adjacent slops.

Blue Wing district The Blue Wing mining district is a few miles (few km) south of Badger Pass; it adjoins the Bannack district farther south. The Kent Mine, discovered in 1864, has the distinction of being the first silver mine in Montana (Shenon, 1931). The district takes its name from the Blue Wing Tunnel, which is part of the Kent workings. Although the Kent and several other mines were good producers, the New Departure may have produced as much as the rest combined. Estimates of production, chiefly in silver, from the New Departure range up to $3 million (Geach, 1972). Exploration continues in the district, but only small shipments were made in 1981.

According to the thrust hypothesis, Paleozoic strata were thrust over volcanic rocks of probable Cretaceous age, and fine-grained granodiorite and andesite were intruded concordantly along the thrust. The Mississippian Mission Canyon Limestone, the oldest of the sedimentary rocks present, lies directly on the volcanic rocks or is in contact with the intervening intrusives, which have bleached and recrystallized the limestone.

The ore bodies are veins and replacement deposits in the bleached Mission Canyon. The most favorable location for ore is near the transition from typical light-gray limestone to white recrystallized limestone. A few veins in granodiorite have been worked, most notably at the Del Monte Mine.

Shenon (1931) reports that galena, tetrahedrite and other sulfosalts, sphalerite, and chalcopyrite are common primary ore minerals, but most of the mines produced oxidized direct-shipping ore that contained cerargyrite, bindheimite, linarite, caledonite, cerussite, smithsonite, hemimorphite, and other secondary minerals. Gangue minerals are commonly quartz, calcite, and rhodochrosite.

15.6 (25.1) 0.1 (0.2)

Contact (Ermont thrust?), not exposed, between tuff and Mission Canyon Limestone.

15.9 (25.6) 0.3 (0.5)

Quadrant Quartzite (Pennsylvanian) on east limb of a syncline.

16.4 (26.4) 0.5 (0.8)

Phosphoria Formation (Permian) in synclinal trough underlies broad meadow. Dinwoody Formation (Triassic) exposed in trough a quarter mile (0.4 km) north of highway.

17.3 (27.8) 0.9 (1.5)

Badger Pass. West of the pass the highway descends into Grasshopper Creek valley, which here is about 8 mi (13 km) wide. For the first 1.5 mi (2.4 km), the highway traverses Mission Canyon Limestone, Amsden Formation, and Quadrant Quartzite before passing into Tertiary sedimentary rocks that once filled the valley to a level above Badger Pass, as judged by remnants scattered about to the north.

18.7 (30.1) 1.4 (2.2)

Roadcuts in Amsden and Big Snowy(?) Formations.

20.9 (33.6) 2.2 (3.5)

Road to Bannack to left.

Bannack mining district Mining in Beaverhead County began on July 10, 1862, when placer gold was discovered in the gravels of a small tributary of the Big Hole River west of the town of Wisdom. The discovery was made by Mortimer H. Lott and eleven companions. Three weeks later the richer gold placers on Grasshopper Creek were discovered by John White and Williams Eads, and by the end of the year, the camp there, called Bannack, had a population of about 400. A year later (1863), however, the rich gold placers of Alder Gulch near Virginia City, in Madison County, were discovered, and the gold placers of Bannack were nearly deserted for the richer diggings.

"In 1866, after completion of ditches to bring in additional water, placer mining at Bannack was revived; after the introduction of dredges in the 1890's it continued on a modest scale until 1916."--(Geach, 1972, p. 6).

Gold-bearing lodes were discovered within weeks on the adjacent slopes above the placer workings, and within a few months, the first stamp mill was constructed, which treated the free-milling ore.

Estimates of production from the placer deposits range from $2.5 million (Lyden, 1948) to $8 million (Shenon, 1931). The lode mines have produced over $2 million (Shenon, 1931).

Grasshopper Creek flows through a narrow valley that crosses the north-trending structural grain of the folded and faulted sedimentary rocks, of Mississippian to Cretaceous age. Two small stocks of granodiorite are also exposed in the valley. Limestones of the Madison Group are the most widespread sedimentary rocks and the most important hosts for ore.

The lode ores are chiefly in the carbonate rocks adjacent to the granodiorite. Garnet-rich skarn is common at the contact, and the best ore has been found on the limestone side of the skarn. Most ore bodies formed by replacement of the limestone, but their location was guided by fractures surrounding apophyses of granodiorite. The ores consisted of quartz and auriferous pyrite and minor amounts of chalcopyrite, galena, sphalerite, and other, less common, sulfides, which were recovered from time to time.

22.2 (35.7) 1.3 (2.1)

Grasshopper Creek. Baldy Mountain (elevation 10,568 ft [3221 m]) is the prominent peak to the north. The contact between the Pioneer batholith and Missoula Group quartzite crosses the top of Baldy Mountain. Most of the south flank of the mountain is drained by Dyce Creek, along which most of the Baldy Mountain mining district is located.

Baldy Mountain mining district This district contains numerous prospects and small mines that have produced small amounts of gold, silver, base metals, and tungsten ores. Placer gold along Dyce Creek attracted miners to the area in the 1860's. In 1870 the Faithful Mine was discovered, and in 1892 a stamp mill was built to treat ore from the Dillon Mine. These and most other mines in the district were dug to explore vein and replacment deposits in Cambrian and Devonian carbonate rocks just south of the Pioneer batholith. In 1951 scheelite was discovered in tactite on the Little Hawk claim, and although a 150-ton (136-metric ton) mill was constructed, only a small amount of concentrates was produced.

24.6 (39.6) 2.4 (3.9)

Mill Point (on right), the southern tip of a narrow north-trending ridge, is formed of massively bedded, east-dipping, coarse sedimentary breccia or boulder conglomerate that may be a synorogenic conglomerate similar to Cretaceous and Tertiary(?) Beaverhead Conglomerate. The conglomerate rests unconformably on steeply west-dipping quartzite, partly Missoula Group (Proterozoic Y) and partly of Cambrian age, in imbricate slices (D. R. Zimbelman, written commun., 1982).

The timbered ridge to the west (Big Hole Divide) is composed chiefly of Missoula Group quartzite. One small patch of Cambrian rocks southwest of Mill Point is in apparent normal contact on Missoula Group rocks.

After passing Mill Point, the highway nearly parallels the west side of the ridge that extends north from Mill Point for the next several miles. The light-colored valley-fill deposits visible at the base of the ridge may be in fault contact with the bedrock of the ridge and also with the straight east side of Big Hole Divide to the west. Thus this part of Grasshopper Creek valley is a graben.

28.5 (45.9) 3.9 (6.3)

Turn right on secondary road to Polaris, Elkhorn Springs, and Wise River. Dark-gray rock on lower slopes to right is Jefferson Dolomite that has been juxtaposed by movement along a northwest-trending fault against the quartzites that hold up the ridge near Mill Point. The Jefferson is crumpled into north-trending folds.

30.5 (49.1) 2.0 (3.2)

Jefferson Dolomite becomes bleached and locally recrystallized within about 1 mi (1.6 km) of the Pioneer batholith.

31.4 (50.5) 0.9 (1.5)

Steep-sided hill to the northeast consists of the Missoula Group quartzite on west side and top that has been thrust over the Jefferson, here recrystallized and weakly mineralized.

Occasional road cuts in Tertiary valley fill for next few miles.

32.9 (52.9) 1.5 (2.4)

Polaris School. Farlin Creek.

35.2 (56.6) 2.3 (3.7)

Polaris Post office. Road to right past post office goes to Polaris Mine.

Polaris Mine. Discovered in 1883, the Polaris Mine (Fig. 2) has been a small and sporadic producer. It has been in reasonably steady production since the early 1960's. The deposit is in a N. 60° E. fault zone that separates Proterozoic Y quartzite on the northwest side from bleached, recrystallized dolomite of Cambrian or Devonian age on the southeast side. The Polaris fault is a very short steep offset of a north-trending thrust. The block of Paleozoic rocks is interpreted as a window through the thrust. The Pioneer batholith is about 0.5 mi (0.8 km) east of the mine. The deposit is in veins adjacent to the main fault. Most of the ore was oxidized, but tetrahedrite and minor galena and sphalerite are probable primary sulfides.

39.6 (63.7) 4.4 (7.1)

Cross the buried contact of the Pioneer batholith with Missoula Group quartzite near Maverick Mountain ski area. The west contact of the batholith trends north, east of the valley, from a point south of Polaris to a point east of Grasshopper Inn, where it bends to the west and crosses the valley. Road traverses the batholith for next 12.1 mi (19.5 km) (7 mi [11.3 km] map distance).

40.9 (65.8) 1.3 (2.1)

STOP 2. Roadcut in fresh granodiorite typical of main pluton of Pioneer batholith.

41.6 (66.9) 0.7 (1.1)

Turn right onto new road and cross Hot Springs Creek. Old road, straight ahead, goes to Elkhorn Springs (hot springs, pool, and other amenities). After crossing Hot Springs Creek, road traverses granodiorite weathered to grus for next 2 mi (3.2 km).

43.8 (70.5) 2.2 (3.5)

Cross Hot Springs Creek again. Next outcrop on right shows marginal effects of large hydrothermally altered zone, the Hot Springs Creek zone that extends about 1 mi (1.6 km) to the northwest. Northeast-trending fracture zones, 1 in (2.5 cm) to 2 ft (0.6 m) thick in this outcrop, contain limonitic quartz veins and traces of pyrite.

44.0 (70.8) 0.2 (0.3)

STOP 3. Altered quartz-porphyry dike. Contains disseminated pyrite and occasional flakes of molybdenite. Adjacent granodiorite variably altered -- limonite after pyrite, muscovite, and rutile are alteration products; adularia is common to abundant farther to the northwest.

44.9 (72.3)   0.9 (1.4)

Intersection of old road to Elkhorn Springs. Altered quartz porphyry dike over 300 ft (91.4 m) wide is crossed by the road in this saddle. This dike is part of a 2 mi (3.2 km) long altered zone (the Price Creek zone) that is subparallel to the Hot Springs Creek zone (Pearson and Berger, 1980).

45.1 (72.6)   0.2 (0.3)

Cross Price Creek.

45.7 (73.5)   0.6 (1.0)

Crossing southern tip of large inclusion of Proterozoic quartzite in batholith (inconspicuous along road).

46.6 (75.0)   0.9 (1.4)

STOP 4. Crystal Park. For decades euhedral quartz crystals were gathered from the residual soil on the low ridge above the parking lot, most of them colorless but some smoky, amythestine, and citrine. In recent years the crystal hunters more and more have taken to digging and screening the soil. Most of the crystals are of poor quality, being intergrown with muscovite, limonite, and other quartz crystals. The quartz-crystal diggings are within a large hydrothermally altered zone marked to a large extent by development of muscovite and locally K-feldspar, as well as quartz. The former presence of pyrite is revealed by widespread limonite. Only on a few dumps are unweathered sulfide minerals present, mainly pyrite but locally molybdenite and arsenopyrite. Although the altered rock resembles greisen, it lacks characteristic fluorine and boron minerals.

Claims were staked over both altered zones in 1980, and one exploratory hole was drilled in 1981. According to the company, further work is warranted, but the significance of these altered zones is unknown.

47.2 (76.0)   0.6 (1.0)

Lateral moraine of Wise River glacier.

50.1 (80.6)   2.9 (4.7)

Outcrop of granodiorite surrounded by moraine. K-Ar date on hornblende is 72.6 ± 1.16 Ma (Sample MM1, Snee, 1982).

50.6 (81.4)   0.5 (0.8)

Road crosses top of landslide scar and is in landslide moraine to bottom of hill. Wise River below flows along the approximate boundary between this small landslide and a larger one that came from the north. The dam formed by the two caused the 1 mi (1.6 km) long alluviated Jacobson Meadows to the east.

The larger landslide is typical of several along the east side of the Wise River valley from this point northward. Most of these landslides developed in weak tuffaceous Tertiary sedimentary rocks. A fission-track age on zircon from tuff in the head of this landslide, almost 2 mi (3.2 km) north of this point, is 27.9 m.y.

51.2 (82.1) 0.6 (1.0)

Road to right (Fig. 1) goes to Jacobson Meadows and to Coolidge, a mining camp built as part of a grand scheme to exploit the Elkhorn mining district.

Elkhorn mining district The Elkhorn district is at the west base of Comet Mountain and can be reached by one of several fair to poor roads that branch from the Grasshopper Creek - Wise River road. The first discovery of ore was made in 1872, and small, sporadic production was attained for the next several decades. In 1913, W. R. Allen formed the Boston and Montana Company with the purpose of developing the numerous veins in the northern part of the district. The company succeeded in building a 35 mi (56 km) railroad and a 42 mi (67.6 km) electric line from Divide (the Montana Southern), a town named Coolidge, a 750-ton mill, and extensive underground workings. All this was completed in 1921, but alas, there was little ore in the veins. The company went into receivorship in 1923 and ceased operations altogether in 1930. Production since 1902 is listed by Geach (1972) as about $327,000. Much of the high-grade oxidized ore was probably mined before 1902 so that a reasonable estimate of total production might be $500,000.

The Elkhorn district is in the Pioneer batholith, strung out along the north-trending Comet fault. The batholith in this vicinity is largely hornblende-biotite granodiorite cut locally by small dikes and irregular masses of quartz porphyry and even smaller bodies of alaskite. The Comet fault cuts the batholithic rocks through the entire length of the district, trending on average N. 30° E. In the mines, the Comet fault dips 45° W., and a complementary east-dipping fault, the Mono, lies 1,200 ft (365.8 m) west of the Comet (Geach, 1972).

The ores are in two sets of quartz fissure veins that trend about N. 50° E. and N. 90° E. Most of the veins are west of the Comet fault. The veins are generally several feet thick and continuous, but ore shoots seem to be small and scattered. Sulfide minerals are pyrite, tennantite, galena, sphalerite, chalcopyrite, wolframite, and molybdenite. Exploration in recent years has focused on tungsten and molybdenum, most notably perhaps are the numerous molybdenite-bearing veins exposed during the reopening of the 1,000-level adit in 1980.

51.7 (83.2) 0.5 (0.8)

Bridge over Wise River. Mono Creek Campground. Northwest contact of Pioneer batholith projects through campground.

52.6 (84.6) 0.9 (1.4)

Scree-covered slope with scattered outcrops across valley is east face of Seymore Mountain made up of quartzite of Missoula Group (Mount Shields(?) Formation).

55.0 (88.5) 2.4 (3.9)

Big Point. Prominent outcrop on east side of road consists of thin-bedded, fine- to medium-grained, gray to white quartzite and argillaceous quartzite. Gray to reddish-gray silty and sandy argillite present mostly as mud chips in quartzite and thin laminae on bedding surfaces. Ripple marks, mud cracks, water-expulsion structures, and salt crystal casts common. Rocks may correlate with lower part of Mount Shields Formation (Proterozoic Y) (M. W. Reynolds, C. A. Wallace, Don Winston, oral communication, 1978-81).

55.5 (89.3)   0.5 (0.8)

Bridge over Wise River. Road to left (Fig. 1) goes up Wyman Creek and to the Armor Creek molybdenum prospect that has been drilled in recent years.

56.6 (91.1)   1.1 (1.8)

Bridge over Wise River. View 2.5 mi (4.0 km) ahead, before crossing bridge, of landslide scar in Tertiary sedimentary rocks preserved in graben about 0.8 mi (1.3 km) wide. Quartzite of Mount Shields(?) Formation on both sides of graben at that place.

60.6 (97.5)   4.0 (6.4)

Terminus of Wise River glacier. Thin remnant of Wise River lateral moraine is less than 100 ft (31 m) above road on east side. Low ridge ahead is capped by terminal moraine of tributary Boulder Creek glacier. The Black Lion Lake molybdenum prospect is near the head of Boulder Creek.

Outcrops of Missoula Group quartzite along road for next few miles.

63.4 (102.0)   2.8 (4.5)

Bridge over Pattengail Creek. Fresh appearance of the bouldery surface of the valley bottom caused by flood in 1927, when dam on Pattengail Creek went out. Town of Wise River was destroyed except for hotel (the present Wise River Club).

Stone Creek molybdenum prospect, about 6 mi (10 km) up Pattengail Creek, has been explored in recent years.

66.4 (106.9)   3.0 (4.8)

Bridge over Wise River. South contact of gray, medium grained biotite granite in the Stine Creek pluton is just south of bridge. The pluton is elliptical, 2 mi (3.2 km) wide by 4 mi (6.4 km) long, and oriented west-northwest.

After crossing the pluton, the Wise River valley gradually widens, and for several miles the road is on Quaternary gravels probably underlain by Tertiary deposits. The low terrace to the west is cut into Tertiary deposits through which protrude low hills of Proterozoic quartzite.

73.5 (118.3)   7.1 (11.4)

Highway 43. Turn right. Highway continues on terrace gravels and alluvium for about 3 mi (5 km). Slope to south is composed of Tertiary volcanic and sedimentary rocks interspersed with landslide debris.

76.5 (123.1) 3.0 (4.8)

Cliff exposure on right is thin-bedded, dark-gray Lodgepole Limestone. Low highly deformed outcrops beyond Lodgepole cliff is Devonian and Mississippian Three Forks Formation in uncertain structural relation to adjacent formations.

76.8 (123.6) 0.3 (0.5)

Rusty talus and cliffs of Quadrant Quartzite. As road bends to right, after passing the Quadrant cliffs, it crosses to axis of a tight syncline in the Quadrant according to Fraser and Waldrop (1972).

78.7 (126.7) 1.9 (3.1)

Quartz Hill Gulch road. Turn right. The road climbs 2,700 ft (823 m) in about 10 mi (16 km) to Vipond Park traversing folded Cambrian to Cretaceous strata. The adit on right side of road about 2 mi (3.2 km) from highway explored the Phosphoria Formation for phosphate.

84.4 (136.8) 5.7 (9.2)

Foundation of Lone Pine mill (in Jefferson Dolomite) on left. This mill treated ore from the Lone Pine Mine, the largest in the Quartz Hill-Vipond Park district.

Quartz Hill-Vipond Park mining district The district is accessible by way of the Quartz Hill Gulch road that passes through the district and continues south to Canyon Creek and from there on to Melrose. According to Geach (1972), mining began about 1867. Mills to treat the ore were constructed by the late 1880's. Total production from the district may not have exceeded $2 million. Geach (1972) lists production of $841,000 from 1902 to 1965, derived mainly from the West Lone Pine ore body. The Lone Pine ore body, mined out in the 1890's, was about as large as the West Lone Pine. Smaller amounts were won from numerous other mines.

The important host rocks of the district are the Cambrian Hasmark Formation. It and other Paleozoic strata have been folded about northwest-trending axes and broken by norhtwest- and north-northeast- to northeast-trending faults. A block of Proterozoic X granitic gneiss on the north side of Sheep Mountain is flanked by conglomeratic and quartzitic strata of Proterozoic or Cambrian age (Zen and others, 1980; Zen, Taylor, and Wilson, 1979). Proterozoic Y quartzite northwest of the Lone Pine Mine may be allochthonous.

The deposits are in veins and replacements mainly in the Hasmark. The veins trend north-northeast and northeast. Although veins have been mined in the Proterozoic X gneiss, and the Proterozoic Y(?) quartzite and conglomerate, the bulk of the ore came from the replacement deposits in the Lone Pine Mine. Replacement was localized by fractures in the Hasmark and near a fold crest beneath the less permeable Red Lion Formation (Cambrian).

87.5 (140.8) 3.1 (5.0)

Enter Vipond Park. Sheep Mountain, visible ahead, is capped by the Cambrian Silver Hill and Hasmark Formations.

87.7 (141.1) 0.2 (0.3)

Gray Jockey Mine to right, a quartz vein in Hasmark Formation.

89.7 (144.3) 2.0 (3.2)

(Mileage approximate.) Turn right to Cannivan. Resume mileage at this point after trip to Cannivan.

STOP 5. Cannivan Gulch Molybdenum deposit.

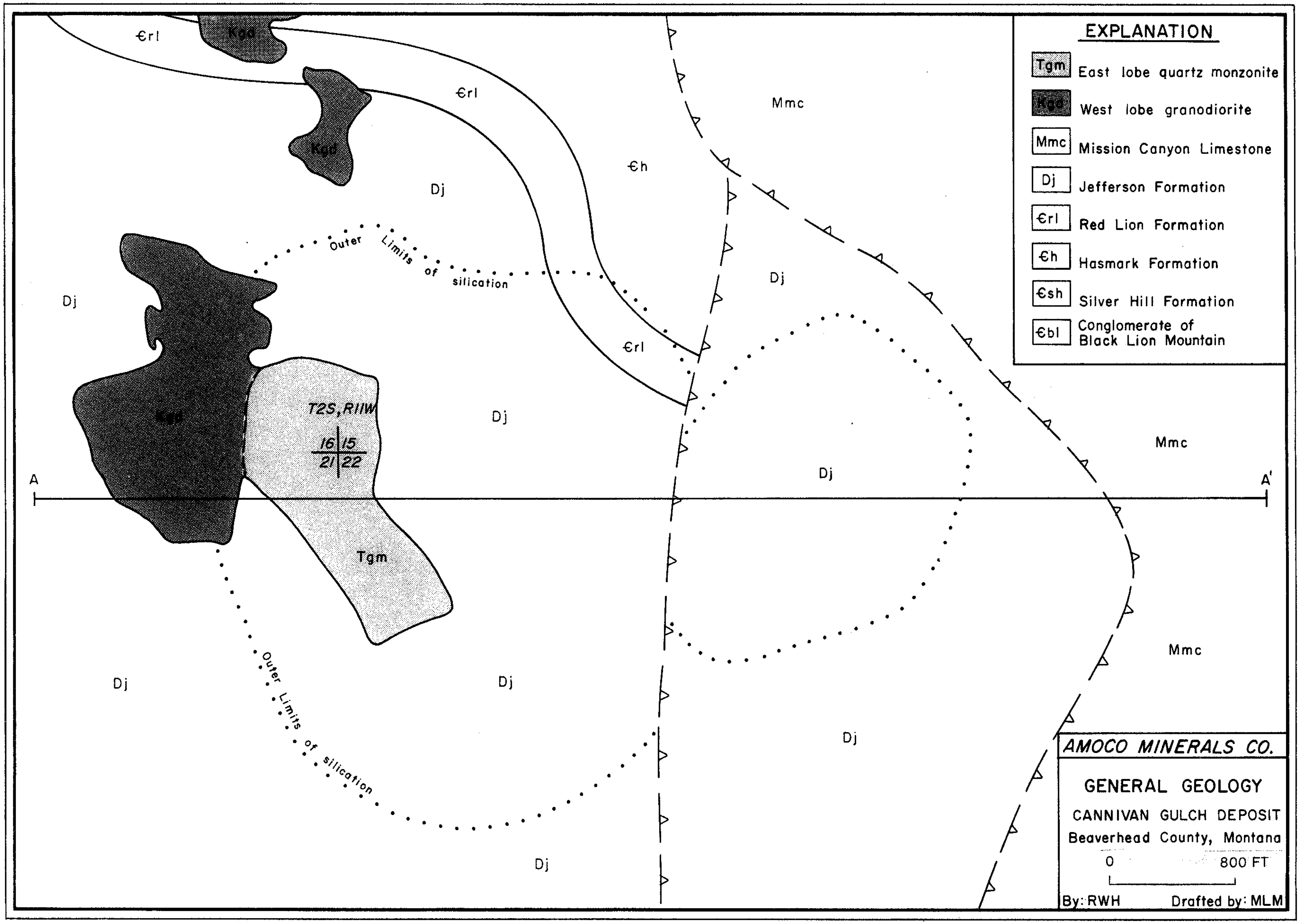
GEOLOGY AND MINERALIZATION OF THE CANNIVAN GULCH DEPOSIT, BEAVERHEAD COUNTY, MONTANA

by

R. W. Hammitt and E. A. Schmidt
Amoco Minerals Company

The Cannivan Gulch deposit is a calc-alkaline type stockwork molybdenum occurrence located in the East Pioneer Mountains approximately 30 air miles (42 km) southwest of Butte, Montana. The deposit was discovered by Cyprus Exploration Company in 1968 during a reconnaissance survey of the area. Follow-up geological and geochemical surveys and subsequent drilling of 55 diamond-drill holes, totaling 88,451 ft (26,960 m) from 1969 through 1980, have outlined a major molybdenum deposit amenable to open-pit mining methods. An exploration adit and crosscut totaling 2,371 ft (727.7 m) and raises on two of the drill holes totaling 143 feet (43.3 m) were completed during 1980 and 1981. The underground exploration confirmed interpretations made from drilling.

The Cannivan Gulch deposit is associated with a satellitic stock of the Upper Cretaceous Pioneer batholith (Fig. 3). The Cannivan stock has intruded Paleozoic sedimentary rocks, including the Cambrian Silver Hill, Hasmark, and Red Lion Formations, and the Devonian Jefferson Formation (Fig. 4). The Silver Hill and Red Lion Formations are calcareous detrital units, whereas the Hasmark and Jefferson Formations are dolomitic units. These sedimentary units are domed over the Cannivan stock as a result of forceful intrusion. The Cannivan stock is a miltiphase calc-alkaline intrusion consisting of an older single-phase west lobe and younger east lobe which has several phases. The older


Ꞓrl
Kgd
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Outer Limits of silication
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16 15
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A'
Tgm
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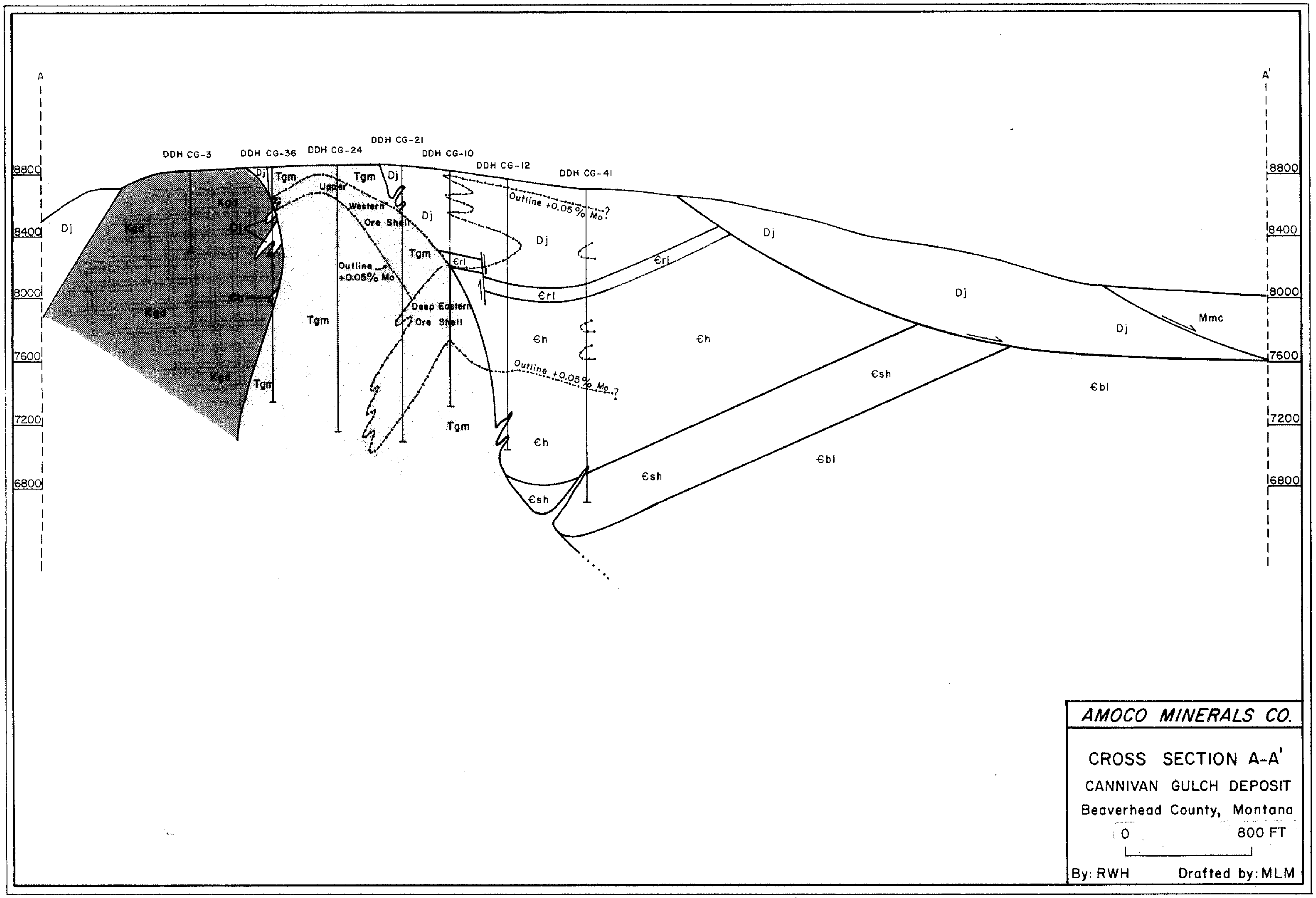
Outer Limits of silication
Dj
Mmc
Dj
EXPLANATION
Tgm East lobe quartz monzonite
Kgd West lobe granodiorite
Mmc Mission Canyon Limestone
Dj Jefferson Formation
Ꞓrl Red Lion Formation
Ꞓh Hasmark Formation
Ꞓsh Silver Hill Formation
Ꞓbl Conglomerate of Black Lion Mountain
AMOCO MINERALS CO.
GENERAL GEOLOGY
CANNIVAN GULCH DEPOSIT
Beaverhead County, Montana
0 800 FT
By: RWH
Drafted by: MLM

Figure 3.


A
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8800
8400
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DDH CG-36
DDH CG-24
DDH CG-21
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DDH CG-12
DDH CG-41
Dj
Kgd
Tgm
Upper Western Ore Shell
Outline +0.05% Mo
Outline +0.05% Mo?
Deep Eastern Ore Shell
Outline +0.05% Mo ?
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AMOCO MINERALS CO.
CROSS SECTION A-A'
CANNIVAN GULCH DEPOSIT
Beaverhead County, Montana
0
800 FT
By: RWH
Drafted by: MLM

Figure 4.

west lobe is composed of weakly altered and mineralized granodiorite which contains no economic mineralization. Biotite from this granodiorite has been dated at 68.6 ± 2.5 and 69.8 ± 2.5 m.y. (Table 1). The east lobe is composed of rocks originally ranging in composition from granodiorite to quartz monzonite which are highly altered and mineralized. Muscovite from quartz-molybdenite veins within this lobe has been dated at 60.5 ± 2.1 and 64.2 ± 2.3 m.y. Phases within this lobe may represent magmatic differentiates enriched in volatiles, potassium, and molybdenum which separated from the same magma chamber as the west lobe and intruded the west lobe and the adjacent Paleozoic sedimentary rocks.

Hydrothermal alteration at Cannivan Gulch centers on the mineralized east lobe of the Cannivan stock. However, the presence of chemically dissimilar wall rocks, granodiorite of the west lobe to the west and Paleozoic carbonates to the east, prevented development of symmetrical alteration seen in many stockwork molybdenum systems. Alteration assemblages typical of stockwork molybdenum deposits are restricted to the Cannivan stock. At least two intrusive phases in the east lobe have each produced their own zoning pattern, with the younger overlapping the older. Two potassic cores resulting from pervasive K-feldspar metasomatism of rocks within each phase of the east lobe are recognized, an older upper western zone and a younger, deeper eastern zone. Typical of most stockwork molybdenum systems, K-feldspar metasomatism occurred before, during, and after molybdenite mineralization as revealed by crosscutting relationships. To the east, potassic alteration of the east lobe ends abruptly at the contact with Paleozoic sedimentary rocks. To the west, within the west lobe, the potassic cores grade into quartz-sericite-pyrite zones with up to 2 percent disseminated pyrite. These zones in turn grade into outer argillic zones and peripheral propylitic halos.

These typical alteration assemblages terminate abruptly at the contact between the Cannivan stock and Paleozoic sedimentary rocks. Emplacement of the east lobe of the Cannivan stock resulted in the development of a complex suite of silicate minerals within the intruded Paleozoic rocks. Silicate minerals are distributed outward in a zonal pattern from forsterite near the intrusive contact, through a clinohumite zone, and into a peripheral tremolite halo. Solutions from the east lobe migrated throughout fractures in the dolomite and silicated wall rock adjacent to these fractures. Where fracture density is closely spaced, silication is intense. Intense silication is confined to within 1,000 ft (305 m) of the east lobe. Beyond 1,000 ft (305 m), silication becomes patchy and has generally disappeared by 2,000 ft (610 m) from the east lobe contact. Retrograde alteration has converted most of the original silicate minerals to assemblages containing antigorite, talc, and chlorite, particularly along fractures, veins, and breccia zones.

The Cannivan Gulch deposit centers on the eastern contact of the east lobe of the Cannivan stock. The deposit is approximately equally hosted by altered quartz monzonite of the east lobe and adjacent silicated Paleozoic sedimentary rocks. Molybdenite is the principal ore mineral, but its mode of occurrence differs between the two host rocks.

Table 1. K-Ar analytical data, Cannivan Gulch

Sample[1]	Mineral	Percent K	$^{40}Ar^*$ (mol/g)	$^{40}Ar^*/Total^{40}Ar$	Age[2] (m.y.)
CG-2-305/325	Biotite	7.463	9.218×10^{-10}	0.706	69.8 ± 2.5
CG-2-275/279	Biotite	7.272	8.823×10^{-10}	.406	68.6 ± 2.5
CG-10-618/625	Muscovite	8.924	10.12×10^{-10}	.614	64.2 ± 2.3
"Cannivan"	Muscovite	9.395	10.03×10^{-10}	.80	60.5 ± 2.1

[1] "CG" samples from drill core; analyses performed by Geochron in 1976. "Cannivan" sample data from Armstrong, Hollister, and Harakel (1978). Biotite separates from medium-grained pyrite-bearing biotite granodiorite of the west lobe. Muscovite separates from veins that also contain quartz, pyrite, molybdenite, and K-feldspar.

[2] Ages have been recalculated from the originally reported values using the following constants:

$$= 4.962 \times 10^{-10} yr^{-1},$$

$$= 0.58 \times 10^{-10} yr^{-1},$$

$$^{40}K/K = 1.167 \times 10^{-2} \text{ atom percent.}$$

In the quartz monzonite, molybdenite occurs in a stockwork of quartz veins and veinlets which often show a subparallel, steeply dipping orientation. Pyrite is a common constituent of the quartz-molybdenite veins and veinlets. Sericite and K-feldspar frequently form narrow envelopes around veins and veinlets. At least two periods of molybdenite mineralization and a late stage of barren quartz veining are indicated by crosscutting relationships. Ore-grade molybdenite mineralization within the east lobe occurs in two ore shells coincident with the tops of the potassic cores and inner quartz-sericite-pyrite zones. This distribution is typical of most stockwork molybdenum systems. The two ore zones overlap in the northeast portion of the east lobe, resulting in higher grade mineralization.

Mineralization within the silicated Paleozoic sedimentary rocks is atypical of previously known stockwork molybdenum systems. Molybdenite occurs mainly in steeply dipping quartz-pyrite-magnetite-chlorite-serpentine veins. Any one or more of these constituents may be present in any one vein. K-feldspar, epidote, and fluorite are locally common gangue minerals within veins. Chalcopyrite, which is rare in the quartz monzonite ores, is found in many of the veins in the sediments. Sphalerite is also common, particularly in veins on the periphery of the deposit. Molybdenite also occurs in breccia zones in dolomite where dolomite fragments are cemented by quartz, calcite, chlorite, pyrite, magnetite, and/or molybdenite.

The Cannivan Gulch deposit must be classified as a typical calc-alkaline type stockwork molybdenum deposit. Whereas most plutons associated with calc-alkaline molybdenum deposits have intruded less reactive shales, schists, gneisses, and felsic batholiths, the Cannivan stock intruded highly reactive carbonates. Thus, much more complex hydrothermal alteration and mineralization assemblages were developed at Cannivan Gulch.

DESCRIPTIVE ROAD LOG
(Continued)

Cumulative Mileage mi (km)	**Increment Mileage mi (km)**	
100.7 (162.1)	11.0 (17.7)	Return to Highway 43. Turn right.
101.0 (162.5)	0.3 (0.5)	Dewey.
101.5. (163.3)	0.5 (0.8)	Roadcut in mafic rock intrusive into Madison Group limestone. This is an outlier of the Mount Fleecer stock

exposed ahead in Big Hole River canyon.

For next 2 mi (3.2 km) observe abundant mafic inclusions in the stock. Are the inclusions fragments of Archean basement, metamorphosed carbonate rocks, early phases of the stock, or mixed magmas?

103.8 (165.8) 2.3 (3.7)

Approximate east boundary of stock. Next deep roadcut is steeply dipping hornfelsed Cretaceous sedimentary rocks.

105.4 (169.6) 1.6 (2.6)

Bridge over Big Hole River. East of bridge, granite crops out along highway, and near Divide is an exposure of young mafic volcanics. Similar volcanic rocks visible across river to south are Miocene and Eocene (Zen, Hammerstrom, Marvin, and Arth, 1979).

107.1 (172.4) 1.7 (2.7)

Village of Divide. After crossing railroad tracks, road climbs through slightly lithified Tertiary sandstone and conglomerate. Note fault in the Tertiary sedimentary rocks across gully to left.

107.9 (173.6) 0.8 (1.3)

Enter Interstate Highway 15 heading south. With minor exceptions, highway is on Tertiary valley fill and Quaternary alluvium for next 40 mi (64.4 km).

East of Divide, the Moose Creek stock (monzogranite) rises above the Tertiary deposits. The stock intruded Paleozoic and Proterozoic Y sedimentary rocks. The latter are exposed on the treeless grassy slopes for the next several miles to the south.

109.9 (176.9) 2.0 (3.2)

Hogback ridges to right for next 3.5 mi (5.6 km) held up by Quadrant Quartzite.

110.9 (178.5) 1.0 (1.6)

Moose Creek. Maiden Rock phosphate mine and mill located near mouth of Moose Creek, 2 mi (3.2 km) to west.

113.9 (183.3) 3.0 (4.8)

Highway drops down onto alluvium in the Big Hole River valley. Low outcrops across river to west are of a stock that is largely buried beneath the valley fill, as indicated by a large aeromagnetic anomaly.

114.5 (184.3) 0.6 (1.0)

Mouth of Soap Gulch. Several miles to the east were a few precious-metal mines and the site of recent exploration for shale-hosted massive-sulfide deposits in Proterozoic Y strata.

117.1 (188.4) 2.6 (4.2)

Melrose exit. Mouth of Trapper Creek and road to Hecla mining district across valley just south of Melrose.

Hecla (Bryant) mining district The Hecla district is in a large compound cirque at the head of Trapper Creek, which joins the Big Hole River at Melrose. A road from Melrose follows the creek to its head.

This district, the largest producer in Beaverhead County, produced silver, lead, and minor copper, zinc, and gold valued at nearly $20 million. Ore was first discovered in 1872, and other discoveries followed soon after. The camps of Trapper City, Lion City, and Hecla sprang up in the 1870's, and in 1874 a smelter was built at Glendale, 10 mi (16 km) down the valley between Hecla and Melrose.

The district is located in Paleozoic sedimentary rocks on the flanks of a dome that lies less than 1 mi (1.6 km) north of the Pioneer batholith. Paleozoic units are thinned on the flanks of the dome, and they are locally folded disharmonically.

The deposits are chiefly replacement bodies localized by fractures and minor fold crests. The largest deposits, in Lion Mountain, were irregular tubes, pipes, and pods that pitched about 20° down the dip of the beds to the west-northwest. The deposits are in certain favorable stratigraphic zones near the middle of the Hasmark Formation, at the top of the Hasmark directly beneath the Red Lion Formation, and near the middle of the Jefferson Dolomite. The stratigraphy interpreted by Karlstrom (1948) has been revised by E-an Zen (unpub. mapping, 1970-80).

The ores were mainly oxidized (Karlstrom, 1948, p. 50), but the presence of traces of galena and sphalerite on the dumps suggests that mixed sulfide-oxide ores were shipped.

120.2 (193.4) 3.1 (5.0)

Cross McCartney Creek. McCartney Mountain ahead on east side of highway is composed chiefly of Colorado Group (Lower and Upper Cretaceous) intruded by a monzogranite stock and fine-grained sills. ^{40}Ar/^{39}Ar cooling date on biotite from the stock is 73.8 ± 0.6 Ma (Snee, 1982). Low, bare hills to the west are underlain by folded Mesozoic formations and locally by unconformably overlying Eocene volcanic rocks visible in cliffs along river.

123.5 (197.8) 3.3 (5.3)

Large roadcuts in Colorado Group.

124.9 (201.0) 1.4 (2.2)

Bridge over Big Hole River.

125.2 (201.5) 0.3 (0.5)

Glen exit. Access to Lost Creek-Browns mining district.

Lost Creek-Browns Lake district The east margin of the Pioneer batholith is in contact with the Amsden Formation (Mississippian(?) and

Pennsylvanian) for the better part of 7 mi (11 km) from Twin Adams Mountain north to Strom Peak. Contact metasomatism of the marly Amsden by the batholith has produced garnet-epidote tactite that locally contains scheelite. The scheelite is commonly disseminated in the garnet, especially where it is andradite rich (Collins, 1975).

Although a small amount of silver and copper was mined in the 1920's and 1930's, the principal product has been tungsten. The largest producer, the Ivanhoe Mine near Browns Lake, produced 625,107 tons (567,087.5 metric tons) of ore from 1954 to 1957 that averaged 0.35 percent WO_3 (Pattee, 1960). The ore was treated at a mill near Glen about 0.5 mi (0.8 km) west of Interstate Highway 15, and concentrates were shipped to Salt Lake City.

The Lost Creek deposit on the north flank of Twin Adams Mountain is geologically similar to the Ivanhoe deposit except that the batholith contact is straight and regular and the beds dip away from the contact instead of toward it. Production at Lost Creek was 21,150 tons (19,187 metric tons) averaging 0.18 percent WO_3 from 1952-56.

135.0 (217.3)   9.8 (15.8)

Apex exit. Pennsylvanian and Permian strata are exposed on hill to east (Ruppel, O'Neill, and Lopez, written commun., 1982). Access to Birch Creek mining district.

Birch Creek (Utopia) district The Birch Creek district is about 6 mi (10 km) west of Interstate Highway 15, both north and south of Birch Creek. The numerous small mines and prospects are in Paleozoic carbonate rocks, silicated along their contact with the Pioneer batholith where it makes a large protrusion to the southeast.

Scheelite, magnetite, chalcopyrite, and molybdenite are present in the tactite at one place or another and the mineralogy seems to vary with the formation. Scheelite and molybdenite are most common in the Amsden, chalcopyrite in the Madison, and magnetite in the Hasmark. The only mine with sizable production is the Indian Queen in the bottom of Birch Creek at the site of a mining camp called Farlin. Its heyday was 1902 and 1903 when over 1,000,000 lbs (453,592 kg) of copper and 28,000 oz (793,787 g) of silver were extracted; total production is 1,729,204 lbs (784,354 kg) of copper and 42,219 oz (19,150 g) of silver. The Indian Queen ore was in garnet-epidote tactite in Mission Canyon Limestone (Geach, 1972).

Magnetite ore from a small contact metasomatic deposit in Hasmark Formation was probably mined for smelter flux.

147.3 (237.1)   12.3 (19.8)

Dillon. End of field trip.

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ROAD LOG FOR FIELD TRIP TO SAGE CREEK, HORSE PRAIRIE, AND LEMHI TERTIARY BASINS, MONTANA AND IDAHO

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INTRODUCTION

This trip will focus on Tertiary terrestrial valley fill in three intermontane basins of Montana and Idaho. Tertiary sediments in these basins range in age from Paleocene to late Miocene and Pliocene. The route will be from Dillon to Sage Creek, then to Horse Prairie, over Bannack Pass to Railroad Canyon and the Upper Lemhi Valley of Idaho, north to Tendoy, Idaho, and returning to Dillon over Lemhi Pass and through Horse Prairie (Fig. 1). In this region there has been little geologic work emphasizing Tertiary geology, but a Ph.D. study of the Sage Creek area is being completed by Tabrum at the University of Montana. The senior author has done paleontological work in Horse Prairie and the upper Lemhi Valley (Nichols, 1976, 1979). Figure 2 shows the general correlation of the Tertiary sediments in this area.

The last part of the trip over Lemhi Pass is on a steep, narrow mountain road and not to be tried in inclement weather or by the faint-hearted.

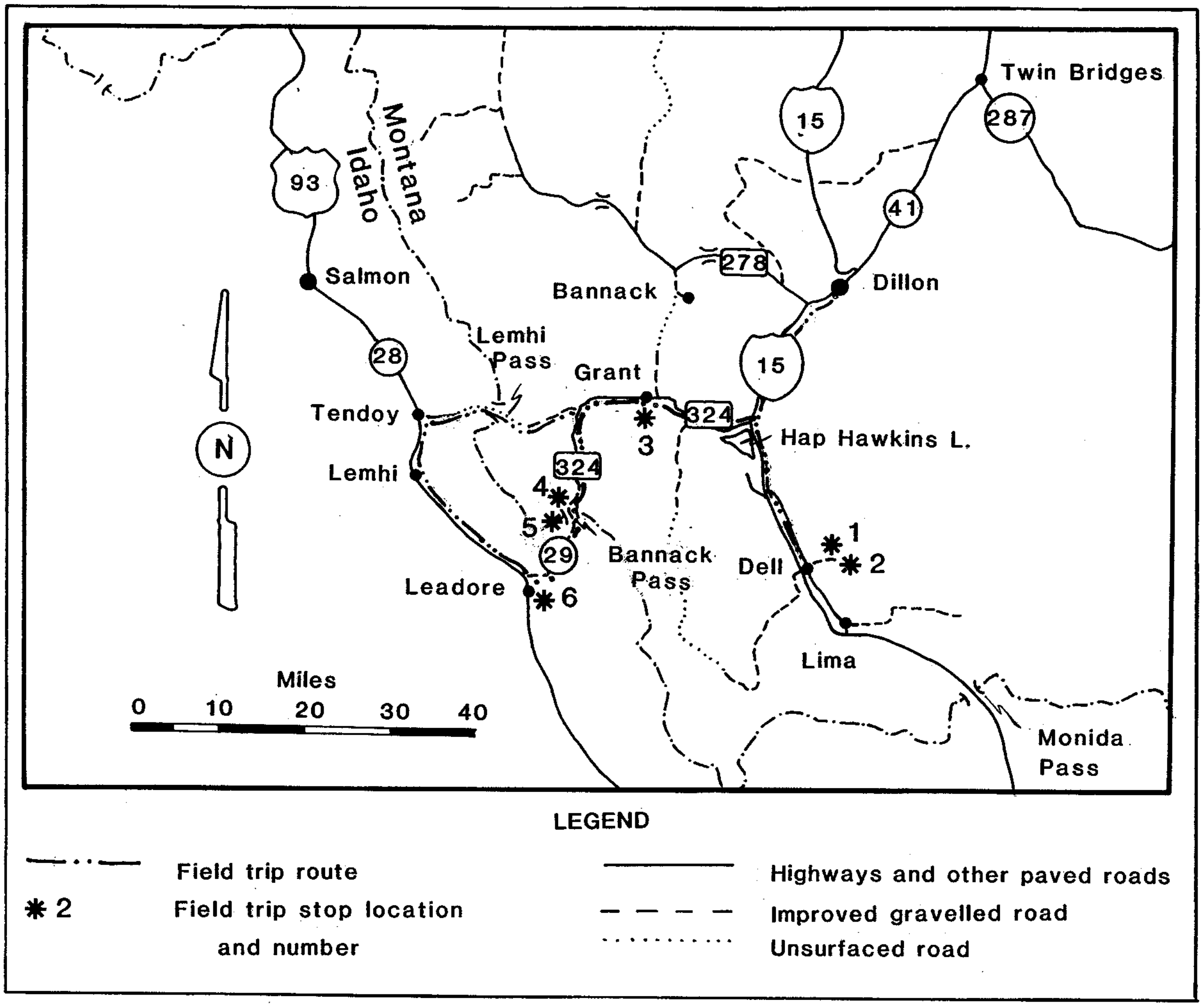

Figure 1. Tertiary Basins field trip route.

Epochs	North American Mammalian Ages	Sage Creek	Horse Prairie	Lemhi Valley
Pleist.				
Pliocene	Blancan			
	Hemphillian			Middle Ridge
Miocene	Clarendonian	Cook Ranch Conglomerate		
	Barstonian		Smith Ranch Maiden Creek	Railroad Canyon Stops 4 & 5 Mollie Gulch
	Hemingfordian	Mid-Tertiary Unconformity		
	Arikareean		Everson Creek	Peterson Creek
Oligocene	Whitneyan		Grant Plant loc. Stop 3	
	Orellan	Cook Ranch beds Stop 2		
	Chadronian			
	Duchesnean	Sage Creek Upper Eocene beds		
Eocene	Uintan			
	Bridgerian	Sage Creek Lower Eocene beds Stop 1		Challis Volcanics
	Wasatchian			
Paleocene		Beaverhead Conglomerate		

Figure 2. Relative stratigraphic positions of Tertiary beds in southwestern Montana and east-central Idaho.

DESCRIPTIVE ROAD LOG

Cumulative Mileage mi (km)	Increment Mileage mi (km)	
0.0 (0.0)	0.0 (0.0)	Assemble at Western Montana College, intersection of South Atlantic and Cornell Streets, Dillon. Proceed south on Interstate Higway 15 Business Route.
3.7 (5.9)	3.7 (5.9)	Junction of Montana 278 which leads west through the Grasshopper Valley to the Big Hole Basin. Continue south on Interstate Highway 15.
5.0 (8.0)	1.3 (2.1)	Blacktail Range at 9 o'clock. Paleozoic rocks form most of the range. Tertiary deposits of volcanic ash are visible at the north end of the range.
7.0 (11.3)	2.0 (3.2)	Pfizer's talc plant on the left. The talc comes from the northern Ruby Mountains.
7.6 (12.2)	0.6 (1.0)	Rattlesnake Cliffs comprised of porphyritic rhyolite of Oligocene age (Chadwick, 1981).
9.0 (14.5)	1.4 (2.2)	Note beds of white altered volcanic ash in roadcut to the right.
9.2 (14.8)	0.2 (0.3)	Across valley to the left is a waterfall fed by warm springs.
10.3 (16.6)	1.1 (1.8)	Grasshopper Creek joins the Beaverhead River. Bannack, the first capital of Montana, and old placer diggings are 10 mi (16 km) upstream. On the right is a ridge of brown Dinwoody Limestone of Triassic age (Lowell, 1965).
10.9 (17.5)	0.6 (1.0)	On the left is a landslide in altered Tertiary ash. During construction of the interstate highway, the slide was reactivated by rerouting the Beaverhead River and the Union Pacific Railroad tracks. Cliffs of Pennsylvanian Quadrant Quartzite on the right.
11.6 (18.7)	0.7 (1.1)	Red clinker in the draw at right is formed from oil shale in the Retort Shale Member of the Phosphoria

Formation that burned.

13.3 (21.4) 1.7 (2.7)

Pipe Organ Rock on right shows crude columnar jointing in basalt of Eocene age (Chadwick, 1981) which fills ancestral Beaverhead Canyon.

13.5 (21.7) 0.2 (0.3)

On left, outcrops of the reddish-colored Beaverhead Conglomerate of Late Cretaceous to Paleocene age.

14.5 (23.3) 1.0 (1.6)

Across the valley on right is the Tendoy thrust which brings Mississippian Mission Canyon Limestone over red synorogenic Beaverhead Conglomerate (Ruppel 1978).

18.4 (29.6) 3.9 (6.3)

Clark Canyon Dam and Hap Hawkins Lake. (See Hildreth, 1981, for a description of the Armstead anticline.)

21.6 (34.8) 3.2 (5.1)

Extensive slope on the east side of the valley may be an oversteepened pediment, coallescing alluvial fans, a dip slope, or none of the above.

22.7 (36.5) 1.1 (1.8)

Upper end of Hap Hawkins Lake has warm springs discharging into it. Before the lake was impounded, old timers reported oil slicks on the springs.

33.9 (54.5) 11.2 (18.0)

On the right, Dixon Mountain, capped by Quadrant Quartzite, is a large plunging anticline (Scholten and others, 1955). Triassic rocks outcrop in the canyon to the north of Dixon (Klecker, 1981). Red Rock fault (Johnson, 1981) is visible along the west side of the valley at the front of the range.

39.0 (62.8) 5.1 (8.2)

Exit right at Dell, and turn left under Interstate Highway 15.

39.1 (63.0) 0.1 (0.2)

Turn left on old highway (frontage road).

39.5 (63.6) 0.4 (0.6)

Turn right and cross railroad tracks. Watch for trains.

40.2 (64.7) 0.7 (1.1)

Cross Red Rock River. Drive up Sage Creek road.

40.8 (65.7) 0.6 (1.0)

Gravel pit on right.

41.5 (66.8) 0.7 (1.1)

Outcrops of Beaverhead Conglomerate on right.

42.1 (67.7) 0.6 (1.0)

Sharp left curve.

42.4 (68.2) 0.3 (0.5)

Cross Sage Creek.

42.7 (68.7) 0.3 (0.5)

Sharp right curve. Beaverhead Conglomerate on left. Series of basaltic flows capping ridges across valley to right are stair-stepped by a series of small faults.

45.9 (73.9) 3.2 (5.1)

STOP 1. Lower Eocene (latest Wasatchian) fossil locality. Teeth of two titanotheres *Eotitanops* and *Palaeosyops* and the tillodont *Trogosus* collected from here. We will have a half hour stop.

46.4 (74.7) 0.5 (0.8)

Upper Eocene beds to left disconformably overlain by lower Cook Ranch beds of middle or late Chadronian age.

47.6 (76.6) 1.2 (.19)

STOP 2. To left are Cook Ranch beds of middle Oligocene (Orellan) age unconformably overlain by probable late Tertiary conglomerate (Fig. 3). Many microfossils (small teeth and jaws) of rabbits, rodents, marsupials and insectivores, as well as a bat, along with larger fossils from carnivores, horses, rhinos, camels and other artiodactyls have been collected at this locality. We will stay here for 45 minutes.

47.7 (76.8) 0.1 (0.2)

Turn around, return to Dell.

55.8 (89.8) 8.1 (13.0)

Turn left to Dell.

56.2 (90.4) 0.4 (0.6)

Turn right across tracks. *Watch for trains.*

56.3 (90.6) 0.1 (0.2)

Turn right onto Interstate Highway 15 north. Mountains ahead in distance are the southern end of the East Pioneers. Prominent peak is Baldy Mountain.

69.4 (111.7) 13.1 (21.1)

Exit at Red Rock. Turn left under Interstate Highway 15.

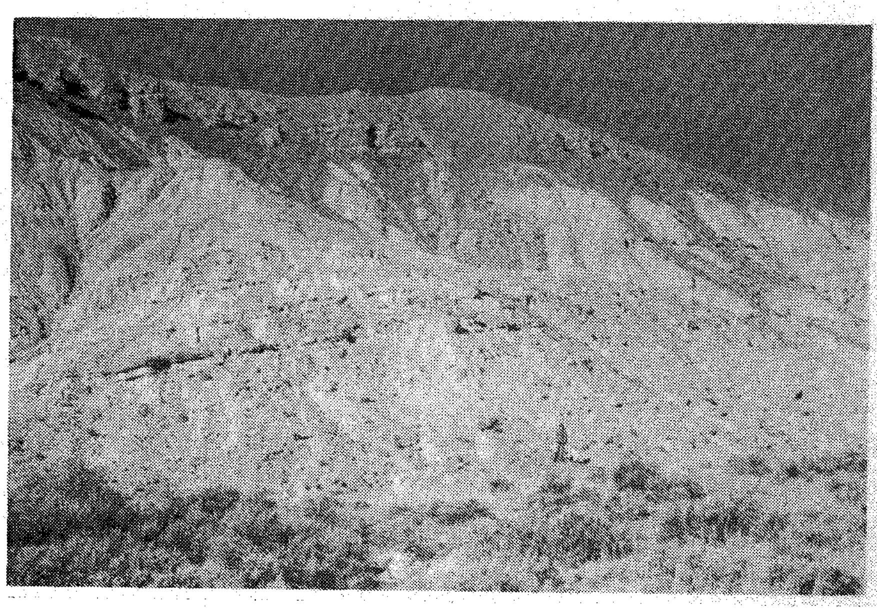

Figure 3. Cook Ranch middle Oligocene (Orellan) beds unconformably overlain by late Tertiary conglomerate.

69.8 (112.3) 0.4 (0.6)

Turn right.

72.0 (115.9) 2.2 (3.5)

Turn left.

73.0 (117.5) 1.0 (1.6)

Note arch in limestone to the left.

74.6 (120.1) 1.6 (2.6)

Note deformation in Mississippian Big Snowy Group sediments to the left.

76.1 (122.5) 1.5 (2.4)

Tree-covered ridge on right is comprised of Pennsylvanian Quadrant Quartzite. Indian pictographs are reported in this area.

76.5 (123.1) 0.4 (0.6)

Entering Horse Prairie.

78.5 (126.3) 2.0 (3.2)

Turn left onto pavement. Watch for traffic.

79.5 (127.9) 1.0 (1.6)

Cross Medicine Lodge Creek. Medicine Lodge valley to the left. In the Tertiary sediments in this valley beds of coal occur which were mined in the early part of the century for local use.

79.8 (128.4) 0.3 (0.5)

Highway follows grade of old Gilmore and Pittsburg Railroad which connected Salmon and Gilmore, Idaho, with the Union Pacific Railroad at Armstead, now covered by Hap Hawkins Lake.

82.1 (132.1) 2.3 (3.7)

Road to left goes to the Kenn Luff well site about 3 mi (5 km) south. Hydrocarbon shows were reported in the Cretaceous.

84.5 (136.0) 2.4 (3.9)

The "town" of Grant. Horse Praire Hilton on right.

87.2 (140.3) 2.7 (4.3)

STOP 3. Pull off highway to the right to park. Late Oligocene-Early Miocene fossil plant locality (Becker, 1961). Bloody Dick Peaks on skyline. We will remain here for one half hour. Proceed west on pavement.

88.0 (141.6) 0.8 (1.3)

Cretaceous-Tertiary volcanic rocks at 9 o'clock lapping up on mountains.

91.8 (147.7) 3.8 (6.1)

Bloody Dick road turns off to right. Red Butte and Round Hill to right. These are comprised of red Precambrian quartzite and may be remnants of Tertiary slide blocks or exhumed mountains. Bachelor Mountain, at 4 o'clock, is also capped by Precambrain quartzite.

93.9 (151.1) 2.1 (3.4)

At 1 o'clock is Goat Mountain in Idaho, at 2 o'clock Trail Creek Canyon and Lemhi Pass, and at 3 o'clock Bloody Dick Canyon.

94.5 (152.5) 0.6 (1.0)

Lemhi Pass road on right. Continue south on pavement.

95.4 (153.5) 0.9 (1.4)

Uranium prospect on top of ridge at left. A small plug of granitic rock is exposed in the draw at left. Tertiary volcanic rocks form the hill and cliffs. There was a buffalo jump off these cliffs.

96.7 (155.6) 1.3 (2.1)

Cattle guard. Upper Oligocene(?) rocks outcrop across valley to right.

100.9 (162.4) 4.2 (6.8)

Road to Chinatown on left. Site of old gold placer diggings. End of pavement.

104.2 (167.7)   4.2 (10.7)

Old railroad tunnel at 10 o'clock. At 9 o'clock upper Miocene fossil locality.

105.3 (169.5)   1.1 (1.8)

At left in roadcut is the contact between Tertiary and Precambrian rocks.

106.0 (170.6)   0.7 (1.1)

Fossil horse bones have been collected from this road cut.

106.1 (170.7)   0.1 (0.2)

Overlook Horse Prairie to north. Buff beds at 10 o'clock are of late Miocene age and overlie light-colored beds of earlier Miocene age. Valley was once filled with Tertiary sediments at least up to the level of the pass.

106.4 (171.2)   0.3 (0.5)

STOP 4. Bannack Pass. At least 2,000 ft (610 m) of Tertiary section is exposed in Railroad Canyon on the Idaho side. There is stream channel gravel on the top of the pass to the left. The mid-Tertiary unconformity is visible between the buff-colored beds and the older, lighter colored beds. Lunch stop for one-half hour.

107.4 (172.8)   1.0 (1.6)

Mouth of railroad tunnel at 11 o'clock.

107.7 (173.3)   0.3 (0.5)

STOP 5. Late Miocene (Barstovian) fossil locality. Railroad Canyon has yielded an extensive vertebrate fauna of horses, camels, rhinos, antelopes, carnivores, rabbits and rodents, along with snakes, lizards, and tortoises (Nichols, 1976, 1979). We will remain here one half hour.

108.9 (175.2)   1.2 (1.9)

Mid-Tertiary unconformity in railroad cut to left.

109.6 (176.4)   0.7 (1.1)

Tertiary conglomerates in hill to left.

110.7 (178.1)   1.1 (1.8)

Tertiary sediments extend to the top of the hill to the left. Many large landslide areas to the left.

111.7 (179.8)   1.0 (1.6)

Enter Railroad Canyon proper. Cruikshank Creek to the left. Base of the visible Tertiary section in this area. Approaching Paleozoic rocks complicated by multiple thrust faults. High elevations may have been the original Continental Divide (Ruppel, 1967).

115.7 (186.2) 4.0 (6.4)

Pavement begins. Lemhi Valley ahead.

116.4 (187.3) 0.7 (1.1)

Mines on the right from whence Leadore (lead ore) gets its name (Anderson, 1961).

117.3 (188.7) 0.9 (1.4)

At 9 o'clock in the distance is Middle Ridge which has outcrops of Pliocene ash and sand. Gypsum was mined here. Amoco drilled a dry hole at the south end of Middle Ridge in 1981. The valley fill in the Leadore area may be as much as 10,000 ft (3,048 km) deep.

119.6 (192.5) 2.3 (3.7)

STOP 6. Rest stop. Turn north on Idaho Highway 28.

119.8 (192.8) 0.2 (0.3)

Range-front fault on right along Beaverhead Range. Many prospects indicate mineralization along the fault.

123.7 (199.1) 3.9 (6.3)

Stream terrace on left slopes upward toward the north opposite to the grade of the river. The Lemhi River used to flow south until Pleistocene arching at Gilmore Summit reversed the flow (Ruppel, 1967).

124.4 (200.2) 0.7 (1.1)

Mollie Gulch fossil locality across valley at right. This locality has produced a middle Miocene fauna of numerous small oreodonts, horses, rhinos, camels, carnivores, rodents, and tortoises.

128.0 (206.0) 3.6 (5.8)

Across Lemhi River at 3 o'clock are the remains of a mill that never "got off the ground" to treat the ores from prospects at the base of the range behind.

130.3 (209.7) 2.3 (3.7)

Buff colored outcrops of Peterson Creek beds to the right. This is an early Miocene fossil locality.

132.3 (212.9) 2.0 (3.2)

At 2 o'clock Tertiary volcanic rocks probably related to the Challis Volcanics are exposed.

135.3 (217.7) 3.0 (4.8)

Tertiary beds are exposed far up the canyon to the right.

136.3 (219.3) 1.0 (1.6)

Bluffs ahead are a massive spring deposit of tufa. They are known as the Indian Caves and are an old Indian burial ground.

137.1 (220.6) 0.8 (1.3)

Very coarse volcanic breccia to the right.

137.6 (221.4) 0.5 (0.8)

Site of old Lemhi Indian Reservation. Note truncated spurs on right.

138.6 (223.0) 1.0 (1.6)

Precambrian quartzites outcrop on right. Note Idaho Fish and Game Department salmon trap in river.

139.7 (224.8) 1.1 (1.8)

Dry Gulch is the hanging canyon at 2 o'clock. Note that the bottom of the canyon has been filled by cloudburst debris.

140.7 (226.4) 1.0 (1.6)

Main Bitterroot Range ahead.

145.1 (233.5) 4.4 (7.1)

Tendoy Store. Turn right.

145.3 (233.8) 0.2 (0.3)

Turn right.

145.6 (234.3) 0.3 (0.5)

Turn left up Agency Creek road. This is the old stage road that ran from the Lemhi Valley to connect with the Union Pacific Railroad at Red Rock, Montana.

146.8 (236.2) 1.2 (1.9)

Enter canyon. Precambrian quartzites are exposed in the canyon walls.

150.3 (241.9) 3.5 (5.6)

The Narrows. Old timers say that the stage was held up here.

151.0 (243.0) 0.7 (1.1)

Cattle guard. Challis volcanics exposed.

153.2 (246.5) 2.2 (3.5)

Tertiary conglomerate in the Challis(?) volcanics.

153.9 (247.7) 0.7 (1.1)

Precambrian quartzites.

154.6 (248.8) 0.7 (1.1)

Forest boundary.

154.7 (249.0) 0.1 (0.2)

Stay left; road to the right goes to the old Copper Queen mine.

156.2 (251.4) 1.5 (2.4)

Horse Shoe Bend. Not for overlarge vehicles.

157.3 (253.1) 1.1 (1.8)

STOP 7. Top of Lemhi Pass. Note prospect pits for thorium (Staatz, 1979)

158.8 (255.5) 1.5 (2.4)

Cross Trail Creek. This is where the members of the Lewis and Clark expedition could say, "Thank God I have lived to bestride the Mighty Missouri."

159.3 (256.4) 0.5 (0.8)

Cliffs are formed in agglomerates of Challis Volcanics.

159.8 (257.2) 0.5 (0.8)

Road to Thorium City on right. This was an old stage stop, and later homesteaded by Gotlieb Sohner. The cabin is still used by range riders.

162.0 (260.1) 2.2 (3.5)

Mooney Ranch. Please drive slowly. Precambrian quartzites and siltites and Challis Volcanics outcrop in the canyon.

165.2 (265.9) 3.6 (5.8)

Contact of Tertiary sediments and Challis Volcanics.

167.0 (268.8) 1.8 (2.9)

Junction with road to Bloody Dick Creek. Go straight.

168.8 (271.7) 1.8 (2.9)

Cross Horse Prairie Creek.

169.1 (272.1) 0.3 (0.5)

Junction with Montana State Highway 324. Turn left.

183.4 (293.4) 14.3 (22.9)

Indian Head Mountain at 11 o'clock. Pattern of slide rock and sagebrush forms the image of an Indian chief with a war bonnet in profile.

184.9 (295.8)	1.5 (2.4)	Stay on pavement.
186.3 (298.1)	1.4 (2.2)	Cross Horse Prairie Creek. Quadrant Quartzite outcrops to the left.
186.9 (299.0)	0.6 (1.0)	Note chevron folds in Big Snowy Group sediments.
187.3 (299.7)	0.4 (0.6)	Axis of Armstead anticline (Hildreth, 1981).
187.6 (300.2)	0.3 (0.5)	Cross Clark Canyon dam.
188.1 (301.0)	0.5 (0.8)	Turn left onto Interstate Highway 15 north and return to Dillon.
206.7 (330.7)	18.6 (29.9)	Western Montana College and end of trip.

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LARAMIDE BASEMENT DEFORMATION IN THE ROCKY MOUNTAIN FORELAND OF MONTANA: A HORIZONTAL COMPRESSION PHENOMENON

by

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Laramide uplift of the Rocky Mountain Foreland of southwestern Montana occurred by response of demonstrably anisotropic Precambrian basement to west-east horizontal compression. The major planar anisotrophy was a set of 25 to 30 steeply-dipping, regularly-spaced (5 to 10 km) (3.1 to 6.2 mi), northwest-trending fault zones which had developed initially as normal faults, were reactivated by compression, and underwent left-reverse movement, producing northwest-plunging folds in the overlying sedimentary section. The larger faults are over 150 km (93.2 mi) long and have net slips between 4 and 10 km (2.5 and 6.2 mi). Horizontal shortening of several tens of kilometers occurred by a combination of clockwise rotation of rigid basement blocks during large scale simple shear and by the reverse component of movement on the faults.

Major northwest shear zones appear to be absent in the southern Madison, Greenhorn, Snowcrest, and Gravelly Ranges where the initial Late Precambrian faults were either absent or were cohesive enough to inhibit reactivation. Instead Laramide deformation in these ranges occurred along two roughly north-trending zones of low angle, west-dipping basement thrusts in comparatively weak, anisotropic gneisses, schists, and marbles. One of these thrusts (the Snowcrest-Greenhorn thrust) has a minimum west-east displacement of 21 km (13.0 mi) (Perry, et al., 1981).

ROAD LOG FOR THE RUBY RANGE, PART OF THE HIGHLAND RANGE, AND ADJACENT INTERMONTANE BASINS, SOUTHWEST MONTANA WITH EMPHASIS ON RECURRENT TECTONIC HISTORY

by

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INTRODUCTION

This road log through the Ruby Range and part of the Highland Range is designed to complement and update one assembled for the first Tobacco Root Geological Society Field Conference, held in 1976. That log (Garihan, 1976) followed a west-to-east traverse along the Stone Creek and Cottonwood Creek drainages across the uplifted block; it described mainly the Precambrian structural and metamorphic history of the central Ruby Range. In this log, features at the northern and eastern range margins will be visited. The present road log and the previous road log (Garihan, 1976) followed sequentially comprise one extended trip through the Ruby Range.

Since the 1976 conference, additional detailed mapping in the Highland Range (Duncan, 1976; Gordon 1981; Schmidt and Garihan, in preparation), the northern Ruby Range (Karasevich, 1980, 1981; Karasevich and others, 1981), and the Upper Ruby Basin (Monroe, 1976, 1981) has provided important new geologic information and a better perspective on the regional recurrent tectonic history. Therefore, this field trip will emphasize the following additional features: (1) A more complex structural history than previously envisioned, possibly involving nappe emplacement of Cherry Creek rocks (2,750 to 1,600 m.y.B.P.) in the Carter Creek area and in the northern Ruby Range east of the Kephart fault. Autochthonous marble beneath the nappe pile will be viewed along the field trip route at Ruby Dam. (2) The metamorphic sequence and structural style of Archean basement rocks of the Highland Range which contrast markedly with that of the Ruby Range; according to Duncan (oral commun., 1982) Archean folding is less intense in the Highland Range. The field trip participants will appreciate the difficulty of inter-range correlation of Archean units by making a comparison between lithologies exposed along Rochester Creek and those in the Cherry Creek section along Stone Creek. (3) An understanding of the tectonic framework of recurrently active northwest-trending faults adds continuity to the Archean, Proterozoic, Laramide, and Cenozoic structural events of both regions.

Although Laramide (late Cretaceous-Eocene) arching of the cratonic shelf is responsible for the general outcrop pattern of Archean rocks in southwest Montana, mid-late Cenozoic oblique extensional faults have blocked out the individual ranges and intervening basins, thereby controlling in large measure their geometry. The intermontane valleys have been depositional basins since late Eocene time or earlier (Fields and Petkewich, 1967). Recent mapping indicates the South Rochester fault (along Rochester Creek) probably extends from the Highland Range 18.6 mi (30 km) southeastward across the Jefferson Basin into a position which flanks the flatirons at the northeast margin of the Ruby Range (Garihan and others, 1981). Southward, the fault bounds the northern margin of the narrow "isthmus" of Precambrian rocks between the Ruby and Greenhorn Ranges. Striking similarities with the Sweetwater fault in the southern Ruby Range, in terms of proximity of Proterozoic diabases and abrupt physiographic expression, are apparent from stops in the Sweetwater Basin.

The field trip route (Fig. 1) begins at the Blue Anchor Cafe in Twin Bridges, Montana, and proceeds northwestward into the Rochester Basin. Retracing our steps, we will follow the trend of the South Rochester fault southeastward across Tertiary sedimentary rocks. We will note its effect on the course of the Ruby River, and uplift and dissection of late Pliocene/Pleistocene pediment surfaces at the northern tip of the Ruby Range. Evidence of upthrust or gravity slide (Tysdal, 1970) will be considered for an exposure of Archean rocks south of Sheridan. At several stops we will view Archean marbles at Ruby Dam and the late Miocene Sixmile Creek Formation in the Upper Ruby Basin. The field trip will consider, at an overview of the Stone Creek fault, the evidence for recurrent Proterozoic, Laramide, and Cenozoic movements along major faults of the Rocky Mountain foreland in the Ruby Range. Final field trip stops in Sweetwater Canyon and the Sweetwater Basin will show the recent displacement on the Sweetwater fault. At this point, the 1976 road log can be used to traverse the Archean of the Ruby Range along the Cottonwood Creek - Stone Creek Road. This extended trip ends at the intersection of the Stone Creek road and State Route 41, about 6 mi (10 km) north of Dillon, Montana.

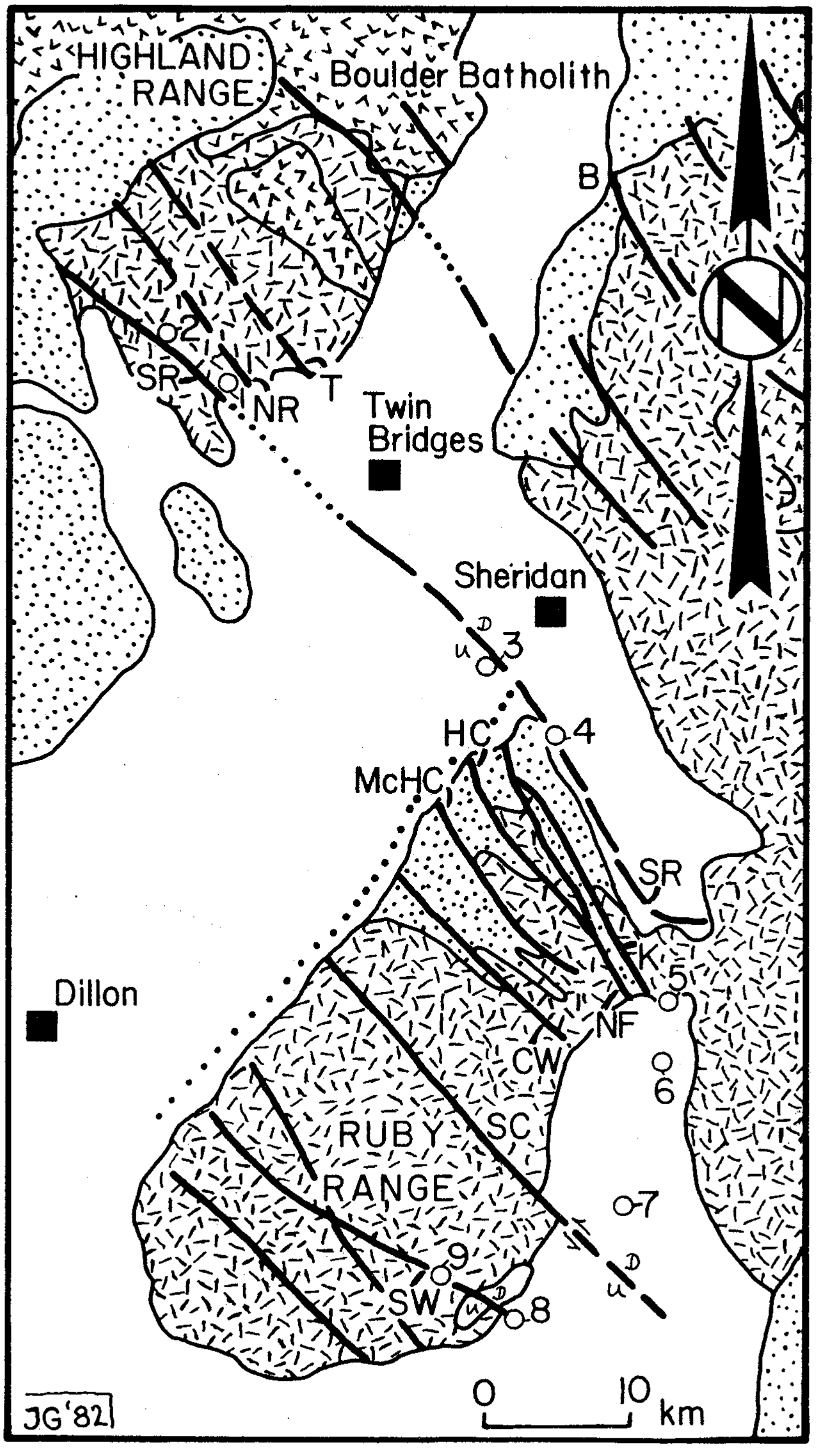

Figure 1. Index map of field trip route, Highland and Ruby Ranges. Stops are numbered sequentially. Regional faults (modified after Schmidt and Hendrix, 1981): B – Bismark; T – Twin Bridges; NR – North Rochester; SR – South Rochester; K – Kephart; NF – North Fork; HC – Hinch Creek; McHC – McHessor Creek; CW – Cottonwood Creek; SC – Stone Creek; SW – Sweetwater. Stipled are Beltian–Mesozoic sedimentary rocks; slash pattern is Archean metamorphic rocks.

DESCRIPTIVE ROAD LOG

Cumulative Mileage mi (km)	Increment Mileage mi (km)	
0.0 (0.0)	0.0 (0.0)	Begin measuring mileage at the Blue Anchor Cafe in Twin Bridges (29.2 mi [47.0 km] from Western Montana College in Dillon); junction State Routes 287 and 41 (south). Proceed west on Route 41, toward Dillon.
0.1 (0.2)	0.1 (0.2)	Bridge across Beaverhead River. Entrance to fairgrounds.
0.5 (0.8)	0.4 (0.6)	Turn right (north) at the bend, after passing a retirement home (former state children's center). Watch for sharp curves! (28.7 mi [31.9 km] from Dillon.)
1.7 (2.7)	1.2 (1.9)	Bridge across Big Hole River. Pavement ends.
2.6 (4.2)	0.9 (1.4)	Road forks (elevation 4,747 ft [1,447 m]). The left fork goes to Melrose, about 20 mi (32 km) distant. Follow the right fork along Rochester Creek into the Highlands. Continue gradually up the bench across poorly exposed Tertiary sediments and Quarternary alluvium.
4.8 (7.7)	2.2 (3.5)	Road to the right (north) climbs up onto Tertiary rocks and gravels. It follows northwestward along a linear swale which marks the trace of several splays of the North Rochester fault (Fig. 2). Numerous prospects and the Germania mine, last operated in 1910, have attempted to exploit gold-bearing massive quartz veins of a northwest trend in the area (sec. 3, T. 3 S., R. 7 W.).
4.9 (7.9)	0.1 (0.2)	Turn left (south) off the Rochester road.
5.0 (8.0)	0.1 (0.2)	<u>Stop 1.</u> Small quarry, south side of Rochester Creek (NW corner, sec. 24, T. 3 S., R. 7 W.). This location (Fig. 2) is near the southeasternmost exposures of Archean rocks in the Highlands, in an area mapped by Duncan (1976). The North Rochester Creek fault lies in the stream bed just northeast of the open cut.

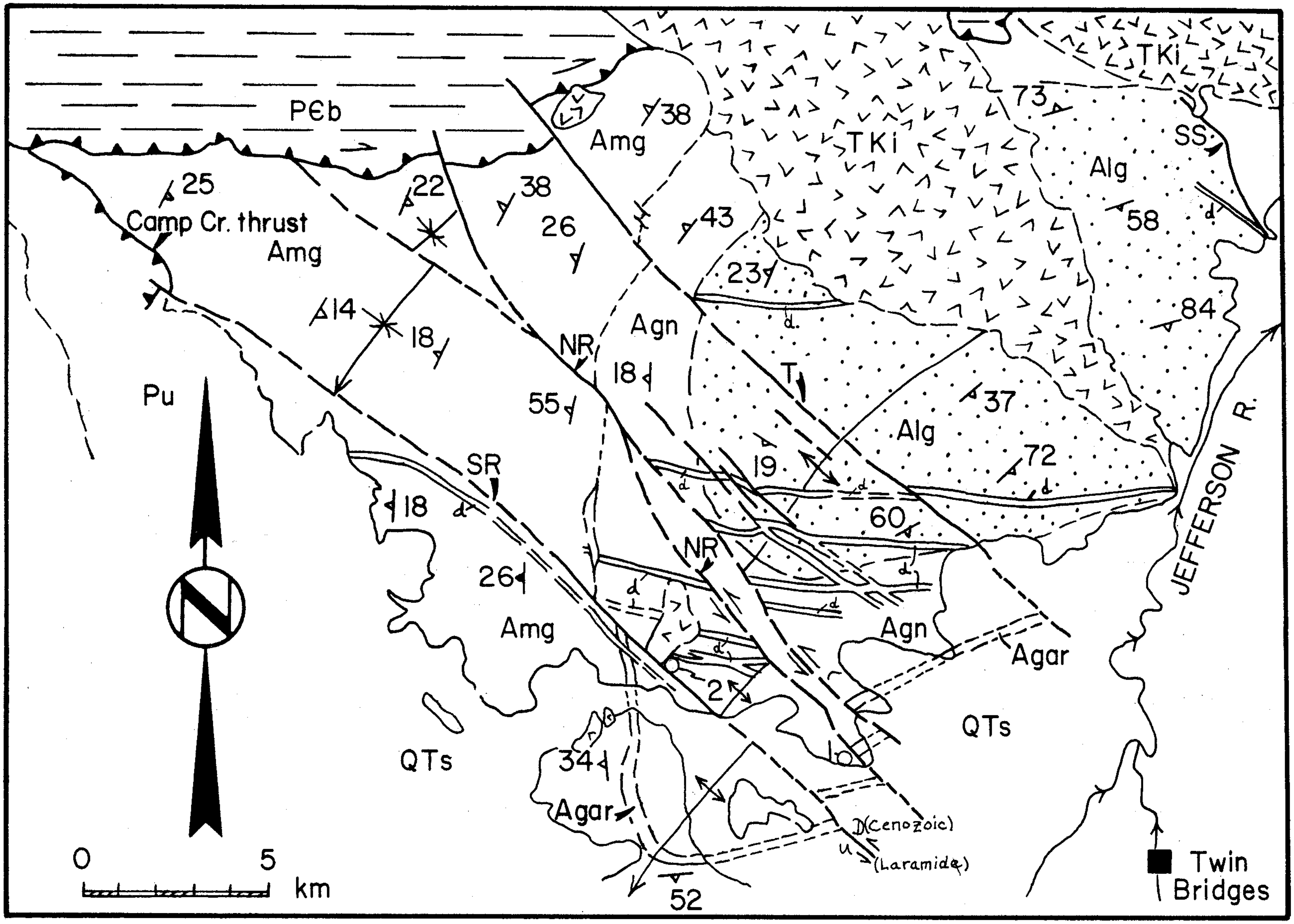

Figure 2. Composite geologic map of the Highland Range. Archean geology by Duncan (1976). Late Precambrian diabases and some northwest-trending faults mapped by Schmidt and Garihan (1980). Archean units: Alg - Leucocratic gneiss; Agn - Gray gneiss; Agar - Garnet gneiss, marble sillimanite schist; Amg - Micaceous gneiss. d - diabase. Pu - Paleozoic rocks. Tki - Tertiary-Cretaceous intrusions. SS - Silver Star fault. Other faults as in Figure 1. Stops 1 and 2 are located on the map.

Fresh, gray, well-foliated biotite gneiss and minor amphibolite with boudins and abundant isoclinal folds are present. Foliation is N. 50° E., 87° S.E.; the location is the southeast flank of the Rochester antiform, an open southwest-plunging structure. The most prominent shear surface in the quarry (N. 42° W., vertical) parallels the fault, which most recently had late Cenozoic movement. Slickenside data from this quarry (to compare with the entire Highland Range) are shown in Figure 3a; motions are nearly dip slip on the fracture surfaces seen here. Where several slickensides are developed on one fracture surface, we note the older set tends to plunge southeastward at shallower angles. It is tempting to speculate whether the movements which are more nearly strike slip could be Laramide age.

A mafic dike (amphibolite) at the northwest end of the quarry shows incipient boudinage and anti-clockwise rotation near the quarry floor. Refolding of isoclinal folds in adjacent plastic gneiss may be due to forcible intrusion or compression associated with rigid body rotation of the dike.

5.1 (8.2) 0.1 (0.2)

Turn left (west) onto the Rochester Road. Several sharp turns. The North Rochester fault lies between the road and the creek and has several prospect pits and some silicification along it.

5.7 (9.2) 0.6 (1.0)

Cross trace of fault.

5.8 (9.3) 0.1 (0.2)

At the bend is a slump scar. Nearly horizontal conglomerates unconformably overlie Archean rocks. The unconformity in the next drainage to the north may be faulted, but relationships are not clear. No Archean exposures occur for the next mile. Note that the fault-controlled valley of Rochester Creek takes on a markedly linear northwest trend; on the southwest side of the South Rochester fault, a prominent scarp-like hillside extends 10 to 11 mi (16 to 18 km) to the vicinity of Camp Creek. Physiographic expression suggests young movement on a normal fault, with up being to the south. Structurally, the Rochester Basin between the Twin Bridges fault (Fig. 1) and this fault is a graben. A view back to the southeast shows the fault's trace can be lined up with the northern Ruby Range.

7.5 (12.1) 1.7 (2.)

Cross the axial trace of a large open antiform, the major Archean fold structure in the range. Foliation strikes northwesterly, and consistent dips at its crest suggest the fold plunges about 30° S. W. Duncan's (1976) map unit here is "Gray gneiss." Below it, "Leucocratic gneiss" looks similar to Dillon quartzofeldspathic gneiss. Above it, the "Garnet gneiss" lithologies include sparse marble and metapelitic sillimanite schist, the only clearly metasedimentary rocks in the basement complex of the Highlands. The uppermost unit, "Mica gneiss," is a mylonitic, thinly foliated, biotite-rich gneiss. Mineral assemblages indicate upper amphibolite metamorphic grade. In actuality, there is no evidence to correlate any

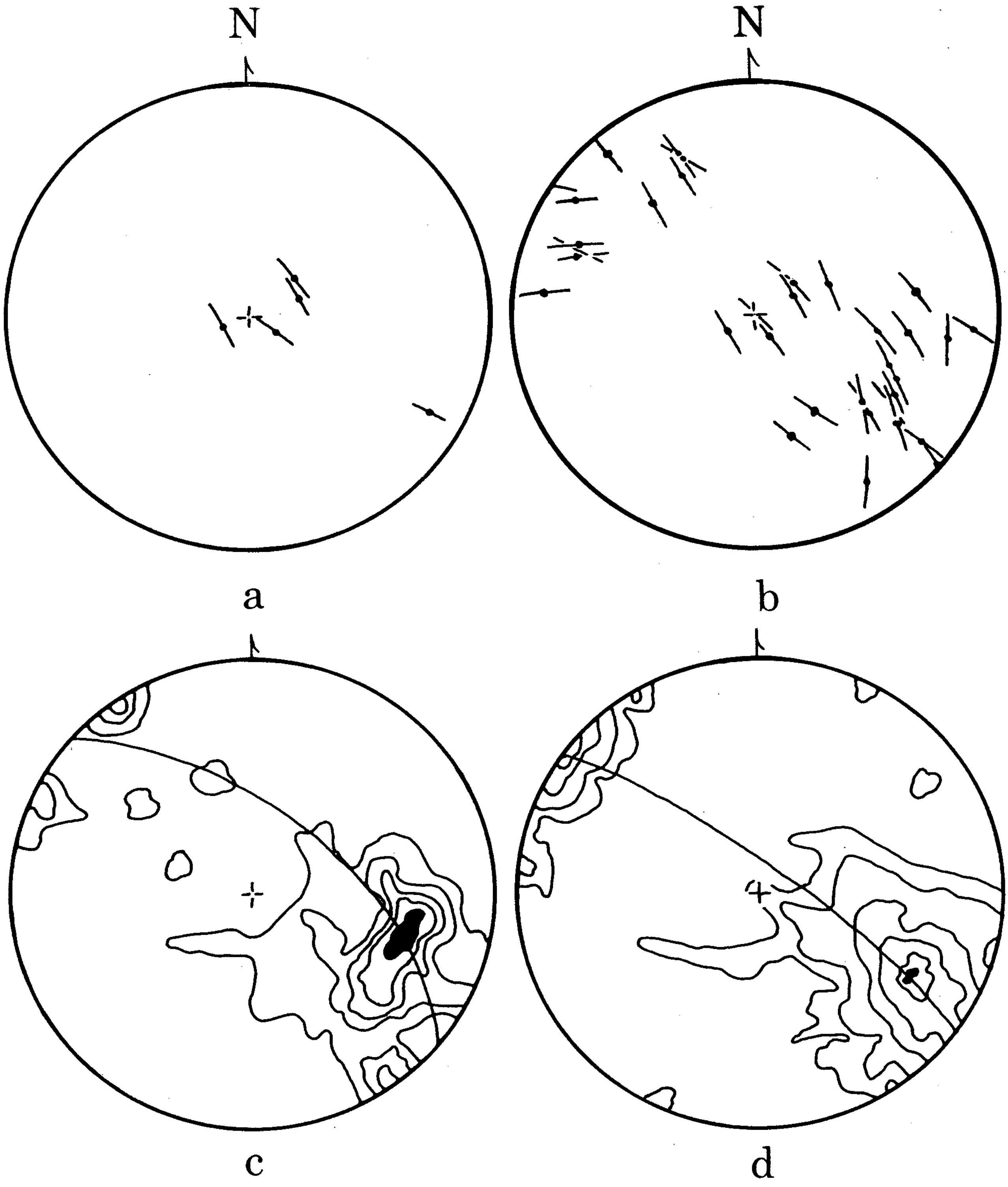

Figure 3. (a) Stop 1. Southern hemisphere equal area stereoplot of bearing and plunge of slickenside lineations on great circle traces of fracture surfaces roughly parallel to North Rochester. (b) Slickensides on traces of fracture surfaces roughly parallel to the North and South Rochester faults, entire Highland Range. (c) Stone Creek fault, Ruby Range. Contoured stereoplot of 76 slickensides on fractures roughly parallel to the fault (contours: 1%, 3%, 5%, 7%, 9%; maximum density: 13%). Great circle trace of the fault's orientation is N. 50° W. 60° N.E. (d) Bismark fault, Tobacco Root Range. Contoured stereoplot of 170 slickensides on fracture surfaces roughly parallel to the fault (contours: 1%, 3%, 9%, 15%, 25%, 30%; maximum density: 32%). Great circle trace of the fault's orientation is N. 53° W., 80° N.E.

of these Archean rocks with metamorphic units in the Ruby Range. They may be facies equivalents or they may be of an entirely different age.

8.5 (13.7)　　1.0 (1.6)

Stop 2. Along a small drainage, north side of the road. Near the contact of a small (0.5 mi^2 [1.3 km^2]), rectangular stock of Cretaceous-Tertiary quartz monzonite, presumably related to the Hell Canyon pluton. Late Precambrian diabase uphill trends N. 80° W.

The purpose of this stop is to summarize some evidence for recurrent tectonic activity in the Highlands, based partly on recent mapping of diabases and northwest faults. Continuous east-west and northwest dike sets of late Precambrian diabase transect metamorphic foliation. In terms of abundance, they are reminiscent of a swarm of N. 70° W. dikes in the southern Tobacco Roots (Koehler, 1976) and anastomosing dike sets in the Carter Creek area of the southern Ruby Range (Karasevich and others, 1981). A large diabase of northwest trend, indicating major late Precambrian weakness of this orientation, is adjacent and parallel to the South Rochester fault for 4 mi (6.4 km). An early ancestry for the Cenozoic fault is thereby suggested; probably it was also a normal fault in Proterozoic time. The orientation is duplicated by similar dikes throughout southwest Montana, and we interpret the northwest trend as due to regional rifting and extension of Archean continental crust as the Belt Basin to the north was opened. Mantle-derived basic magmas (diabases) intruded the rifts. The fact that nearly 25% of 117 measured dike orientations in the Highland, Ruby, and Tobacco Root Ranges lie betweeen N. 70° W. and east-west, strongly indicates an east-trending Proterozoic fault set was also important. In the field, we note numerous northeast Archean metabasite dikes are cut by younger diabases but show no apparent offset.

Consistent left separation along the three major faults of Figure 2 is shown by the offset diabase dikes and the offset axial trace of the Rochester antiform. Based on similar geologic occurrences in the Ruby and Tobacco Root Ranges, the movement is inferred to be Laramide age. Slickenside data indicate the component of strike slip movement dominated over dip slip; this is also the case for Laramide slickensides we have collected from other recurrently active basement-controlled faults (Fig. 3). Finally, post Laramide (late Cenozoic) movement is suggested by right separation along the South Rochester fault of the trace of the Camp Creek thrust (Duncan 1976; Garihan and others, 1981). Displacement of the thrust trace is consistent with dip slip.

Three miles farther up the Rochester road is the Rochester mining district. It was first operated for gold, silver, lead, zinc, and copper in the late 1860's and was most prosperous from 1898 to 1905 (Sahinen, 1939). After being largely inactive for 75 years, a new concentrator began operation in 1980. The large rain catchment area of the Rochester Basin has caused flooding of many of the old mines.

In this mining district, Sahinen (1939; p. 26) recognized northwest fractures as the "strongest and most persistent zones of breaking," although these fractures and veins are not as well mineralized as those trending northeast. He suggested "slight" lateral slippage along these breaks resulted in northeast tension breaks between the main fissures, which affected circulation of ore-bearing solutions and caused higher grade, northeast-trending pay zones. It is interesting to speculate that northwest and east-west metalliferous veins, which are less persistent, narrower, and less uniformly mineralized, may have inherited their orientations from weaknesses developed in late Precambrian time during regional diabase emplacement.

Sahinen (1939) believed that quartz monzonitic rocks related to the Boulder Batholith underlie the pre-Belt crystallines of the Highlands at very shallow levels, with cupolas developed locally, as at Stop 2. Certainly crustal uplift associated with shallow intrusion could re-open ancient fractures. Sahinen termed the diabases "lamprophyre dikes", which he incorrectly interpreted as the latest basic differentiates of the Boulder Batholith magmas. However, proximity to a potent source of metalliferous hydrothermal solutions certainly caused mineralization in the Highland Range. Away from Cretaceous-Tertiary silicic intrusion, this recurrent fault history exhibits insignificant mineralization. For example, some secondary copper but no gold or silver occurs along the Stone Creek fault zone in the Ruby Range.

Retrace route to Twin Bridges, and re-set the mileage there.

Cumulative Mileage mi (km)	**Increment Mileage mi (km)**	
0.0 (0.0)	0.0 (0.0)	Blue Anchor Cafe, Twin Bridges. Head south on State Route 287 into the Ruby Valley. Northern tip of the Ruby Range straight ahead. A regional map of simple Bouguer gravity measurements (Biehler and Bonini, 1969) shows an elongate, northwest-trending gravity minimum underlying this part of the basin. It is plausible that subsidence on the northeast side of the South Rochester fault, which bounds the closed gravity contours on the southwest side, produced thick accumulation of low-density basin fill between the fault and the southern Tobacco Roots.
9.8 (15.8)	9.8 (15.8)	Downtown Sheridan. Turn right (west).
12.4 (20.0)	2.6 (4.2)	Crossroads. Straight ahead.
13.0 (20.9)	0.6 (1.0)	Cross the meandering Ruby River.
13.5 (21.7)	0.3 (0.5)	Road intersection. Turn right (north) and travel along the edge of the floodplain. For the next few miles, we

pass along the base of a series of dissected pediments, cut on soft Tertiary rocks. The highest surface may be as old as late Pliocene (R. W. Fields oral commun., 1982), so faulting which initiated its dissection must be even younger.

16.8 (27.0) 3.5 (5.6)

STOP 3. Small borrow pit in semi-consolidated surficial materials. From about this point northwestward the linear margin of the Ruby River floodplain is the trace of the South Rochester normal fault. Two gravelly marker beds in the pit are displaced 3 to 4 ft (0.9 to 1.2 m) on a small normal fault sympathetic to the major one. Recent uplift along the fault has caused downcutting and dissection of the pediment surfaces and the development of a steep east-facing erosional escarpment. Headward erosion of north-flowing drainages cutting back into the escarpment will behead northwest-flowing streams leaving the western range. A buried normal fault bounds the northwest edge of the Ruby Range (Fig. 1), and at its intersection with the South Rochester fault, structures in steeply dipping Tertiary rocks are complex (Fields, oral commun., 1982).

18.2 (29.3) 1.4 (2.2)

Optional scenic stop. Drive uphill onto the pediment, past exposures of sandstone and mudstone capped by conglomerate. View northwest toward the high peaks of the Highland Range. Early Oligocene rocks in this area are pebbly mudstones; Pliocene rocks are over 1,000 ft (305 m) thick at the northern range tip (Fields and Petkewich, 1967). Return to the pit.

Turn right (south) onto road.

23.0 (37.0) 4.8 (7.7)

STOP 4. Silver Spring. Road to the right (west) leads up onto the pediment and follows the West Bench Canal.

Mississippian and (occasionally) Cambrian carbonates form prominent flatirons along the northeast margin of the range; they dip 30° to 50° N. E., with bedding attitudes tending to steepen (50° to 70°) up section (map of Tysdal, 1976). These rocks are part of a complex system of Laramide northwest-trending upthrusts or reverse faults with associated drape folds in the northern Ruby Range (discussed at Stop 7).

The South Rochester fault probably passes through or near Silver Spring and lies buried beneath older Quaternary alluvium approximately 1 mi (1.6 km) northeast of the base of the flatirons (map of Karasevich, 1981). The apex of a large alluvial fan heads at the mouth of Laurin Canyon. In the Madison and other intermontane valleys, such fans are locally cut by recent fault movements, but this one is not.

At the northern tip of the range at elevations below the tree line (mostly less than 5,800 ft [1,768 m]), Archean gneisses, amphibolites, ultramafic rocks, and metasedimentary lithologhies (marble, sillimanite schist, metaquartzite, and iron formation) structurally overlie with fault contact massive, resistant Mission Canyon limestones (compare the geologic map of Karasevich, 1981 with Tysdal, 1976).

Small gravity-slide masses on the western and eastern range flanks are composed of intricately interfaulted Paleozoic rock slices, with variable dips and no preferred order with respect to stratigraphy. It is not uncommon that Precambrian metamorphics are also involved. Clearly these masses developed by sliding from the rising Blacktail-Snowcrest arch of mid-Cretaceous to early Eocene age. Their source was probably the most uplifted part of the range, that is, the Ruby Peak block bounded by the Hinch Creek and North Fork faults (Tysdal, 1970) (Fig. 1). Nonetheless, the Archean occurrences at Stop 4 may be something entirely different, possibly the result of upthrust faulting. Admittedly, the fault contact must dip at unusually shallow angles basinward for such an upthrust (15° to 25°, by a 3-point calculation). Perhaps erosion has exposed only the highest structural levels. The Gardner upthrust, for example, can be seen to flatten markedly upward (Garihan and others, 1982). Our field observations are: (1) The fault, a presumed detachment surface by a slide interpretation, is not confined to one lithology (marble), but cuts lithologic contacts. (2) Foliation shows a dominant northeast orientation, and marker units can be traced laterally. Scatter in orientation may be the result of multiple deformational periods, but in any case, the rocks certainly are not totally "brecciated" and "chaotic." (3) Iron formation occurs in the Archean at this place, being similar to Cherry Creek metamorphic units in the Taylor Canyon block east of the Kephart fault. In the Ruby Peak block, no iron formation has been mapped because the rocks are mostly stratigraphically below the Cherry Creek. Therefore, it is unlikely to be the tectonic source area for the 1 mi^2 (2.6 km^2) exposure of Archean rock. Moreover, there is no reason to correlate marble at the tip of the range wih the Ruby Peak marble; thick marble is also abundant in the Taylor Canyon block. (4) Most convincing, we believe, are two diabase dikes (one 5 ft [1.5 m] and the other 7 ft [2.1 m] wide) which strike N. 20° W. Their orientation is completely consistent with the northerly trends of dikes in the northern Ruby Range. It seems unlikely the trend would be maintained after a gravity sliding emplacement of the Archean block over a distance of 4 to 5 mi (6 to 8 km). The strongest evidence for an upthrust origin would be participation of basement units in an anticlinal drape fold adjacent to the fault, but this has not been observed. By whatever mechanism, the block arrived at its position prior to deposition of overlying basin sediments, which contain late Eocene vertebrate fossils. Proceed southward.

28.0 (45.1) 5.0 (8.0)

Laurin. Join Route 287 and proceed south.

30.0 (48.3) 2.0 (3.2)

Alder. Turn right (west) at the gas station and cross the tracks. To the right is an excellent local steakhouse. At the end of the Burlington Northern spur, talc from the Beaverhead mine (Cyprus Industrial Minerals Co.) is washed and stockpiled. Turn south and follow the paved road. Leaving Lower Ruby Basin.

34.9 (56.2) 4.9 (7.9)

Cross the trace of the South Rochester fault; note the sharp topographic break on the left as we enter the steep-walled canyon on the Upper Ruby road. The fault seems to end abruptly about 2 mi (3 km) east of here, near the head of Dryden Creek (Berg, 1979). Correlation of metamorphic units across the linear canyon indicates it is not fault-controlled. Probably it was cut by superposition following Tertiary basin filling. Pass folded marble and amphibole outcrops on the east side of the road.

37.3 (60.0) 2.4 (3.9)

STOP 5. Ruby Dam (spillway elevation 5,392 ft [1643.5 m]). Marble on the south limb of an east plunging F_3 Archean fold.

The structurally complex region between the Kephart fault and the northwest end of the Greenhorn Range (Karasevich, 1980, 1981) is one of the most elegant pieces of Archean geology anywhere in southwest Montana (Fig. 4). A pair of conspicuous macroscopic F_4 folds (antiform, axis plunging 57° / N. 71° E.; synform, axis plunging 40° / N. 63° E.) deform several upright, concentric macroscopic F_3 folds, which plunge 30° to 70° east.

The schematic evolution of the area is shown in Figure 5 (Karasevich and others, 1981; Garihan and Karasevich, 1982). The geometry of the folds can be explained by postulating a pair of nappes; a higher one composed of marble (stippled) underlain by a second nappe, composed of quartzofeldspathic (Dillon) gneiss (Fig. 5a). During eastward motion (2,500 to 1,600 m.y.B.P.), autochthonous F_3 folds were truncated and bent into a synform by compression and drag (Fig. 5b). The upper nappe overrode the lower one and restricted its further eastward translation. Final movement of the lower nappe resulted in arching of the upper marble nappe into macroscopic F_4 folds (Fig. 5c). In the process, the lower limb was dramatically thinned. The F_4 synform affects the entire Cherry Creek metamorphic section, including rocks thought to underlie the nappes. Nappe emplacement occurred prior to intrusion of northwest diabase dikes dated in the range at 1,450 m.y.B.P. (Wooden and others, 1978).

Arching contemporaneous with uplift (F_4) of the central Ruby Range, in the waning stages or subsequent to high-grade metamorphism (2,750 m.y.B.P.) is shown in Figure 6. The Treasure Chest and Ruby antiforms and the earliest movements along the ancestral Stone Creek and Kephart faults are manifestations of the arching. The source area for allochthonous Cherry Creek and Dillon gneiss rocks involved in the two sets of nappes is interpreted to be between these major faults, where F_1 and post-F_1 folds are essentially coaxial (but not coplanar). Elsewhere macroscopic fold orientations are more diverse, at least partly a result of nappe movements. (Data showing consistent orientation: In the area between the Hinch Creek and North Fork faults, F_{1-2} axes: 26° plunge / N. 54° E., direction of plunge; F_{3-4} axes: 32° / N. 55° E. In the area between the Cottonwood Creek and Stone Creek faults, F_1 axes: 35° / N. 27° E.; post-F_1 axes: 30° / N. 21° E.)

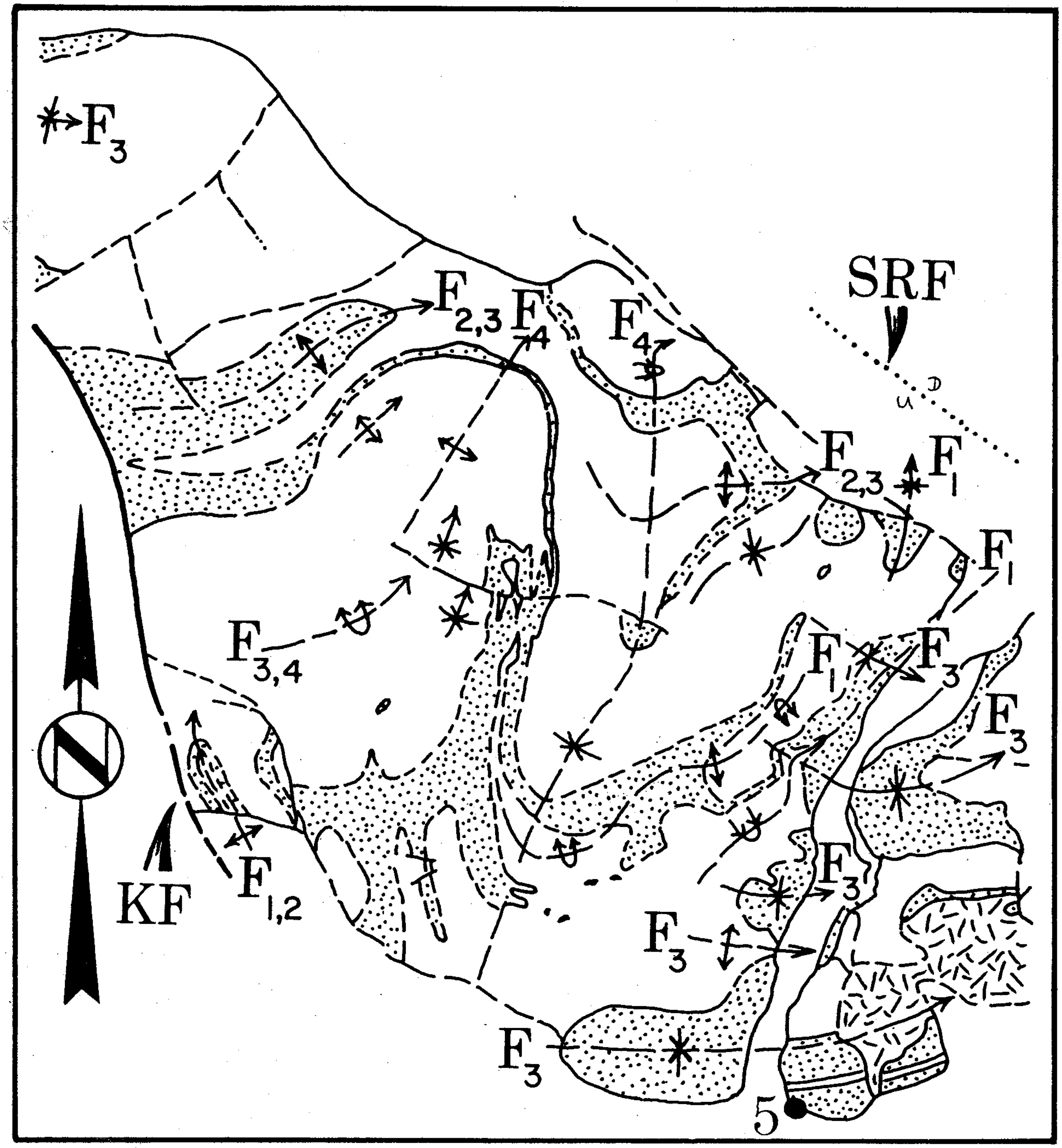

Figure 4. Tectonic map of the northern Ruby Range, east of the Kephart fault. Axial traces of macroscopic Archean folds are shown. F_1 and F_2 are tight to isoclinal similar folds; F_3 are tight to gentle concentric folds; F_4 are open to gentle concentric folds. Stipple pattern is marble, blank areas are largely quartzofeldspathic gneiss and amphibolite. KF – Kephart fault; SRF – South Rochester fault. Contacts in Greenhorn Range by Berg (1979). 5 – Stop 5.

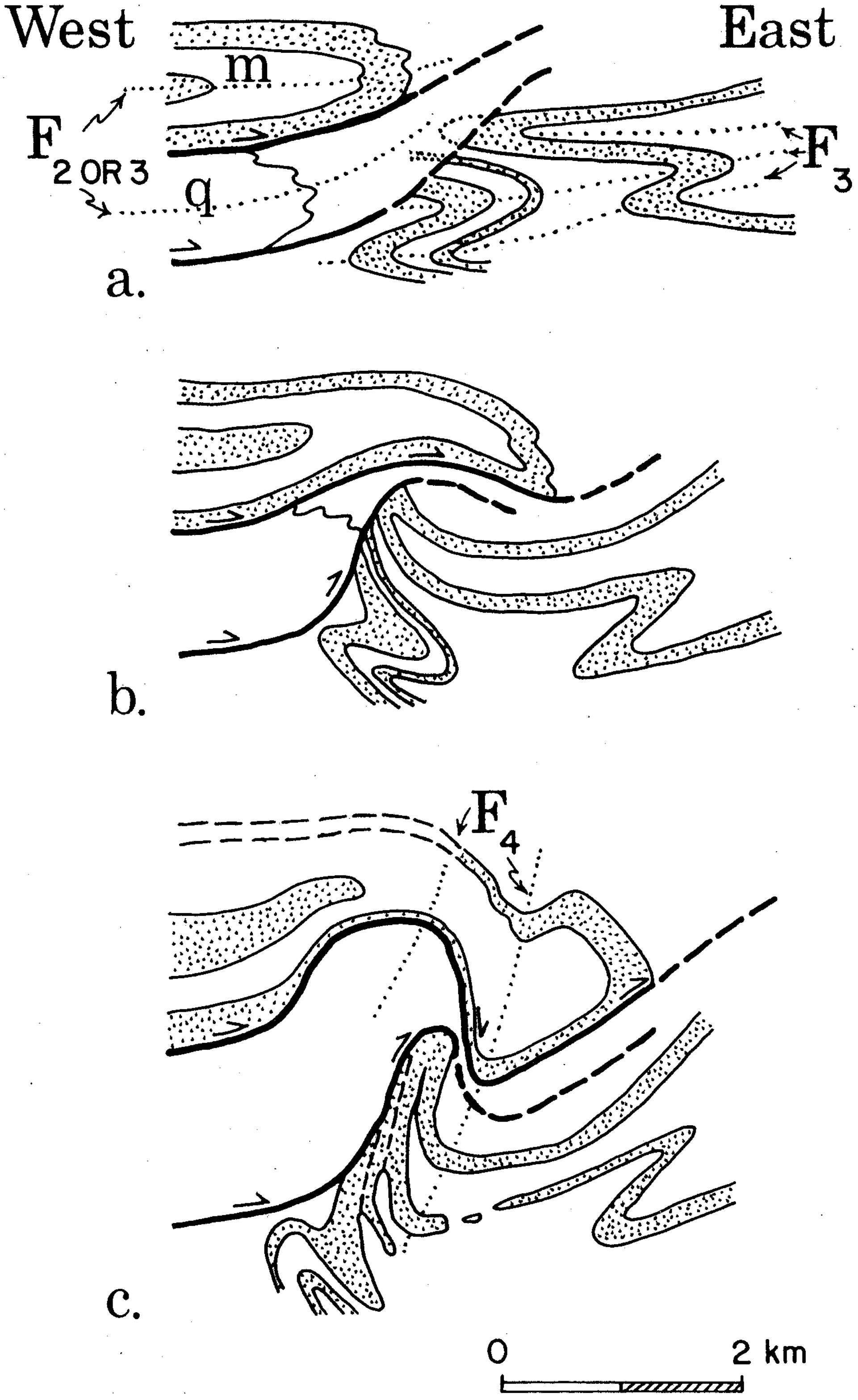

Figure 5. Schematic cross-sections showing evolution of area east of the Kephart fault. Marble layers are stippled. Axial surfaces are dotted. m – marble nappe, q – nappe of quartzofeldspathic gneiss.

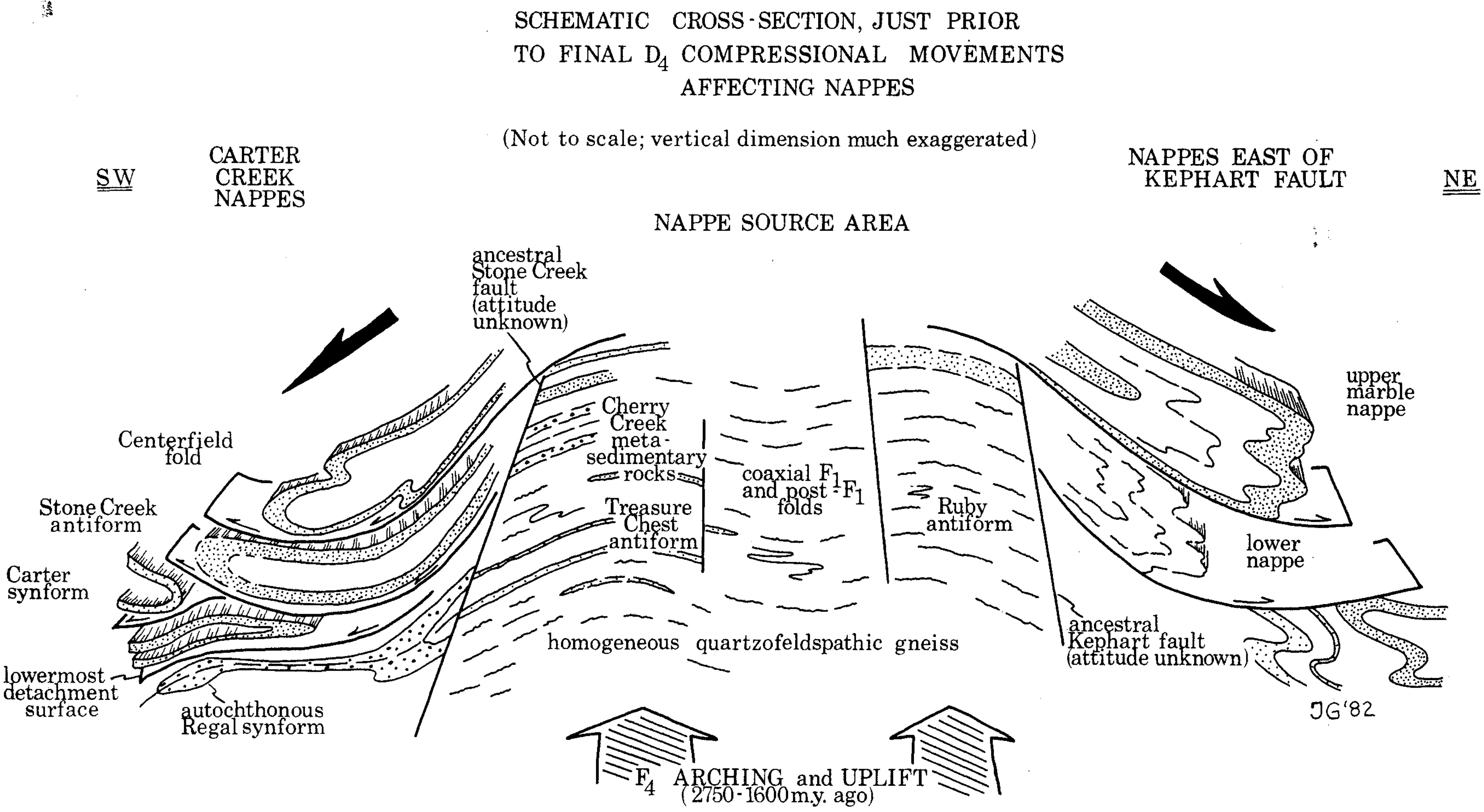

Figure 6. Schematic cross-section showing nappe emplacement in the Ruby Range.

The dip direction of newly arched metamorphic foliation, to a first approximation, probably controlled the direction of nappe emplacement. Thus the Carter Creek nappes were derived from the west flank of the arch, where foliation dips consistently northwest at moderate angles. Nappes east of the Kephart fault were derived from an area of north- and northeast-dipping metamorphic foliations, generally between the McHessor Creek and Kephart faults (Garihan and Karasevich, 1982).

No field evidence for the detachment surface at the base of the nappe pile in either region has been found. An important blastomylonitic zone in gneiss or marble could be thin and difficult to recognize, especially since widespread intense ductile shearing has developed cataclastic textures on a regional scale parallel to metamorphic foliation and F_1 fold axial surfaces. Moreover, movements by gravitational spreading or sliding of a Cherry Creek superstructure may have been distributed across a wide zone of shearing in autochthonous Dillon gneiss, particularly if the rocks were still hot enough or the strain rate was slow enough. For convenience, the detachment zones are shown as discrete faults with exaggerated dips in Figure 6.

Finally, we note the lowermost detachment horizon or zone near the base of the Carter Creek nappe pile lies stratigraphically near the top of the main mass of Dillon gneiss, where microcline gneiss and thin, persistent marbles are interlayered. Below this level the gneiss is less well-layered and mechanically more isotropic. In contradistinction, flexural fold mechanisms on a large scale near Ruby Dam may have been facilitated by the presence of anisotropic interlayering of metasedimentary lithologies.

Retrograde cordierite in anthophyllite schist and sillimanite meta-pelite (mostly from autochthonous terrane) may have formed contemporaneously with nappe emplacement as a result of the regional arching and significant decompression. If so, geobarometric work by Peter Dahl (1979) on garnet-cordierite pairs from these rocks yields a load pressure estimate of about 4.0 ± 1.0 kbar for the cordierite-producing retrograde metamorphic event; this contrasts with pressure estimates of 6 to 8 kbar for the upper-amphibolite event at 2,750 m.y.B.P. Roughly, uplift of 2 to 12 mi (3 to 19 km) is indicated.

Proceed into the Upper Ruby Basin, which probably has as much Cenozoic bedrock exposure as all other basins combined. For the next 3 mi (4.8 km), pass outcrops on the left of mostly fluvial late Miocene Sixmile Creek Formation, Metamorphic Fanglomerate Member (Monroe, 1976). These are popular places to hunt for agates. The rocks dip gently (5 to 10°) eastward, toward the Greenhorn Range. They unconformably overlie fine-grained rocks of the Renova Formation (fluvial and lacustrine deposition). Across the Ruby Reservoir, the margin of this tectonic basin is a sharply defined normal fault; locally it is the locus of volcanic intrusions and Holocene hot springs activity. Fetid thermal activity was recorded by the Hayden Survey in the area 100 years ago.

39.5 (63.6) 2.2 (3.5)

STOP 6. Outcrop of Sixmile Creek

Formation. A 3,674.5 ft (1,120 m) section of earliest Oligocene to middle or late Miocene sediments (both formations) were deposited in the basin. Becker's (1960) well-known "fossil basin" with beautifully preserved fossil plants in paper shales is interpreted by Monroe (1981) as a marginal lacustrine facies of a shallow, 57.9 mi^2 (150 km^2) perennial lake (Lake Passamari) which occupied this closed basin in late Oligocene-early Miocene time. Lake level fluctuations in response to climatic changes and rapid depositional episodes are responsible for complex repetition of sedimentary lithologies. The pattern of faults mapped by Monroe (1976) in this basin is much less systematic than fault orientations in the range itself.

40.8 (65.7) 1.3 (2.1)

Pass Metzel Ranch on Idaho Creek, near the southern end of the reservoir. The 7-1/2' quadrangle was named for the old ranch. Newer dwellings now occur nearby.

41.2 (66.3) 0.4 (0.6)

Road to the right (west) goes up Cottonwood Creek. The end of the 1976 log (Garihan) can be picked up at this intersection. When ore trucks were running between Alder and the Beaverhead talc mine, this dirt road was better maintained.

42.9 (69.0) 1.7 (2.7)

Good exposures of Tertiary sediments to the left.

43.8 (70.5) 0.9 (1.4)

Road intersection. To the left (southwest) the road goes to Ruby Gap, which divides the Snowcrest and Greenhorn Ranges. Turn right onto the Sweetwater road. Steep cliffs 0.5 mi (0.8 km) north of here are an old buffalo jump.

44.2 (71.1) 0.4 (0.6)

Cross Ruby River.

45.1 (72.6) 0.9 (1.4)

Pass near Ball Place; on the right (west side) are outcrops of gently tilted Sixmile Creek Formation, with late Miocene vertebrate fossil remains. Several faults cut the section.

47.8 (76.9) 2.7 (4.3)

STOP 7. Belmont Park Ranch. Rocks of the early Miocene Passamari Member (Renova) underlie the slopes adjacent to the road (on the left) for the next few miles (few km). A panorama to the west across the basin shows rounded hills of dark Archean rocks, truncated on their north side by an eroded scarp of the Stone Creek (normal) fault. Its trace crosses the road 1.2 to 1.4 mi (1.9 to 2.2 km) south of the Belmont Park Ranch, and Monroe (1976) shows the fault cuts early or middle Pliocene sediments in the vicinity of Dry Hollow 3 mi (4.8 km) to the southeast. Following Peterson and Kuenzi (1974), it is likely that late Cenozoic movement on the Stone Creek fault closed the Sweetwater Basin to the south, thereby causing a new drainage to initiate downcutting. Thus, Sweetwater Canyon was formed. Similarly, the canyon at Ruby Dam is related to movement on the South Rochester fault. The conspicuous light-colored rocks in the basin to the west are Climbing Arrow, Dunbar Creek, and Passamari Members of the Renova Formation.

At this point, we would like to review the recurrent fault history in the Ruby Range. The northwest-trending faults, possibly established in the Archean during nappe emplacement, but certainly active in the late Precambrian, were reactivated as Laramide upthrusts during the rise of the Blacktail-Snowcrest arch in mid-Cretaceous to Eocene time. Paleozoic-Mesozoic cover sediments were draped over differentially uplifted and shifted basement blocks. Four major drape folds developed along the Hinch Creek, McHessor Creek, Peterson Creek, and Cottonwood Creek upthrust faults (see Fig. 1). Older faults were reactivated, with the northeast side always upthrown.

To demonstrate pre-Laramide offset along the Hinch Creek fault, one can show (Fig. 7) that the sense and amount of separation of metamorphic units in the Archean produced by Precambrian faulting differ from Laramide offset of the Precambrian-Paleozoic unconformity. It is significant that a major, thick Archean marble underlying Ruby Peak does not appear southwest of the Hinch Creek fault when one restores 4 mi (6.4 km) of Laramide left separation of the unconformity. Also, the figure shows the axial trace of an antiform outlined by another thin Archean marble is displaced about 3.5 mi (5.6 km) in a right separation sense across the fault. According to this interpretation, the Ruby Peak marble is now buried beneath Phanerozoic rocks west of the fault. Pre-Laramide (Precambrian) right separation of the order of 7 to 8 mi (11 to 13 km) is thus demonstrated on the Hinch Creek fault.

In Figure 7, foliation orientations from Archean metamorphics near the Hinch and McHessor faults are compared with folded bedding in Cambrian rocks. The direction of plunge of each Laramide anticline in the metamorphic rocks matches closely the plunge of the sedimentary cover, proving as anisotropic rocks they were folded together during fault movement. The circled dots (Fig. 7) are poles to the pi-planes, which are best fits through foliation and bedding attitudes. The Paleozoic rock folds plunge roughly 5° to 40° less than the Archean rock folds, but in the same direction. Thus an angular unconformity has been deformed in the core of each drape fold adjacent to the fault.

Left reverse oblique slip in response to east-west regional compression characterizes Laramide fault movements in the northern Ruby Range as well as elsewhere in southwest Montana. For example, note the position of the lineation maximum for Laramide slickensides collected along the Stone Creek fault (Fig. 3). A strike slip component dominates the movement.

51.0 (82.1) 3.2 (5.1)

Enter Sweetwater Canyon, which connects the Sweetwater and Upper Ruby Basins. Archean rocks near the canyon floor are overlain by basin fill and volcanic rocks. A dissected basalt flow (dated by the U. S. Geological Survey at 4.2 m.y.B.P. ± 2 m.y.) forms the canyon rim. It is important in demonstrating the late

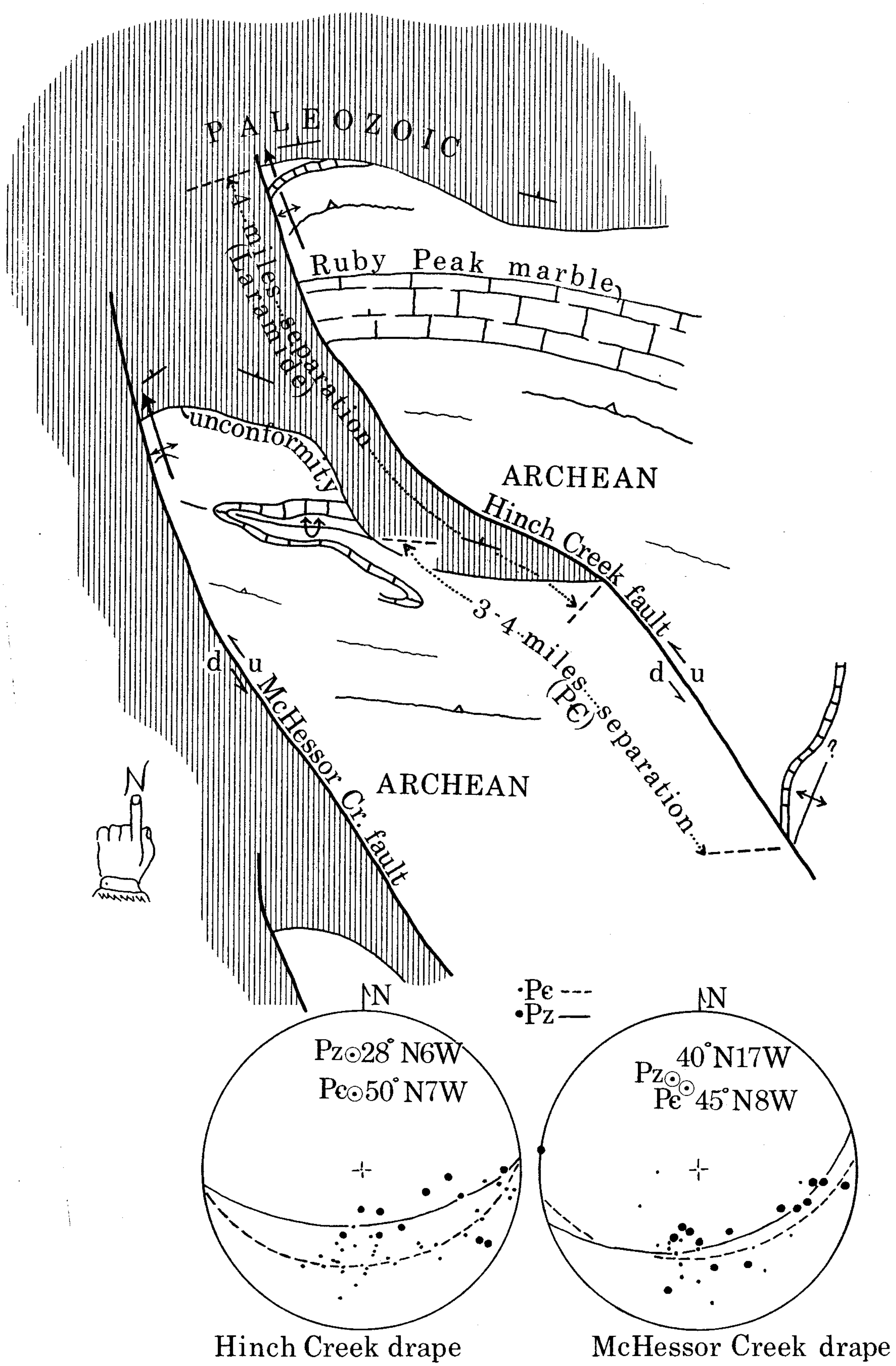

Figure 7. Sketch map of pre-Laramide offset along the Hinch Creek fault, and basement-cover rock drape fold relationships in the northern Ruby Range (see text for discussion). Map not to scale.

Cenozoic age of canyon cutting. Tertiary flows and minor epiclastic rocks crop out in the steep cliff face to the left (400 ft [121.9] high).

52.9 (32.9) 1.9 (3.1)

Road intersection. Turn left (southwest) and cross Sweetwater Creek. Campsites among the Cottonwoods. Proceed southward up Spring Brook.

54.4 (87.5) 1.5 (2.4)

Turn sharply right 500 ft (152.4 m) (northwest) past gate onto trail and cross Tertiary sediments into the next major drainage to the west. Trail not to be taken in inclement weather!

55.9 (90.0) 1.5 (2.4)

(Mileage approximate.) Road intersection at a spring. Turn left (southwest).

56.1 (90.3) 0.2 (0.3)

STOP 8. (Mileage approximate.) Base of Timber Hill. The throw on the Sweetwater fault here is 600 to 700 ft (183 to 213 m), as measured on the base of the displaced basalt flow. Precambrian lithologies (ultramafic rocks, amphibolite, Dillon gneiss, anthophyllite schist, garnet-biotite schist and gneiss) crop out uphill, and 100 to 200 ft (30 to 61 m) of Tertiary sandstones, mudstones, and conglomerates underlie the basalt flow. A 1,500 ft (457 m) northwest-trending diabase lies southeast of the fault (sec. 19, T. 9 S., R. 5 W.). The Sweetwater fault has been traced for 1 mi (1.6 km) to the southeast of Timber Hill; like the Stone Creek fault, it has no topographic expression as it crosses the basin fill. Without knowledge of basin stratigraphy, it cannot be traced. One mi (1.6 km) farther to the southwest, the Red Canyon fault (Okuma, 1971) also displaces this extensive basalt flow in a similar manner. It has less than 100 ft (30 km) of throw, and a fault scarp is well developed. It is significant that this young displacement (up to the south) cannot explain the 0.5 mi (0.8 km) left separation of the Pre-Cherry Creek - Dillon gneiss contact across the fault in an area between Red Canyon and Wood Canyon. Therefore, Laramide left reverse oblique slip is also likely for this fault.

59.3 (95.4) 3.2 (5.1)

Return to Sweetwater Road. Turn left onto the Sweetwater Road.

60.2 (96.9) 0.9 (1.4)

Pass through a canyon 600 ft (183 m) deep, apparently cut by superimposed drainage. Basalt flow caps mesas on both sides.

60.8 (97.8) 0.6 (1.0)

Pass old ranch at bend; proceed uphill away from the creek.

61.0 (98.2)   0.2 (0.3)

Pass light-colored outcrops of tufa at road level. Climb up onto Tertiary sediments.

62.1 (100.0)   1.1 (1.8)

STOP 9. Sweetwater Basin. The Sweetwater fault forms a spectacular physiographic break clearly visible for nearly 18.6 mi (30 km). In this regard, it is remarkably similar to the Stone Creek and South Rochester faults, and it shows an identical recurrent fault history. At places the scarp is barely eroded, and disrupted drainage lines across it have not yet reached equilibrium. Several large diabases within 2,000 ft (610 m) of the Sweetwater fault are parallel to it, indicating late Cenozoic reactivation of late Precambrian weakness directions.

End of roadlog. To follow the 1976 roadlog, return to the Cottonwood Creek road south of Metzel Ranch. Otherwise follow the Sweetwater road west to Dillon. Ruby corundum can be found in diggings a few 100 yards (a few 100 m) north of the intersection of Sweetwater Creek and the Sweetwater road. There sillimanite schist is deeply weathered.

ACKNOWLEDGEMENTS

The writers thank Dick Berg for compiling the roadlog mileages. Hugh Dresser has kindly provided us with low sun angle oblique photographs of some of these faults. They have helped us recognize the faults' basinward extensions. Regional recurrent tectonic studies in southwest Montana have been partly supported by N. S. F. Grant EAR 7926380 to Schmidt and Garihan.

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THE THRUST BELT IN THE LIMA - DELL, MONTANA AREA

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INTRODUCTION

This trip will examine the front of the Tendoy thrust sheet in the Lima area, the Beaverhead Formation in front of and structurally beneath the Tendoy sheet, and the southeastern limb of the Blacktail-Snowcrest uplift east of Lima, which geophysical and other evidence increasingly shows to be allochthonous - the hanging wall of a major Laramide basement-involved, northwest-dipping, range-front thrust. The route is given in the following road log and shown in Figure 1 (base map source: the Dubois 1:250,000 quadrangle).

DESCRIPTIVE ROAD LOG

Cumulative Mileage mi (km)	Increment Mileage mi (km)	
0.0 (0.0)	0.0 (0.0)	Leave Dillon, southbound on Interstate Highway 15, toward Dell, Montana. For road log to Dell, see Nichols and Brenner (this volume).
39.0 (62.8)	39.0 (62.8)	Exit Interstate Highway 15 at Dell. Red Butte on left exposes Lima limestone conglomerate unit (Ryder and Scholten, 1973) of Beaverhead Formation.

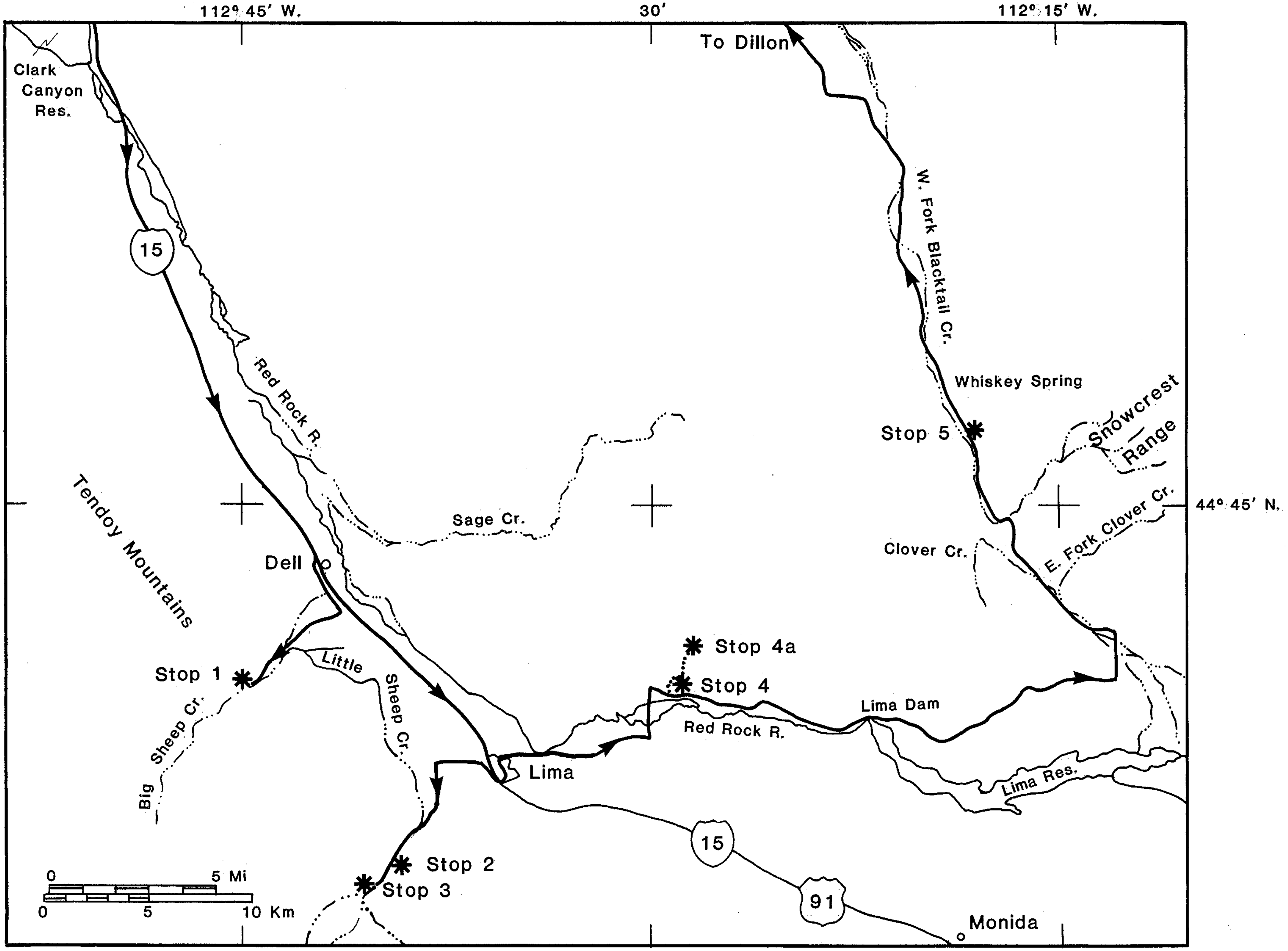

Figure 1. Route of field trip through the thrust belt in the Lima - Dell area.

39.2 (63.1) 0.2 (0.3)

Turn right, pass under Interstate Highway 15.

39.3 (63.2) 0.1 (0.2)

Turn left (south) on frontage road, west side of Interstate Highway 15. Faceted scarps are visible to the southwest along west side of Red Rock valley. These scarps mark probable Holocene movement on down-to-east Red Rock normal fault.

41.0 (66.0) 1.7 (2.7)

Turn right on Big Sheep Creek Road.

43.2 (69.5) 2.2 (3.5)

Cross trace of Red Rock fault. McKnight limestone conglomerate unit (Ryder and Scholten, 1973) of Beaverhead Formation on upthrown (western) side.

45.1 (72.6) 1.9 (3.1)

STOP 1. Leading edge of Tendoy thrust sheet at Big Sheep Creek. Location: SW1/4, sec. 30, T. 13 S., R. 9 W., on west edge of Dell 7-1/2' quadrangle, east edge of Dixon 7-1/2' quadrangle.

Very thin to medium-bedded limestone interbedded with gray shale of Chesterian (Upper Mississippian) age forms the leading edge of the Tendoy thrust sheet at this stop. These beds contain finely costate productid brachiopods and much algally laminated micrite. Formerly mapped as Madison Group (Scholten and others, 1955), Betty Skipp (oral commun., 1982) has recovered Chesterian foraminifera from the basal exposed limestone at this locality. Pre-Chesterian rocks probably do not occur in the Tendoy thrust sheet south of the Kidd 7-1/2' quadrangle. The limestone exposed at Stop 1 has been correlated with the Surrett Canyon Formation by Skipp (oral commun., 1982) and has close affinities with the Lombard facies of the Big Snowy Formation (E. K. Maughan, oral commun., 1982). Approximately 800 ft (244 m) of Amsden Formation and 2,350 ft (716 m) of Quadrant Sandstone occurs sequentially above the Big Snowy on this part of the Tendoy plate.

Abundant disharmonic folds and some contraction faults (small-scale imbricate thrusts) are present within the Lombard rocks at this locality. A recumbent fold north of the road, about 400 ft (122 m) east of the first sharp curve, plunges 15° with an axial strike of N. 20° W., convex to the northeast. At Stop 1, the base of the Tendoy plate lies in low-angle thrust contact on previously folded conglomerate beds of Cretaceous to Paleocene(?) Beaverhead Formation. Northeast-trending folds in the Beaverhead near here are truncated by the Tendoy thrust, additional evidence that the Blacktail-Snowcrest Laramide uplift, with its northeast-trending folds in this area, developed prior to emplacement of the Tendoy thrust sheet.

An upper detachment in folding is present beneath the Quadrant Sandstone north and west of Stop 1 (for other examples, see Dahlstrom, 1969). The Quadrant Sandstone and immediately underlying dolomite beds form a 30 to 40° W. inclined roof to the locally intensely deformed Amsden and Big Snowy rocks of high ductility contrast. For stratigraphers, this means that all thickness estimates of the sub-Quadrant rocks are here suspect due to tectonic thickening. For structural geologists, this means that the Quadrant Sandstone and underlying stiff dolomite beds have been transported from somewhat farther west than the Lombard limestone facies we see at the road level.

51.0 (82.1) 5.9 (9.5)

Return to Interstate Highway 15, Dell interchange. Turn south on Interstate Highway 15 to Lima.

59.6 (95.9) 8.6 (13.8)

Exit Interstate Highway 15; turn right and then right again on frontage road.

60.3 (97.0) 0.7 (1.1)

Turn left on Little Sheep Creek Road, first good gravel road to west.

61.9 (99.6) 1.6 (2.6)

Gravel road take 90° bend to left. Very large exotic block of Mississippian limestone in Beaverhead Formation 1.6 mi (2.6 km) to southwest, on west (upthrown) side of Red Rock fault.

65.2 (104.9) 3.3 (5.3)

Turn left on unmarked side road toward Little Sheep Creek.

65.3 (105.1) 0.1 (0.2)

STOP 2. Exotic limestone block in Beaverhead conglomerate. Locality: NW 1/4 NW 1/4, sec. 25, T. 14 S., R. 9 W., on NE part of Gallagher Gulch 7-1/2' quadrangle. Pull in as close as practical to Little Sheep Creek. Traverse southeast across ruined bridge across creek up to large limestone exposure at 6,900 ft (3,103 m) elevation (350 ft [107 m] climb), 1,100 ft (335 m) southeast of creek.

This large block of Mississippian Mission Canyon Limestone (200 ft [61 m] thick by about 900 ft [274 m] long) lies within the Beaverhead Formation 6,000 ft (1,829 m) in front of (northeast of) the Tendoy thrust sheet. This is one of 10 large exotic blocks of Mississippian carbonate rocks mapped by Ryder (1968) in his Divide quartzite conglomerate unit of the Beaverhead in the Little Sheep Creek area (Ryder and Scholten, 1973). In this area, the Divide quartzite conglomerate unit dips 44 to 65° S.W., whereas bedding in this limestone unit block dips 70° S.W. and approximates the attitude of the basal margin of the block. This block lies about 4,800 ft (1,463 m) stratigraphically below the youngest Beaverhead exposed beneath the Tendoy thrust at Little Sheep Creek. This large subangular slab is composed of medium to dark gray, medium- to thick-bedded to massive limestone which varies in composition from micrite to encrinite and pelsparite to biosparite. Beds of medium gray pelsparite and biosparite occur near the top, interstratified with channel-like layers of dark gray oolitic grainstone, a distinctive rock type not found in the Mississippian rocks of the Tendoy sheet in this area. A coral, collected in 1964 from this block by Perry Rohn, assisting Ryder, has been recently identified by W. J. Sando as Vesiculophyllum sp., a genus restricted to the Madison Group according to Sando.

The attitude of this block with respect to the surrounding Beaverhead suggests that it slid in from the southwest, probably off the front of an advancing thrust sheet. The reasoning is as follows: (1) the source of the surrounding conglomerate of the Beaverhead was from the southwest as indicated by clast imbrication direction and fining to the northeast; (2) the dip of the large exotic block is steeper than the surrounding Beaverhead just as the smaller imbricated clasts dip more steeply southwest than the beds in which they occur; and (3) the clast composition of the surrounding Beaverhead is compatible only with a southwestern source (Ryder and Scholten, 1973). The age of the the Divide quartzite conglomerate unit of Ryder and Scholten (1973) of the Beaverhead Formation is poorly known; it lies with apparent conformity on their Lima limestone conglomerate unit. The latter unit contains a mid-Campanian to Maestrichtian microflora (D. J. Nichols, written commun., 1982), 4 mi (6.4 km) southeast of Stop 2. Therefore the Divide unit and the period of thrusting which it apparently represents could be as young as Paleocene.

65.4 (105.2) 0.1 (0.2)

Return to Little Sheep Creek Road; turn left.

66.6 (107.2) 1.2 (1.9)

STOP 3. Leading edge of the Tendoy thrust sheet on Little Sheep Creek. Locality: SW 1/4 SW 1/4, sec. 26, T. 13 S., R. 9 W., Gallagher Gulch 7-1/2' quadrangle. Pull right as far as possible.

The front of the Tendoy thrust sheet here dips steeply southwest approximately parallel to the axis of the nearly isoclinal fold in the hanging wall which may be observed north of the road. The coral Caninia (Siphonophyllia ?) sp. was collected from the frontal hanging wall sequence of limestone with interbedded shale at Stop 3. This coral, identified by Sando (written commun., 1981), indicates that the oldest beds exposed here on the Tendoy sheet are Chesterian (Upper Mississippian), perhaps slightly younger than the rocks exposed at the base of the Tendoy thrust sheet at Stop 1. Therefore, the exotic limestone block at Stop 2 could not have been derived from the Tendoy sheet, unless Madison Group rocks are present on the Tendoy sheet between Big Sheep and Little Sheep Creeks, which appears highly unlikely. The rocks of the exposed leading edge of the Tendoy thrust sheet become younger southward such that Pennsylvanian Quadrant Sandstone occupies the front of the Tendoy sheet at Lima Peaks (Scholten and others, 1955; Hammons, 1981). The steeply dipping front of the Tendoy sheet at Stop 3 is probably caused by folding or imbrication of the Beaverhead Formation of the footwall following emplacement of the Tendoy thrust sheet. Hammons (1981) summarized the evidence that the Tendoy thrust was emplaced as a low-angle thrust and later rotated to its present steep attitude at Stop 3, as the enclosing beds were warped by post-Tendoy deformation.

72.7 (117.0) 6.1 (9.8)

Return to frontage road (Interstate Highway 15); turn right.

73.3 (118.0) 0.6 (1.0)

Turn left; pass beneath Interstate Highway 15, into Lima.

73.4 (118.1) 0.1 (0.2)

Turn left just west of EXXON station.

74.0 (119.1) 0.6 (1.0)

Turn right, seven blocks north, onto Lima Dam road. Proceed east across Union Pacific Railroad tracks.

76.0 (122.3) 2.0 (3.2)

Lima limestone conglomerate unit (Ryder and Scholten, 1973) of Beaverhead Formation on hillside to left.

78.7 (126.7) 2.7 (4.3)

Road makes 90° bend to north. Gravel pit just to east contains Beaverhead conglomerate with clasts of Paleozoic limestone and Archean gneiss derived from Snowcrest terrane to north.

80.3 (128.7) 1.6 (2.6)

Pass unimproved road to left; we will return to this junction and proceed north on this road after Stop 4.

81.2 (130.4) 0.9 (1.4)

STOP 4. Southwestern edge of the Snowcrest structural terrane. Location: Center, south edge, sec. 29, T. 13 S., R. 7 W., Henry Gulch 7-1/2' quadrangle.

The limestones exposed just north of Red Rock River at Stop 4 represent the southwestern edge of the Snowcrest structural terrane. Here an inverted sequence of lower Big Snowy and upper Mission Canyon Mississippian carbonates dip 20 to 72° N.W. beneath a capping upper Tertiary basalt flow. This flow has been tilted 7° N.W. following extrusion, assuming original horizontality. Removal of the late Tertiary tilting adds to the degree of overturning of the Mississippian rocks. Immediately beneath the basalt occurs a thin layer of reworked Beaverhead quartzite conglomerate clasts, the same relations observed in the western Centennial Range by Witkind (1977). The intensive brittle deformation of the Mississippian rocks at this locality is pre-late Tertiary, and, from onlap relations of essentially undeformed Beaverhead Formation (Lima limestone conglomerate unit of Ryder and Scholten, 1973) onto these overturned rocks to the northeast, the deformation must be pre-latest Cretaceous.

Gravity-structural modelling of a gravity profile acquired to the northeast indicates that the Snowcrest terrane is allochthonous (Kulik and Perry, 1982) and represents the hanging wall of a major Laramide foreland uplift-margin thrust, the sub-Snowcrest Range thrust of Perry and others (1981). The Mississippian rocks at Stop 4 represent shattered, overturned hanging-wall rocks possibly very close to the lip of this thrust. The thrust itself is obscured by onlap of the Beaverhead Formation and Tertiary to Quaternary cover as well as Tertiary tilting and normal faulting.

At Stop 4, tectonically thinned siltstone and very fine grained sandstone of the Kibbey Formation occupies a thin outcrop band between finely crystalline limestone of the basal part of the Lombard facies near the base of the hill to the east and the inverted Mission Canyon rocks higher on the hillside. This band drops westward to road level. These Kibbey and Lombard rocks are correlated respectively with the Darwin Sandstone Member and Moffat Trail Limestone Member of the Amsden Formation near Haystack Peak, Wyoming, southeast of the Snake River plain (Maughan, oral commun., 1982).

82.1 (132.1) 0.9 (1.4)

Return (west) to unimproved road to north; turn north; proceed northeast across unimproved road and irrigation ditch that parallel valley behind hill of Stop 4. Pull over to right just beyond intermittent-stream gulley which forks to northeast.

83.8 (134.9) 1.7 (2.7)

STOP 4a. Archean gneiss and marble in fault contact with Paleozoic rocks. Locality: NE 1/4 SE 1/4, sec. 20, T. 13 S., R. 7 W., Henry Gulch 7-1/2' quadrangle -- for vehicles with high clearance only.

This stop illustrates a typical stratigraphic-structural problem in the southwestern part of the Snowcrest structural terrane. Here Archean gneiss and marble, similar in age to that of the Ruby Range, is exposed as a distinctive orange-weathered grus in the north-trending gulley occupied by the road. On the west side of the gulley, at least two bedrock exposures of the cataclastically deformed biotite-quartz-microcline-oligoclase gneiss are present. The contact of the gneiss on younger rocks to the east is a hydrothermally altered fault zone which separates the Precambrian rocks from sandy dolomite, dolomicrite, and glauconitic quartzite just to the east. Both Keenmon (1950) and Zeigler (1954) mapped the gneiss as a Tertiary intrusive, but Z. E. Peterman of the U. S. Geological Survey has recently obtain a Rb-Sr date of 2.9 b.y. (written commun., 1982). Both Keenmon (1950) and Zeigler (1954) assigned the adjacent sedimentary rocks to the Pennsylvanian Quadrant Sandstone and underlying Amsden Formations, although Klepper (1950) mapped these as Cambrian-Devonian undivided. The Pennsylvanian age assignment is questioned as these rocks lack the brachiopod coquinas and red beds typical of the Amsden in this area, and these rocks contain thin beds of glauconitic quartzite, a lithology not seen elsewhere in the Amsden or Quadrant in the area. C. A. Sandberg (oral commun., 1981) stated that they were not Devonian, that similar rocks mapped as Devonian in the Antone Peak 7-1/2' quadrangle by Gealy (1953) are actually Cambrian. According to Maughan (written commun., 1982) "glauconite is a common constituent of Cambrian rocks and very uncommon in upper Paleozoic rocks of this region".

It is therefore likely that these dolomicrites and interbedded glauconitic quartzites represent a fault sliver of Cambrian rocks between Precambrian gneiss and associated coarse-grained marble to the west and Mississippian rocks to the east. The ridge of Madison Limestone next to the east is not obviously folded, although Zeigler (1954) shows the Madison to occupy the core of a very tight anticline, the axis of which lies near the center of the Madison ridge, with Upper Mississippian Big Snowy rocks present to either side (east and west) Perry and Richard (unpub. data, 1981) found no Big Snowy rocks on the west side of this ridge nor is there room for a normal section of Big Snowy and Amsden Formations on the west side of the ridge. The structural complexities observed in this part of the Snowcrest terrane, despite the many questions that remain, are consistent with the hypothesis that these rocks are allochthonous above a major basement-involved Laramide thrust.

85.5 (137.6) 1.7 (2.7)

Return to Lima Dam road; turn left (east).

92.6 (149.0) 7.1 (11.4)

Spillway, Lima Dam. Lima limestone conglomerate unit (Ryder and Scholten, 1973) of Beaverhead Formation is exposed on hills to south and north of road.

101.0 (162.5) 8.4 (13.5)

Road makes 90° bend to north; main part of Centennial Range visible across Lima Reservoir to the south.

102.5 (165.0) 1.5 (2.4)

Junction ("T"). Turn left (northwest) toward Dillon.

107.3 (172.7) 4.8 (7.7)

Cross Clover Divide; proceed northwest down West Fork Blacktail Deer Creek.

108.2 (174.1) 0.9 (1.4)

Intensely fractured sandstone beds of Lower Cretaceous Kootenai Formation on right, just north (on hanging wall) of sub-Snowcrest Range Laramide thrust. Beds dip steeply southeast.

108.6 (174.8) 0.4 (0.6)

Exposure of Triassic Dinwoody Formation on right. Beds dip 43° S.E.

108.7 (174.9) 0.1 (0.2)

Exposures of Permian Phosphoria Formation, east side of road. Thickness exceeds 850 ft (259 m) including shale member at top.

110.7 (178.1) 2.0 (3.2)

STOP 5. South limb of concentric fold involving Mississippian rocks, Snowcrest structural terrane. Locality West Fork of Blacktail Deer Creek, NW 1/4 NW 1/4, sec. 23, T. 12 S., R. 6 W.

An extensive solution-collapse breccia occupies the upper part of the Mississippian Mission Canyon Limestone on the south limb of a large concentric anticline at Stop 5. This fold extends for nearly 4 mi (6.4 km) along strike, with an axial trend of N. 65° E. The fold terminates eastward against a major tear fault. It is bounded on the northwest by a late Tertiary normal fault, down-to-the north, that places Mississippian rocks in contact with Miocene(?) basin fill. At Stop 5, the Mission Canyon is about 900 ft (274 m) thick (Zeigler, 1954).

On the southeast limb of the anticline, Zeigler (1954) measured 1,783 ft (543 m) of Big Snowy Formation, the unit immediately above the Mission Canyon. From the map patterns and bedding attitudes recorded by Keenmon (1950) and Zeigler (1954) in the north half of section 23, I have calculated a thickness of 2,350 ft (716 m), over 30% greater than that of Zeigler. Because tectonic thickening is common in this unit, the calculated thickness is probably excessive. In wells drilled to the south, the Big Snowy Formation is thin to absent (Perry and others, 1981).

Along this part of our route, Dolores Kulik has measured 19 gravity stations, from the Shell Oil no. 34x-13 Unit well over 11 mi (18 km) to the southeast, up Clover Creek, through Clover Divide, and down West Fork of Blacktail Deer Creek to 3.8 mi (6.1 km) north of Stop 5. In a sequence of gravity-structural models, constrained by borehole densities, Kulik and Perry (1982) showed that the Snowcrest terrane in the vicinity of West Fork of Blacktail Deer Creek must be underlain by a large volume of low density material, presumably Upper Cretaceous rocks, and is therefore allochthonous.

Continue northwest down Blacktail Deer Creek.

111.5 (179.4) 0.8 (1.3)

Axis of ENE-trending anticline in Mississippian rocks.

111.9 (180.0) 0.4 (0.6)

Cross trace of down-to-northwest Tertiary normal fault.

113.1 (182.0) 1.2 (1.9)

Whiskey Spring to right; Moonshine Gulch to left. Miocene(?) travertine caps ridges to right and to left of road. End of road log; continue north to Dillon.

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FIELD SEMINAR ON THE HORSE PRAIRIE, BLOODY DICK CREEK, BIG HOLE BASIN, AND GRASSHOPPER VALLEY AREAS1/

INTRODUCTION

The purpose of this trip is to stimulate discussion of the geologic structure of southwestern Montana by looking at some of the crucial areas in the field. The route (Fig. 1) was chosen to complement the other field trips conducted during the field conference and to visit some of the more scenic and remote areas in the region. On the trip, the Horse Prairie fault zone, the Medicine Lodge and Grasshopper thrust plates, and the autochthonous Yellowjacket Formation of Precambrian age will be seen.

The geologic descriptions are minimal; this is a "do-it-yourself" road log. This format was adopted, in part, because of the large number of geologists (Ed Ruppel and Bill Perry, U.S. Geol. Survey; Don Winston, Univ. of Montana; Chris Schmidt, Western Mich. Univ.; and John Garihan, Furman Univ.) who will be formally leading the seminar discussions in the field and with the hope that the other professionals participating in the field seminar will make meaningful contributions along the way. This road log is written so that room for notes is available in order for each participant to capture the dynamics of the geology and the dynamism of the seminar participants.

This route should not be travelled without a four-wheel drive vehicle in inclement weather.

(1/ Mileages compiled by Kathy Wilkerson and Elizabeth Brenner. Text written by Elizabeth Brenner, Robert Lankston, and Marian Lankston.)

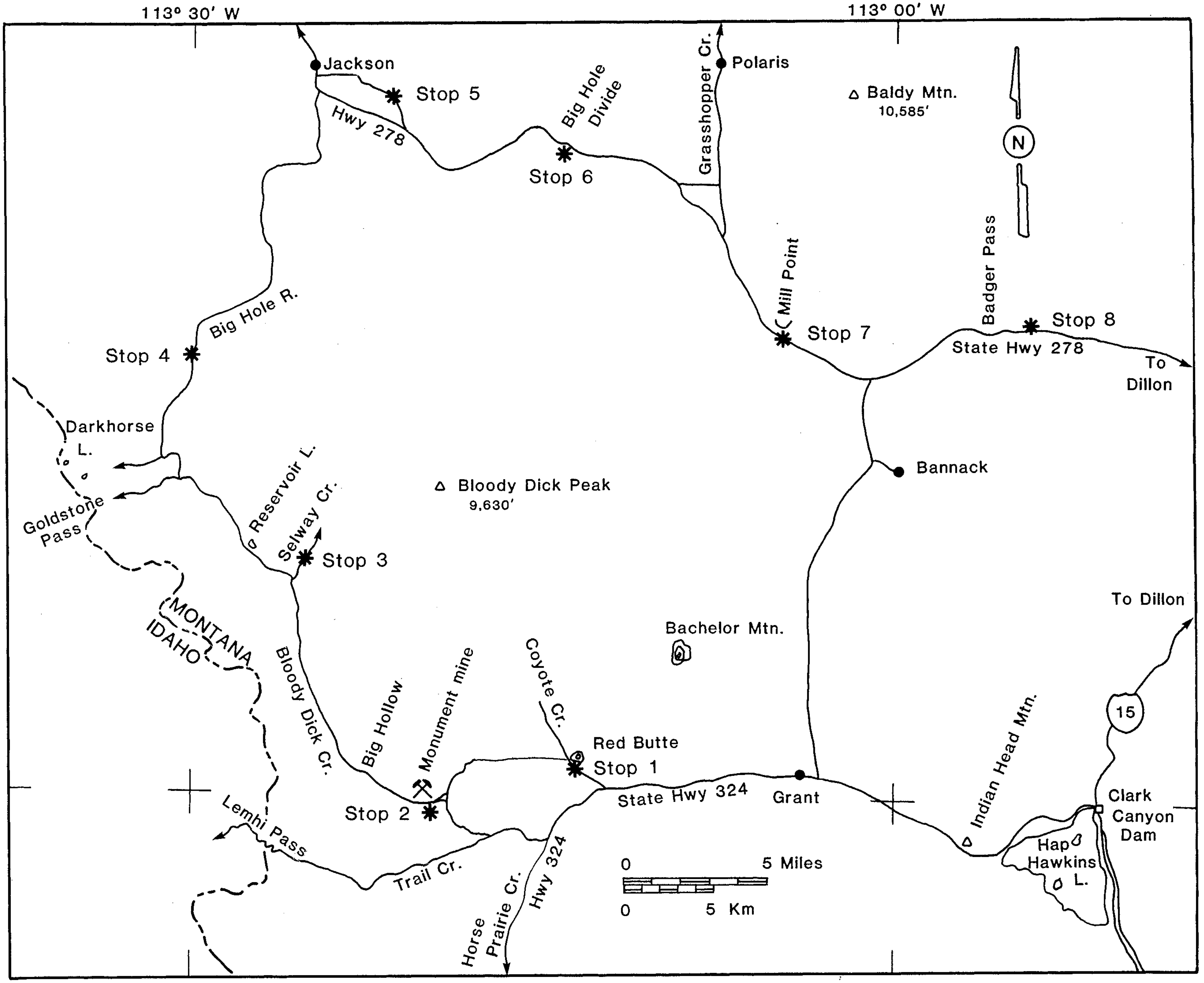

Figure 1. Field seminar trip route.

DESCRIPTIVE ROAD LOG

Cumulative Mileage mi (km)	Increment Mileage mi (km)	
0.0 (0.0)	0.0 (0.0)	Leave Western Montana College, Dillon. See log of Nichols and Brenner (this volume) for the first part of this trip.
18.4 (29.6)	18.4 (29.6)	Exit right onto Montana State Highway 324. Cross Clark Canyon Dam.
30.2 (48.6)	11.8 (19.0)	Road to Bannack to the right. Bachelor Mountain is at 2 o'clock. It is capped by Precambrian quartzite. The Bloody Dick Peaks are on the skyline beyond Bachelor Mountain.
38.0 (61.2)	7.8 (12.1)	Turn right onto the Bloody Dick Road.
39.3 (63.3)	1.3 (2.1)	STOP 1. Red Butte. This was a landmark for Lewis and Clark. Red Butte has supplied stone for many of the fireplaces and barbeques in the valley. It and Round Hill to the south across Horse Prairie Creek are comprised of red Precambrian quartzite. Here we will discuss the Horse Prairie fault. Note the warm spring at the base of the butte.
41.4 (66.7)	2.1 (3.4)	Road to Horse Prairie Ranger Station to the right. Stay left. Cirque on the skyline straight ahead is on the Continental Divide.

42.9 (69.1) 1.5 (2.4)
Junction. Stay right.

43.4 (69.9) 0.5 (0.8)
STOP 2. Overview of Horse Prairie geology. Monument Mine to the right. The mine was worked in the early 1900's; it has been inactive since 1917. The mine produced copper and silver. Local legend has it that the mine was so named because the bodies of some Indians killed in a skirmish were tossed down the shaft.

46.1 (74.2) 2.7 (4.3)
Hollow to the right.

46.8 (75.3) 0.7 (1.1)
Kelly Creek - Hamilton Gulch.

48.2 (77.6) 1.4 (2.3)
On the right is an outcrop of Tertiary tuffaceous sediments containing cobbles of Precambrian green siltite.

48.4 (77.9) 0.2 (0.3)
East and West Peterson Creeks

49.5 (79.7) 1.1 (1.8)
Dutch Hollow to the right.

49.7 (80.0) 0.2 (0.3)
Forest boundary.

50.8 (81.8) 1.1 (1.8)
Kitty Creek on the left.

52.8 (84.2) 1.5 (2.4)
Hughes Gulch. Note glacial features.

53.4 (86.0) 1.1 (1.8)
Cross moraine.

53.6 (86.3)	0.2 (0.3)	Turn right on Selway Creek road.
53.9 (86.8)	0.3 (0.5)	<u>STOP 3.</u> Precambrian quartzite exposures along Selway Creek. After stop return to main road.
54.2 (87.3)	0.3 (0.5)	Turn right on main road.
55.0 (88.6)	0.8 (1.3)	Note ponds on moraine impounded in glacially formed potholes.
55.7 (89.7)	0.7 (1.1)	Junction. Keep right.
55.8 (89.8)	0.1 (0.2)	Entrance to Reservoir Lake Campground to the right. This is a popular local fishing and camping spot. Steep grade ahead.
57.4 (92.4)	1.6 (2.6)	U-Turn Creek.
59.4 (95.6)	2.0 (3.2)	Steep hill.
60.0 (96.6)	0.6 (1.0)	Junction with road to Goldstone Pass. Keep right.
61.6 (99.2)	1.6 (2.6)	Junction with road to Dark Horse Lake. Keep right.
64.1 (103.2)	2.5 (4.0)	Keep to the left on the new road.
65.3 (105.1)	1.2 (1.9)	Cattle guard.

67.4 (108.5) 0.5 (0.8)

Road to South Van Houten Lake to the left. Keep right.

67.5 (108.7) 0.1 (0.2)

STOP 4. Overview of the Beaverhead Mountains and autochthonous Yellowjacket terrane.

67.8 (109.2) 0.3 (0.5)

Road to North Van Houten Lake to left.

69.2 (111.4) 1.4 (2.2)

Saginaw Creek trail to the right.

69.9 (112.5) 0.7 (1.1)

Forest boundary.

70.9 (114.1) 1.0 (1.6)

Cross Big Hole River.

71.2 (114.6) 0.3 (0.5)

Quartzite outcrop. Note numerous glacial cirques on skyline to the left.

74.3 (119.6) 3.1 (5.0)

The Anaconda Range is at 10 o'clock.

78.5 (126.4) 4.2 (6.8)

Intersection with Montana Highway 278. Turn right. Town of Jackson to the left. It contains a small resort and spa which make use of the local hot springs.

78.6 (126.6) 0.1 (1.2)

Tuffaceous Tertiary sediments in roadcut. The Big Hole Basin is the largest and possibly the deepest Tertiary basin in southwestern Montana.

81.8 (131.7) 3.2 (5.2)

STOP 5. Tertiary deposits in the Big Hole Basin. The Grasshopper thrust is near here. Turn left off of highway.

88.3 (142.2) 6.5 (10.5)

STOP 6. Top of Big Hole Pass (Carroll Hill). Big Hole Divide is on the Grasshopper thrust plate. The rocks are Precambrian Missoula Group quartzite (Pearson, this volume). Overview of Big Hole Basin.

95.7 (154.1) 7.4 (11.9)

Junction with road up Grasshopper Creek to Maverick Mountain ski area and Elkhorn Hot Springs.

99.4 (160.1) 3.7 (6.0)

Turn left on dirt road.

99.6 (160.4) 0.2 (0.3)

STOP 7. Mill Point, an outcrop of Beaverhead Conglomerate or synorogenic equivalent. Return to Highway 278.

99.8 (160.7) 0.2 (0.3)
Turn left onto highway.

102.2 (164.5) 2.4 (3.8)
Cross Grasshopper Creek.

103.5 (166.6) 1.3 (2.1)
Road to Bannack and Horse Prairie to right.

108.5 (174.7) 5.0 (8.1)
STOP 8. Overview of leading edge of Grasshopper plate. Cretaceous rhyolites exposed at stop location. Parking may be difficult.

108.8 (175.2) 0.3 (0.5)
Cretaceous tuffs.

111.4 (179.4) 2.6 (4.2)
ALTERNATE STOP 8. Leading edge of Grasshopper thrust plate.

113.8 (183.2) 2.4 (3.9)
Road to Argenta to the left.

120.6 (194.2)	6.8 (10.9)	Junction with I-15. Turn left to Dillon.
124.2 (200.0)	3.6 (5.8)	Western Montana College. End of trip.

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